

# bread science



the chemistry and craft  
of making bread

$E = \frac{P_z^2}{2m_e} + U(z)$     $\rho(0, E_F) = \frac{1}{eV} \cdot \sum_{E_e=eF}^{E_e=EF}$

$d\theta_{on}/dt = k_0\theta_{on} - k_1\theta_{os} + k_2\theta_{us}$     $k_0 = F_{nA}A_{Bn}$ ,  $k_1 = F_{nS}A_{Bn}$ , and  $k_2 = F_{nD}A_{Bn}$     $d\theta_{os}/dt = k_0\theta_{os} - k_1\theta_{on} + k_2\theta_{us}$     $d\theta_{us}/dt = k_1\theta_{os} - k_2\theta_{us}$

$\psi(z) = \psi(0) \cdot e^{-\kappa z}$  where  $\kappa = \sqrt{\frac{2m_e \cdot (U - E)}{\eta}}$    Probability  $\propto |\psi_n(0)|^2 \cdot e^{-2\kappa z}$  where  $\kappa = \sqrt{\frac{2m_e \cdot (U - E)}{\eta}}$

$\theta_{on}(t=0)=1$  and  $\theta_{on}(t)+\theta_{os}(t)+\theta_{us}(t)=1$

$\frac{k_{max}(T)}{k_{min}(T)} = K \cdot e^{-\frac{E_F - E}{k_B T}}$     $R = \frac{K \cdot e^{-\frac{E_F - E}{k_B T}} \cdot A_{Bn}^2 \cdot S_{Bn}}{Z}$

$\theta_{on}(t) = \frac{U_{on} - \eta \cdot \theta_{os}(t) - \eta \cdot \theta_{us}(t)}{U_{on} - \eta \cdot (1 - \theta_{os}(t) - \theta_{us}(t))} = 1 - e^{-\kappa z}$

$E\psi(z) = \frac{1}{2m_e} \cdot \frac{d\psi}{dz^2}$

$\theta_{os}(t) = \frac{U_{os} - \eta \cdot \theta_{on}(t) - \eta \cdot \theta_{us}(t)}{U_{os} - \eta \cdot (1 - \theta_{on}(t) - \theta_{us}(t))} = 1 - e^{-\kappa z}$

$\theta_{us}(t) = \frac{U_{us} - \eta \cdot \theta_{on}(t) - \eta \cdot \theta_{os}(t)}{U_{us} - \eta \cdot (1 - \theta_{on}(t) - \theta_{os}(t))} = 1 - e^{-\kappa z}$

# Emily Buehler

# **Bread Science**

## The Chemistry and Craft of Making Bread

### Emily Buehler

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## BREAD SCIENCE

The Chemistry and Craft of Making Bread

by Emily Buehler

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# Note to the reader on the organization of this book

I have set up Bread Science to be as much like a reference book as possible, enabling readers to open to a section of interest without needing to read the whole book. Chapters three through seven, which describe the process of bread-making, go in chronological order, to aid beginners. Bread Science focuses on learning about the process of bread-making instead of individual recipes. In that sense it is not a traditional cookbook—it contains only basic recipes intended to illustrate the concepts discussed.

I dedicated a separate chapter to bread science so as not to confuse readers trying to focus on the practical aspects of bread-making in later chapters. Thus, chapter two contains a more complete description of the different aspects of science occurring in dough. This science is referred to in relevant places throughout the book, but with less detail. I have included all scientific terms in the glossary.

In chapter two, references are given to research papers. Wherever possible, I have referenced the source documenting the original research, not just a paper that refers to it. This was not always possible: some papers were unavailable or not written in English. The bibliography lists the major papers on each aspect of bread science and is a good place to begin if you would like to read more.

Some readers may find chapter two daunting or a bit overwhelming. If you are eager to get to bread-making, skip chapter two for now and dive right in to the practical chapters. You can return to the science later, perhaps while you are munching on a freshly-baked slice of bread.

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# Dedication

This book is dedicated to Susan and Barry Buehler, the perfect combination of art and science.

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# Introduction

The obvious way to make bread is to find a recipe in a book and follow it. Chances are it will work well enough, but making bread this way confines the baker to one recipe, gives him or her no understanding of how to fix problems that arise, and perpetuates the myth that he or she needs a “good recipe” to begin with. In short, following a recipe is not an empowering way to make bread.

The alternative method explored in this book is more akin to what our ancestors might have done, working with basic recipes to learn about the process of bread-making, with the added benefit of decades of scientific research enabling us to understand the inner workings of the process. Think of the method as starting from the beginning—each time you make dough you see what happens to it and learn something new about the process. The information provided in this book will help you learn faster and understand how and why bread “works.” From there, any recipe will be conquerable.

Reading about bread will not be enough though; the only way to get to know dough and bread is to have your hands in it—practice. Do not be intimidated—mistakes and “failures” are just opportunities to learn. (Besides, messed up bread often still tastes good!) Take data when mixing your dough—use the data sheet in chapter four. Remember what the dough feels like. Write notes for next time in order to remember what to do the same way or differently.

Good bread is not the result of one brilliant mind; it came about by trial-and-error, over the centuries. And it was done by ordinary people; it does not require special talents or an advanced degree. Re-learning the process from the beginning is surprisingly simple. In this day, making bread “by hand” might seem like a lost art, but it remains accessible to anyone who wishes to try it.

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Tabouli with a baguette, Snow Camp, NC, 2003

# **Chapter 1: Bread-making Basics**

This chapter contains information on some basic concepts in bread-making that will help you get off to a good start.

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## 1.1 The basic bread recipe

The basic bread recipe is the “lowest common denominator” of bread recipes—the simplest one possible. It gives new bread makers a simple recipe to use and illustrates that all recipes are derived from the same place. There is no secret to them—they all have basically the same percentages of water, yeast, and salt, adjusted to account for the other ingredients. (The percentages, which may seem odd, are described in the following section, “Baker’s percent.”)

What makes good bread is the attention given to the dough, not the recipe. This is especially true for bakers working in distinct climates. A world-famous recipe from a California bakery might need adjustment when used in the humid eastern Carolina summer with a different brand of flour and different water. Bakers make adjustments by paying attention to the dough’s characteristics.

The basic bread recipe for a one kilogram (about two pound) loaf of bread is

	Percent	Weight
White flour	100%	0.580 kg
Water	70%	0.406 kg
Instant Yeast*	0.7%	0.004 kg
Salt	2%	0.012 kg
<b>Total</b>	<b>172.7%</b>	<b>1 kg</b>

\* If fresh yeast is used, the amount of yeast is about 2% or 0.012 kg.

This recipe is converted to cup and teaspoon measures in the following section, “Weight versus volume.”

If you slap together this recipe, do not knead it enough, stick it in the refrigerator overnight because you are too tired to bake it, and then put it in a conventional oven without knowing if it is ready to bake, you will still produce bread that tastes good! From there, you can use your knowledge of bread-making to improve the result—to get more volume (i.e., bigger bread) or a nicer-looking crust, for example. The important thing is just to get started!

Of course, you may want to use a fancier recipe. The scores of great recipes in cookbooks are a bit more exciting than the basic bread recipe. The rules of bread-making still apply—fancier recipes all evolved from a basic recipe like this one.

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Pataha Flour Mill, Pataha, WA, 2003

## 1.2 The four main ingredients

When asked the ingredients of bread, children usually suggest sugar, eggs, butter, and oil. Commercially-made bread includes these, but the only necessary ingredients in homemade bread are flour, a rising agent, water, and salt.

Flour. The most important characteristic of flour for a bread baker is the protein content. Basically, when dough is mixed, protein in the flour forms gluten, a stretchy material that gives dough strength and enables it to rise. Flour with a high protein content makes dough with more gluten. This dough is harder to stretch and requires more force when handling; it may take longer to knead and rise.

Approximate protein contents of some different types of white wheat flour are listed below:

- Pastry flour, 9.0%
- All purpose (AP) flour, 10.5%
- “Bread flour,” 12.5%
- High gluten bread flour, 14.0%

Specific protein contents may not be listed on a package, but the information is often available on websites or by calling the flour company.

Artisan bread needs a protein content of about 11.5%. You may be able to find a specialty flour, made for artisan bread makers, with 11.5% protein. Otherwise, you can make it by mixing two flours (for example, AP flour and bread flour) to get about 11.5%.

A second important factor for bakers is the kind of flour used. Different flours add unique flavors to bread and impart different nutritional benefits. In general, flours with more of the grain kernel in them are healthier but harder to work with.

Whole wheat flour contains the entire kernel of wheat, including the bran. What this means for bread-making is that bran particles are interfering with the formation of gluten during mixing. Whole wheat dough therefore rises

more slowly and produces denser bread. It may need extra attention to rise properly. Bread made with part whole wheat and part white flour will still have the “whole wheat look” and a rich, nutty flavor but will rise more easily.

Other flours can be added to white flour to produce breads with different tastes. Semolina and durum flours (made from wheat) are typically used in pasta. Alone they cannot make a decent loaf, but mixed 50/50 with white flour they add a mild flavor to bread. Spelt flour is made from a distant cousin of wheat. Spelt adds a nutty or bean-y flavor to bread. Some people who have trouble digesting wheat prefer 100% spelt bread; with less gluten than wheat, spelt dough rises slowly and produces denser bread.

Rye flour adds a unique taste to bread. It has less gluten and more sugars than wheat flour and can be added to recipes in small amounts to add rye flavor. True fans will want 100% rye bread. This dough is much different than wheat dough. It is sticky and rips apart easily, and it appears fragile when risen; it must cook for hours at a lower temperature and cool for hours to set in the middle. The resulting bread is dense and gummy.

Rising agent. The term “rising agent” refers to the ingredient that causes fermentation, the reaction that makes the dough rise. Rising agents include yeast, which is a fungus; preferments made with yeast; and starters, which contain bacteria and wild yeasts. (Preferments and starters are discussed in detail in chapter three.)

There are three common forms of yeast: fresh yeast (a.k.a. wet yeast, cake yeast, or compressed yeast), active dry yeast, and instant yeast. Different sources list different specifications for each form of yeast, such as how much to use, how to use it, how the content of one form compares to another, and how long each will last. In addition, confusing multiple names are often used for each form of yeast. The best way to get additional information is to get specifications from the company that made the yeast you are actually using —look online or call them and ask. A general description of each form of yeast follows, to get you started.



Fresh yeast is often hard to find. Many home bakers seem to think there is something magical about fresh yeast, maybe because their excellent-baker-grandmothers used it, or just because they cannot get it. I am not convinced it is any better than instant yeast.

Fresh yeast comes in blocks. It consists of active yeast cells in a sugar-water casing. This yeast has not been dried at all. It needs to be refrigerated and lasts about two weeks. It can be frozen for a few months. When mixing dough, fresh yeast can be added to the flour or crumbled onto the dough later in the process. Two to four times the weight of dry yeast must be substituted in a recipe if fresh yeast is used, to account for the weight of the sugar. (So, if your recipe requires two grams of dry yeast, use four to eight grams of fresh yeast.)

Active dry yeast is the easiest to find. It is the kind of yeast you find in every grocery store in small packets or in a jar. It became popular because it was so

much more convenient than fresh yeast, but it can have detrimental effects on bread dough (described below) and should be avoided if possible. If you cannot find fresh or instant yeast, however, active dry yeast will do the trick.

Active dry yeast is in the form of little granules. It consists of almost totally dried yeast cells. This yeast lasts for well over a year at room temperature in its sealed package. It must be refrigerated once opened but lasts for months. It should be “activated” before use by mixing it with warm water. It is sensitive to cold—adding it directly to cold water can kill it. Because of the harsh drying process, many of the yeast cells are dead. Dead yeast cells release a chemical called glutathione that has a bad effect on gluten.

I have used active dry yeast in bread without activating it because it was mislabeled as instant yeast, and it did just fine. I mix it into the flour before adding water. I always use an autolyse (described in chapter four) before kneading, which would allow the yeast time to activate and may be why I’ve never had a problem.

Instant yeast was developed in the 1970’s as a combination of the convenience of active dry yeast and the quality of fresh yeast. It may still be hard to find in grocery stores, but can be ordered from specialty baking companies.

Instant yeast is also a dry yeast—it takes the form of little granules and consists of yeast cells encased in a sugar coating and dried with a special process. Vacuum-sealed bags last a long time in the refrigerator. Once opened, the activity declines after a few weeks. Instant yeast is not as sensitive to cold as active dry yeast—it does not need to be activated. It should still not be added directly to cold water, however; it can be added to the flour during mixing or sprinkled onto the dough later.

Yeast that is stored too long becomes inactive. The yeast cells do not die all at once—over time, the yeast will work more and more slowly, until eventually it does not work at all. To determine if yeast is still active, mix equal parts of yeast and flour with some warm water, wait a few minutes, and look for bubbles forming in the flour. Bubbles indicate that your yeast is alive and has started producing gas.

Water. Perhaps the simplest ingredient, water deserves much of the credit. Water starts the chemical reactions that make bread happen by hydrating

ingredients, acting as a solvent, and enabling molecules to move about in the dough. In addition, the water temperature determines the dough's temperature, one of the dough characteristics that the baker attempts to control.

The most common question about water in dough concerns the use of tap water. Is it necessary to make bread with bottled water? It depends on the tap water. If it smells and tastes like chemicals, it might give odd flavors to your bread. In addition, chemicals in the water might interfere with the chemical reactions of the dough. Filtered or bottled water costs extra, though, and there is a good chance that your tap water will work just fine. Try using each and see if you notice a difference.

Salt. Salt has many purposes in bread. The most obvious is that it adds flavor. It also acts as a natural preservative by dehydrating bacteria, thus adding shelf-life to bread. During bread-making, salt slows down the fermentation reactions by dehydrating the yeast and bacteria, allowing the dough to ferment for longer before it must be shaped and baked. The longer fermentation time allows more flavor to develop. Salt also stabilizes the gluten network, making the gluten stronger. This creates a better dough that resists the building gas pressure and rises more slowly.

Technically, salt is an optional ingredient. People on low-salt diets can make bread without it, using other ingredients for flavor and slowing down the fermentation process with cold temperatures.

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## 1.3 Weight versus volume

There are two ways to measure ingredients, by weight and by volume. Weighing ingredients requires a scale. Measuring by volume means using measuring cups and teaspoons. Both ways work, but measuring by weight has important advantages.

A certain weight of an ingredient is in effect a certain number of molecules. When dough is mixed, molecules in the ingredients react with each other. By adjusting the weight of each ingredient, the baker controls how much reaction can happen.

It seems that volume is analogous to weight—a bigger scoop of flour has more molecules. The volume of some ingredients can change, however. Flour can settle or become packed and thus become “smaller.” Salt crystals come in different sizes; bigger salt crystals have bigger air spaces between them, in effect giving less salt per teaspoon than salt with small crystals. Also, volume measurements are less accurate—a teaspoon might be slightly heaping or depressed—while weight measurements are consistent.

Another concern is preferments, discussed in depth in chapter three. Preferments are dough-like mixtures made a day early and added to bread dough for extra flavor. Their size increases dramatically from the time when they are mixed to the time when they are used. If you try to measure a preferment using volume, how much you use depends on how developed the preferment is. A cup of recently-mixed preferment is denser—more flour and water—than a cup of well-risen preferment that is full of air.

Still, making bread without a scale works. If you measure carefully, cup and teaspoon measurements can be fairly consistent. Preferment amounts can be approximated. Once you are familiar with dough, you will be able to tell if you need to add water or flour by feeling your dough; the actual amount from the recipe loses importance. Recipes in this book are given by weight and volume. (Conversion factors are given in the appendix.) Here is the conversion of the basic bread recipe:

White flour	$0.580 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ cup}}{112 \text{ g}} = 5.10 \text{ cups}$
Water	$0.406 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ cup}}{224 \text{ g}} = 1.81 \text{ cups}$
Instant yeast	$0.004 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ tsp}}{4 \text{ g}} = 1.00 \text{ tsp}$
Salt	$0.012 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ tsp}}{6 \text{ g}} = 2.00 \text{ tsp}$

The resulting recipe in weight and volume is

White flour	100%	0.580 kg	5 cups flour
Water	70%	0.406 kg	1¾ cups water
Instant yeast	0.7%	0.004 kg	1 tsp yeast
Salt	2%	0.012 kg	2 tsp salt
<b>Total</b>	<b>172.7%</b>	<b>1 kg</b>	

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(An important note about flour: these numbers are for fluffy, sifted flour. If you scoop flour up with a measuring cup, it may be packed down and you will use too much flour! Avoid packed-down flour by sifting or by spooning it into your measuring cup one spoonful at a time. For more information on this, see the notes in the appendix.)

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## 1.4 Baker's percent

Baker's percent is a special method of organizing a recipe that is convenient for bakers. It is a helpful tool for understanding the basic structure of recipes. A discussion of baker's percent means doing some math. If you are completely averse to reading about math, you can accept the idea of "baker's percent" on faith and skip this section.

Normally, percentages add up to 100%. For example, a poll might show that 65% of Americans like chocolate ice cream best, while 23% like vanilla, 8% like mint, 3% like purple kiwi passion, and 1% like "other." These numbers add up to 100%, implying that 100% of Americans (i.e., all of them) were polled.

Baker's percent lists the ingredients in a recipe as percentages, but flour is always 100% by weight,\* while the other ingredients are measured relative to the amount of flour. For example, the basic bread recipe is 100% flour, 70% water, 0.7% yeast, and 2% salt. The weight of the water in the recipe is 70% of the weight of the flour. The weights of the yeast and salt are 0.7% and 2% of the weight of the flour, respectively. This means that the ingredients add up to 172.7%. (\*Note: Kilograms are actually units of mass, while pounds are units of weight. In this book, the more common term weight is used in place of the term mass.)

Baker's percent may not seem intuitive—perhaps it seems like an affront to accepted mathematics. How can a percentage greater than 100 exist?

Think of baker's percent as a useful tool. First of all, percentages are useful for comparing recipes. For example, which bread is better for someone avoiding salt? One recipe uses four teaspoons of salt, while another only uses two teaspoons; but the four-teaspoon recipe makes a bigger loaf of bread. A slice from the bigger loaf will not necessarily have more salt than a slice from the smaller loaf. The percentage of salt is important, not the actual amount of salt used.

In addition, bread recipes must be flexible. This is because factors can change—for example, the moisture content of the flour or the humidity of the bakery. This is where baker's percent is useful. If recipes are written with

normal percentages, changing one ingredient's percentage causes the other ingredients' percentages to change, too, because the total must remain 100%. That would result in unwanted changes—too much salt or yeast, for example.

With baker's percent, adjusting recipes is easy. For example, a baker's dough feels very wet, so he holds 5% of the water. Compare the original recipe on the left to the new, drier recipe:

	Percent	Weight	New percent	Weight
White flour	100%	0.580 kg	100%	0.580 kg
Water	70%	0.406 kg	65%	0.377 kg
Instant yeast	0.7%	0.004 kg	0.7%	0.004 kg
Salt	2%	0.012 kg	2%	0.012 kg
<b>Total</b>	<b>172.7%</b>	<b>1 kg</b>	<b>168%</b>	<b>about 1 kg</b>

The water's value has changed, but not the other ingredients' values.

Baker's percent provides bakers with a universal measure. For example, salt values are usually about 2%. Most recipes have approximately 2% salt, just as the basic bread recipe does. Water content (or hydration) and yeast content also have similar percentages in most recipes.

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## 1.5 Four characteristics of dough

There are four characteristics of dough to keep in mind when making bread—time, temperature, gas content, and strength. Controlling these four characteristics is possible at various places throughout the process.

Time. Time is key to making good bread for one simple reason—the longer the dough ferments, the more flavor it will have. Using a preferment is the first way to increase the fermentation time, by adding a whole extra day to the process. There are many other ways to add time to the process: mixing with colder water to make colder dough, keeping the dough in a colder environment during fermentation, punching the dough during the fermentation step so that it must rise several times, shaping the dough more tightly to allow it to proof more slowly, and proofing the dough in a cold place, even overnight in a refrigerator.

On the other hand, warm temperatures and a single first rise can be used to speed up the process for expediency. This may be necessary in a cold house or if the dough is rising too slowly for undetermined reasons. (New bakers often have trouble with dough rising slowly simply because they are new at kneading and did not knead well enough.)

Temperature. Temperatures indirectly affect the flavor of dough by altering the rising time. Colder water and a cold environment are two ways to slow down the process. Colder water is used to counteract the heat caused by friction when you use an electric mixer. Whenever your hands are in the dough, during kneading or shaping, you are imparting heat to the dough. While your dough must be properly kneaded, handle it as little as possible, using brisk, efficient motions. Temperature can also be used to alter rising time, but major changes are made by altering the amount of yeast used.

Finally, the temperature of the oven is what bakes the dough into bread. In chapter seven, the importance of the oven temperature in the first ten minutes of baking, when the most expansion occurs, will be discussed.

Gascontent. With each step of the bread-making process, the gas content of the dough determines when the dough is ready to be taken to the next step. For example, preferments should be full of gas when they are used, dough

should be full of gas when it is punched down or shaped, and the shaped loaf should be full of gas when it goes into the oven. Baked too soon (not enough gas), it may have a dense center; baked too late (too much gas), it may collapse.

The baker repeatedly removes gas from dough and allows it to reform. Instructions for proper gas removal during shaping are given in chapter six. A poor job removing gas during shaping results in bread with gaping holes inside. When the dough goes into the oven, it should have an even distribution of gas inside.

Sometimes dough seems overly gassy—it rises too fast and becomes weak and hard to work with. The main control on gas content is how much yeast is in the recipe and how active the preferment is when it is used. Problems with persistently gassy dough are solved by using less yeast.

Temperature also controls gas content. Extreme high temperatures can cause dough to rise too fast, quickly resulting in an overly gassy dough. Dough with too much gas is sloppy to work with and forms messy bread.

Strength. Dough strength is the characteristic that the baker has the most chances to control, beginning with what type of flour (i.e., how much gluten) is used in the recipe. Strength is subsequently controlled by how long the dough is mixed, how often and how tightly it is folded, how well it is shaped, and how it is scored before it enters the oven.

Dough that is too weak or too strong will not rise properly. Weak dough will not retain gas well, while overly strong dough will resist gas pressure and not allow dough to rise. In addition, controlling the strength of the dough is important for making an aesthetically pleasing loaf of bread. Dough that is too weak or too strong will be hard to shape well. Once shaped, uneven strength causes uneven expansion—weaker spots in the loaf will rise more, ripping during the rapid expansion in the oven. The internal structure will be uneven.

The dough characteristics affected by each step of the bread-making process are summarized below.

### Mixing a preferment

- use of a preferment increases the overall fermentation time

- gas production begins; the preferment should be full of gas when it is used

### Mixing the dough

- the amount of yeast used and the readiness of the preferment when the dough is mixed determine the rising time of the dough
- proper kneading also affects the rising time
- the water temperature controls the dough temperature and thus its rising time
- the amount of yeast and readiness of the preferment when the dough is mixed determine the gas content of the dough
- more kneading increases the strength of the dough

### Fermentation (rising)

- punching down the dough increases the number of rises and therefore the overall fermentation time
- the temperature of the dough's location affects the dough temperature and thus its rising time
- the gas content determines when the dough is ready to be punched and folded or shaped
- folding increases the strength of the dough

### Shaping

- tight shaping of the dough increases its proofing time
- over-handling can overheat the dough
- removing all gas from the dough during shaping produces even bread without gaping holes inside
- shaping adds strength to the dough for slow, even rising

### Proofing (rising)

- the temperature of the dough's location affects the proofing time
- the gas content determines when loaves are ready to bake
- the strength of the dough supports it while it rises

## Baking

- a proper oven temperature causes the dough to expand fully and then to bake
- proper gas content in the dough creates bigger bread
- the strength of the dough causes it to expand evenly

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Jada with a baguette, Carrboro, NC, 2000

## 1.6 Overview of the bread-making process

The basic steps of the bread-making process are summarized and illustrated below.



1. Mixing a preferment (optional). Flour, water, and yeast or sourdough starter can be mixed the day before the dough is made. This preferment rises overnight as fermentation begins.

2. Mixing the dough. Flour, water, a rising agent (yeast, preferment, or both), and salt are incorporated together. There is an optional rest period, and then the dough is kneaded.
3. Fermentation (rising). The covered dough is left to rise.
4. Punch and fold. The dough is punched to remove gas. It is folded to add strength.
5. Fermentation (rising). The dough rises again.
6. Shaping. The dough is cut into pieces if necessary, gas is removed, and it is shaped into boules, baguettes, batards, or other shapes.
7. Proofing (rising). The shaped dough is covered and left to relax (soften) and rise. It fills with gas one last time.
8. Baking. When it is full of gas, the dough is put into the oven, where it expands and solidifies, turning into bread.
9. Cooling. After the bread is baked, it is placed on a rack to let it cool properly.

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## **1.7 Get ready to make bread!**

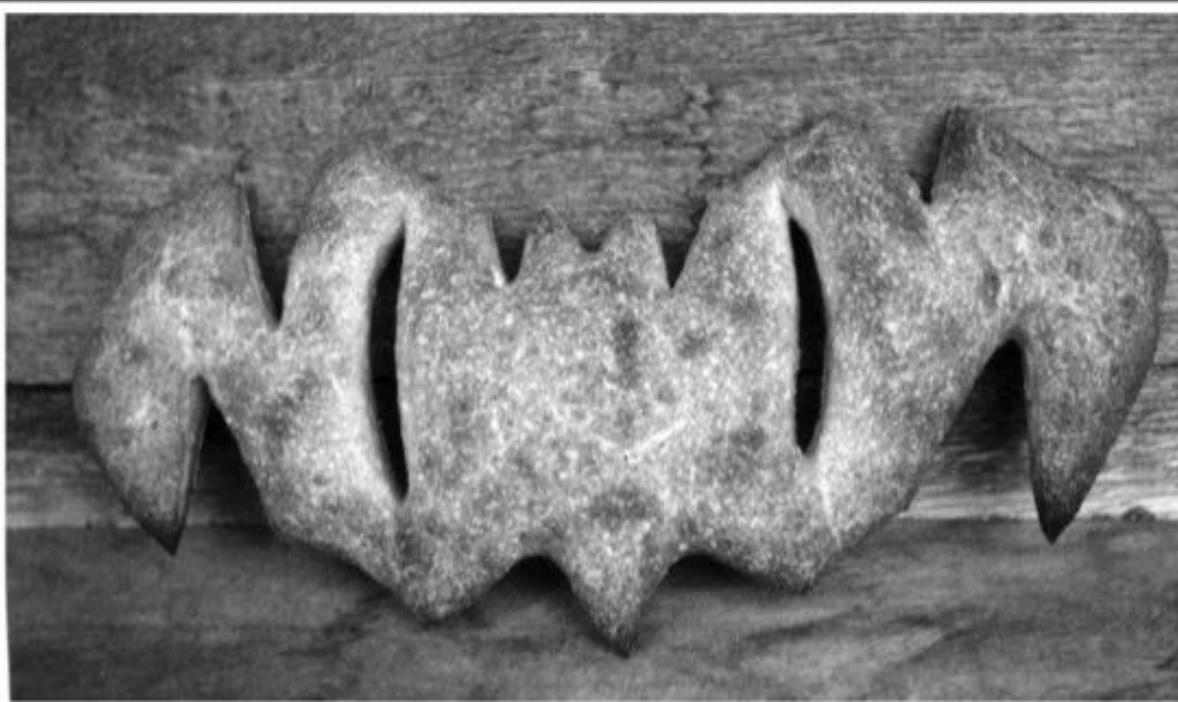
You are ready to set off on your bread-making adventure! Remember that this can be a lot of fun. Your dough might not be perfect the first time you make it, but if it were perfect every time, you would never learn. Keep notes of how it turns out and make adjustments for next time.

To make really great bread, you cannot just follow steps. You have to pay attention to the dough, take care of it, and use it when the time is right. The good baker waits for the dough to be ready and then acts before it is too late.

The following chapter delves into the science occurring in dough throughout the entire process of bread-making. Chapters three through seven split the process into steps, not only describing how to do a step of the process, but also pointing out the little things to watch for to improve your bread.

Improvements can be made each step of the way, from when you choose ingredients until you pull the baked bread out of the oven.

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Batbread, Carrboro, NC, 2002

# **Chapter 2: Bread Science Basics**

This chapter is about the science of bread-making, organized by subject. References to specific research studies are located at the end of each section.

[2.1 Starch and sugar](#)

[2.2 Yeast and bacteria](#)

[2.3 Fermentation](#)

[2.4 Flavor and color](#)

[2.5 Water and protein](#)

[2.6 Gluten structure](#)

[2.7 Gas retention](#)

[2.8 Proteases](#)

[2.9 Salt and fermentation](#)

[2.10 Salt and gluten](#)

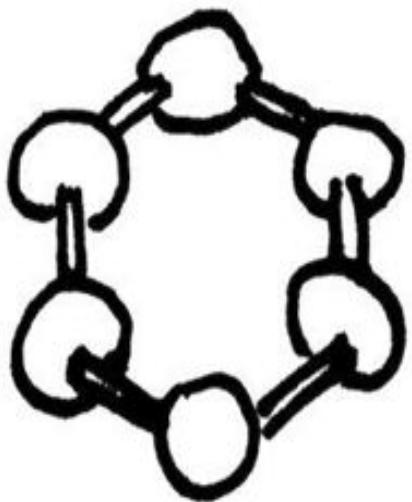
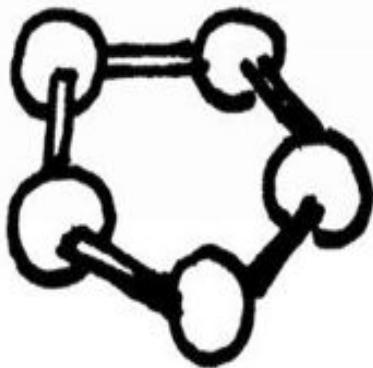
[2.11 Miscellaneous](#)

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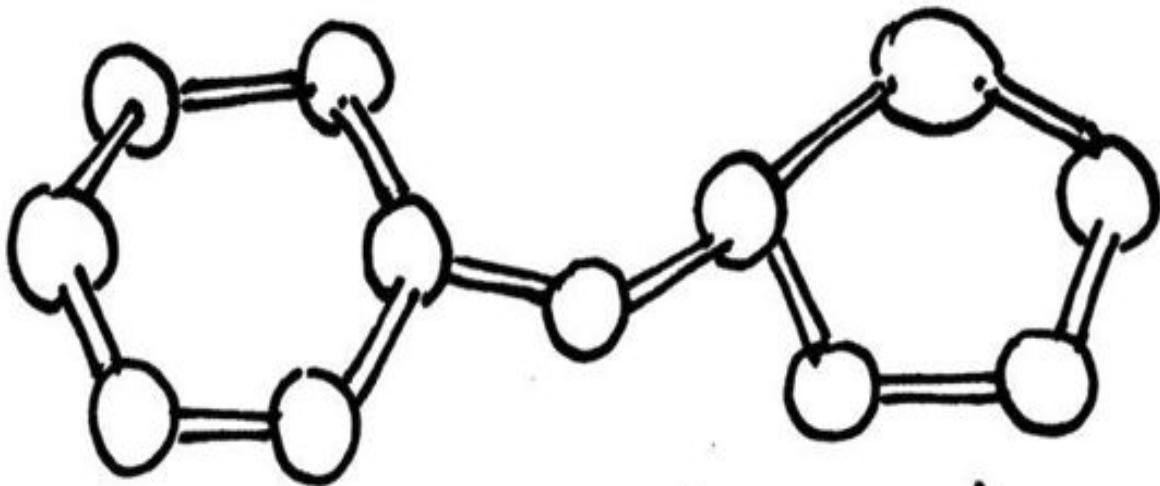
## 2.1 Starch and sugar

Sugar is one of the main players in dough chemistry—it is the “food” needed by yeast during fermentation, the reactions that occur in dough to produce flavor and make the dough rise. But the wheat kernel, and consequently flour, only has small amounts of sugar in it, around one to two percent. [1,2,3] Basic bread recipes do not use added sugar. Where does the sugar come from to support fermentation?

Begin by considering sugar. A simple sugar molecule is a molecule of carbon (C), hydrogen (H), and oxygen (O) atoms, often curled into a ring. Two or more rings join together to form more complex sugars. A two-ring sugar is a disaccharide. The pictures below are ball-and-stick models of sugar molecules. Balls represent atoms and sticks represent the bonds between atoms. Only the main atoms are shown.

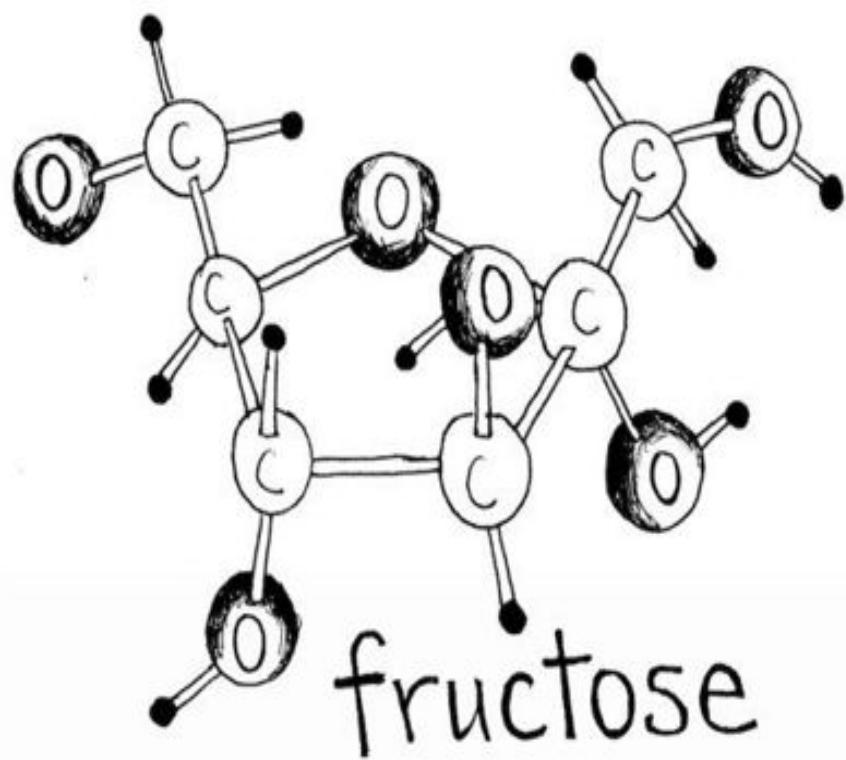
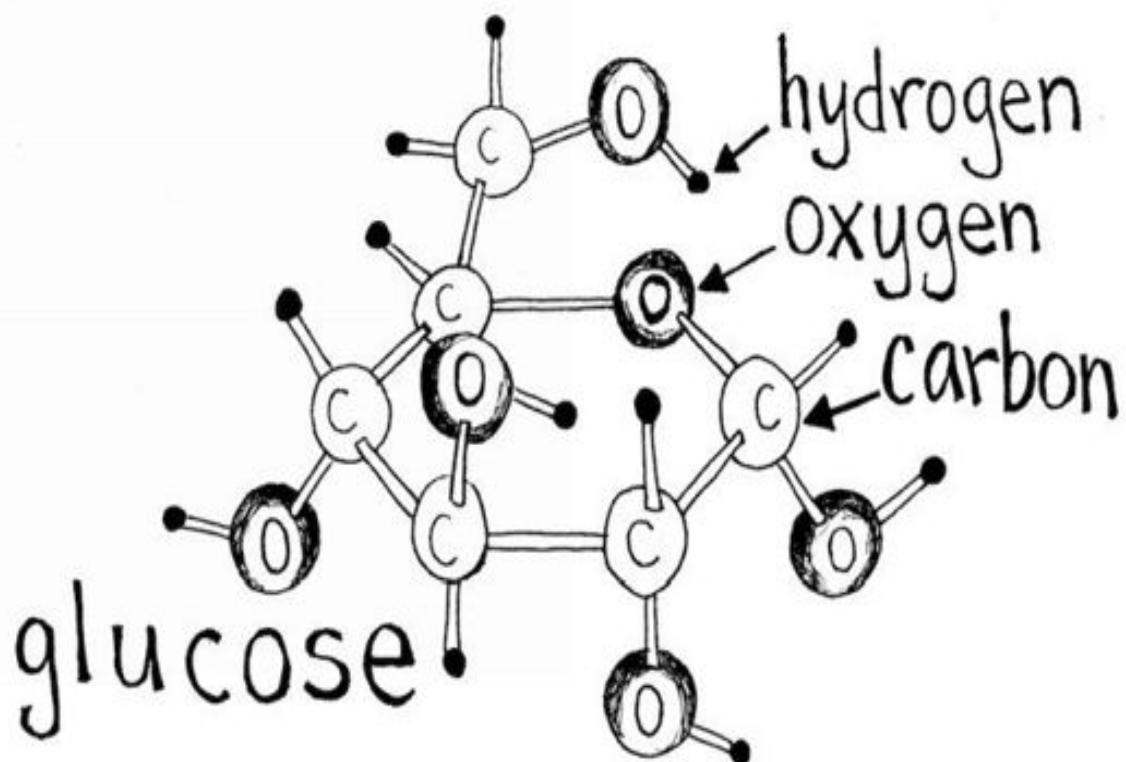


simple sugars

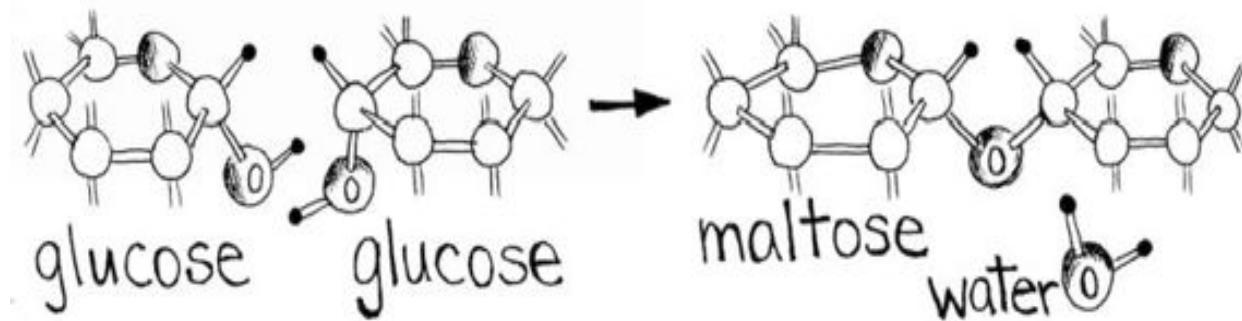


a disaccharide

There are four important sugars in bread-making. Glucose and fructose are simple sugars that form six- and five-member rings, respectively.



Maltose is a disaccharide of glucoses. Maltose formation is shown in the following diagram.

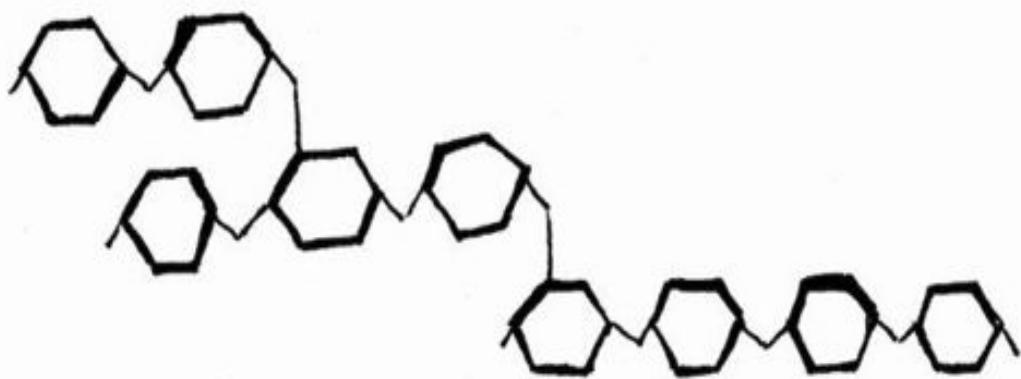


Note that the loss of a water molecule enables the two glucose rings to join to form maltose. To break a maltose molecule, water must be added back. Sucrose is a disaccharide of one glucose and one fructose; it forms in a reaction similar to the one shown above.

Starch is a polysaccharide, a chain of many sugar rings. The most important starches in flour are amylose and amylopectin. Amylose is a straight chain of glucose sugars. Amylopectin is also made of glucose sugars, but it branches.



amylose (straight)



amylopectin (branched)

Starch can be broken down to simpler forms of sugar by enzymes, special protein molecules that perform specific functions. The enzymes that convert starch are called amylases and are conveniently found in flour. Amylases are activated when flour and water mix. Remember that water molecules are removed when sugar rings join. To break the starch, water molecules must

be added back. Also, water serves as a medium in which the enzymes move, allowing them to reach the starch.

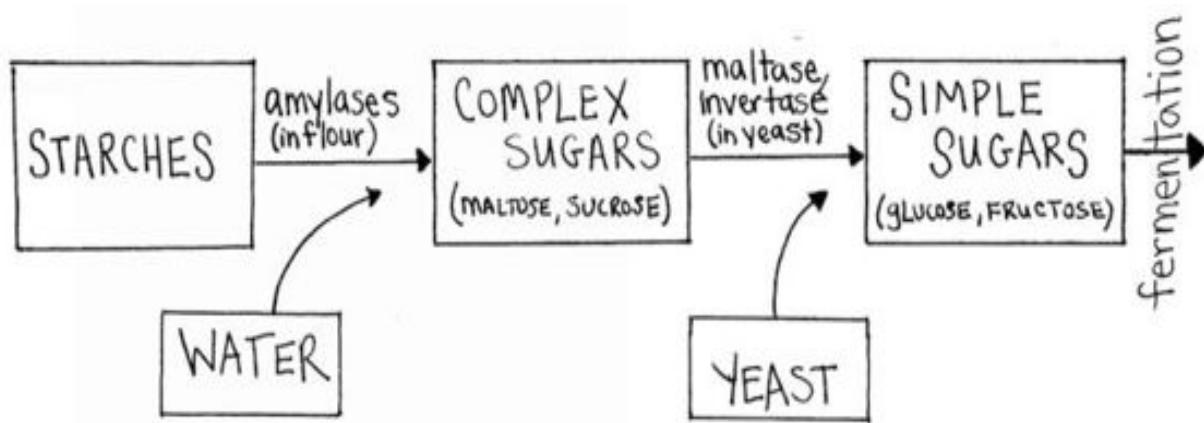
One kind of amylase, called alpha-amylase ( $\alpha$ -amylase), breaks starch chains into smaller pieces. The other, beta-amylase ( $\beta$ -amylase), breaks maltose units off the ends of the starch chains. The two enzymes help each other break down starch effectively—tests show that together, they break up more starch than the sum of what they can break up working solo. [4]

Sugars are able to move about in dough. When a sugar molecule nears a yeast cell, the yeast either processes it at the cell membrane or transports (absorbs) it through the membrane into the cell. Maltose is transported and broken down in the yeast cell, but sucrose cannot be transported and must be broken down at the yeast's membrane. The products of this reaction are then transported into the cell. [5] The yeast's transport system is important because it moves the sugar into the cell much faster than ordinary diffusion would.

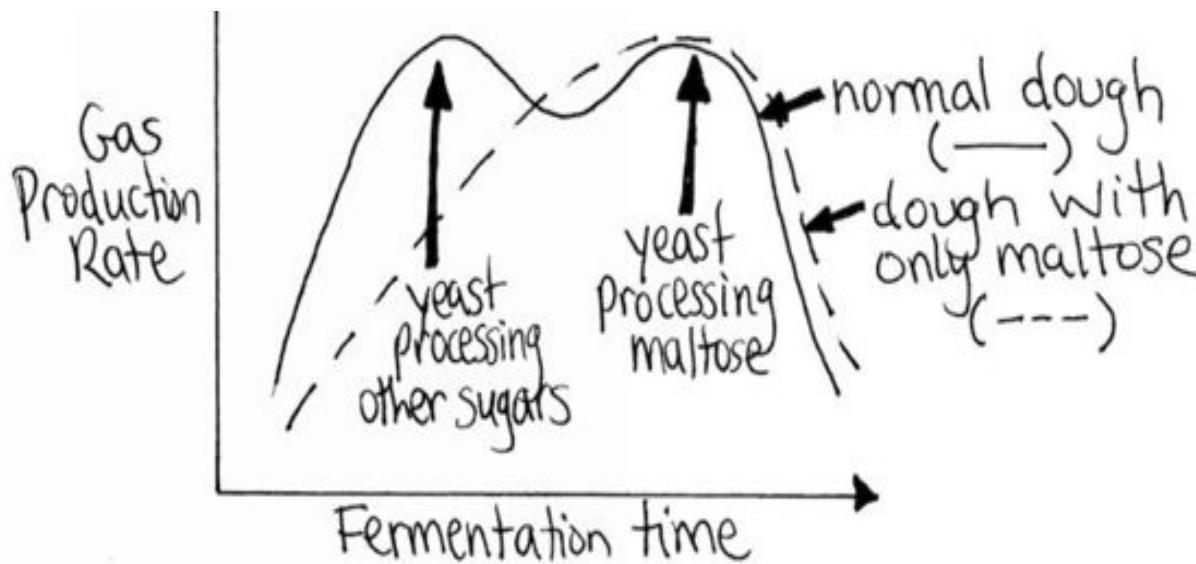
The yeasts used in bread-making are those with enzymes for processing complex sugars. Originally, scientists called the enzyme system that processed maltose into fermentation products zymase or maltozymase . In 1895, the enzyme maltase was discovered. Scientists then broke the fermentation process into smaller parts with specific enzymes described for each part. [6]

When yeast absorbs a maltose molecule, maltase breaks it in half, into two glucose molecules. When yeast encounters a sucrose molecule, the enzyme invertase is at the yeast's membrane to break the sucrose into one glucose and one fructose, which are then absorbed. Once the simple sugar molecules glucose and fructose are available, fermentation can begin.

The process of breaking starch into simple sugars is illustrated in the following diagram. Sugars other than glucose, fructose, maltose, and sucrose are fermented very slowly or not at all. [7]



Yeast processes the available glucose, fructose, and sucrose before working on maltose. Gas is produced by the fermentation reactions and can be used to monitor the amount of reaction occurring. In the following plot of gas production versus time, there is a dip in the middle, when yeast cells are switching from the glucose, fructose, and sucrose molecules to maltose. Adding glucose, fructose, or sucrose to the mix increases the size of the plot's first hump, postponing the time when the yeast must switch to maltose. If enough of these sugars is added, this first hump appears to go on forever. The curve of a special dough containing only maltose has only the second hump, with a slower increase in gas production at the start. [8]



Maltase and invertase are the simple names for the enzymes in yeast. Other more confusing names you might encounter for maltase are  $\alpha$ -glucosidase, glucoinvertase, glucosidosucrase, maltase-glucoamylase, and the “official”

scientific name,  $\alpha$ -D-glucoside glucohydrolase. Invertase is also called  $\beta$ -fructofuranosidase, saccharase, and the “official” name,  $\beta$ -D-fructofuranoside fructohydrolase. [9]

It may seem strange that the ingredients of bread happen to contain all the enzymes they need for bread-making reactions—amylases to convert starch, maltase and invertase to break down sugars. It makes sense, however, when you consider that the ingredients were (or are) living things—wheat plants, fungi, and bacteria—who possess the enzymes for their own uses. They produce sugars or break them down for energy to keep themselves alive. In making bread, we are stealing their technology and using it for our own purposes.

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- [1] Jenson, I. “Bread and baker’s yeast.” Microbiology of Fermented Foods , Volume 1. London: Blackie Academic and Professional, 1998 175.
- [2] Hosney, R.C. Principles of Cereal Science and Technology . St. Paul, Minnesota: American Association of Cereal Chemists, Inc., 1986 95.
- [3] Kulp, K. “Baker’s yeast and sourdough in U.S. bread products.” Handbook of Dough Fermentations . New York, Basel: Marcel Dekker, Inc., 2003 99.
- [4] Walden, C.C. “The action of wheat amylases on starch under conditions of time and temperature as they exist during baking.” Cereal Chemistry 32 (1955) 421-431.
- [5] De la Fuente, G. and A. Sols. “Transport of sugars in yeasts II. Mechanisms of utilization of disaccharides and related glycosides.” Biochimica et Biophysica Acta 56 (1962) 49-62.
- [6] Fisher, R. Chem. Ber. 38 (1895) 1429-1438 (in German); referenced in Robertson, J.J. and H.O. Halvorson. “The components of maltozymase in yeast, and their behavior during deadadaptation.” Journal of Bacteriology 73 (1957) 186-198.
- [7] Kulp, K. (2003) 100.
- [8] Larmour, R.K. and H.N. Borgsteinsson. “Studies of experimental baking tests. III. The effect of various salts on gas production.” Cereal Chemistry

13 (1936) 410.

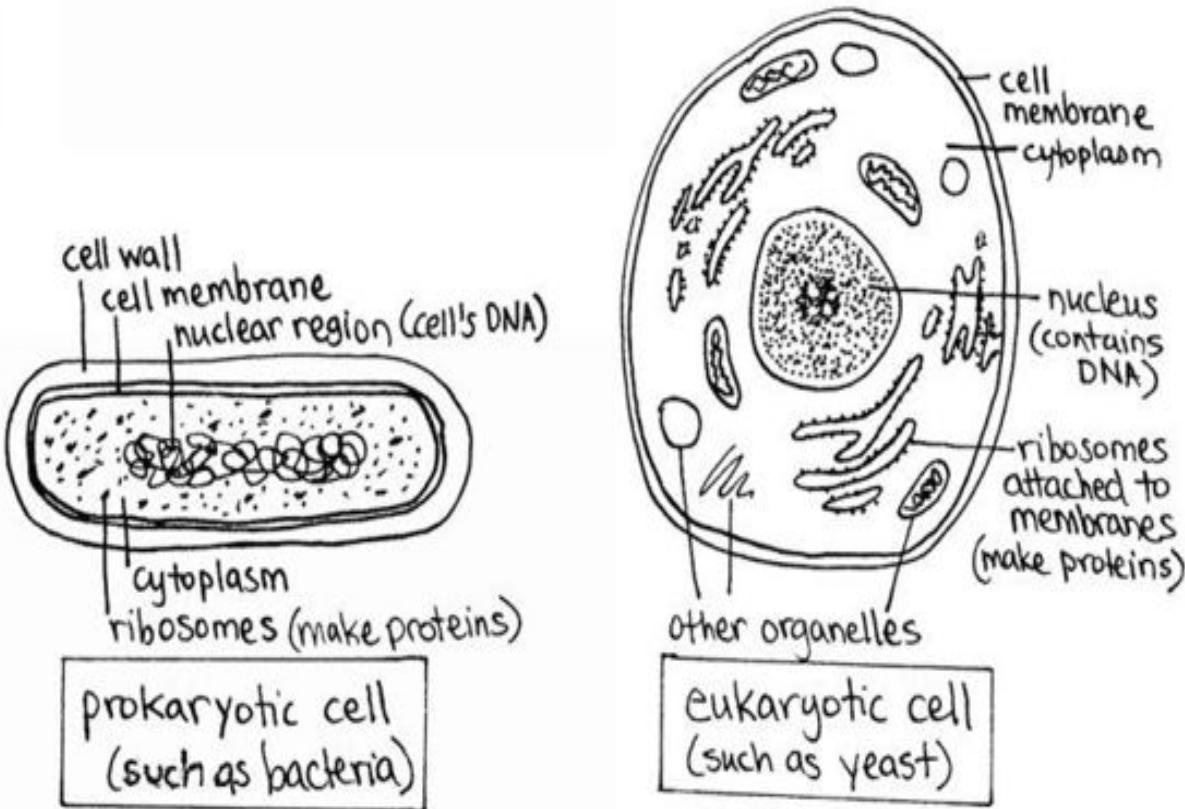
[9] Enzyme Nomenclature 1992: recommendations of the Nomenclature Committee of the International Union of Biochemistry and Molecular Biology on the nomenclature and classification of enzymes . Prepared by E.C. Webb. San Diego: Academic Press, Inc., 1992 348-349.

## **2.2 Yeast and bacteria**

Bread needs a rising or leavening agent. Cakes and quick breads use baking soda to produce the gas needed for rising. Bread, however, uses microorganisms to process sugars into gas. There are two types of microorganisms in bread-making—yeasts and bacteria. Baker's yeast, a yeast strain picked because it is good for bread-making, can be bought at the grocery store. Sourdough starter contains a mixture of wild yeasts and bacteria from the environment.

### Microorganism basics

Yeasts and bacteria are both one-celled organisms. (Thus they are small enough to be called “micro.”) Bacteria are examples of prokaryotes. Prokaryotic cells are the simplest cells; they do not have a separate nucleus or clearly defined organelles (internal parts). Yeasts are in the fungus family. They are examples of eukaryotes, a more complex class of cells. They have a separate, membrane-bound nucleus containing DNA in chromosomes, as well as several types of organelles.



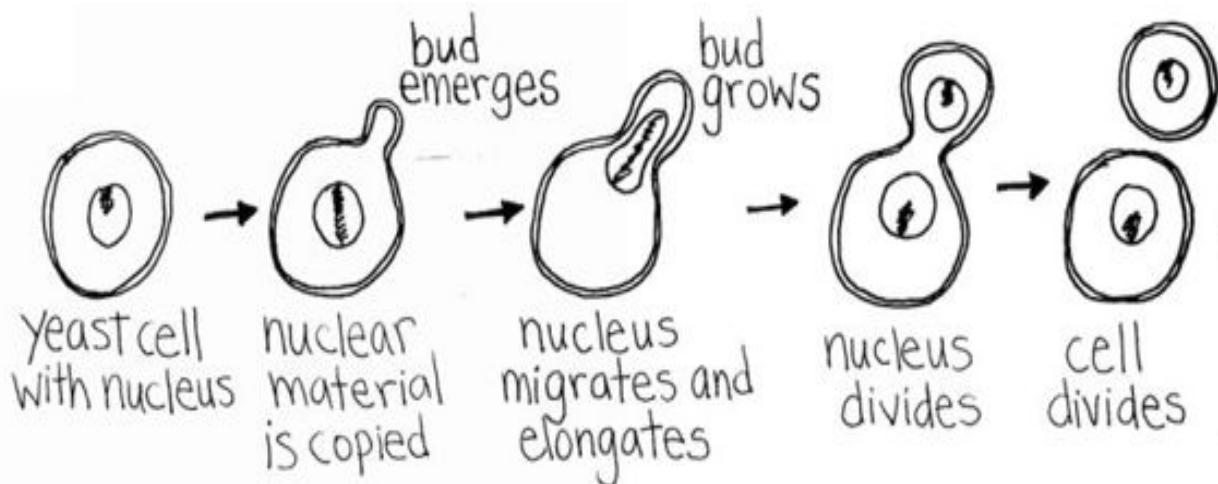
Yeasts and bacteria reproduce when conditions are right—when they have the nutrients and energy they need. Under optimal conditions, the cycle of resting and reproducing takes about one and one-half hours. [1] In bread dough, they reproduce as long as there is a supply of oxygen. Oxygen enables them to process food (sugar) efficiently. When oxygen runs out, they must get energy by a less efficient method and they stop reproducing. [2]

Every textbook seems to have a different description of microorganism reproduction, some of them contradictory. While bacteria stick to one asexual method, yeasts often have both an asexual method and a sexual one. Different species of yeast have different methods, and one species of yeast will switch between methods depending on conditions. Below we will look at reproduction in baker's yeast.

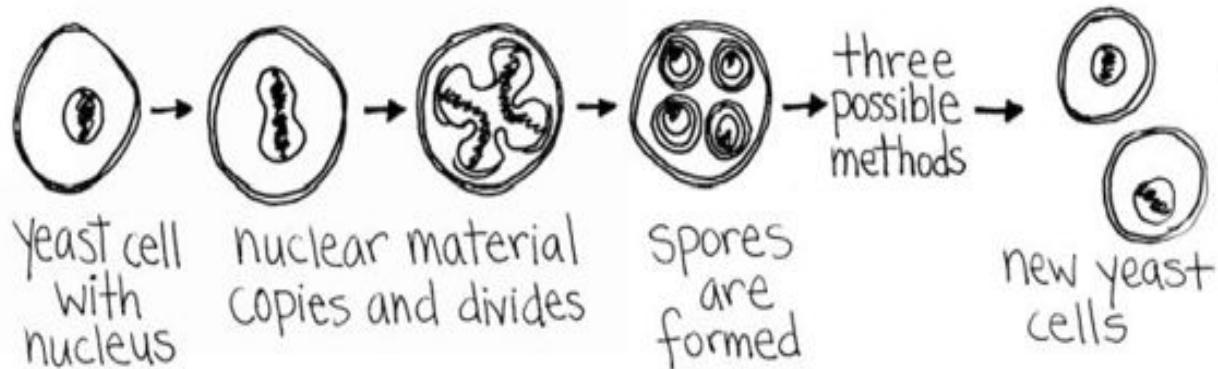
Bacteria reproduce by asexual fission, illustrated below: the nuclear material, a DNA molecule, is copied (1), and the copies separate (2). The cell membrane pinches the cell in half with nuclear material in each new cell (3 and 4), and a new cell wall forms (4 and 5).



The common form of reproduction in yeasts is budding, which is asexual. A new cell (the bud) forms at the edge of the old cell. The nuclear material is copied. The nucleus migrates to the neck where the old and new cells meet. The nucleus elongates and divides, with one copy of the nucleus in each cell, and new cell walls form, separating the new cell from its parent.

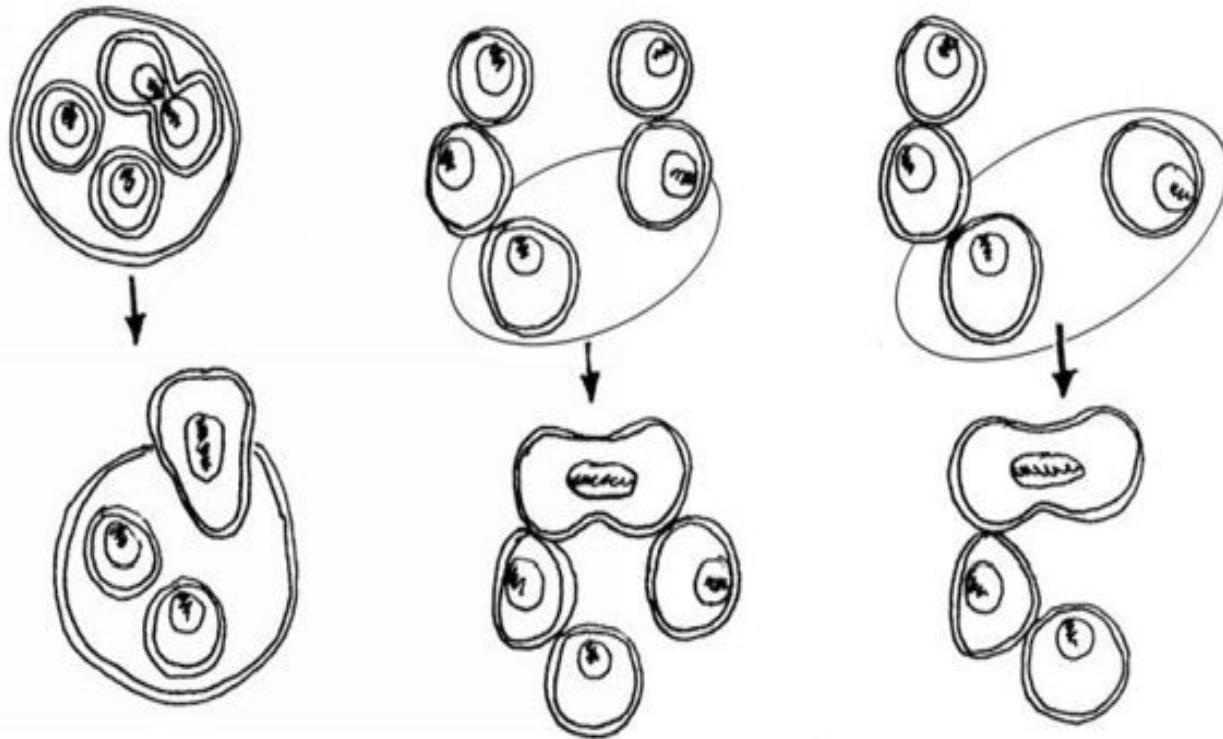


Baker's yeast can also reproduce via a sexual method. First, the nucleus copies and divides, resulting in four spores, cells with "half-nuclei." Two spores join to form a yeast cell.



Each spore needs to join with another spore to form a cell with a whole nucleus. This happens three different ways. Sometimes two of the spores join immediately and form a new yeast cell (below, left). Sometimes the spores are released and reproduce asexually, and then two of their

descendants join to form a new cell (middle). Lastly, a descendent spore might join with an original spore to form a new cell (right). [3]



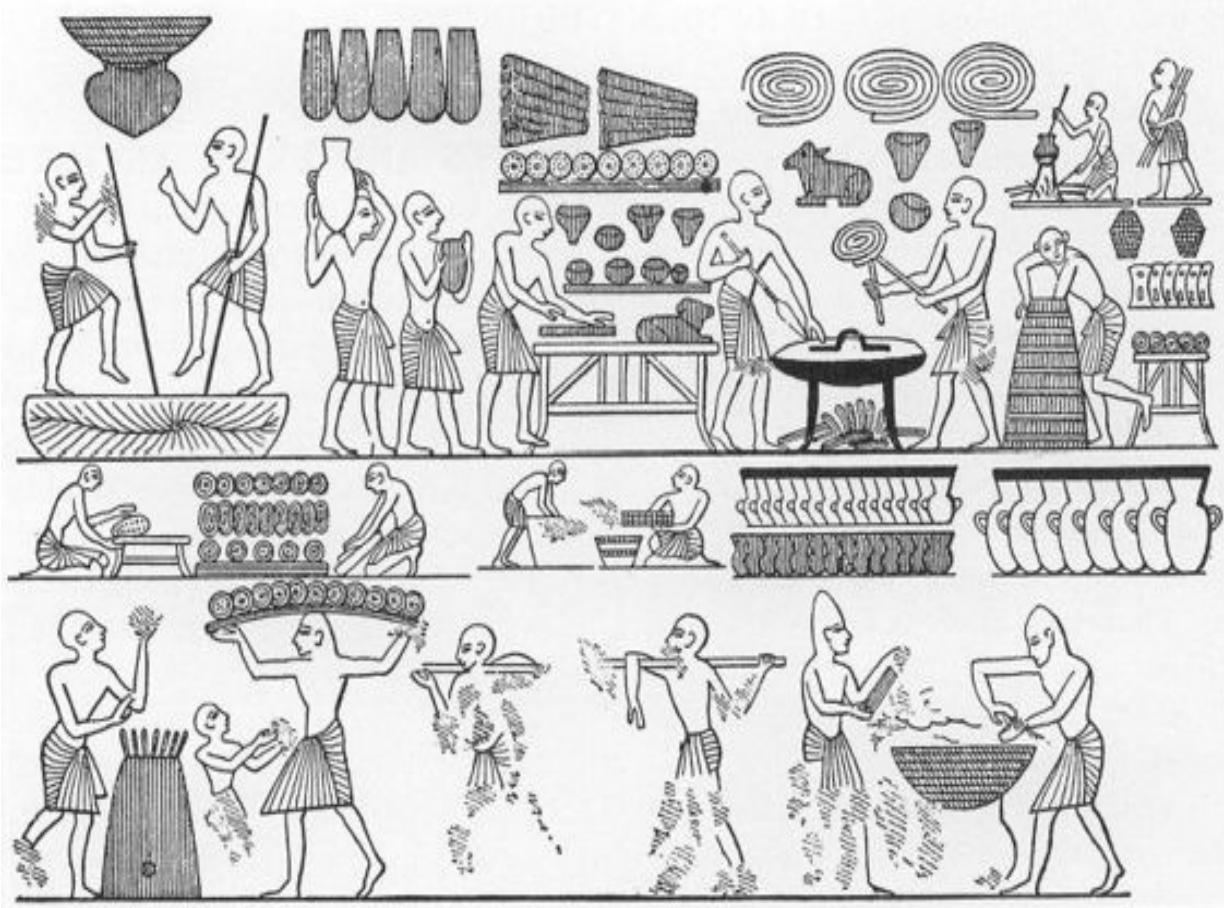
### History of yeast

Microorganisms have been used to leaven bread for thousands of years. Their leavening ability was probably discovered by accident—someone forgot to bake a flour-water mixture, microorganisms from the air moved in, and when the baker returned he discovered his mixture full of gas and decided to bake it anyway.

The ancient Egyptians are usually credited with the start of leavened bread around 2500 B.C. Archaeological evidence, however, shows the existence of leavened bread in Europe before 3800 B.C. [4] Still, the Egyptians get credit for developing bread-making technology, notably the oven, and for mass producing bread, which was used to feed the thousands of workers who built the pyramids.

Early research on Egyptian bread-making focused on data gleaned from writings and art. Discrepancies and different interpretations occurred, however, and there was little data on some aspects of the process.

The image below depicts the bakery of King Ramses, based on an Egyptian tomb painting. [Source: The Oxford encyclopedia of ancient Egypt (public domain, copyright expired)]



More recently, researchers attempted to recreate ancient bread-making processes. In one study, a bakery site near the pyramids was used, together with clay pots handmade in Cairo to resemble those shown in tomb art, emmer wheat (the wheat available to the Egyptians), and local yeasts and bacteria lured to a flour-water mixture left in a researcher's hotel window. When loaves were finally baked, the researchers noted a similarity with the shape of the nearby pyramid. [5]

A 1996 study used optical and electron microscopes to gather bread-making data in new ways. [6] Researchers studied tiny samples of ancient bread from museums. Optical microscopes showed a dense crumb, a thin crust that was darker on top, indicating baking, a fine texture with little chaff or husk, and emmer wheat as the main ingredient.

Electron microscopes provided them with more details. First, researchers examined modern bread and correlated starch characteristics with aspects of processing. For example, adequate moisture resulted in fully-merged starch granules, and certain enzymes resulted in broken-down starch. Then they examined Egyptian bread and recognized starch characteristics that were similar to those in modern bread. It appeared that Egyptian bread dough had adequate moisture but was under-mixed. Malt was an ingredient, indicated by starch-degrading enzymes. In addition, they saw yeast cells.

The technology of leavened bread spread from Egypt to the Greeks and then to the Romans, who developed the technique. Leavening came from two sources: they used yeasty foam skimmed off the top of brewing beer to leaven their finer bread, while ordinary bread was leavened with a culture of microorganisms trapped from the air and saved from one batch to the next (i.e., a starter like sourdough starter). [7] With the fall of the Roman Empire, bread baking technology all but disappeared, surviving in abbeys and monasteries until it reappeared in Europe in the 12<sup>th</sup> century. [8]

It was not until the 1800's that yeast cells were finally recognized as the cause of fermentation. In 1680, Anthony van Leeuwenhoek saw yeast cells with his microscope and sketched them but did not identify them. In 1810, Joseph Gay-Lussac described the fermentation equation but did not know that microorganisms were responsible for carrying out the process. In the 1830's, data showed that fermentation was the result of yeast, which was named "saccharomyces," but the results were not accepted.

The work of Louis Pasteur from 1857 to 1863 finally garnered for yeast the credit it deserved. He showed the role of yeast and other microorganisms in fermentation and described the different fermentation pathways possible. In the following decades, the new field of microbiology grew. Specific microorganisms were separated and grown.

In the 1800's, a switch in beer-making technique made unavailable the yeast that bread bakers had been appropriating for dough; the yeast was no longer at the top of the brew and easy to skim off. Bakers had to find a new source of leavening power. Production of yeast specially made for bakers helped standardize the fermentation process that had been irregular with the use of brewers' yeast or starters. It also enabled bakers to produce bigger bread.

Production of yeast involves obtaining a pure sample of yeast cells (i.e., the correct strain of the desired species), putting it on a surface for growth called a substrate, and encouraging it to grow and multiply. When enough yeast cells have been produced, they are washed and packaged. Starting in 1846, yeast for bakers was obtained with the Vienna Process in which yeast cultures were grown on grain. In 1877, the Air Process was developed in Copenhagen, based on Pasteur's observation that blowing air over the substrate would stimulate yeast growth. [9] The air provided aerobic conditions for the yeast, helping them work efficiently and eliminating production of alcohol (discussed in the following section "Fermentation.") Other advances in yeast production included replacing grain with molasses as a substrate for yeast growth and using a feeding schedule to maintain a proper concentration of sugar available as food. [10]

### Classification of bread-making microorganisms

There are many different yeasts and bacteria in the world, some of which work for bread-making and most of which do not. Most of the bread-making yeasts are in the genera (i.e., genus-es) *Saccharomyces* or *Candida*, while most of the bacteria are in the genus *Lactobacillus*. Baker's yeast consists of certain strains of one yeast species, *Saccharomyces (S.) cerevisiae*. Sourdough starter contains a combination of yeasts and bacteria that depends on where the starter was created.

*S. cerevisiae* has been chosen for baker's yeast because it performs well—it has the enzymes needed to process maltose (some yeasts do not) and it does so efficiently, producing the biggest loaf of bread in baking tests. When you use baker's yeast, other yeasts and bacteria may be present, floating in from the air, but the large population of baker's yeast remains in control of the system.

Sourdough starter will be discussed in detail in chapter three, but a brief explanation is given here. To create a starter, flour and water are mixed and left at room temperature. Yeasts and bacteria from the air and flour take hold in the mix, fermenting sugars and producing gas. The starter needs to be fed more flour and water to stay alive. After some time, the population stabilizes into a thriving system or culture.

Starters created in different locations have different populations of yeasts and bacteria. The flour used for feeding can also influence the inhabitants of the starter. In a 1971 study of San Francisco sourdough starter, starters from five bakeries were examined and all found to have the same yeast, *Saccharomyces exiguum*. Only one starter had another species of yeast as well. The bacteria present were a new type, christened *Lactobacillus sanfrancisco*. [11]

The 1971 paper indicated a system of yeasts and bacteria that resisted contamination by other microorganisms. There were a few hints as to how. The common yeast in all the starters was one that thrived at acidic conditions, such as those found in starter. It was also resistant to an antibiotic substance released by the bacteria, which would kill off other types of yeast. Finally, the bacteria fermented maltose but the yeast did not, instead fermenting the small percent of other sugars present. Thus the two microorganisms were not competing for food.

For years I thought the microorganisms in a starter would change if it changed location—new local yeasts and bacteria would move in, displacing the old ones. This bothered me because companies sell starter marketed as the authentic starter of a region of the world. I now know of the evidence (described above) that the system resists contamination. It seems possible, however, that a foreign starter could succumb to local invasion, perhaps by a local species that thrives in the starter better than its current community members.\* As a home baker, you can decide for yourself by maintaining starters from different locations and comparing the flavors of the bread they produce. (\*Note: There is support for both sides of the issue. One of my students had a half-dozen starters in his fridge and insisted they were all different. Another student told me she had bought San Francisco starter several times, and it always ended up tasting just like her Carrboro, NC, starter.)

Much effort has been spent trying to identify the yeasts and bacteria present in sourdough starters and other starter cultures. [12] In 1894, yeasts and bacteria were first found in sourdough starter. In 1921, lactobacilli (one kind of bacteria in starter) were observed to produce gas and acid. In 1924, 200 strains of bacteria were identified in dough.

The first attempt to classify the bacteria of bread-making was in 1919. Many different criteria can be used for classification—which pathways of fermentation do the microorganisms use? Which sugars do they ferment? Which genetic family are they in? In addition, new species are discovered, and new research methods reveal new characteristics of old species. Studies still attempt to classify the microorganisms, called the microflora of sourdough.

The following lists should give an idea of the variety of organisms possible. Lactic acid bacteria, a.k.a. lactobacillaceae, include fourteen genera: *Bifidobacterium*, *Streptococcus*, *Carnobacterium*, *Tetragenococcus*, *Enterococcus*, *Vagococcus*, *Lactobacillus*, *Weissella*, *Lactococcus*, *Aerococcus*, *Leuconostoc*, *Alloiococcus*, *Pediococcus*, and *Atopobium*. Some of the lactic acid bacteria identified in sourdough are *Lactobacillus* (*Lb.*) *acidophilus* , *Lb. amylovorus*, *Lb. crispatus*, *Lb. delbrueckii* (strains—*bulgaricus*, *delbrueckii*, *lactis* ), *Lb. johnsonii*, *Lb. farciminis*, *Lb. alimentarius*, *Lb. casei*, *Lb. plantarum*, *Lb. brevis*, *Lb. buchneri*, *Lb. fermentum*, *Lb. fructivorans*, *Lb. reuteri*, *Lb. pontis*, *Lb. sanfranciscensis*, *Lb. confusus* (now called *Weissella confusus* ), *Pediococcus acidilactici* , and *Pediococcus pentosaceus* . Some of the yeasts identified in sourdough are *Candida* (*C.*) *boidinii*, *C. guilliermondii*, *C. stellata*, *C. tropicalis*, *C. holmii*, *C. krusei*, *C. milleri*, *Hansenula* (*H.*) *anomala*, *H. subpelluculosa*, *H. tropicalis*, *Pichia* (*P.*) *polymorpha*, *P. saitoi*, *Saccharomyces* (*S.*) *cerevisiae*, *S. dairensis*, *S. ellipsoideus*, *S. fructuum*, *S. inusitatus*, *S. exiguum*, and *Torulopsis holmii* .

The following section on fermentation focuses on the reactions that occur in baker's yeast, *S. cerevisiae* . Similar reactions occur in the microorganisms of sourdough starter.

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- [1] Phaff, H.J., M.W. Miller, and E.M. Mrak. *The Life of Yeasts* , 2nd edition. London, Cambridge: Harvard University Press, 1978 56.
- [2] Kulp, K. "Baker's yeast and sourdough in U.S. bread products." *Handbook of Dough Fermentations* . New York, Basel: Marcel Dekker, Inc., 2003 103.
- [3] Phaff, H.J., M.W. Miller, E.M. Mrak (1978) 55-57, 75-80.

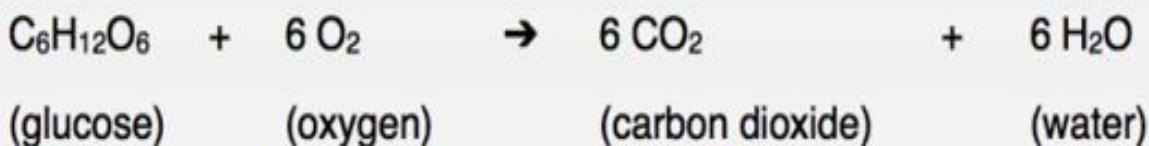
- [4] Wirtz, R.L. "Grain, baking, and sourdough bread: a brief historical panorama." Chapter 1 in *Handbook of Dough Fermentations*. New York: Marcel Dekker, Inc., 2003 5.
- [5] Roberts, D. "Rediscovering Egypt's bread-baking technology." *National Geographic* (January 1995) 32-35.
- [6] Samuel, D. "Investigation of ancient Egyptian baking and brewing methods by correlative microscopy." *Science* 273 (1996) 488-490.
- [7] Oura, E., H. Suomalainen, and R. Viskari. "Breadmaking." Chapter 4 in *Economic Microbiology*, Volume 7: *Fermented Foods*. London, New York: Academic Press, 1982 88.
- [8] Wirtz, R.L. (2003) 8.
- [9] Sanderson, G.W. "Yeast products for the baking industry." *Cereal Foods World* 30 (1985) 770-775.
- [10] Phaff, H.J., M.W. Miller, and E.M. Mrak (1978) 253-254.
- [11] Sugihara, T.F., L. Kline, and M.W. Miller. "Microorganisms of the San Francisco sour dough bread process, I. and II." *Applied Microbiology* 21 (1971) 456-458, 459-465.
- [12] Stoltz, P. "Biological fundamentals of yeast and lactobacilli fermentation in bread dough." Chapter 2 in *Handbook of Dough Fermentations*. New York: Marcel Dekker, Inc., 2003.

## 2.3 Fermentation

The main reactions occurring in dough are referred to as fermentation . The simplified story is that yeast “eats” sugar, turning it into alcohol and carbon dioxide gas. The alcohol results in bread flavor. The carbon dioxide causes the dough to rise; the holes in bread were once bubbles of carbon dioxide before the bread was baked.

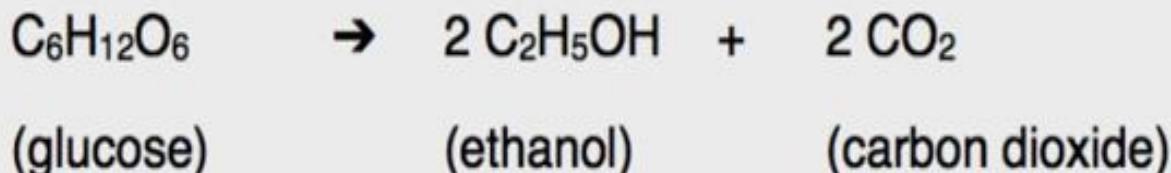
The real story is much more complicated. The bread-making term “fermentation” actually encompasses two processes, called by the scientific names respiration and fermentation . When oxygen is present, yeast is able to perform respiration. In the absence of oxygen, it switches to fermentation.

The basic reaction of respiration is

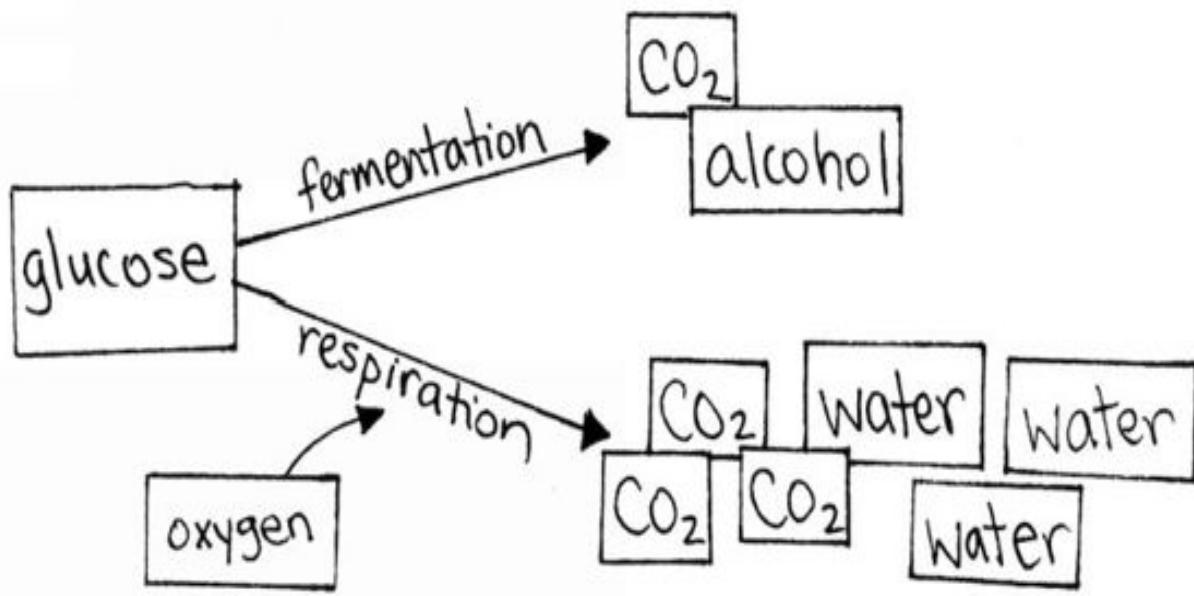


This produces lots of carbon dioxide gas, causing the dough to rise faster. It does not produce any alcohol, however.

In the absence of oxygen, yeast performs fermentation. There are different fermentation pathways with different products. The products depend on which enzymes are present—different yeasts contain different enzymes. With bread-making yeast, the reaction is

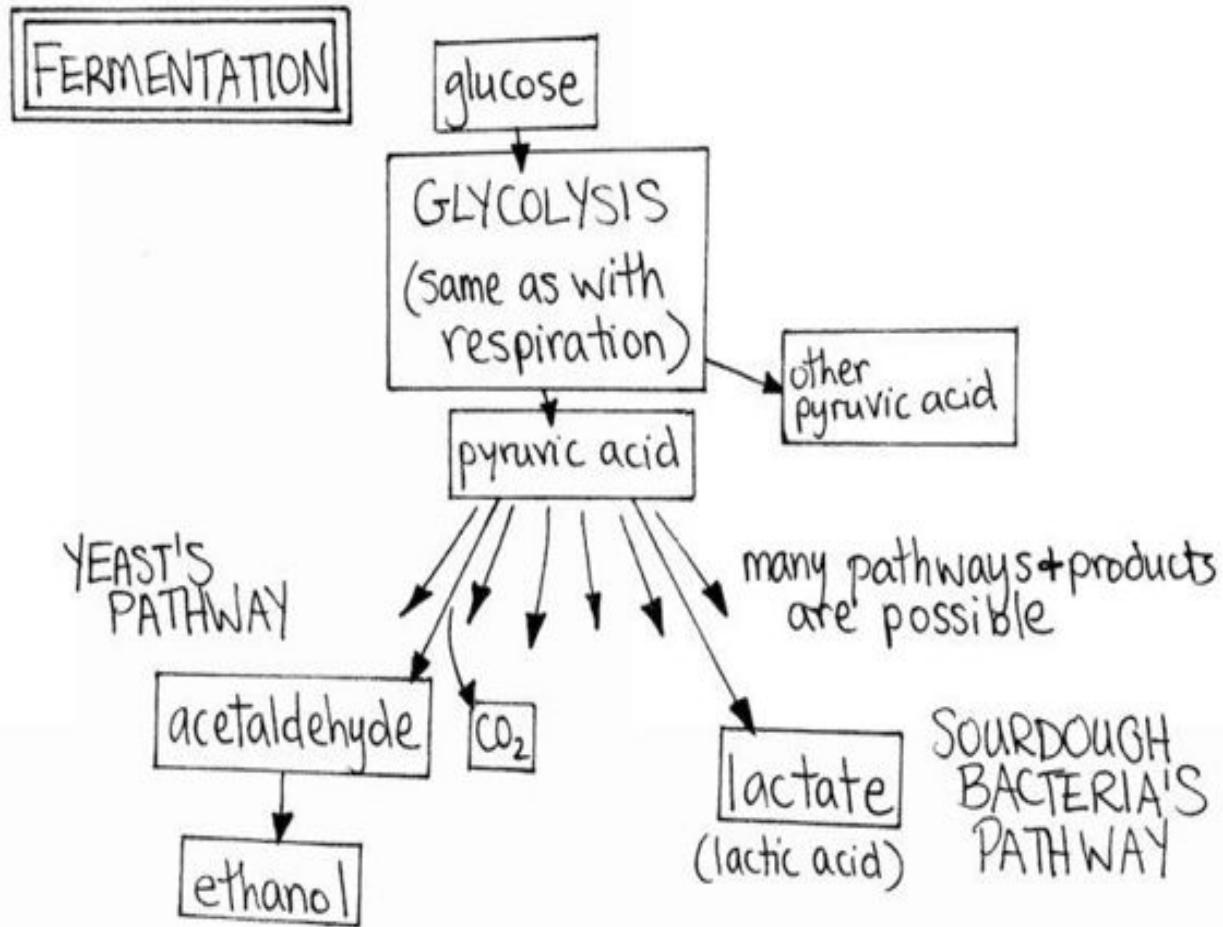


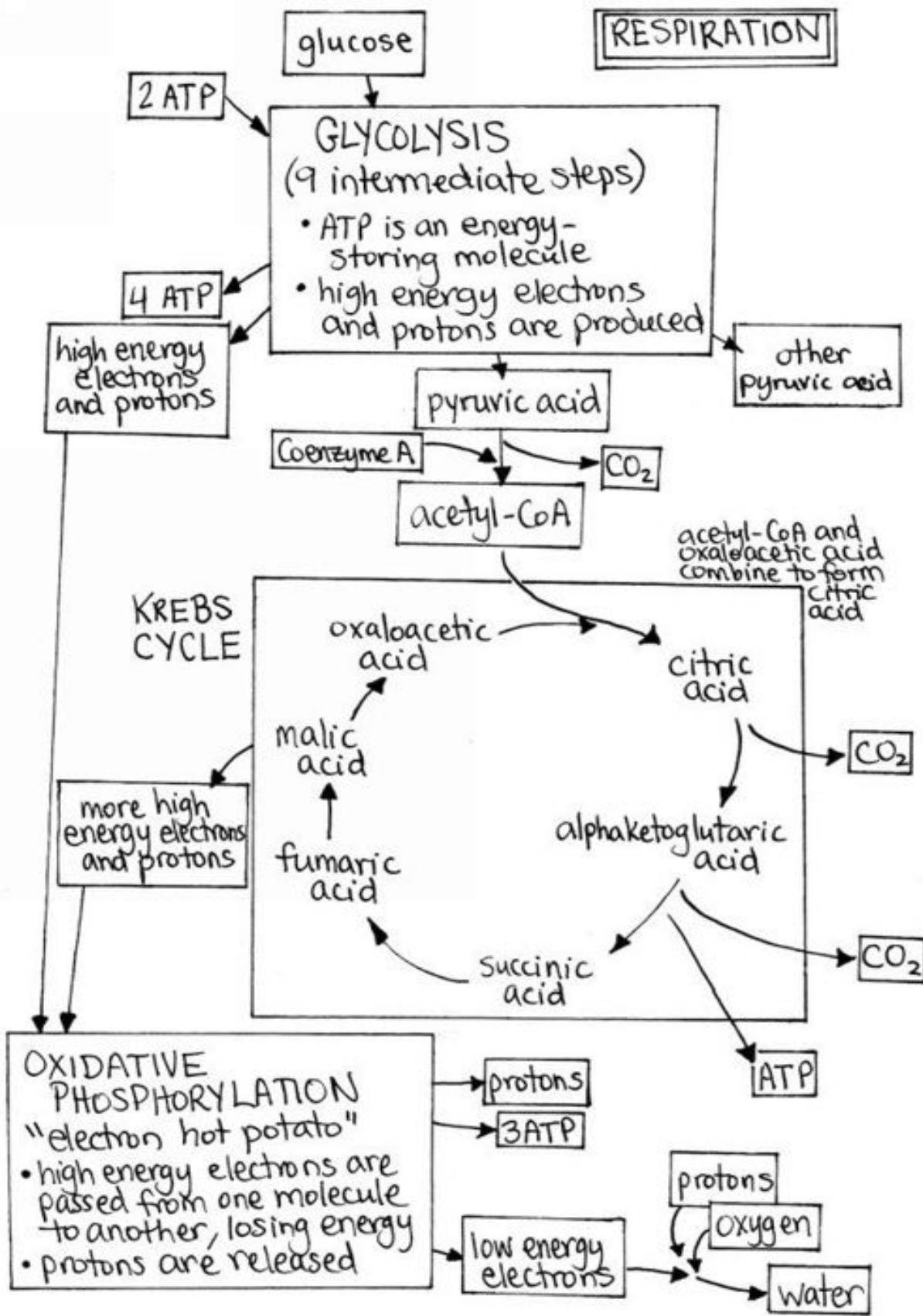
This process produces less carbon dioxide than respiration but also produces ethanol. This ethanol increases the flavor of the bread. As a side note, the microorganisms in sourdough starter perform a fermentation reaction that produces lactic acid, resulting in a different flavor.



In dough, respiration occurs until the oxygen is used up and then fermentation begins. Adding air (and therefore oxygen) to dough while kneading enables more respiration to occur, resulting in faster-rising but less flavorful dough. This effect can easily be amplified when mixing in a mixer. Commercial bakeries often strive for more respiration because it speeds up the bread-making process. The balance of the two processes found in homemade dough results in a dough that rises in a timely manner and also has good flavor.

Even this more complicated picture of fermentation is simplified. For example, what exactly does yeast do to a glucose molecule to turn it into carbon dioxide? The specifics of the respiration and fermentation reactions—the steps, the intermediate molecules, and the mechanisms of each step—can be found in a microbiology textbook. There are numerous pathways and cycles; basic diagrams adapted from those in textbooks are shown below.





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## 2.4 Flavor and color

Flavor in bread comes from both fermentation and baking. The fermentation reactions result in organic “flavor molecules.” At the crust, sugars and amino acids react in the heat of the oven to form flavor molecules. These crust reactions also affect the bread’s color.

### Flavor from fermentation

Recall from the previous section that more flavor is produced when yeast performs fermentation than when it performs respiration. The fermentation equation shows ethanol as a product, while respiration does not appear to produce any organic molecules. Oven temperatures are above the boiling point of ethanol, however, and most ethanol evaporates during baking. A little is left in the dough, trapped inside where it cannot evaporate into the air. [1]

Most of the fermentation flavor actually comes from “side reactions.” Once ethanol is produced, it can convert into other organic molecules. Midway through fermentation, a molecule might step out and do something different, converting to a flavor molecule or reacting to form one. (Presumably this could happen during respiration, too.) Reactions not associated with fermentation (such as the conversion of amino acids to organic molecules by yeast) can also produce flavor molecules. [2,3,4]

Microorganisms in the dough other than those used intentionally (i.e., the baker’s yeast) can also form flavor compounds.[5]

### Flavor from baking

Originally, it was thought that crust flavor and color came from caramelization reactions in the oven. Basically, at high temperatures, sugars melt and then oxidize or burn. First the sugars split into single rings. These rings then come undone, and the new molecules form chains. At this point, the color of the system changes from clear to yellow to dark brown. Other new, small molecules form too, some of which are organic acids that are good for bread flavor. Over time, different, bitter-tasting molecules will form.

Other reactions that cause flavor and color development are carbonyl-amine reactions or Maillard reactions, named after the man who first described them in 1912. These are reactions between sugars and amino acids or other small amines. On heating, sugars split into single rings that open to form small carbohydrate molecules, specifically aldehydes and acids. Proteins are likewise degraded into single amino acids. The carbohydrates and amino acids react to form many chemicals. The chemicals react with each other to form flavor compounds. Numerous combinations are possible with Maillard reactions. Which combination occurs is highly dependent on temperature, acidity, neighboring chemicals, and chance. [6]

In 1947, it was proposed that Maillard reactions might be at work in baking. Subsequent research in 1953 showed that Maillard reactions, not caramelization reactions, are mainly responsible for crust color: low protein flour with adequate sugar produced loaves with a grey-white crust. Caramelization reactions could have occurred in this system but did not. Adding gluten to this flour helped the color, as did adding egg (i.e., protein). A final test of “doughs” made with only starch, protein, and/or sugar confirmed that both proteins and sugars are needed for crust color to develop. [7]

Since 1953, scientists have been quick to note that Maillard reactions are the predominant crust-browning reactions. Decreasing amino acid levels and the appearance of certain carbonyl compounds are considered evidence of Maillard reactions at work in the crust. [8,9]

There is still evidence that caramelization reactions are occurring, however [10], and a 1999 source suggests that pH and water content affect the browning reactions: Maillard reactions dominate at low water levels and higher pH's, while caramelization reactions cause browning when a lot of water is present. [11]

### Identifying flavor compounds

Much work has been done to identify the flavor compounds in dough and bread. In 1966, over 70 compounds had been identified, although it was not supposed that all of them survived the oven. [12] By 1991 this number was up to 296, including bases, aldehydes, ketones, furans, esters, acids, alcohols, sulfur compounds, and hydrocarbons.

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- [1] Maloney, D.H. and J.J. Foy. "Yeast fermentations." *Handbook of Dough Fermentations* . New York: Marcel Dekker, Inc., 2003 53-54.
- [2] Drapron, R. and B. Godon. "Role of enzymes in baking." Chapter 10 in *Enzymes and their Role in Cereal Technology* . St. Paul, Minnesota: American Association of Cereal Chemists, Inc., 1987 303.
- [3] Maloney, D.H. and J.J. Foy (2003) 53.
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- [7] Bertram, G.L. "Studies on crust color. I. The importance of the browning reaction in determining the crust color of bread." *Cereal Chemistry* 30 (1953) 127-139.
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- [9] El-Dash, A.A. and J.A. Johnson. "Influence of yeast fermentation and baking on the content of free amino acids and primary amino groups and their effect on bread aroma stimuli." *Cereal Chemistry* 47 (1970) 247-259.
- [10] Linko, Y. and J.A. Johnson (1963).
- [11] DeMan, J.M. *Principles of Food Chemistry* . Gaithersburg, MD: Aspen Publishers, 1999 128.
- [12] Johnson, J.A., L. Rooney, and A. Salem (1966).

## 2.5 Water and protein

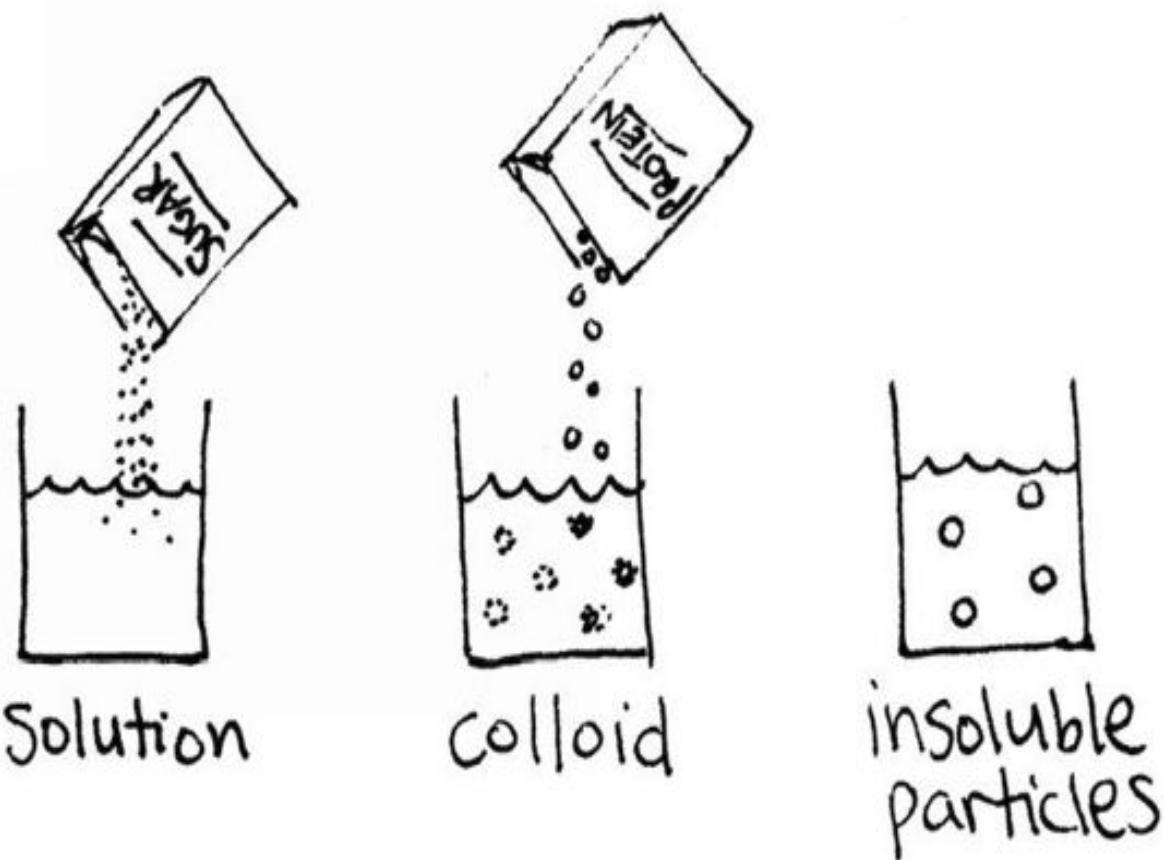
Water “hydrates” flour to make dough. What exactly does this mean? The two main parts of flour are starch granules—starch molecules packed together—and protein molecules. The large protein molecules bond with water to form the network called gluten. Water molecules move among the starch and gluten, forming bonds in certain places and causing changes in the starch and gluten structure.

As early as 1820, scientists were studying water’s behavior toward wheat starch. [1] Scientists (and bakers) knew that some flours (“strong”) produced good, big loaves of bread, while others (“weak”) did not. There were different theories on why. Some thought strength depended on how much water had been absorbed. Others thought it was the presence of acid and salt that changed the strength, not an actual property of the flour. [2]

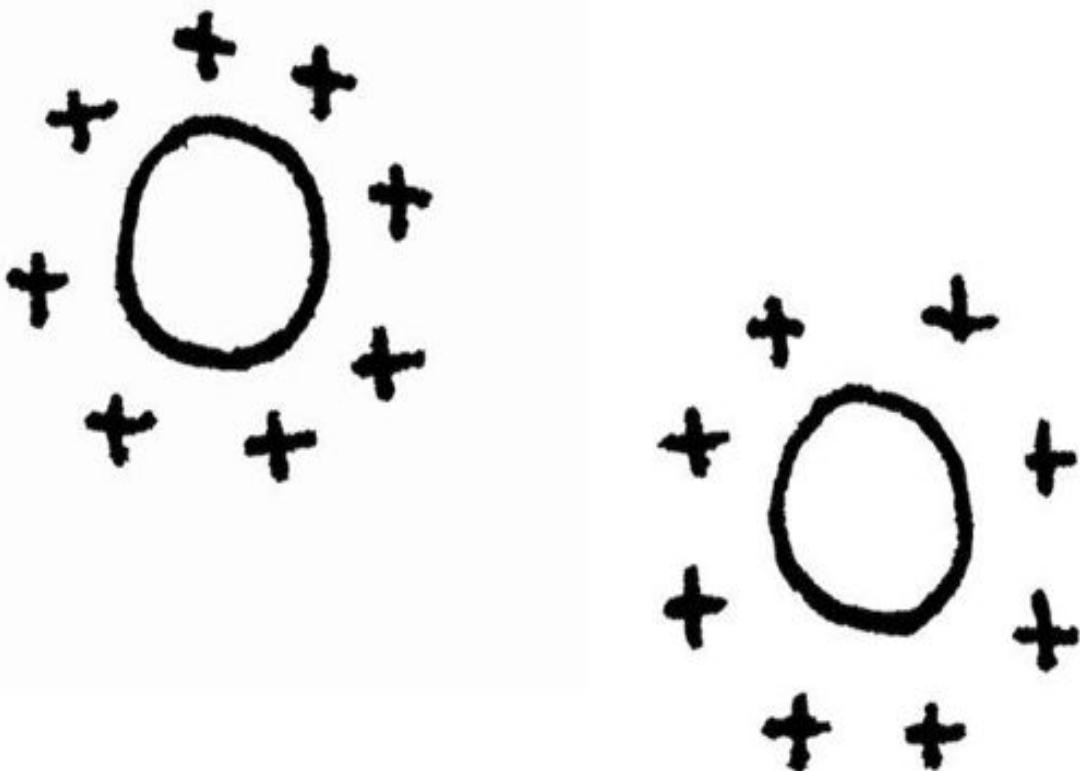
A hydration study in 1918 used gluten from five different flours, both strong and weak. Pieces of gluten were submerged in water and then weighed. Changes in weight measured how much water each absorbed. Data was taken with acid and salt water too. The study concluded that flour strength is an inherent property of the gluten and is related to the colloidal nature of the proteins, discussed below.

### Basics of the protein-water system

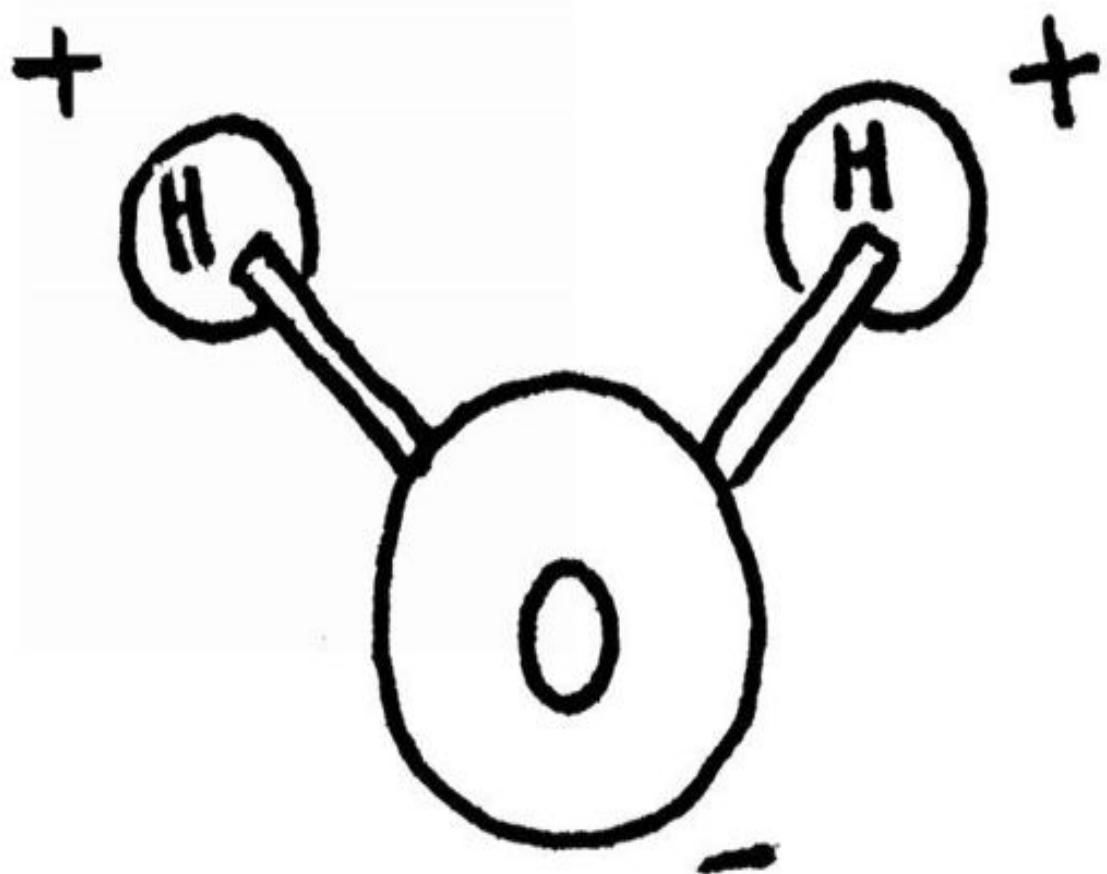
A colloid is a suspension of particles in a medium, such as water. It is somewhere between a solution of dissolved particles—like relatively teeny sugar molecules in water—and an insoluble mix—like non-polar oil molecules or relatively large grains of sand in water. The colloid particles do not dissolve because they are too big. They can be big molecules or aggregates of molecules. Colloids are relevant to bread-making because dough is a colloid of protein molecules suspended in water. (Technically, this is a sol, a colloid of a solid in a liquid.)



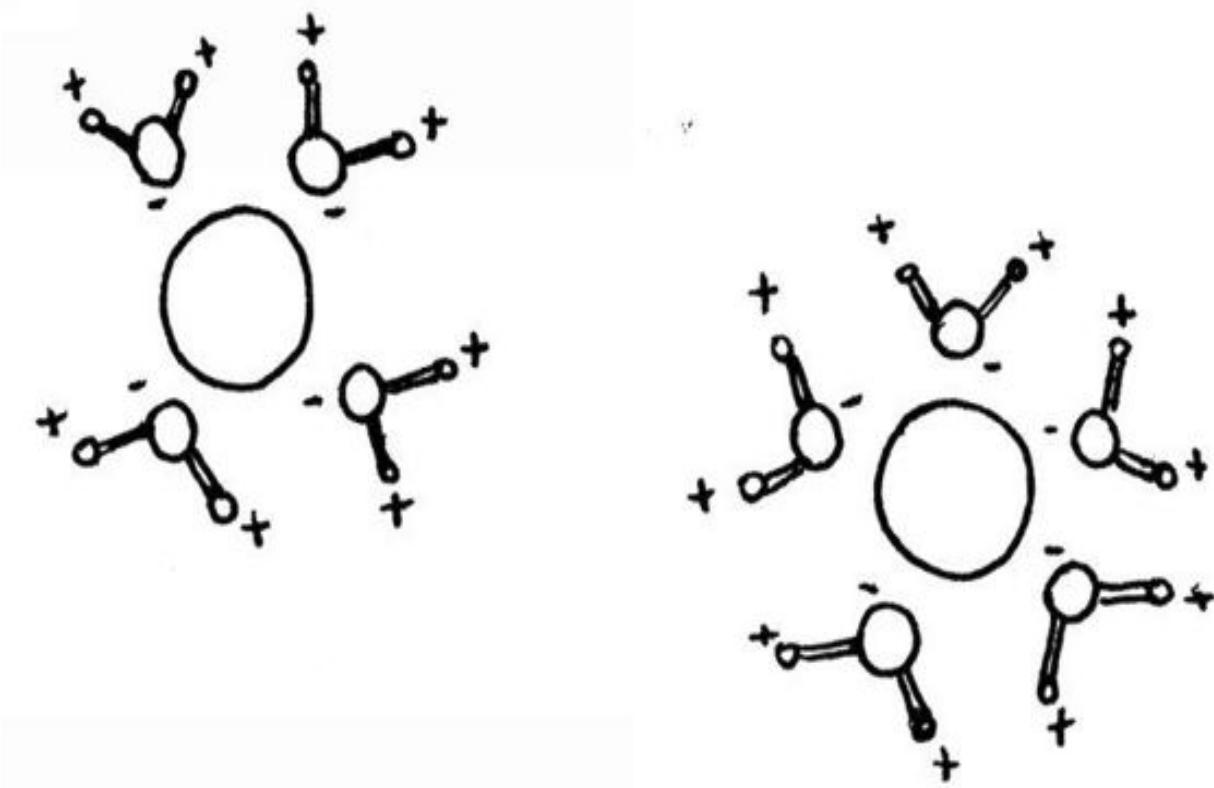
Colloids are stabilized by electrostatic repulsion, the repulsion due to charges on the colloid particles. Even though the solid particles may be neutral overall, there are charges on their surfaces that attract ions or polar molecules in the medium. Thus the particles end up with charged layers around them (below). These charged layers repel each other, preventing the particles from aggregating and stabilizing the colloidal system.



Water molecules are polar. This is because the oxygen atom in water has a greater ability to attract electrons than the hydrogen atoms do. The oxygen atom hogs the molecule's electrons and thus has a slight negative charge while the hydrogen atoms have slight positive charges (below).



If the colloidal medium is water, polar water molecules orient themselves around each particle (below). This water layer is effectively a charged layer—more specifically, it is a charged double layer with a negative inner layer and a positive outer layer. The positive outer layers of the particles repel each other.



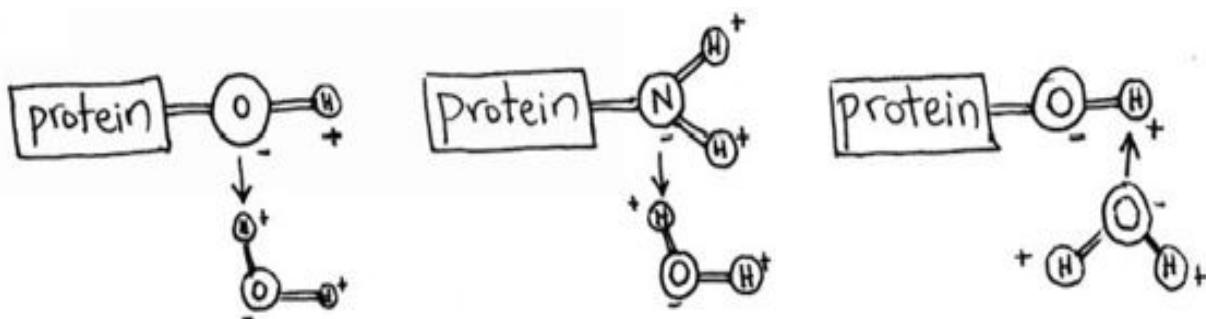
Colloids can be destroyed by heat or the addition of salt. Heat increases the energy of the particles, causing them to move about faster. They bump each other more and with greater force, so they are more likely to overcome their repulsion and aggregate. Adding salt, which dissolves into charged ions, interferes with the electrical layers stabilizing the particles and results in aggregation.

#### Research on water's role in dough

In the 1920's, research on the hydration of colloids became popular. A 1921 study classified five different types of water retention based on the effort it took to remove the water from the system. A 1924 study found seven forms of water. The general idea was that water in colloidal systems was not all held equally. A concept of "free" and "bound" water developed. [3,4] Researchers measured percentages of bound water in colloidal systems, including dough.

In 1933, two mechanisms for water binding in protein were proposed. The first, now known as hydrogen bonding, consisted of water molecules partially sharing electrons with certain atoms on the proteins. Recall the

partial charges on the atoms of the water molecule. Similar charges occur on certain atoms in proteins—partial negative charges on oxygen (O) and nitrogen (N) atoms and partial positive charges on hydrogen (H) atoms that are bonded to them. (Other atoms do not have the electron-pulling capability of oxygen and nitrogen and thus, though they can be partially charged, they do not have big enough charges to form a hydrogen bond.) Water molecules form hydrogen bonds with oxygen, nitrogen, and hydrogen atoms in the proteins as shown by the arrows in the figure below.



A second mechanism proposed for water-protein binding was electrical attraction. Certain sites on the protein may have a positive or negative charge caused by an atom missing an electron or gaining an electron, respectively. Polar water molecules are attracted to these charged sites and orient themselves around them, forming a kind of bond.

These two proposed mechanisms illustrated the point that there is not one kind of bound water. In addition to the two mechanisms, water held by each may be held with varying amounts of strength, depending on the atoms involved, the distance of the bond, and the neighboring atoms. Another complication is that hydration can change with changes in the system, such as adding acid or salt, and with changes in the protein configuration. For example, if the protein stretches out, more binding sites may become available and hydration will increase. [5]

Over the next three decades, bound water continued to be a topic of study. The 1960's brought the advent of nuclear magnetic resonance (NMR), a technique that can identify the components of a sample based on how they respond to a magnetic field. Basically, as the strength of a magnetic field is increased, the nuclei of the different atoms in a sample in the field respond at different field strengths. This is represented by a plot showing peaks at the

field strengths where there was a response. The peak height is relative to the amount of response and therefore the amount of that kind of atom present. NMR could be used to study bound water because the hydrogen atoms of the water molecules give different signals when they are bound or free.

A 1969 study used NMR to study water bound to proteins. In addition to finding evidence of bound water that existed well below the freezing point of normal, free water, the bound water percentage changed with changes in the conformation of the protein. This suggested that there were different types of bound water, such as water bound to the surface of the molecule versus water trapped in cavities that would be freed when the molecule unfolded. The energy needed to free a bound water molecule equaled the energy of a hydrogen bond, suggesting the presence of this kind of bonding. [6]

Studies throughout the 1970's continued to use NMR to study bound water in dough. A relatively recent review in 1986 of the role of water in baking focuses mainly on NMR data. Even in this subset of the data, there is disagreement on the percentage of bound water. [7] The general theme that emerges is that, while a basic understanding of the possibilities of water binding in dough has been found, many of the details are still up for debate.

Thankfully, a basic understanding of water's behavior is all that a home baker needs. When dough is mixed, water hydrates protein by forming several types of bonds with it. Some water molecules are tightly held, while others can come loose fairly easily. Some are trapped within folds of protein and released when the protein changes shape. This protein-water system is the well-known substance gluten. More and stronger bonds with water form stronger gluten and therefore stronger dough.

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[1] Kuhlmann, A.G. and O.N. Golossowa. "Bound water in bread making." Cereal Chemistry 13 (1936) 202-217.

[2] Gortner, R.A. and E.H. Doherty. "Hydration capacity of gluten from 'strong' and 'weak' flours." Journal of Agricultural Research 13 (1918) 389-418.

[3] Skovholt, O. and C.H. Bailey. "Free and bound water in bread doughs." Cereal Chemistry 12 (1935) 321-355.

- [4] Kuhlmann, A.G. and O.N. Golossowa (1936).
- [5] Lloyd, D.J. and H. Phillips. “Protein structure and protein hydration.” *Transactions of the Faraday Society* 29 (1933) 132-146.
- [6] Kuntz Jr., I.D., T.S. Brassfield, G.D. Law, and G.V. Purcell. “Hydration of macromolecules.” *Science* 163 (1969) 1329-1331.
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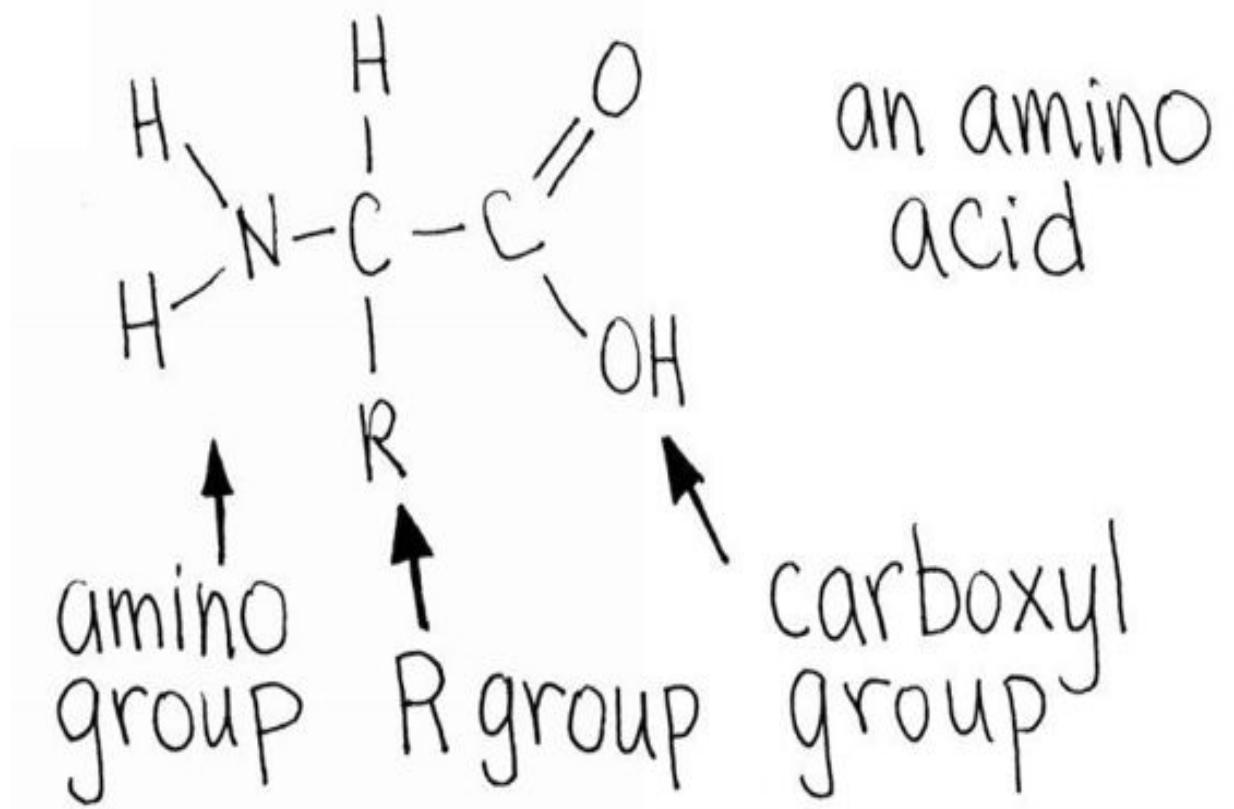
## 2.6 Gluten structure

When dough is mixed, the proteins in the flour combine with water to form longer chains, called gluten. Kneading the dough enables the gluten to form a network of chains and sheets. This network of gluten is strong and elastic. It resists the building pressure of carbon dioxide in the dough, slowly stretching and allowing the dough to rise.

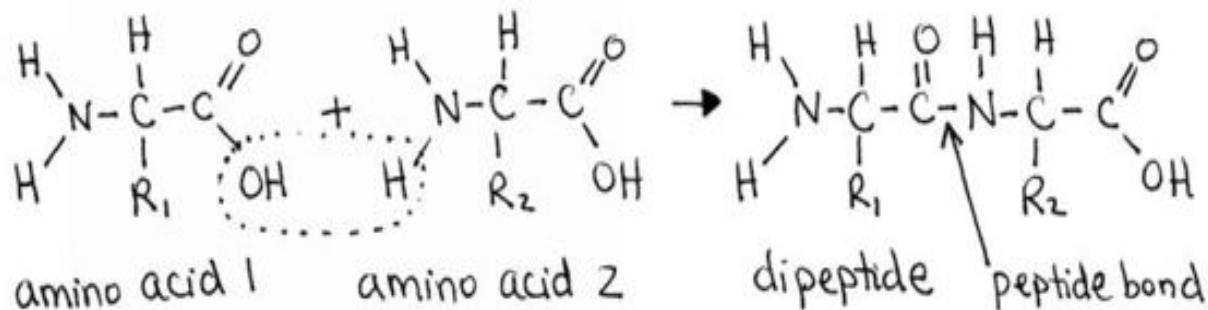
The amount of scientific literature on gluten is monstrous. To present it in a somewhat organized fashion, I will begin with basic protein information, then give a brief discussion of what is now believed about gluten structure, and finally give a chronological history of gluten research.

### Protein basics

Proteins are chains of molecules called amino acids, pictured below. In these pictures, each letter represents an atom (H=hydrogen, C=carbon, N=nitrogen, and O=oxygen) and lines represent the chemical bonds between atoms. An amino acid has an amino group and a carboxyl group ; amino just means the group contains nitrogen, and carboxyl means it contains carbon and oxygen. Each amino acid is the same except for a third group, the R group. There are twenty common R groups and therefore twenty amino acids commonly found in proteins.



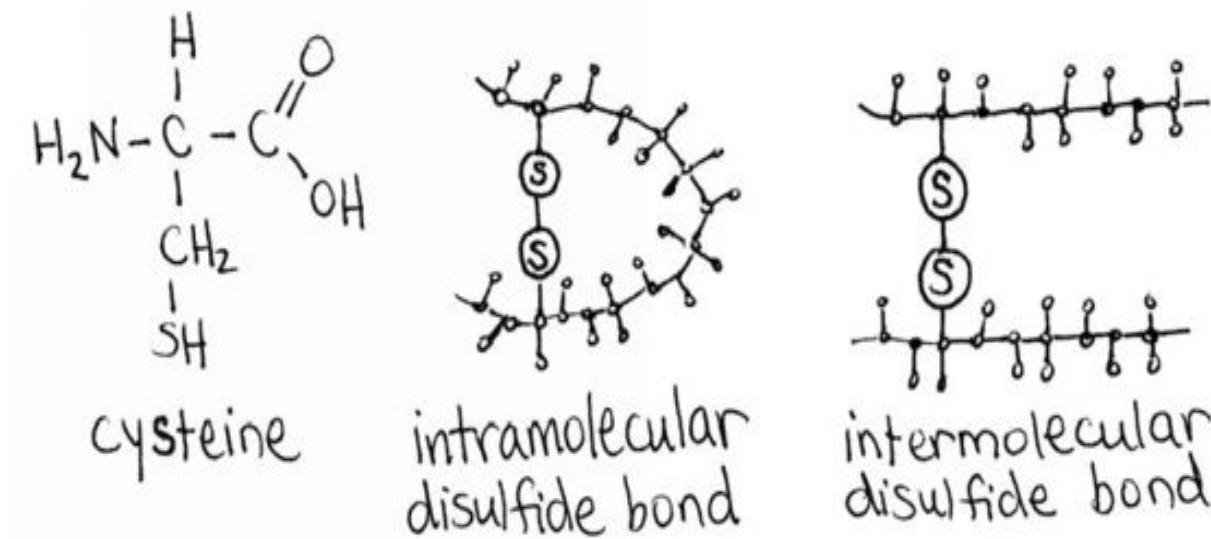
Amino acids can join to form a dipeptide, as shown in the following picture. The bond that forms is called a peptide bond. Note that when the peptide bond forms, a water molecule is liberated from the amino acids. A chain of amino acids linked by peptide bonds is called a polypeptide. A protein can be one polypeptide or many bonded together.



When amino acids form a protein chain, the amino and carboxyl groups and the peptide bonds form a backbone, with the R groups or side chains sticking off. A protein chain is not a static molecule. Many of the bonds can rotate, allowing the chain to wiggle. Some amino acids in the chain form bonds with others or attract them, while some amino acids repel each other.

These interactions cause the protein to twist and turn. The type and order of amino acids in the chain determine how the protein twists and therefore its structure.

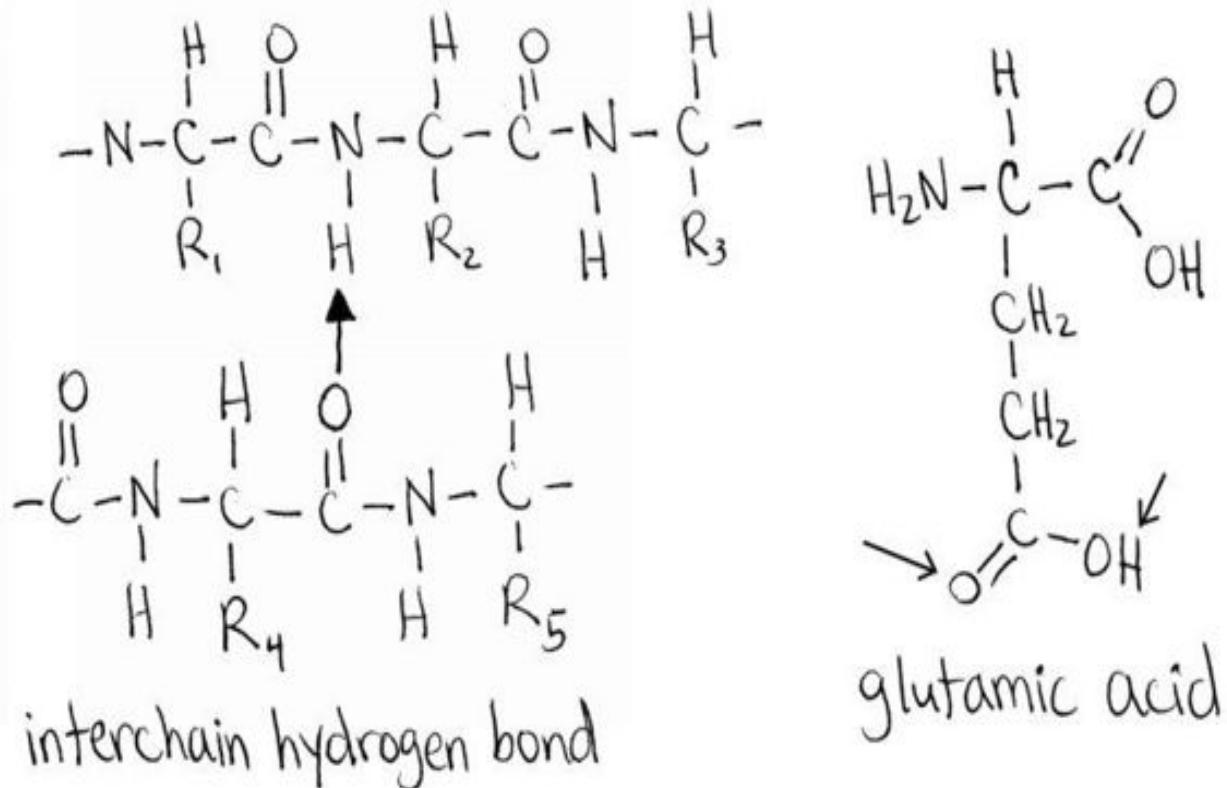
The strongest bonds that form within or between proteins are covalent disulfide or S—S bonds, in which two sulfur (S) atoms share electrons. Covalent bonds are permanent chemical bonds that take a lot of energy to break. In addition to being the strongest, their stability may help weaker bonds form and persist in the protein. A disulfide bond forms when two cysteine amino acids, which contain sulfur, are close to each other. They can be in the same protein molecule, forming an intramolecular bond, or in different proteins, forming an intermolecular bond. In the pictures below, the protein chain is simplified for clarity.



Another bond is a hydrogen bond, which forms because of partial positive charges on hydrogen atoms that attract partial negative charges on oxygen and nitrogen atoms in molecules. The hydrogen bond was described in the previous section “Water and protein.” Recall that for the partial charges to be big enough to form a hydrogen bond, the hydrogen atom must be bonded to an electron-sucking oxygen or nitrogen atom, giving it a bigger positive charge.

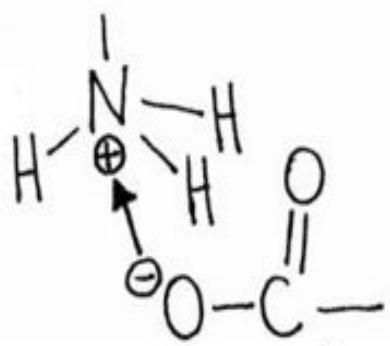
All amino acids can form hydrogen bonds between their amino groups and carboxyl groups, as shown by the arrow in the picture. Many amino acids also have side chains containing nitrogen, oxygen, or hydrogen bonded to

nitrogen or oxygen that can form hydrogen bonds. An example is glutamic acid, whose side chain contains an oxygen and an oxygen-bound hydrogen.

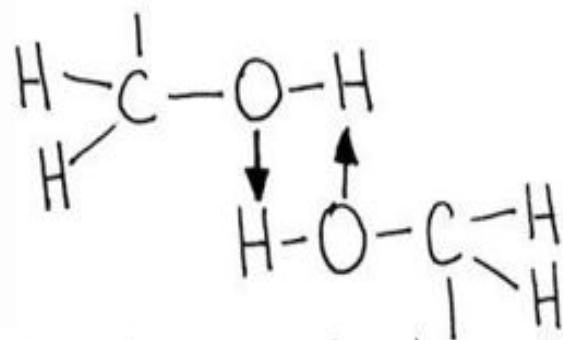


Some amino acid side chains gain or lose an electron fairly easily, resulting in a negative or positive charge. Oppositely charged groups attract each other and form an ionic bond. They are essentially stuck together because of their electrostatic attraction for each other.

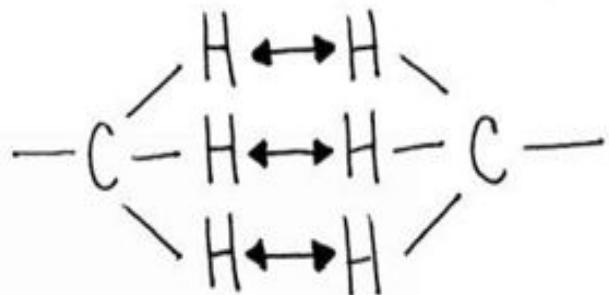
Any polar part of a molecule where electrons are not shared equally between atoms is able to form a dipole-dipole bond. This is a weaker form of an ionic bond because the atoms involved are only partially charged. Weaker still is the London dispersion force or Vander Waals force. This bond is the result of temporary dipoles created on non-polar atoms due to the general swishing around of their electrons.



ionic bond

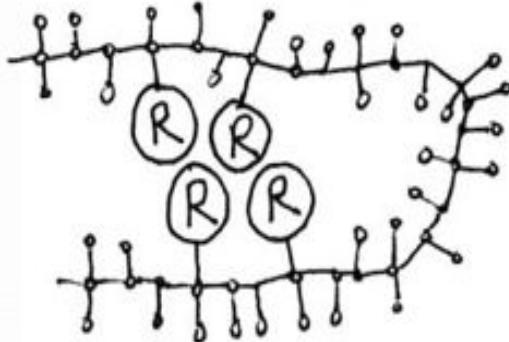
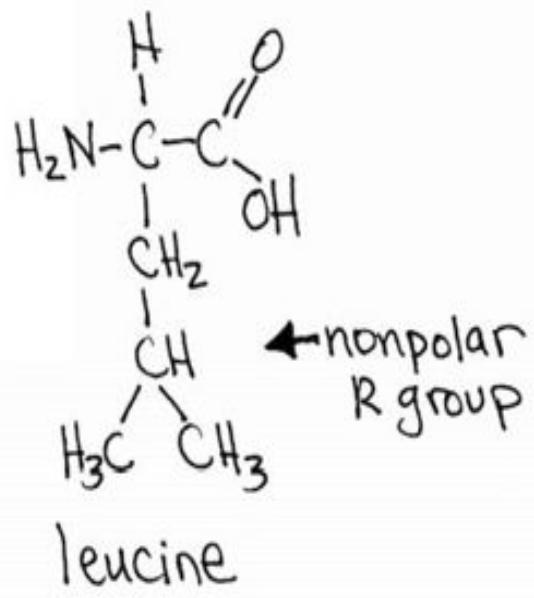


dipole-dipole bond



London dispersion  
force (van der Waals)

A final kind of bonding is hydrophobic bonding, a term used to describe the association of non-polar, hydrophobic parts of molecules that occurs simply because they are repelled by the polar parts. There is no actual attraction between the non-polar groups (except for maybe van der Waals forces); but it requires less energy for them to be near each other than for them to be exposed to polar groups, so they stay near each other. Many amino acids have non-polar side chains, containing only carbon and hydrogen atoms, and form hydrophobic bonds. An example is leucine.



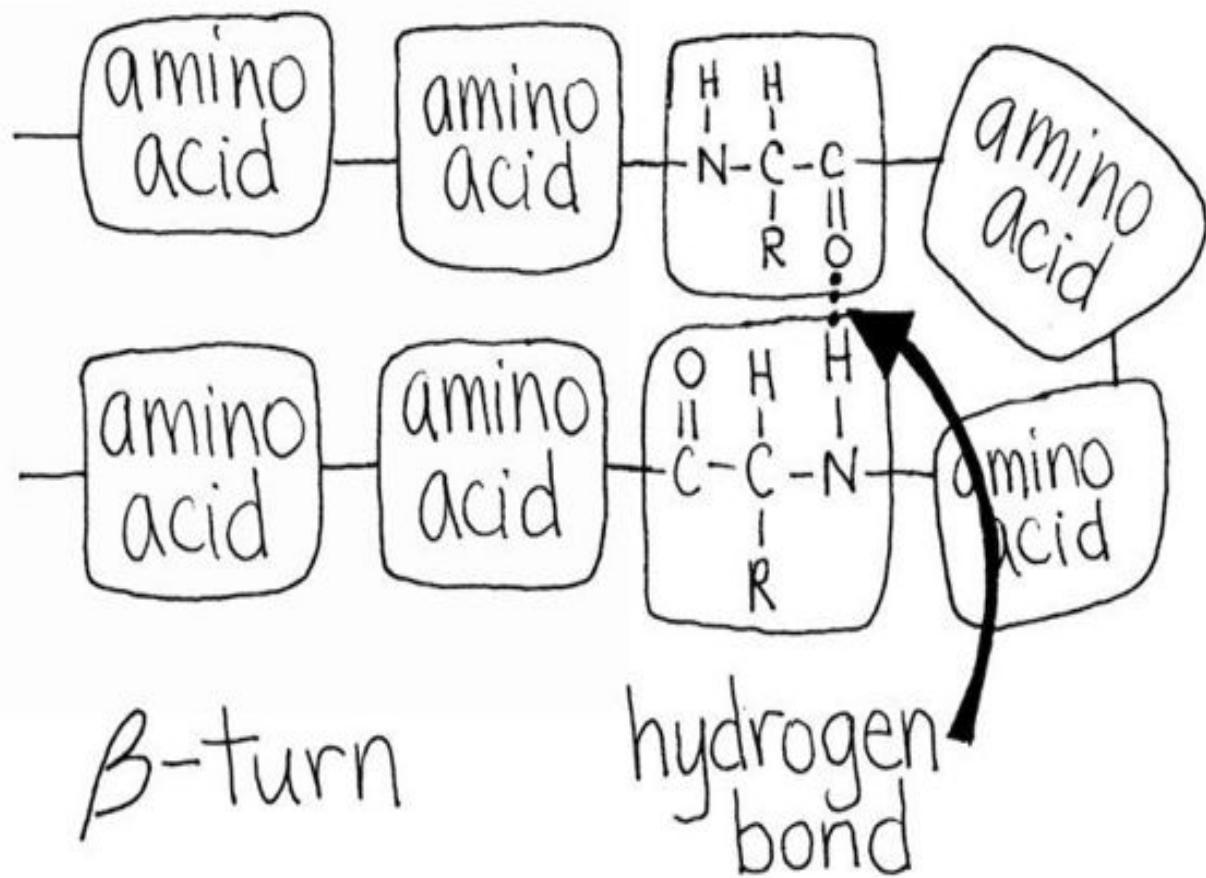
hydrophobic bond between nonpolar R groups

It is important to remember that different kinds of bonds have different strengths, measured by the energy it takes to break the bond. Bond strengths are listed in the table below. [1]

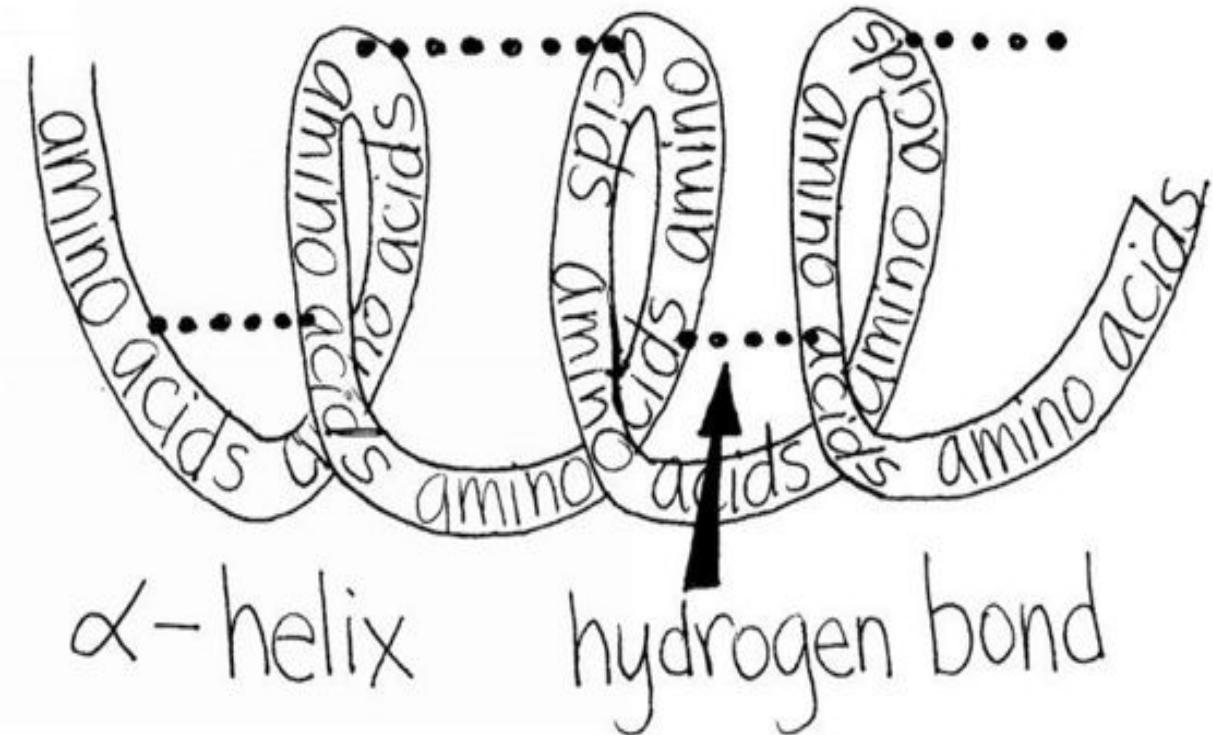
Bond	Bond energy (kilocalories/mole)
Covalent S-S	50
Hydrogen	3-7
Ionic/Electrostatic	3-7
Hydrophobic	3-5
Van der Waals	1-2

The order of amino acids that make up a protein is known as its primary structure. Its secondary structure is the arrangement of the protein chain. This is determined by attractions and repulsions between amino acids and the bonds they can form. Essentially, the primary structure determines the secondary structure. [2]

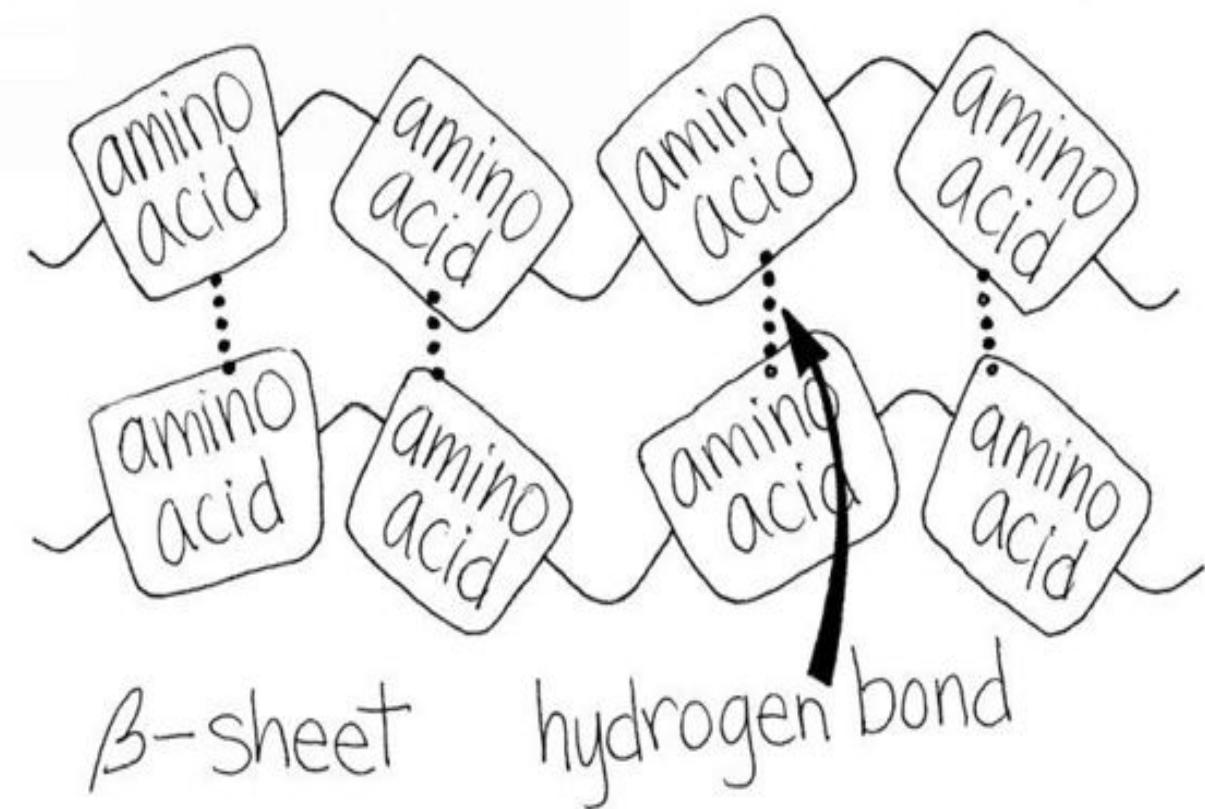
One common element of secondary structure is the  $\beta$ -turn or fold. This occurs when a protein chain folds and a hydrogen bond forms to hold the fold in place.



Sometimes a protein forms a stable, repeating secondary structure. Some chains form the  $\alpha$ -helix, a loop-de-loop structure stabilized by periodic intramolecular hydrogen bonds.



Two chains can form a series of hydrogen bonds between them, resulting in a flat, wavy, double-wide chain called a  $\beta$ -sheet or a pleated sheet.



A protein can be stretched out in a chain or curled in a ball. This overall shape is known as the tertiary structure. A chain-like structure is also called fibrous or a random-coil configuration. A ball-like protein is called globular.

To some extent, the tertiary structure of a protein is controlled by all the bonds it forms. A lot of intramolecular bonds and  $\beta$ -turns will produce a globular protein. Tertiary structure is also affected by the protein's surroundings. For example, a protein in a dissimilar solvent will curl up on itself, repelled by the solvent, and adopt a globular configuration. This concept will be discussed more in the subsequent section "Salt and gluten."

#### Overview of gluten structure

Gluten forms when flour and water are mixed. Water hydrates the protein: it forms polar bonds and hydrogen bonds with the protein [3] and stimulates hydrophobic bonding within and among proteins. (The hydrophobic parts of the protein are repelled by the surrounding water, so the protein structure changes to minimize contact.) [4] Gluten is about one-third protein and two-thirds water. [5]

Water also enables protein molecules to move and find each other. One way to think of gluten development is that when water is added to flour, proteins bond with the first protein they meet. It is as if the protein molecules grab at the first thing they see, paying no attention to placement or order. The proteins are disoriented. This does not make strong, flexible dough. If this dough is stretched, it rips.

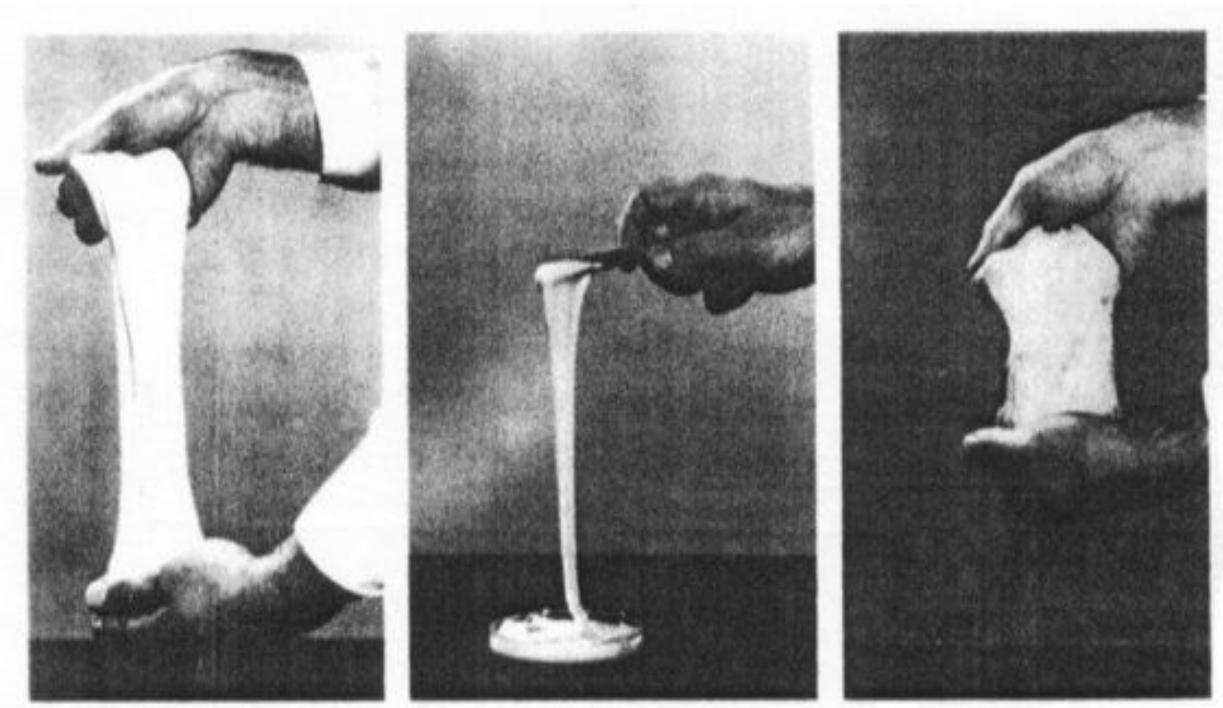
Kneading allows the protein and water molecules of the gluten to rearrange and form new, “better” bonds. The physical force of kneading breaks weak bonds, leaving sites on the protein available for new bonds. If the new bonds are aligned to work together to resist kneading then they keep from breaking. The baker sees the organization of protein molecules as sheets of gluten forming in the dough. The dough begins to feel strong as kneading continues.

Dough left to sit relaxes, becoming soft. This occurs as the tightest gluten bonds break, allowing the chains to slip past each other. Gas production stretches the chains and encourages this relaxation.

About one third of gluten’s amino acids are glutamic acid, which is able to form hydrogen bonds. About 14% are proline and 7% are leucine, both non-polar amino acids that could contribute to hydrophobic bonding. A small amount of cysteine is present, able to form disulfide bonds. [6,7]

Flour contains five basic kinds of proteins. The albumins and the globulins are characterized by their solubility in water—that is, they can be separated from the rest of the flour protein by mixing flour with water and letting them dissolve. They are not involved in gluten formation. The two proteins involved in gluten are the glutenins, sometimes called glutelins , and the gliadins, sometimes called prolamines . The fifth protein is proteases , discussed in a later section.

Glutenin proteins are long chains, while gliadins are shorter and globular. Glutenin is responsible for the elasticity of dough, while gliadin is responsible for the extensibility—the dough’s ability to stretch without ripping. This can be seen by separating the two and making dough with just glutenin or just gliadin. The glutenin-dough is extremely tough and resists stretching (below, right), while the gliadin-dough is flow-y (below, middle). Whole gluten (below, left) is somewhere in between. [8]



Picture reproduced from R.C. Hosney's Principles of Cereal Science and Technology , 1986, page 77 with permission of the American Association of Cereal Chemists.

The cause of gluten elasticity is still debated. Different models have been proposed to explain it; they will be discussed later in this section.

#### Chronology of gluten research—early work

In 1665, Francesco Grimaldi saw gluten and gave it its name, which is Latin for “glue.” [9] In 1728, the Italian scientist Giambattista Beccari said he had separated wheat flour into two parts. In 1745, he published a paper describing how to wash flour and obtain gluten. In 1805, Einhof described extracting a substance from flour using alcohol. [10] In 1820, M. Taddey described using alcohol to separate gluten into two parts, which he called gliadine and zimome. Gliadine dissolved in alcohol; zimome did not. [11] Subsequently, there were numerous attempts to separate parts out of gluten, and everyone gave different names to the parts they found. [12]

In 1862, Günsberg agreed with Taddey that there were two proteins in gluten, and he correctly separated and analyzed gliadin. In the following decades, however, the parade of names and protein descriptions continued. Many still believed there were more than two proteins in gluten. It was not

just multiple names causing problems. For example, a 1904 study identified three separate alcohol-soluble proteins. A 1905 study responded that all three were gliadin, but impurities had caused them to separate from pure gliadin.

In 1896, E. Fleurent (who apparently believed there were two parts in gluten) suggested that the ratio of gliadin to glutenin was important. More gliadin created more extensible gluten and therefore dough. [13] In 1899, Snyder determined the amounts of different proteins in flours and related the information to bread-making. Good bread flours had 65% gliadin and 35% glutenin. Poor flours might have more protein overall, but less of it was glutenin. [14]

### The work of Osborne

In the 1890's, Thomas B. Osborne began publishing data on gluten that was compiled in his 1907 book *The Proteins of the Wheat Kernel*. He attempted to clear up the confusion of names. Osborne observed that proteins are sensitive in solution—minor differences in solubility cannot be used to characterize an individual type of protein.

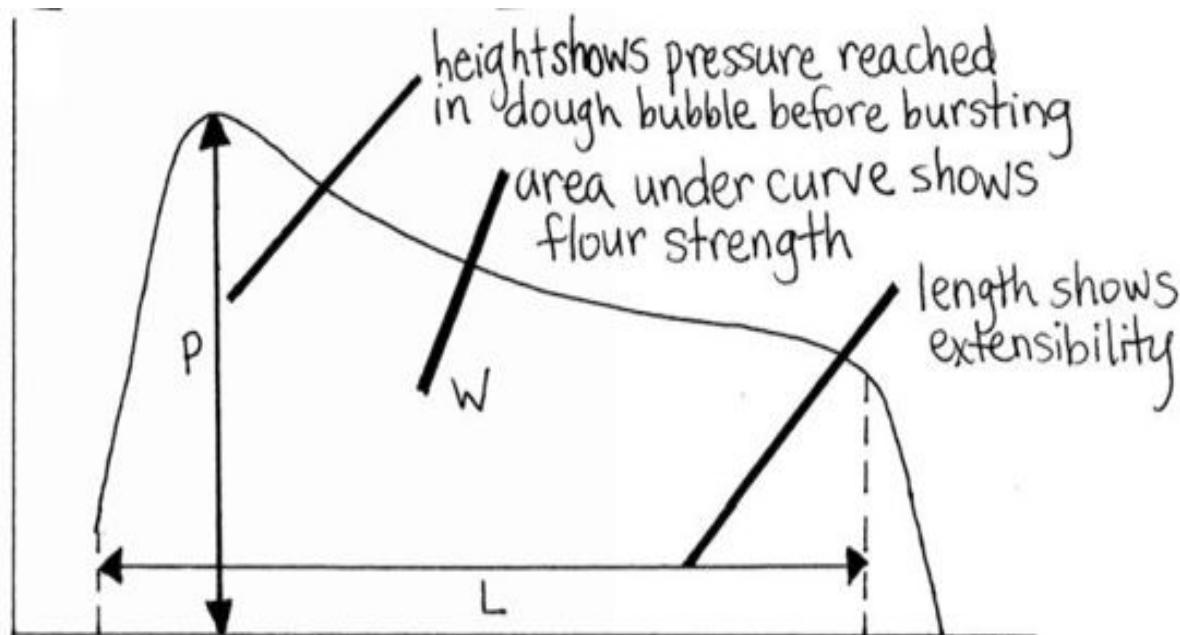
Osborne identified five different forms of protein in wheat—proteins that had different compositions, solubilities, and physical characters. These he called gliadin, insoluble in water but soluble in alcohol; glutenin, insoluble in water and alcohol but soluble in acids and bases; leucosin, a water-soluble albumin; a globulin; and proteoses. The gliadin and glutenin represented most of the wheat kernel's protein and were the proteins in gluten. He described the roles of the two major gluten proteins as glutenin forming a nucleus to which the gliadin sticks. The name "glutenin" was suggested by Osborne's mentor, and Osborne used it because the other names used for that protein (such as "gluten-casein") had no basis.

### Dough testing machines

Another line of research that overlapped gluten separations was the invention of dough-testing machines. The basic idea was that instead of baking bread to test the suitability of a flour, scientists would test properties such as strength and stretchiness of dough made from the flour. One of the first such machines was the 1848 "aleurometer" which measured the expansibility of gluten on heating. Subsequent machines were the

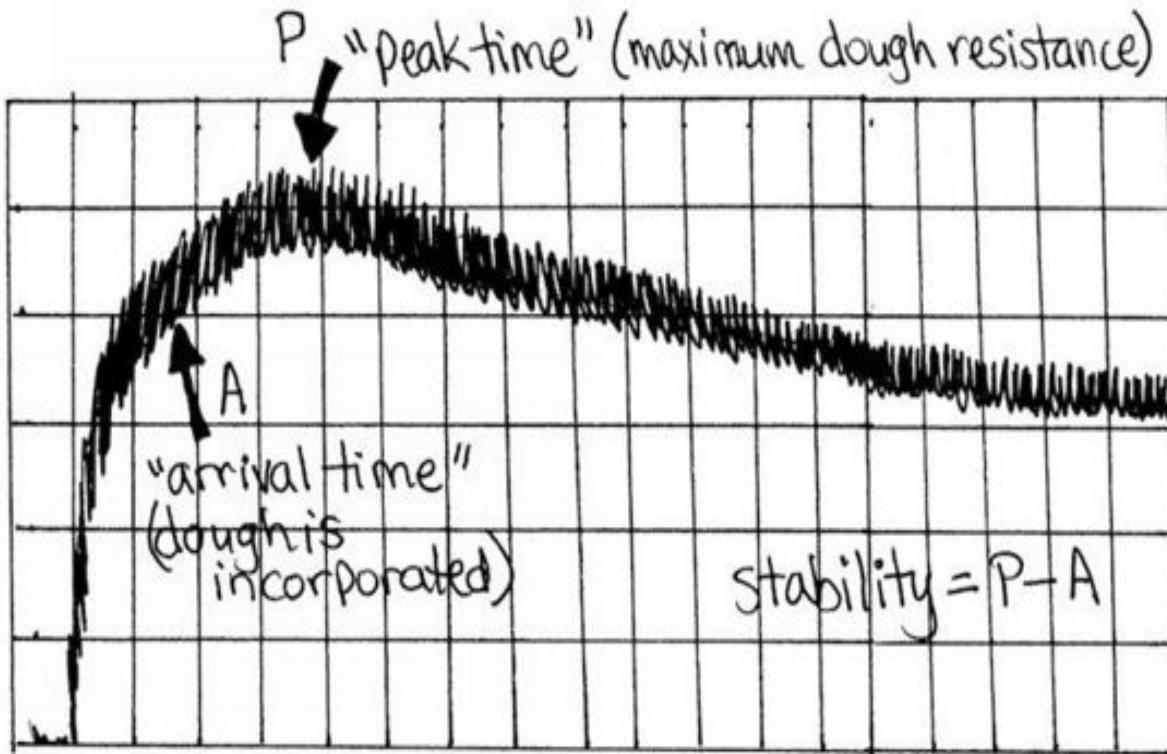
“farinometer,” the “gluten tester,” the “viscometer,” and the “Perfekdo viscometer,” all of which stretched gluten. [15]

A second kind of machine was introduced in 1905 that simulated dough changes during fermentation. It pressed gluten between plates with holes. Air blown through the plates forced the gluten to form a bubble. The maximum volume of the bubble before it burst indicated the gluten expansibility. In 1921, Marcel Chopin independently debuted a similar machine. In the 1930’s, Chopin added a special mixer to the machine. During mixing, the machine recorded the force needed to mix the dough. After mixing, the mix bowl’s direction reversed, a gate opened, and thin sections of dough were sliced off and sent to the bubble-blower. The whole device was known as the Chopin Alveograph; they are still made today in France. [16] A typical alveogram is shown below.



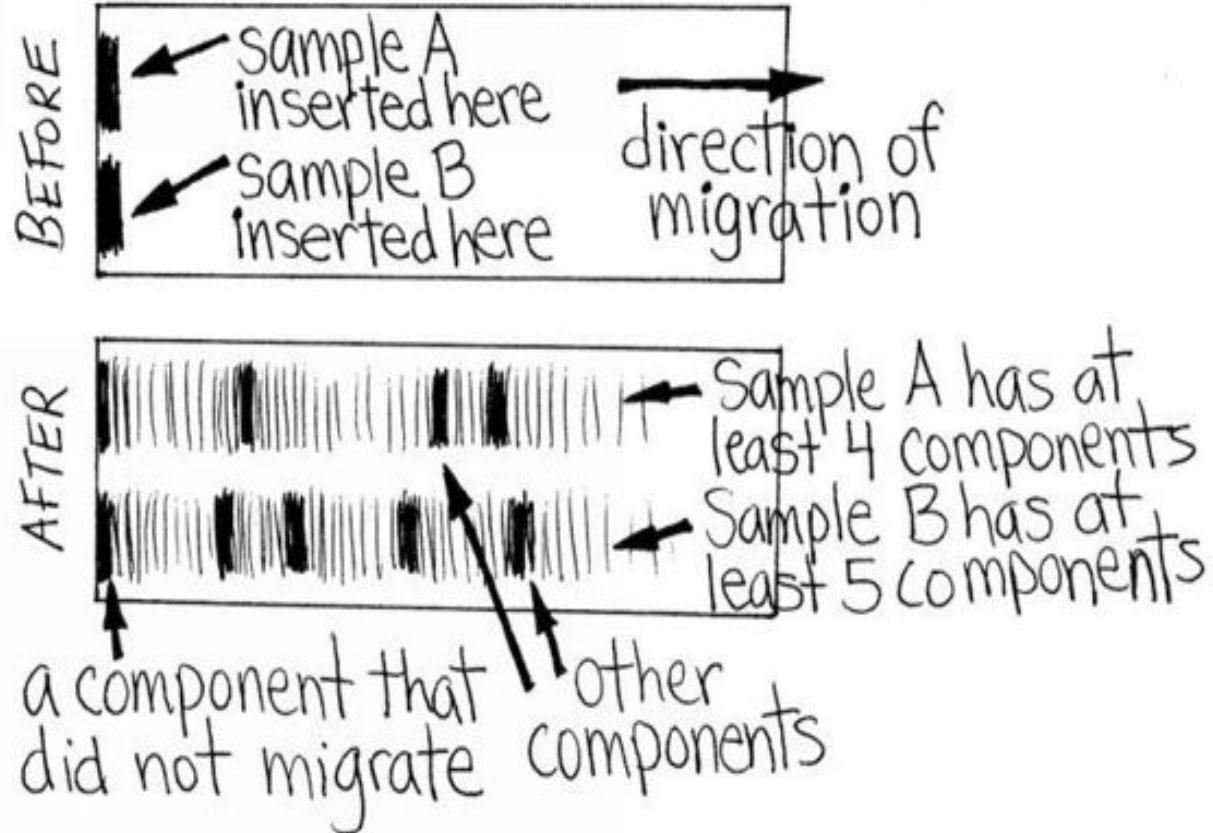
Other dough testing machines still in use today are the farinograph (a.k.a. mixograph) and extensigraph; both look at forces on dough without using air pressure. The farinograph is a mixing bowl that measures the resisting force of the dough during mixing. The extensigraph forces the dough into a uniform shape and size and then stretches it, measuring the resistance to stretching. A farinogram of a medium-strength flour is shown below. Strong flours take longer to arrive at their peak and do not drop off in strength after.

Weak flours arrive at their peak quickly and then rapidly break down, resulting in a sharper peak.

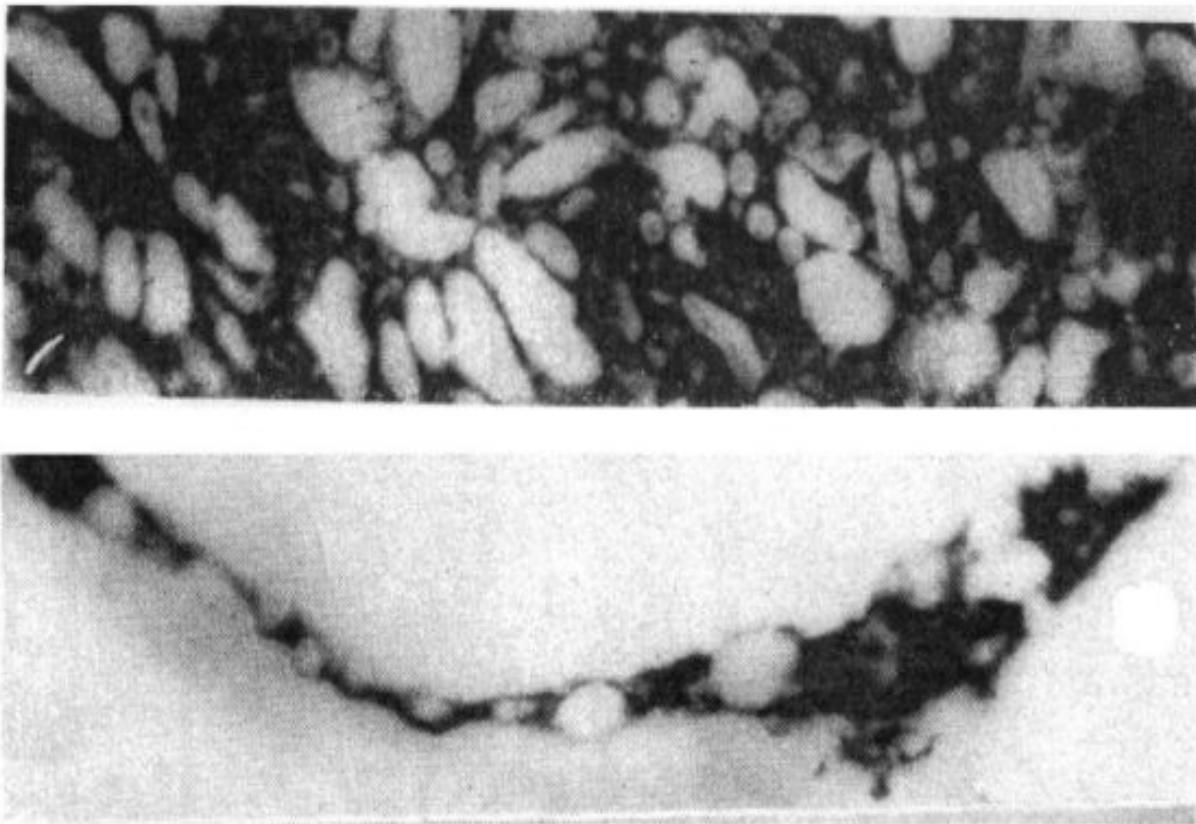


### More research on gluten

Decades of research focused on separating gluten into parts with new or better techniques. Centrifuges were used to separate liquid from solid; the liquid was then tested for the proteins dissolved in it. With diffusion techniques, liquid passing through membranes carried some proteins with it but not others, providing a means of separation. [17] In the 1950's, electrophoresis was used: a sample is inserted into one end of a gel block and an applied electric field causes molecules to migrate. Different molecules migrate with different speeds because of their different sizes and compositions and are thus separated. A generic example is shown (below). After all this, gluten is still considered to have two main parts, glutenin and gliadin, as described by Osborne in 1907.



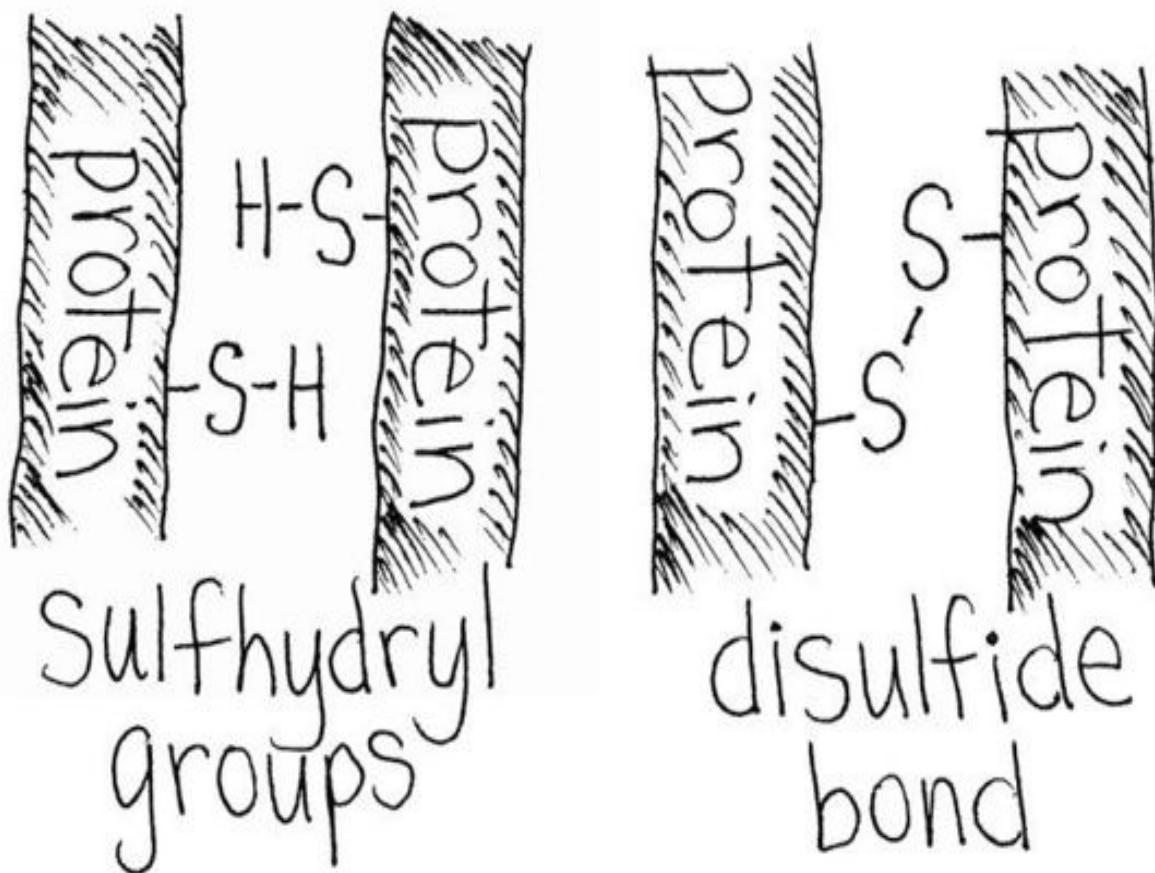
In the 1940's, microscopic studies of dough became popular as a direct method of watching what happens in dough. Dough was frozen at various stages of the bread-making process and sliced for viewing. A 1954 study showed the protein as a continuous film between gas bubbles and the starch in granules separated by protein (below). [18]



The dark area is the continuous protein film, and the white blobs in it are starch granules. In the top image is freshly mixed dough with no gas cells (magnification x360). In the bottom image is dough that has fermented; protein is stretched into thin films between gas cells (magnification x350). Pictures reproduced from R.M. Sanstedt et al, Cereal Chemistry 31 (1954) 43-49 with permission of the American Association of Cereal Chemists.

### Sulfur groups

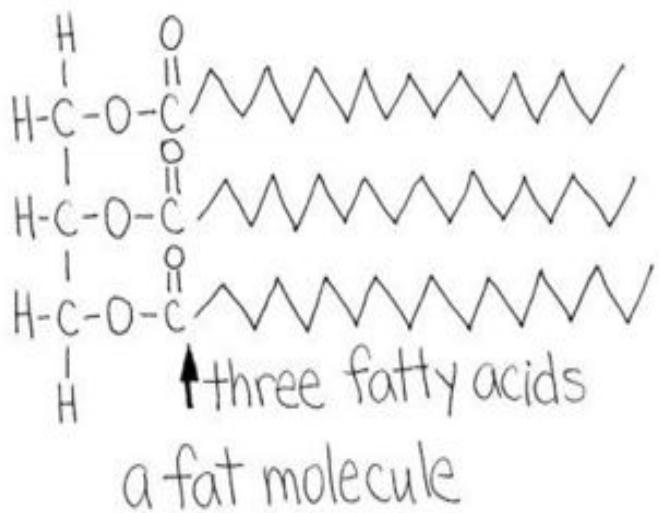
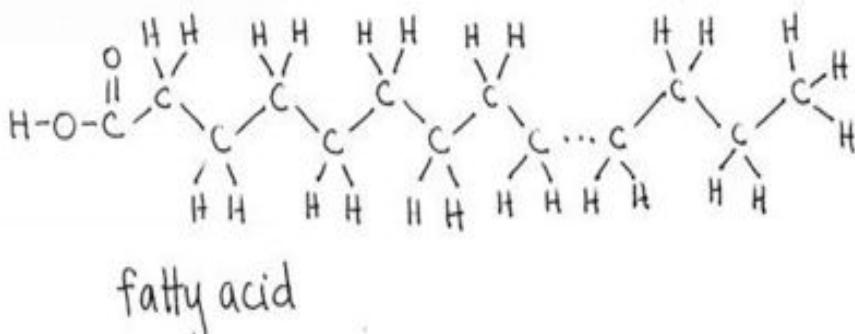
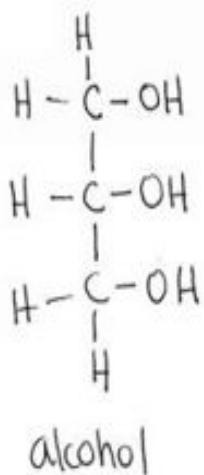
As early as 1940, Betty Sullivan had looked at the role of sulfur in gluten. Wherever there was a sulfur-containing cysteine amino acid, there was either a sulfhydryl group (a sulfur bonded to a hydrogen, denoted  $-SH$ ) or a disulfide ( $S-S$ ) bond. She felt these sulfur groups were important to dough structure but acknowledged a lack of means to study them. In 1954, she again wrote about the potential importance of sulfur groups in dough. She believed that dough improvers, chemicals added to dough to make it behave better, were affecting the dough via the sulfur groups.



Subsequently, other researchers began to look for the presence and role of sulfur groups. One method consisted of adding a known amount of reactant to dough. This reactant bonded with sulfhydryl groups. The excess reactant was removed and measured. The amount of reactant used showed how many sulfhydryl groups were present. Results indicated few sulfhydryl groups—therefore, the cysteines present were participating in disulfide bonds. [19]

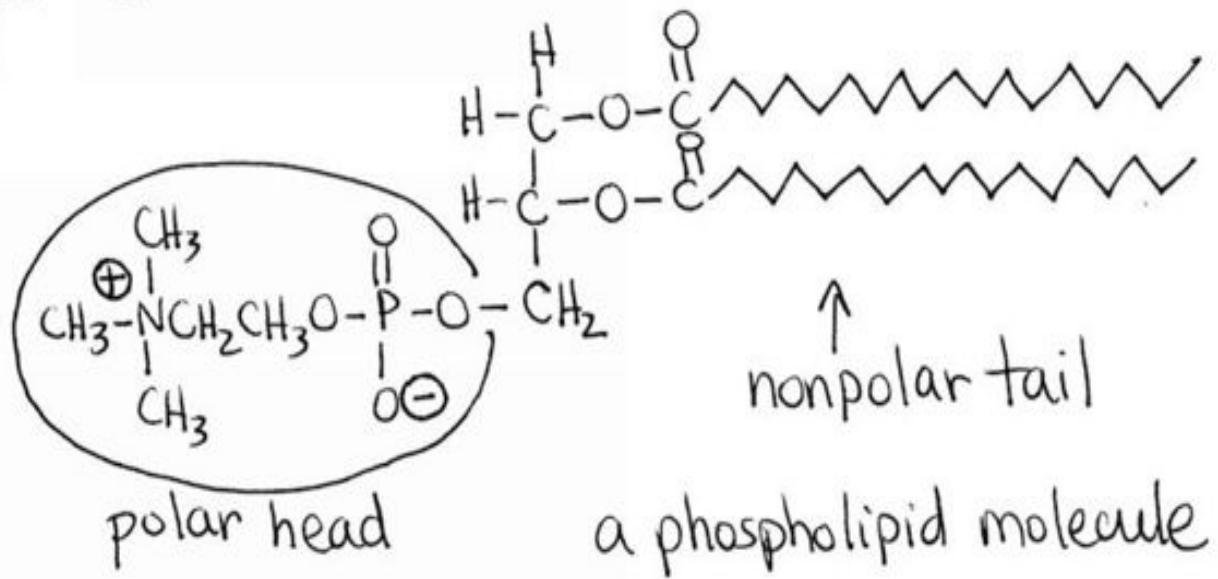
### Lipids

Lipids are a group of substances insoluble in water but soluble in non-polar, organic solvents. (Remember that non-polar molecules are those in which electrons are shared equally between atoms and no partial electric charges exist.) We think of lipids more commonly as fats. The basic fat has an alcohol molecule with fatty acid molecules attached, as shown in the pictures below.

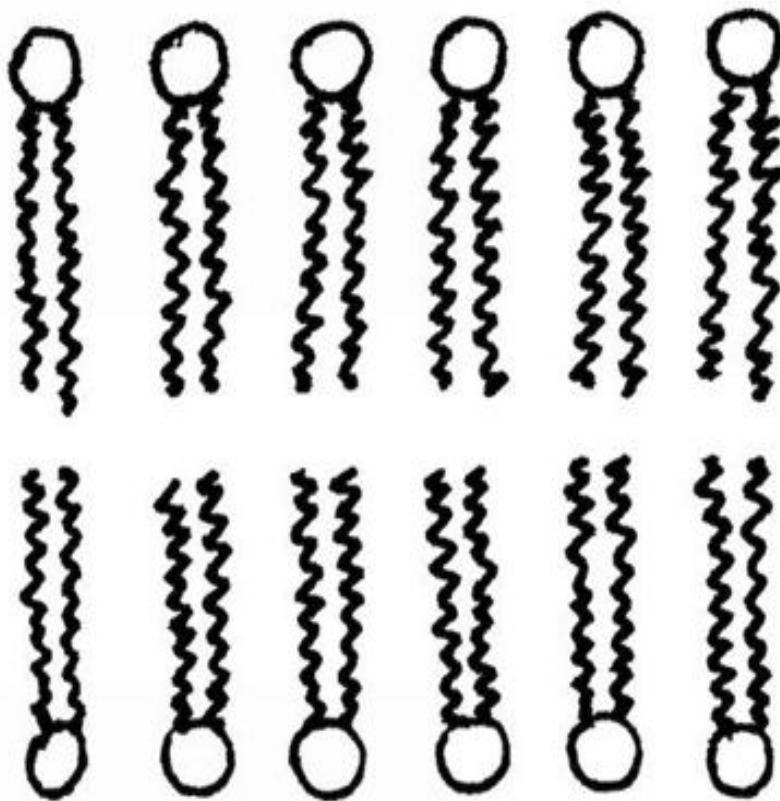


The fat molecule has oxygen atoms at one end, but most of it consists of long, non-polar chains.

A fat is only one kind of lipid; another is a phospholipid. Phospholipids have a structure similar to fats but one fatty acid is replaced with a phosphate group. This group is polar; a phospholipid molecule therefore has a distinct polar “head” and a long, non-polar “tail” (below).



Phospholipids form bilayers in water (below)—they line up with their tails together, shielding the non-polar tails from the polar water surrounding them.



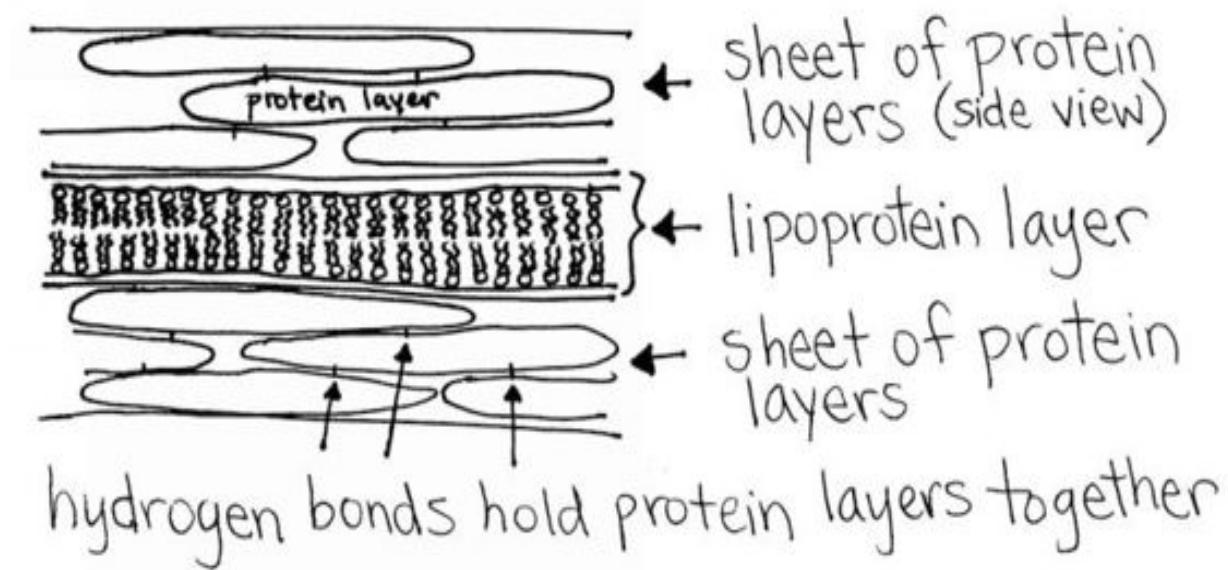
## a phospholipid bilayer

In 1924, E.B. Working suggested that lipoids (fat-like molecules) at the interfaces of a gluten network would help lubricate it. He showed that lipoids decreased gluten viscosity and hurt flour quality. Washing the lipoid out of a cheap flour made it behave like a good-quality flour. [20]

In 1928, Working was studying ways to imitate what happens in dough during fermentation, to eliminate the need for bread bakers to wait for dough to rise. (In other words, bread producers would save money by adding a chemical to dough to affect the gluten instead of taking the time to let the gluten develop as usual!) He proposed a model for gluten that explained its elasticity and expansibility and matched his test results. In Working's model, gluten was an interlacing meshwork of protein strands surrounded by a liquid phase of protein dispersed in water. Elasticity was a property of the strands—when stretched, they returned to their original state. Extensibility

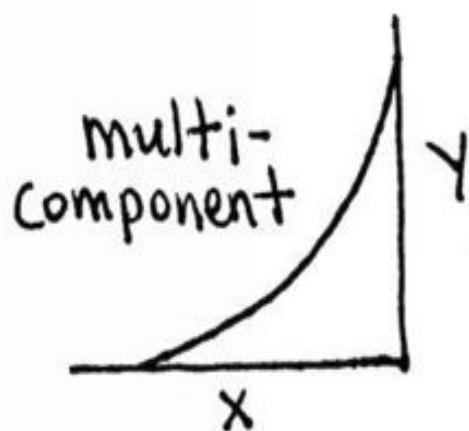
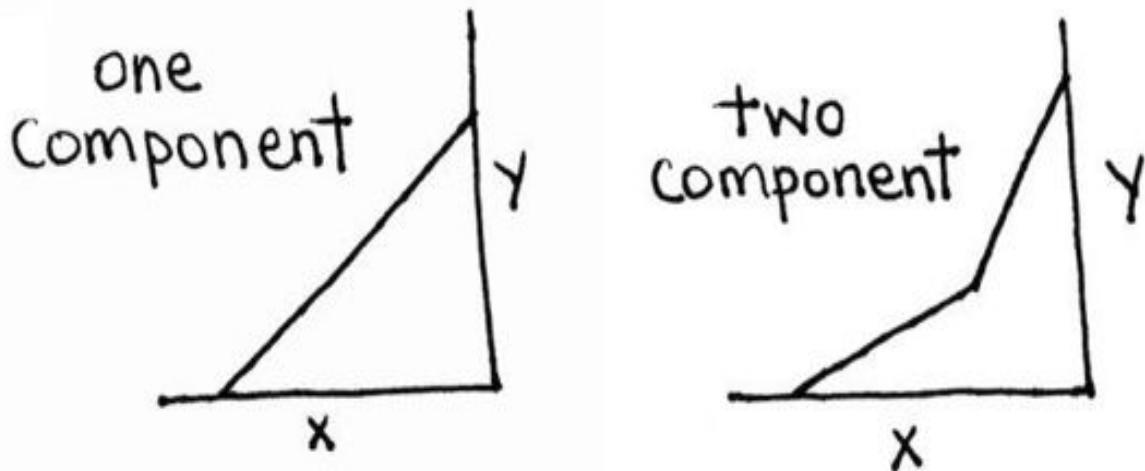
was a result of the forces binding the strands together and the ability of strands to slip past one another. Lipids increased the extensibility by lubricating the strands. [21]

In 1960-1961, J.C. Grosskreutz proposed a gluten model based on X-ray diffraction and electron microscope studies. The X-ray patterns from gluten matched patterns from another protein that was curled into an  $\alpha$ -helix formation and folded. Details suggested that overall, the gluten was in sheets of parallel layers that had bonded together. Stress reduced the sheets to a network of strands, and lipid removal eliminated them. Grosskreutz suggested lipoprotein layers between sheets enabled slippage, allowing the sheets to exist without ripping. [22]



Details of gluten structure are uncovered

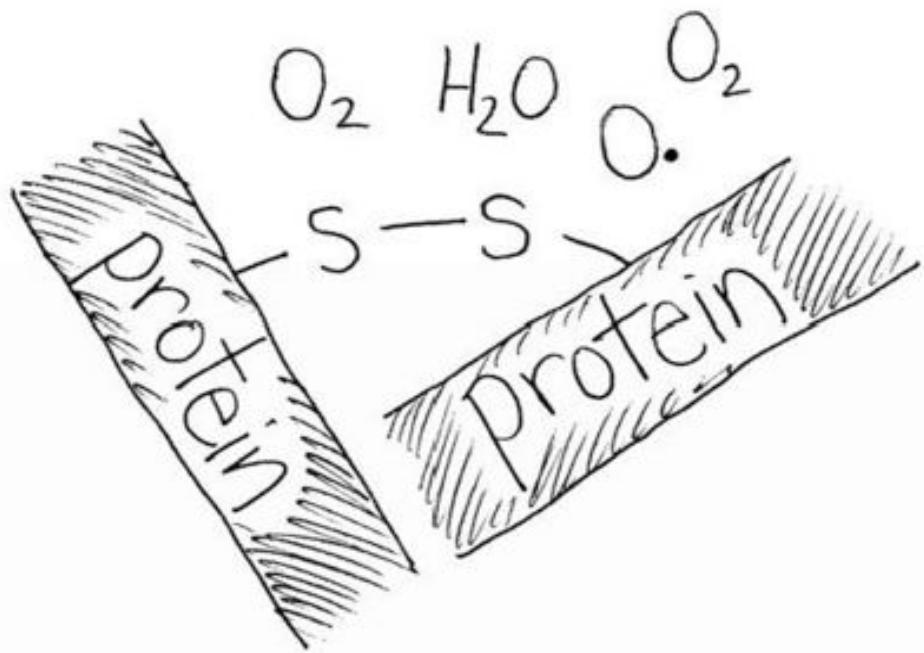
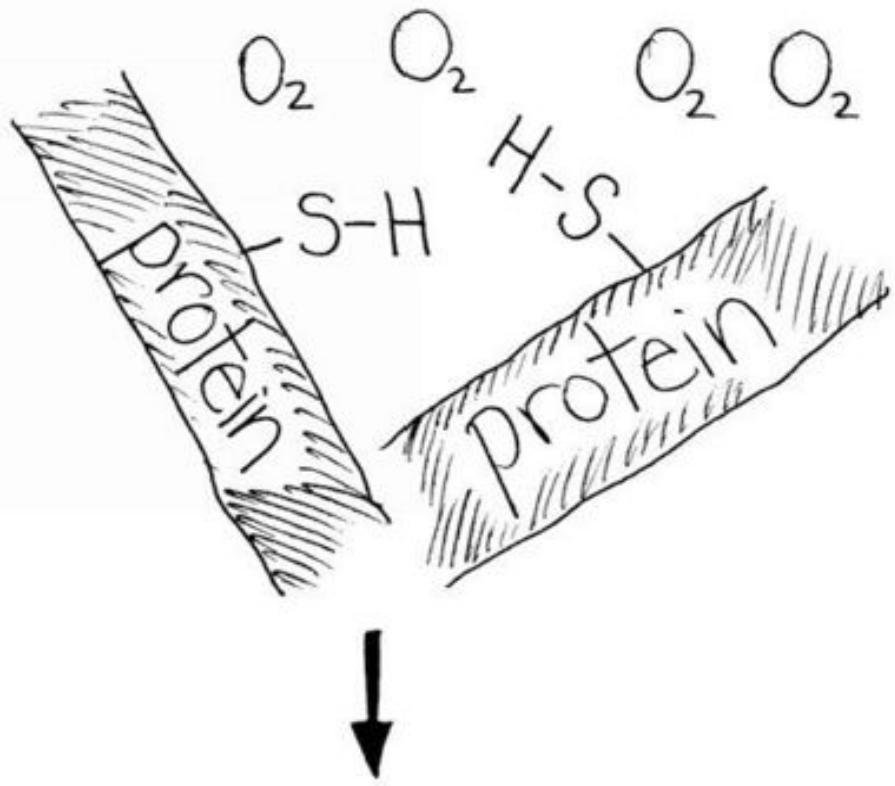
In the 1960's, scientists found the molecular weight of gluten proteins. They separated protein solutions in a centrifuge and took data such as the concentration of protein in samples separated at different speeds and times. This data was plotted, and the shape of the plot told the researchers how many protein components were in each sample:



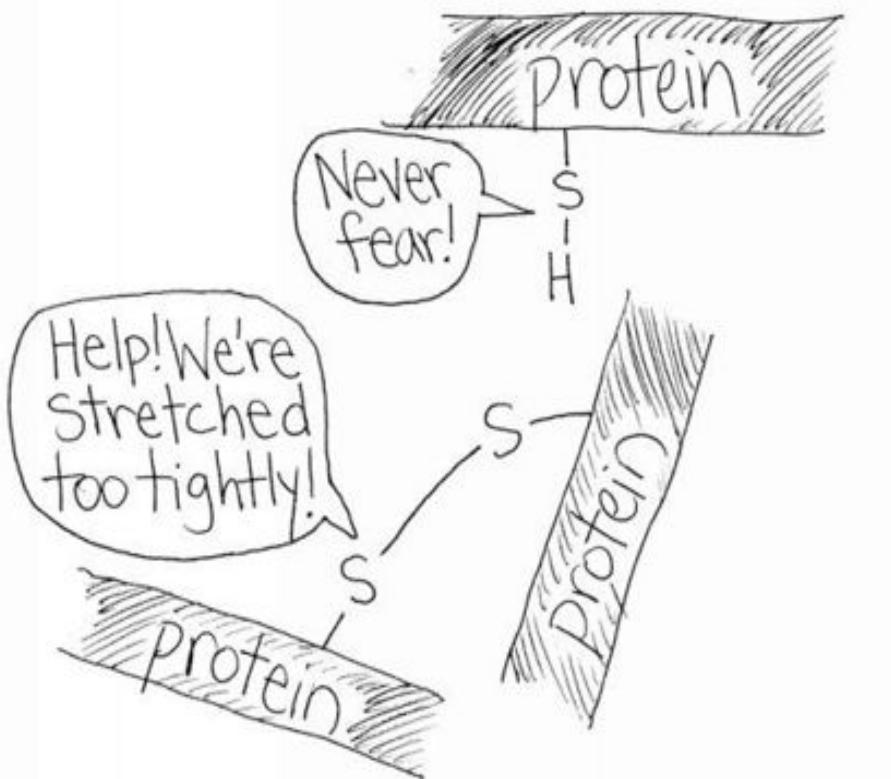
Once a sample had only one component, the slope of the straight line was related to the component's molecular weight. Gliadins were found to have weights of 42,000 and 47,000. Glutenins were found with weights everywhere from 50,000 to two or three million.\* [23] (\*Note: Units for the molecular weights are not given in the paper, but they are probably atomic mass units, a.k.a. daltons. One atomic mass unit is one-twelfth of the mass of a carbon-12 atom, or  $1.6604 \times 10^{-24}$  gram.)

In 1963, A.H. Bloksma found that dough could not be over-mixed when the mixing bowl was surrounded by nitrogen gas instead of air. This implied that over-mixing, which appears to be the ripping of gluten and loss of its coherent structure, somehow involved oxygen, present in air but not in the

nitrogen atmosphere. He proposed that dough got tougher during mixing because oxygen from the air was reacting with –SH groups to form S—S bonds, shown below.



The S—S bonds were able to undo themselves and relieve stress in the dough when they encountered an –SH group.



Dough breakdown occurred when so much reaction with oxygen had occurred that few –SH groups remained. The S—S bonds were no longer able to interchange with –SH groups and relieve internal stress, so when proteins became too stressed, they ripped and the dough lost its strength. [24]

Two studies in 1963 and 1965 provided evidence of hydrogen bonding in gluten. In one, amide groups (groups of one nitrogen atom with hydrogen atoms attached to it) on gluten were “removed” by converting them with chemicals to other groups. Changes were seen in the solubility, viscosity, and cohesiveness of the dough, which indicate the amide groups were helping to cause these dough properties. Hydrogen bonding between amide groups of proteins and between amide groups and water would explain how. [25]

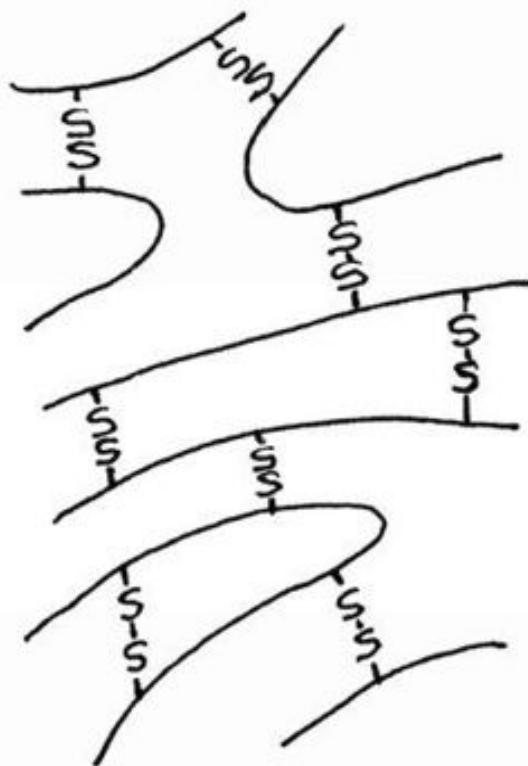
The other study used D<sub>2</sub>O, water with its hydrogen atoms replaced by heavier deuterium (D) atoms. Dough made with D<sub>2</sub>O was stronger than usual dough, indicating the involvement of the deuterium atoms in bonds, presumably hydrogen bonds. When the D<sub>2</sub>O was replaced by H<sub>2</sub>O, the dough resumed normal characteristics. [26]

### Models of gluten structure

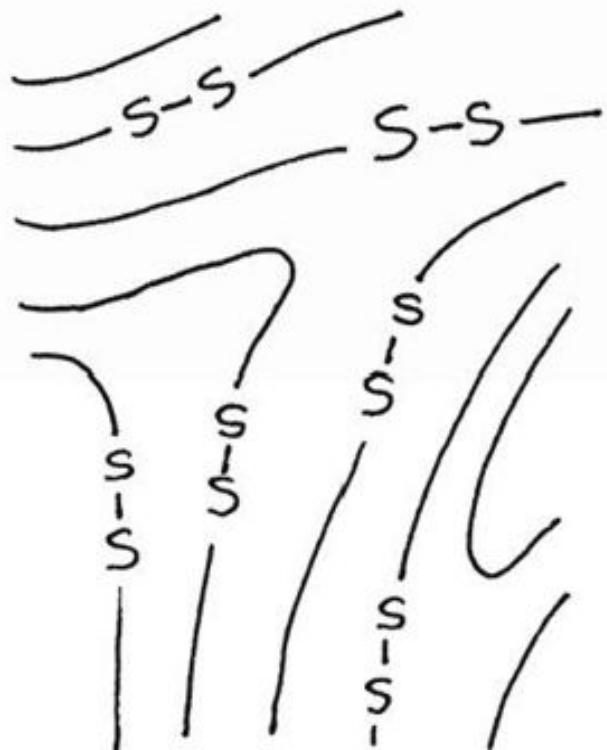
By now, scientists had found enough information on gluten to support theories on its structure. No one proposed more models for gluten structure than J.A.D. Ewart. His first came in 1962. He proposed that the protein existed in a compact form, able to stretch out when stressed but then retracting back to its stable compact form, thus giving elastic gluten. The gluten was cross-linked with S—S bonds. It also contained proline amino acids, which are unable to twist into the  $\alpha$ -helix conformation. The segments between S—S bonds and prolines, however, could form short stretches of springy  $\alpha$ -helix. Also, protein chains had been observed to turn at proline amino acids, so the high percentage of prolines might result in a zigzag-shaped protein, able to stretch out when stressed. [27]

Ewart’s 1968 paper described glutenin as linear. Subunits of about 180 amino acids were bonded together at their ends with S—S bonds. There were no branching cross-links, as this would make the viscosity of dough too high.

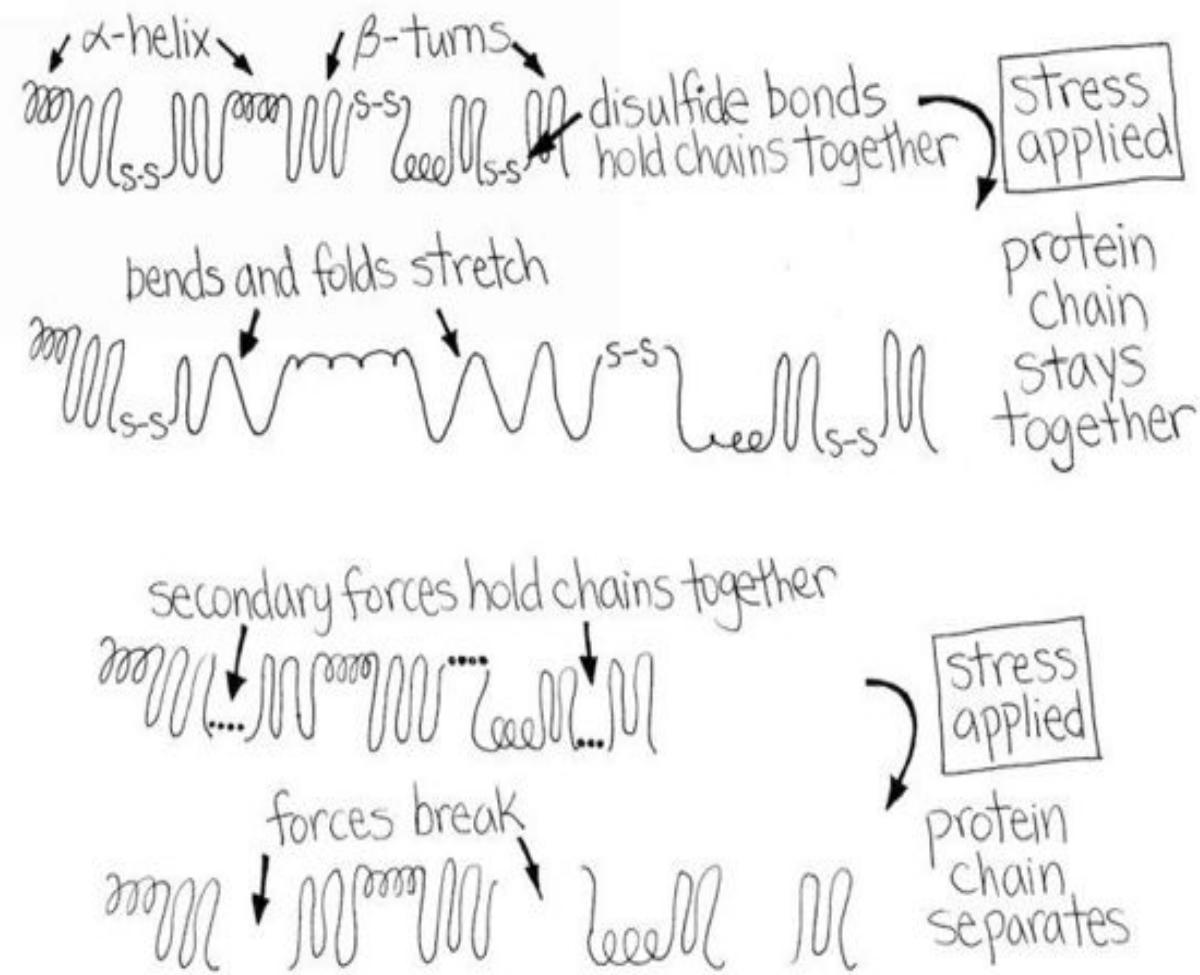
old  
model:  
branched  
glutenin



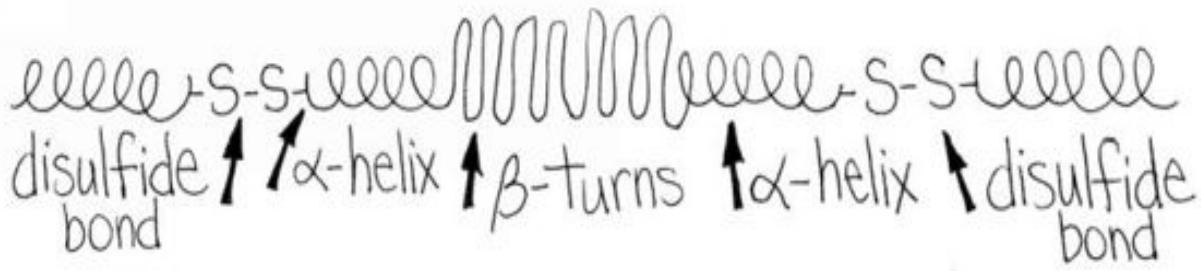
new  
model:  
linear  
glutenin



The elasticity of gluten resulted from bends and folds in the protein. These bends and folds stretched out under stress and re-formed when the stress was removed. The S—S bonds prevented the gluten chains from coming apart, as shown in the first diagram below. [28] Without the S—S bonds, the chain would pull apart under stress, as shown in the second diagram below. Subsequently, Ewart modified his hypothesis several times, but the basic idea of linear glutenin molecules remained.



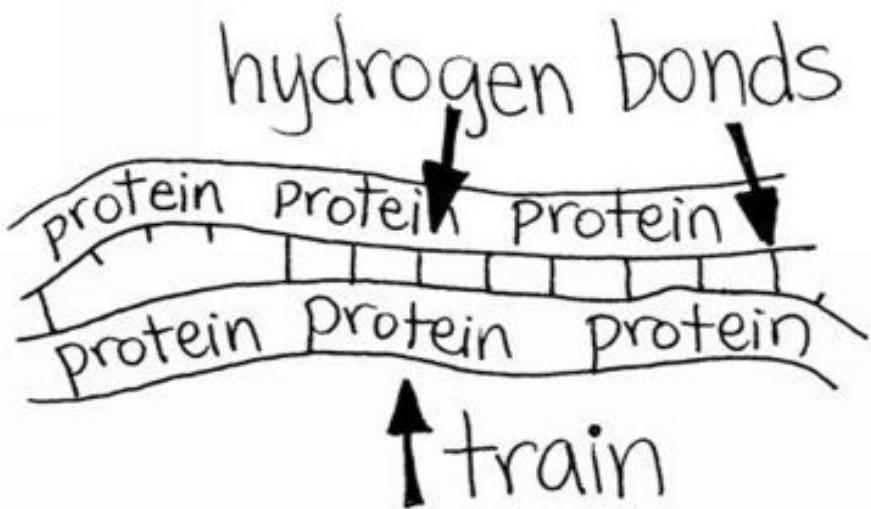
In 1984, researchers used a new kind of spectroscopy to study the structure of gluten. The structure they described was remarkably similar to the early proposals of Ewart. They found linear glutenin connected by S—S bonds at its ends. The glutenin had an  $\alpha$ -helix region near each end and a  $\beta$ -turn region in the middle. This is shown below.



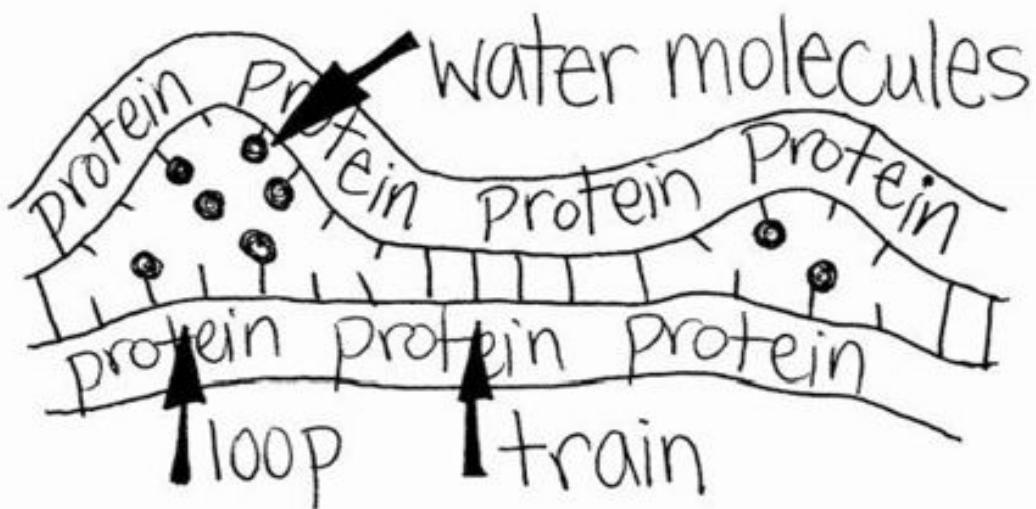
These regions were in accord with the amino acid makeup of the chains. The researchers proposed that the  $\alpha$ -helices were stabilized by the hydrogen bonds of glutamine amino acids and the  $\beta$ -turn regions were stabilized by hydrophobic bonds between tyrosine amino acids. The stable conformation was the reason for gluten's elasticity, since stretching would disturb it and it would re-form after. [29]

#### More recent work on gluten structure

Research papers continue to appear, proposing ideas and discussing gluten chemistry. For example, a 1999 paper proposes a "loop and train" structure of gluten, in which loops of protein hydrogen-bonded to water molecules allow stretching, but trains of protein hydrogen-bonded to each other resist and cause elasticity. The number of loops increases as water is added to flour, as shown in the following figure. [30]



trains: protein molecules bonded to each other



loops: protein molecules bonded to water

A gluten conference has been held for several years. The proceedings include all manner of high tech studies on gluten, including computer modeling and high pressure liquid chromatography—a separation technique more advanced than those of the 1930's, but essentially the same. [31] In 2004, one scientist wrote, "There is currently no adequate theory of gluten and dough rheology." [32] I believe that the general idea, however, has been conveyed.

[Return to start of Chapter 2](#)

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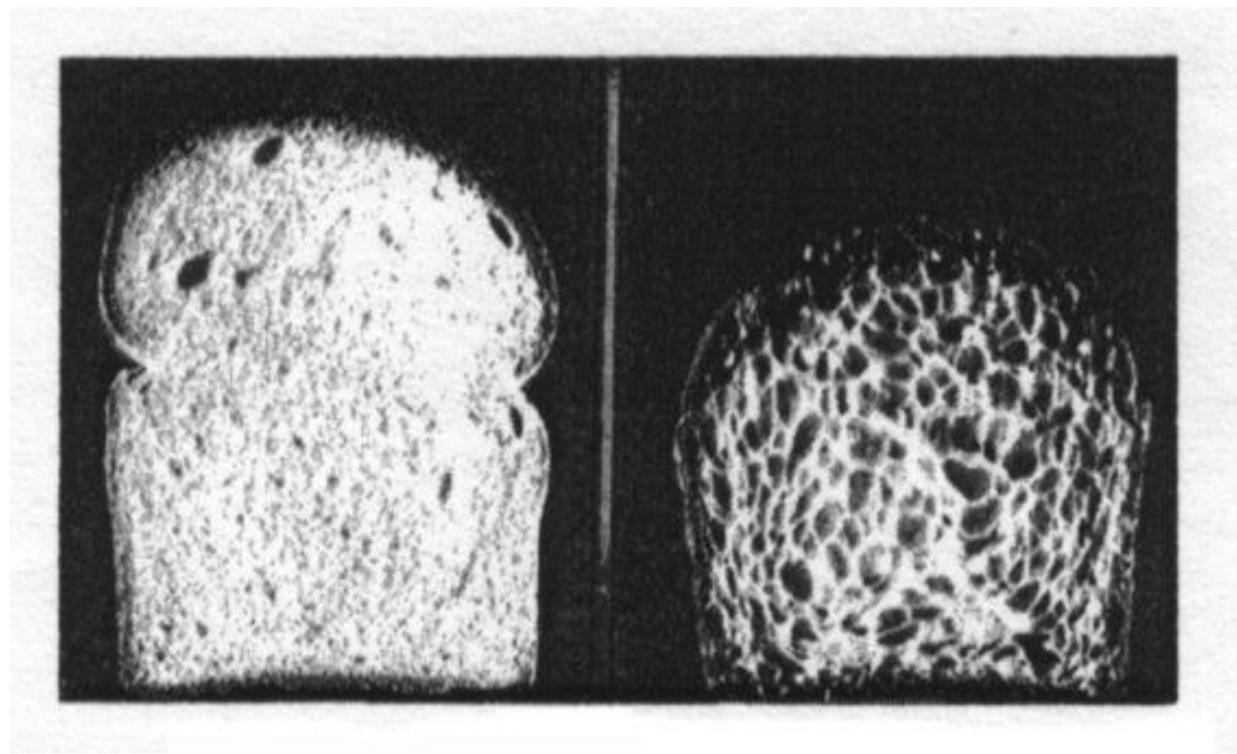
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## 2.7 Gas retention

The commonly held view of gas retention in dough is that gluten, like a balloon, traps carbon dioxide gas produced by fermentation. Recently, however, this idea has been reconsidered and challenged. The emerging picture is one in which lipids and protein work together to hold gas in dough.

### Early research

Several studies by a research group in the 1940's looked at gas production and retention in dough. In one study, they examined how gas bubbles originate in dough. They could exist in the wheat kernel or flour, the yeast could create them, they could be added during mixing, or they could be added during punching, folding, and shaping. The researchers mixed dough under different conditions—for example in a vacuum versus in air, or while under a high pressure that squeezed out all gas bubbles. They concluded that gas bubbles are only added to dough during mixing. The pre-existing bubbles are negligible, and the yeast do not make new ones. Punching, folding, and shaping dough subdivide existing bubbles but do not create new ones. [1]



(Above) Mixing in air (left) versus mixing in vacuum (right). Lacking the air bubbles added to dough during mixing, the dough mixed in vacuum did not rise properly. Picture reproduced from J.C. Baker and M.D. Mize, Cereal Chemistry 18 (1941) 19-34 with permission of the American Association of Cereal Chemists.

Later, the physics of bubbles provided an explanation. The equation relating the gas pressure inside a bubble ( $P$ ) to the bubble's radius ( $r$ ) is  $P = 2\gamma/r$ , where  $\gamma$  is the tension on the outside of the bubble. Thus to produce a new bubble, which would begin with a radius of zero, the pressure inside would have to be infinite. This is why yeast cannot produce new bubbles of carbon dioxide. Instead, the  $\text{CO}_2$  they produce goes into solution in the dough, coming out as a gas when it encounters a bubble that already exists.

Another early study, which perhaps led to the “gluten balloon” picture, looked at the structure of the gas bubble. Dough was centrifuged and a layer of bubbles separated out. These bubbles were removed, analyzed, and found to contain a good amount of protein. Analysis of baked dough showed that the films around bubbles contained protein but not starch—picric acid, which stains protein yellow, produced a change in the film color, but iodine, which stains starch blue, did not.

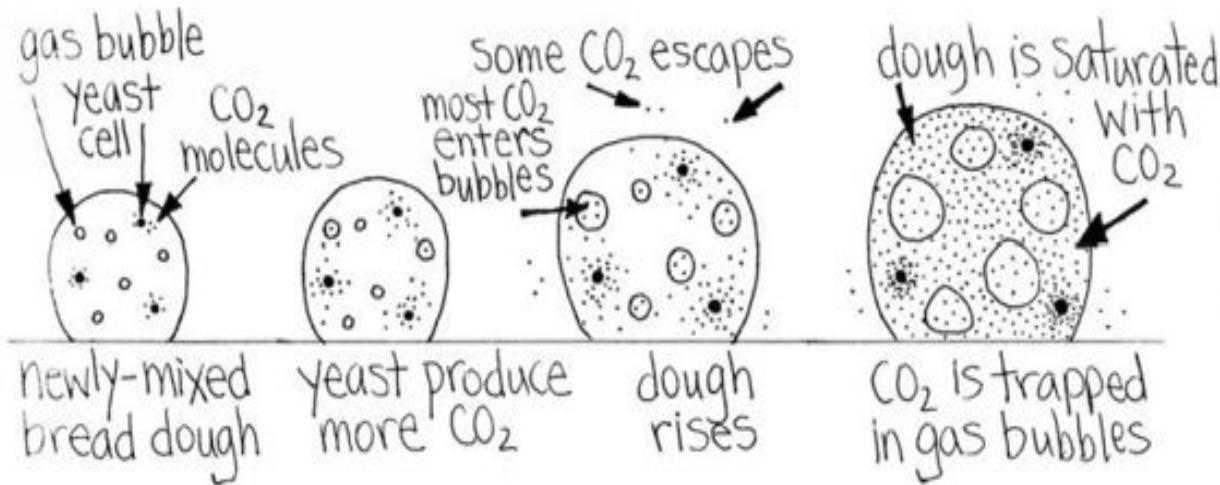
They looked at an undeveloped dough and compared it to a properly developed one. The undeveloped dough had a dull color and doughy gas bubble walls that stained blue with iodine. It did not hold gas well. The developed dough, with bubble walls of protein, had a shine to it and could expand during baking to contain the gas in the bubbles. This led to the conclusion that as the dough developed, it drew protein to the bubble walls. Thus when the dough expanded, as it rose and in the oven, there was enough protein available to allow the bubbles to expand without breaking. [2]

Another study looked at the role of fat during baking. Solid fats (like shortening) helped bread—they resulted in bigger volume, better flavor, and better texture—while liquid fats (like oil) did not. It was the state of the fat that mattered, because one fat was tested in both solid and liquid forms (by doing the experiment at different temperatures) and had good or bad effects depending on its form. [3]

Questioning the “gluten bubble” model

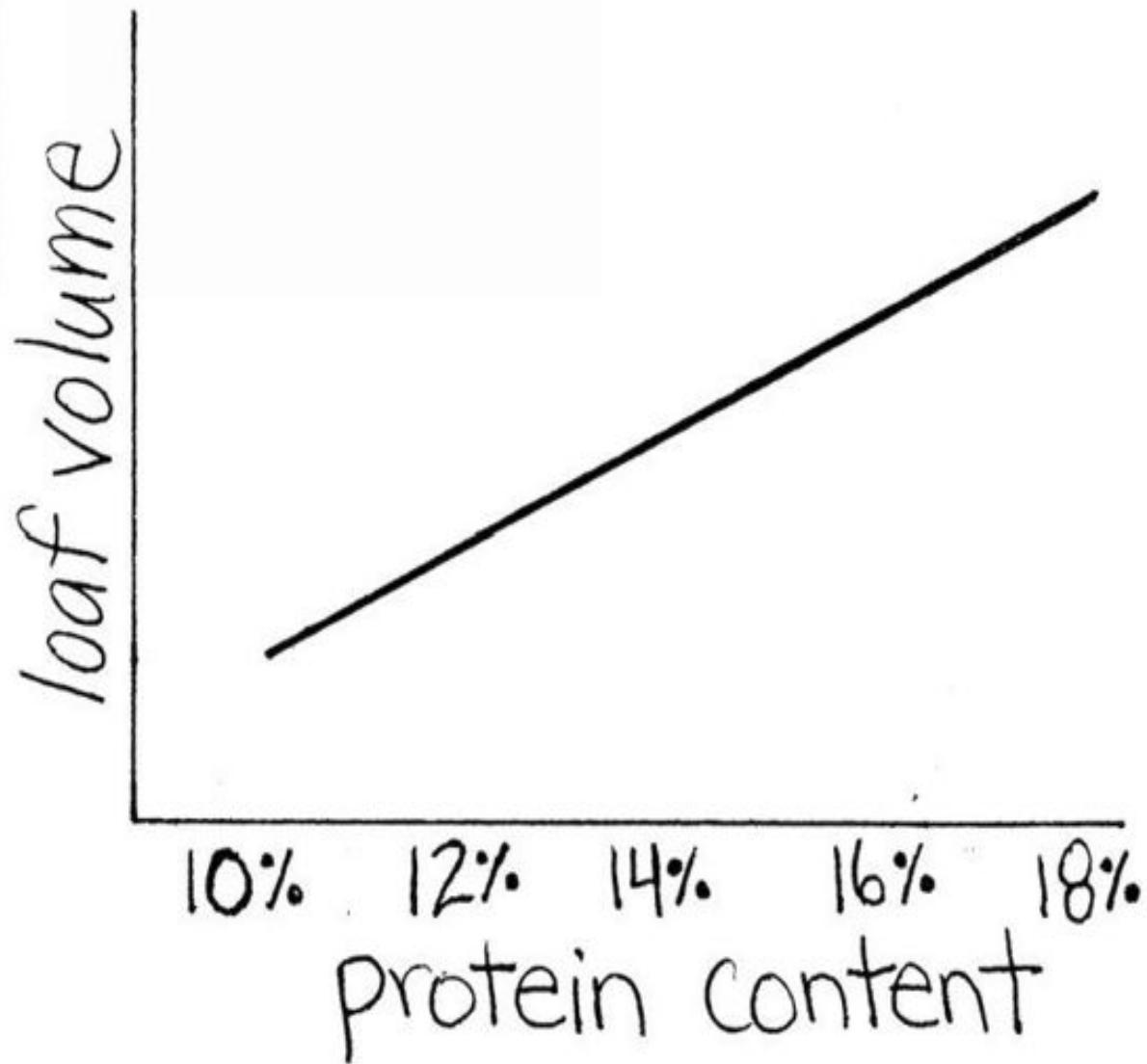
In 1984, R.C. Hoseney questioned the long-accepted picture of gluten acting like a balloon to trap CO<sub>2</sub>. Gluten that prevented gas from leaving a bubble would also prevent gas from entering the bubble in the first place. He offered the explanation that gaseous CO<sub>2</sub> stays in a bubble because the surrounding dough is saturated with dissolved CO<sub>2</sub>, continually produced by the yeast. The gaseous CO<sub>2</sub> stays a gas because the dough is already “full” of dissolved CO<sub>2</sub>. The gaseous CO<sub>2</sub> cannot dissolve into the dough and escape.

When the CO<sub>2</sub> is produced, it diffuses through the dough until it finds a bubble to enter. Some diffuses to the edge of the dough and escapes to the atmosphere, where gas pressure is relatively low. Due to the distance to the edge, however, most CO<sub>2</sub> molecules settle for a nearby, higher pressure gas bubble in the dough. [4,5]



### The role of lipids, surface tension, and proteins

It has long been known that the protein content of flour has a direct effect on the size of bread produced with it. Plots of loaf volume versus protein content show how volume increases with protein. [6]

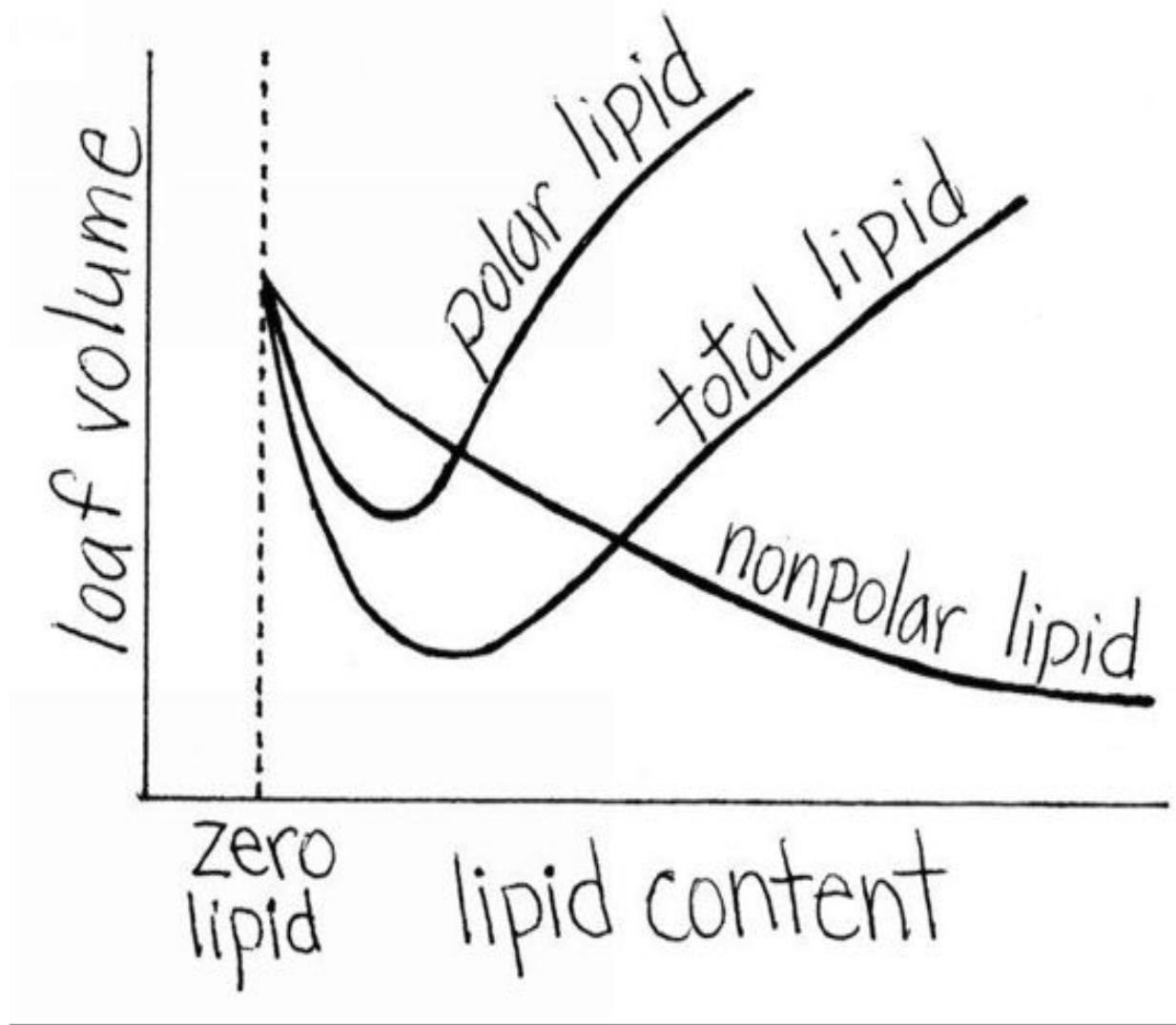


(Keep in mind that these doughs were made in a science lab. Processing conditions were much different than those in your kitchen, and other characteristics, like flavor, were not considered. Even though extreme protein contents show huge results, you would never want to use flour with 18% protein at home!)

The role of lipids in producing bigger loaves is also of interest. Dough has a small amount of lipid in it naturally. Lipid can also be added in the form of shortening or butter (solid lipid) and oil (liquid lipid). To examine the role of

the natural lipid in dough, flour can be “defatted” to produce a lipid-less dough.

Research in the 1970’s concluded that natural lipids do not affect dough properties while it is mixing but do stabilize the rising dough’s foam-like structure. Researchers made dough with defatted flour and then added the lipid back. The plot of loaf volume versus lipid content had a minimum—at first the lipid hurt the volume, but when enough was added it helped. This result was a mystery. The lipid was also separated into polar and non-polar parts, comparable to the solid and liquid lipids of earlier studies, and the polar part was shown to cause the helpful effects on loaf volume, while the non-polar part hurt loaf volume. [7]

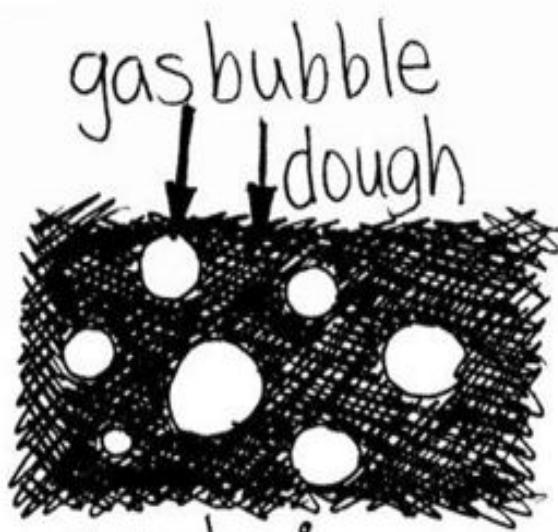


Other papers discussed the importance of surface tension on gas bubbles in dough. These were theoretical treatments with lots of big equations relating things like the pressure in a bubble, the bubble size, and the forces on the edge of the bubble. Different models were proposed. One concluded that surface tension, a force resisting bubble expansion, had a greater effect on bubble size than the gluten's elasticity, [8] while the other said the surface tension mattered little. [9]

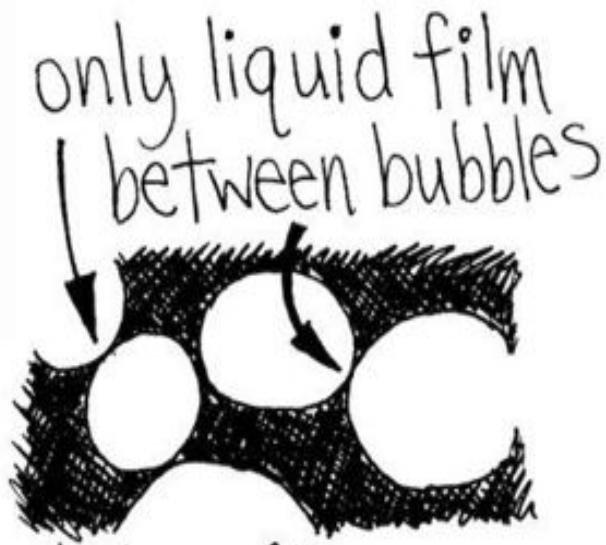
In 1989, Ewart discussed how protein could hold gas in dough with no mention of the flour's lipids. Since he had proposed that glutenin in dough is linear, he suggested that the linear molecules overlapped to form sheets. The sheets were elastic because of the proteins' ability to unfold when stretched. This elasticity resisted the uncontrolled expansion of gas cells. Although this sounds like Ewart is supporting the "gluten balloon" picture, he is not necessarily saying that the gluten prevents the gas from escaping, just that gluten's strength is important for resisting expansion.

### The liquid film hypothesis

Research in the 1990's used an electron microscope to look at slices of bread dough at different stages of the bread-making process. Researchers watched as gas bubbles got bigger and bigger during proofing. After fifty minutes, they observed breaks in the bubble walls, but gas was still retained. Something was holding the gas in. They proposed that gas was retained by some form of liquid film. Upon baking, the dough solidified and the gas bubble walls ruptured completely, releasing the gas.



early in  
proofing



later in  
proofing

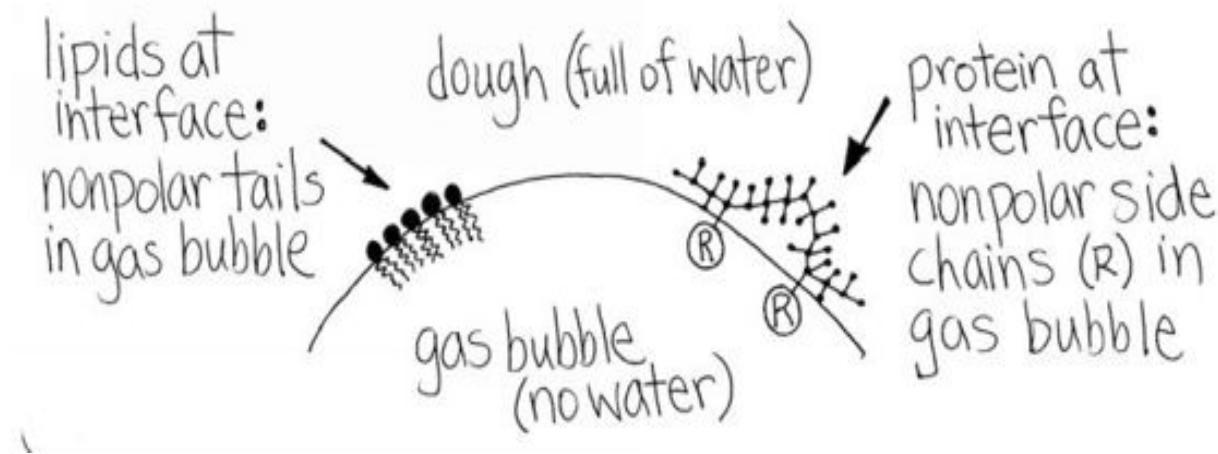


after baking

Ordinarily, the starch and protein network of dough holds gas in; this is adequate at lower gas pressures. The liquid film stabilized gas bubbles and

helped them survive longer because it was more extensible than the starch and protein. It also reduced the surface tension of the bubble.

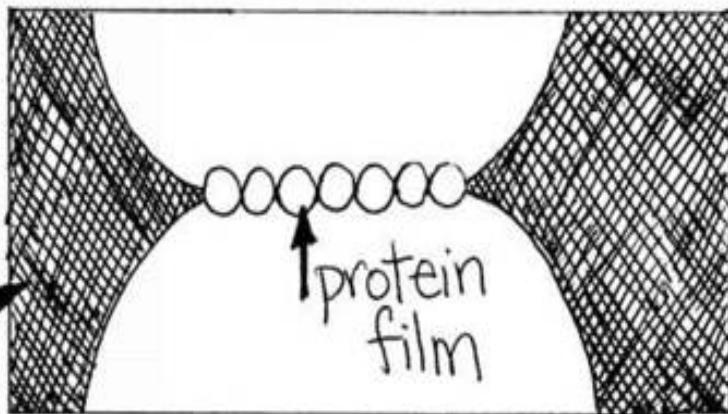
Possibilities for the film's composition included "surface active lipids," with their polar head and non-polar tails that stabilize them at interfaces, and proteins, which can use an interface to stabilize their non-polar side chains. The water soluble proteins, i.e., the non-gluten proteins of flour, were suggested. [10] These possibilities are shown below.



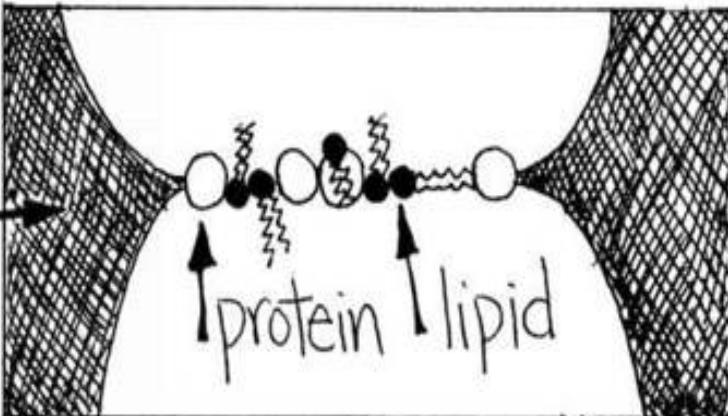
They later proposed that lipids and proteins were both working as a liquid film at the edge of the gas bubble. The lipids and proteins competed for space at the edge. This explained the mysterious minimum in the plot of loaf volume from the 1970's. In the lipid-less dough, gas bubbles were stabilized by a protein film. When some lipid was added, it was not enough to form a lipid film, but it displaced some protein, resulting in a weaker, mixed film. This caused worse gas retention, smaller loaves, and thus the dip in the plot. When enough lipid was added to produce a solid lipid film, the loaf volume increased. These cases are illustrated below. [11]

key:  gas  
bubble  
 dough

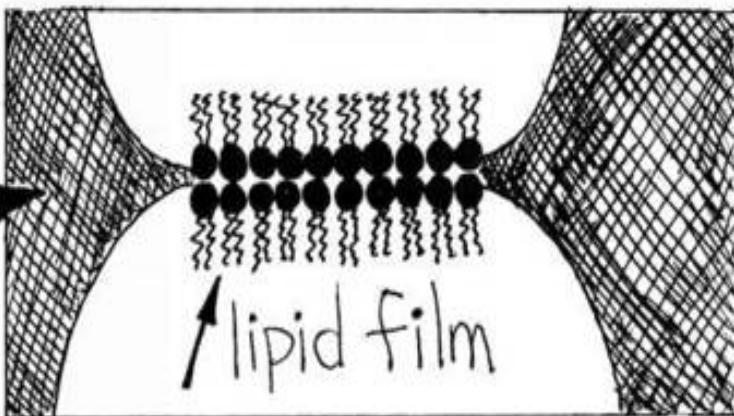
a protein film  
stabilizes  
gas bubbles



a mixed film  
is less stable



a lipid film  
stabilizes  
gas bubbles



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## 2.8 Proteases

Proteases are enzymes, molecules with a specific job to do. Their job is to cut up protein chains, breaking the peptide bonds between amino acids. This results in both smaller protein chains and loose amino acids. Proteases, like all enzymes, are proteins. This makes them seem a little bit cannibalistic to me.

Proteases are important for bread-making because they have a softening effect on dough. They are present in small amounts in flour as well as in yeast, bacteria, and malt. When water is added to flour, proteases move about, attacking protein. A little bit of this action improves dough; in particular, it makes kneading easier. Too much protease, which can be a problem in flour with added protease, will destroy the gluten.

Single amino acids produced by proteases also affect bread. Amino acids can be processed by yeast, resulting in organic molecules that add flavors to bread. They also play a role in developing the flavor and color of the crust during baking, as mentioned in the “Flavor and color” section. [1]

### Overview of protease research

In the scientific literature, numerous terms were used for proteases (proteolyst, proteolytic enzyme, proteinase) and the cutting action they perform (proteolysis, proteolytic activity, auto-digestion). There was also confusion about proteases and a similar molecule called a papainase; eventually a distinction was made between the two. [2]

Most of the experiments done to test protease activity did not use normal bread dough—instead, other protein substrates were added to increase the activity, magnifying the effects and making them easier to observe. This was useful when discovering protease activity or comparing the activity in different flours, but to determine activity of proteases in bread-making it could be misleading.

There was disagreement over the importance of proteases in bread-making. Some people concluded that the activity on normal flour is small enough not to matter. Others felt it might be important. Having observed changes in

my bread dough that can be attributed to protease activity, however, I have to agree that there may be an effect.

### Discovery of proteases

In the late 1800's, scientists observed digestion of the protein in plants. This was eventually attributed to a proteolytic enzyme, an enzyme that cuts protein; the criterion for proteolytic activity was the liquefying of gelatin. Finally, between 1902 and 1909, S.H. Vines did extensive studies of plants and identified proteases. He classified them as two different kinds: some could chop up big proteins, while others had to wait for smaller proteins to be available. [3,4]

In 1908, John Ford and John Guthrie were working with flour and noted interference with their experiments. They suspected proteases and decided to test for proteases in their flour. They made mixtures of flour, water, gelatin, and chemicals, observed liquefying of the gelatin, and concluded proteases were present. They also tested the effect of proteases on gluten by sending mixtures to a baker. He responded that the proteases ruined his bread—gas was still produced but the dough could not retain it. [5]

In 1916, C.O. Swanson and E.L. Tague set up a system to perform auto-digestion for eight weeks. They measured the increase in amino nitrogen, a product of protease activity, as proof that the proteases were working. They observed an increase in amino nitrogen over the first four weeks. They also noted that protease activity was affected by the presence of salts and organic molecules. [6]

In 1920, tests were done on different flours. At the time, some flours worked well for bread and others did not. No one knew why. Low grade flours (the ones that did not work well for bread) were found to have more protease activity. Since different parts of the wheat kernel have different amounts of protease, the low grade flours were probably being made from the high-protease parts of the kernel. [7]

### Measurement of protease activity

The general consensus at this point was that proteases in flour produced inferior bread. As measurement techniques improved, however, it would be observed that a little protease activity could be a good thing.

In 1924, P.F. Sharp and R. Elmer studied proteases and native flour proteins—that is, instead of adding gelatin or other proteins to help monitor protease activity, only the proteins already in flour were used. Without the extra proteins, auto-digestion happened very slowly, but given enough time (five weeks) it happened. [8]

In 1928, Andrew Cairns and C.H. Bailey measured protease activity. They used flour suspensions instead of dough to make any activity easier to observe. They concluded that flour's protease content did not depend on where the wheat came from, but that because different parts of the wheat did or did not have protease, the grade of the flour mattered. With high grade flour, the protease activity would be small enough not to matter in bread-making. [9]

Still, research on proteases continued. In 1936, using a new measurement method, A.K. Balls and W.S. Hale observed protein first coagulating and then breaking down. This led them to suggest that a little protease activity would help bread dough, while too much would be bad. They felt that with absolutely no protease activity, bread dough would be very tough. [10]

A complete study of proteases was done by Byron Miller in 1947. [11] He concluded that the best method for observing protease activity was the “modified Ayre-Anderson method.” The basic method is that auto-digestion occurs, the non-digested protein is removed, and then the nitrogen that is left is measured. An increase in nitrogen indicates protease activity. A protein substrate was used to magnify the effects. Protease activity was measured over time, at various temperatures, and at different pH's. Maximum activity was seen at the start and at acidic pH's (like those in dough).

In 1964, C. McDonald and Lora Chen did a similarly complete study that included measuring protease activity without an added substrate, [12] Though small, the activity was there. Protease activity increased with temperature. There was more activity at lower (acidic) pH's, with maximum activity at a pH of 4.0. Salt inhibited activity, and mixing the dough seemed to inactivate the proteases. (For a definition of the term pH, see the glossary.)

The 1964 study is particularly relevant to bread-making. Mixing a preferment begins the reactions that make dough acidic and gives proteases a chance to work before the dough is mixed and salt is added. One of the effects of the autolyse, the rest period during mixing before salt is added and dough is kneaded, is that subsequently, less kneading is necessary to bring dough to a fully mixed state. This is attributed to the action of proteases during the autolyse. By breaking up the gluten a little, they set it up to form new bonds more easily.

In a study of the structure of gluten, it was noted that a few cuts of the protein chains could have a big effect on dough. [13] This is because dough properties depend on the size of the protein molecules. More recent data of the low but present activity of proteases in flour confirms the belief that a small amount of protease activity can have a noticeable effect on the toughness of dough. [14]

These days, protease content in flour is measured at the mill to avoid the bad-for-bread flours of the old days. Protease content can be controlled by mixing different strains of flour with different protease contents.

#### Proteases in yeast cells

Proteases are also found in yeast cells. This was first discovered in 1898, when the liquefying of gelatin showed that there was a digestive enzyme in yeast. In 1909, S.H. Vines identified different enzymes, the same two kinds of protease found in plants (and flour). In 1917, K.S. Dernby identified three digestive enzymes in yeast, both that of the 1898 study and those of Vines's study. [15]

Subsequently, there was contention about the existence of these enzymes on the outside of yeast cells. Some studies observed proteolytic activity while others did not. Eventually it was concluded that dead or broken yeast cells leak out their fluids, resulting in escape of the proteases to the outside and observed activity in some experiments. Other experiments did not observe activity because the yeast cells were whole and alive or had been washed first, removing any proteases that were outside. [16,17]

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- [7] Johnson, A.H. and C.H. Bailey (1924).
- [8] Sharp, P.F. and R. Elmer (1924).
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- [16] Johnson, A.H. and C.H. Bailey (1924).
- [17] Cairns, A. and C.H. Bailey (1928).

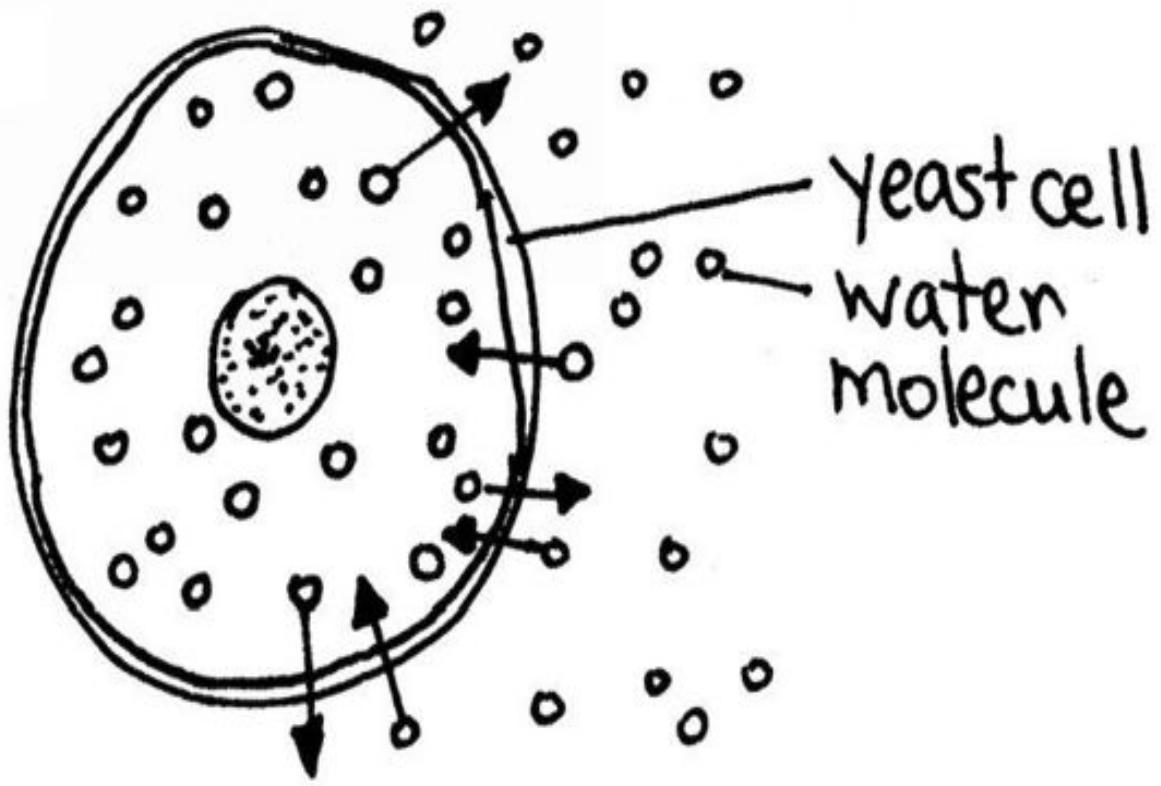
## 2.9 Salt and fermentation

Salt is a crystal made of positive and negative ions that stick together because of the attraction between opposite charges. These ions pack together in a crystal. The bonds in this crystal are strong, but when water is present the bonds break and loose ions become present. The ionic nature of salt is responsible for the effects salt has on bread dough.

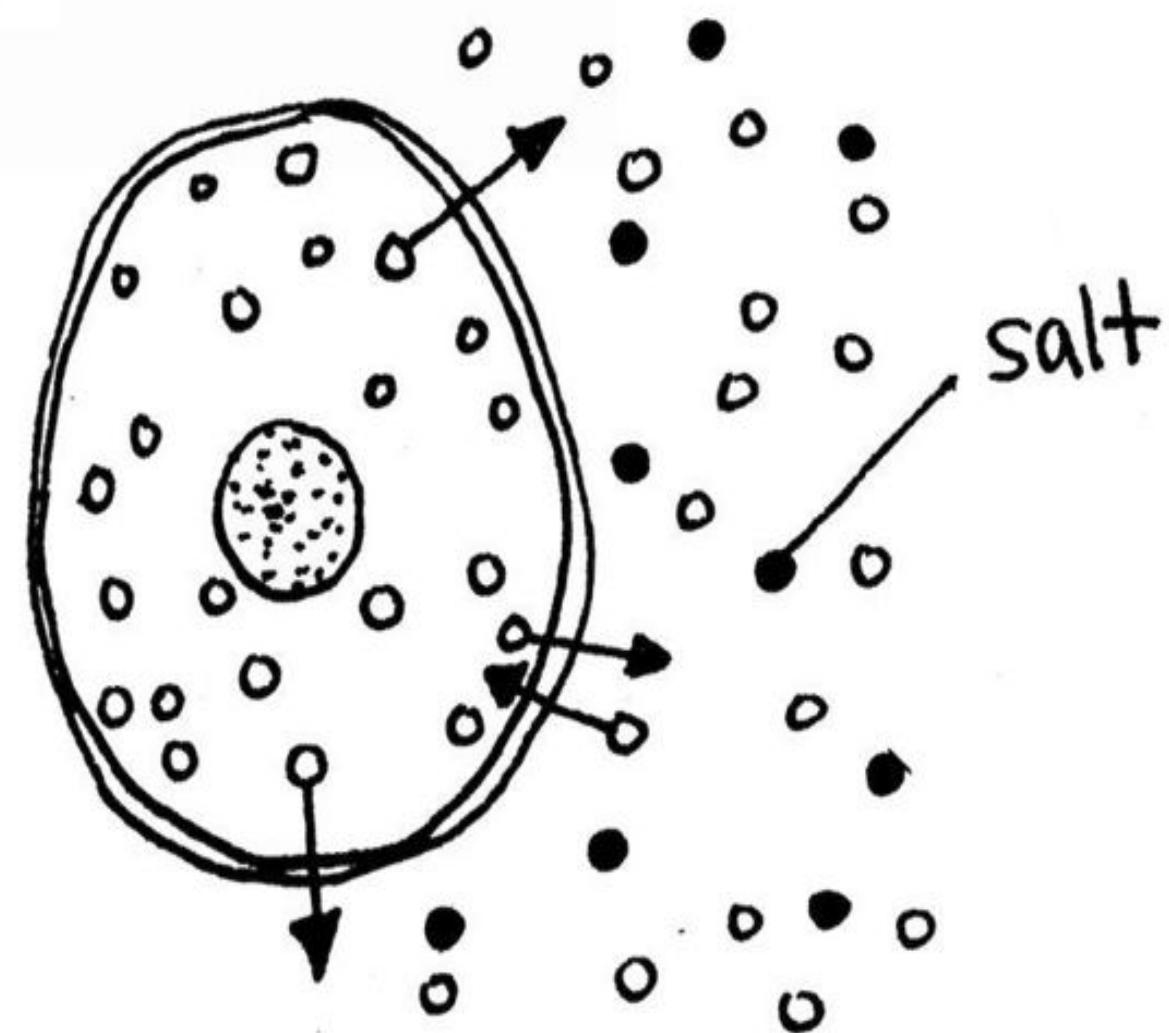
Salt slows fermentation reactions by dehydrating the yeast and bacteria cells. Without the nutrients they need, these cells cannot perform fermentation like usual.

Basically, water molecules are able to pass in and out of cells, a process called osmosis. When there is salty water outside of the cells, the salt interferes with the movement of the outside water molecules. They pass into the cells more slowly. The inside water molecules are unaffected and pass out of the cell at their usual rate. Thus the net movement of water is out of the cells, an effect called crenation . This results in dehydrated yeast cells.

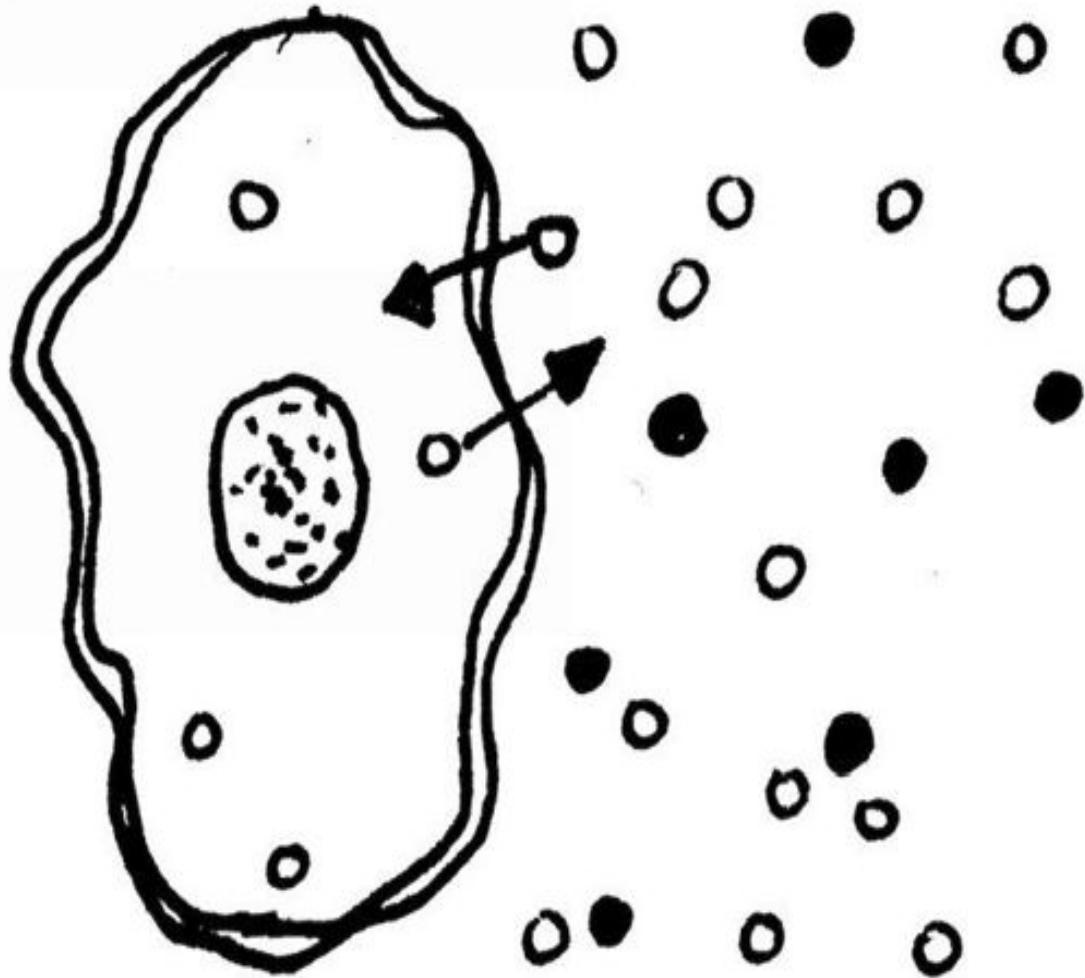
In the following images, a yeast cell in pure water has water molecules coming and going:



When salt is added, water molecules can not enter as easily, and the net movement is out of the yeast cell:



This results in a dehydrated yeast cell:



Salt also affects the uptake of sugar by cells. With less water and sugar, yeast and bacteria do not function as well; fermentation slows down. Mixing prefers (without salt) and adding salt to dough last give fermentation reactions a head-start.

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## 2.10 Salt and gluten

Salt has a profound effect on bread dough. Even more important than its action on yeast fermentation (described in the previous section) are the effects of salt on dough's physical properties like elasticity and strength and subsequent effects on dough's rising time. As early as 1919, researchers noted that salt effects on yeast were secondary. [1]

If you forget to add the salt when mixing dough, you will notice a stickiness to your dough; it will not hold together. Adding salt tightens the dough and helps it hold together instead of sticking to you. This is due to interactions between the salt and the gluten in the dough.

### Early dough tests

In the early days, researchers measured how salt affected dough but were unable to explain the effects. They measured multiple dough properties—viscosity, resistance, extensibility, consistency, mobility. The 1919 study looked at salt and acid's effects on dough viscosity. The best dough for bread-making, which had the lowest viscosity, was found at a pH of five with a small concentration of salt. (For a definition of the term pH, see the glossary.)

The dough tests done over the next decades are too numerous to list. It was accepted that salt was needed to produce a manageable dough. [2] Results did not always appear consistent. In particular, salt affected the strength of dough differently at different concentrations, dough hydrations, and levels of acidity. [3,4,5]

### Protein macromolecules

Without an understanding of how salt affects dough, the piles of data were useless. Fortunately, overlapping this research on dough properties was research on the behavior of protein macromolecules (so called because of their large size) that led to an understanding of salt's effect on gluten.

As early as 1928, Ross Gortner et al were looking at proteins in different salt solutions. Some salts helped the proteins dissolve more (i.e., become more hydrated) while others did not. The same was true when they narrowed their

study to flour proteins. [6] In 1933, Dorothy Lloyd and Henry Phillips looked at protein hydration, describing the bonds between water and protein molecules that constitute hydration. (This was discussed in the previous “Water and protein” section.) They found that salt increased hydration. [7]

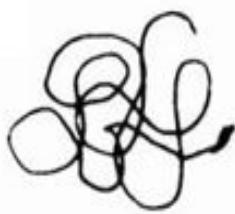
In 1943, J.G. Kirkwood studied the properties of protein solutions by considering the formation of dipoles at certain amino acids. There are sites in proteins where one atom can give an electron to its neighbor. The two atoms are then oppositely charged and attract each other, forming the dipole, but there is no net charge. Kirkwood focused on these sites, which would attract ions in the solvent, as the cause of protein-and-salt properties. [8]

Finally, in the 1960’s, the concept of hydrophobic bonding was applied to the system of proteins in solution. (This kind of bonding was described in the previous section “Gluten structure.”) It was now apparent that many kinds of chemical bonds were present in proteins. These bonds controlled the shape of a protein molecule, keeping it folded or allowing it to stretch out. [9]

When protein molecules were in solution, the surrounding liquid could affect the proteins’ shapes. The numerous possibilities were investigated. (Fortunately, in bread-making, we only need to consider one system, gluten protein in water.) Salt was an added complication that had its own effects on the protein molecules. [10,11,12,13] A major paper in 1977 gave a theoretical treatment of salt effects on proteins in solution, including both electrostatic interactions and hydrophobic interactions, and described the surface hydrophobicity of proteins. [14]

### Basics of protein behavior

Protein molecules in a solvent exist between two extreme forms, called conformations. If the protein is folded up in a ball, with lots of internal bonds, it is in its native conformation. It is a globular protein and is aggregated or folded. If it is stretched out in a long chain, it is in the random coil conformation and is denatured or unfolded.



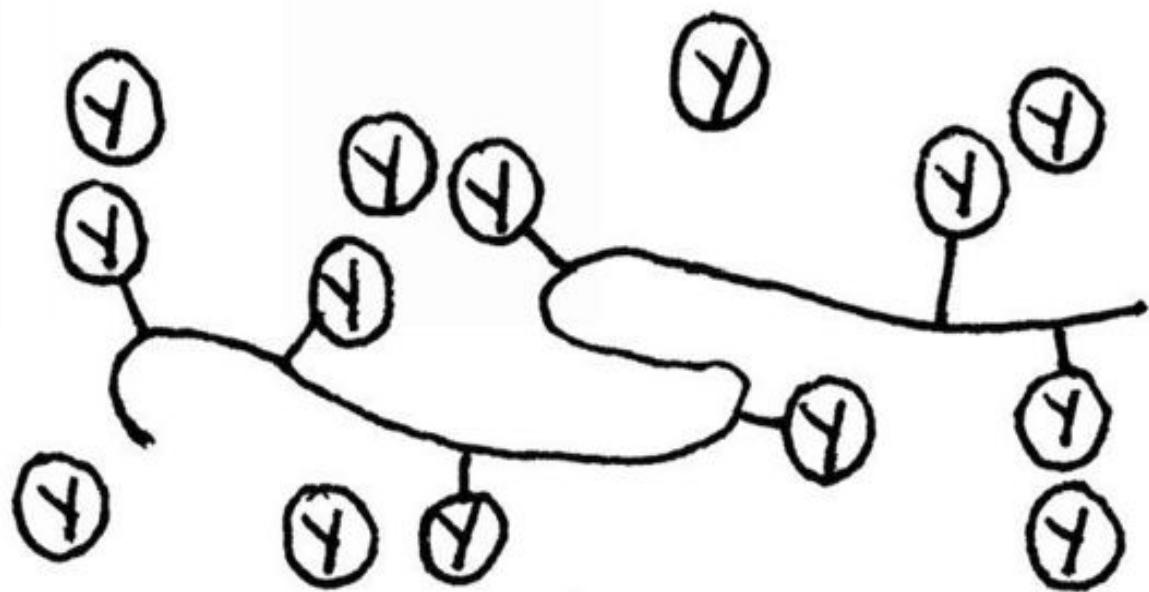
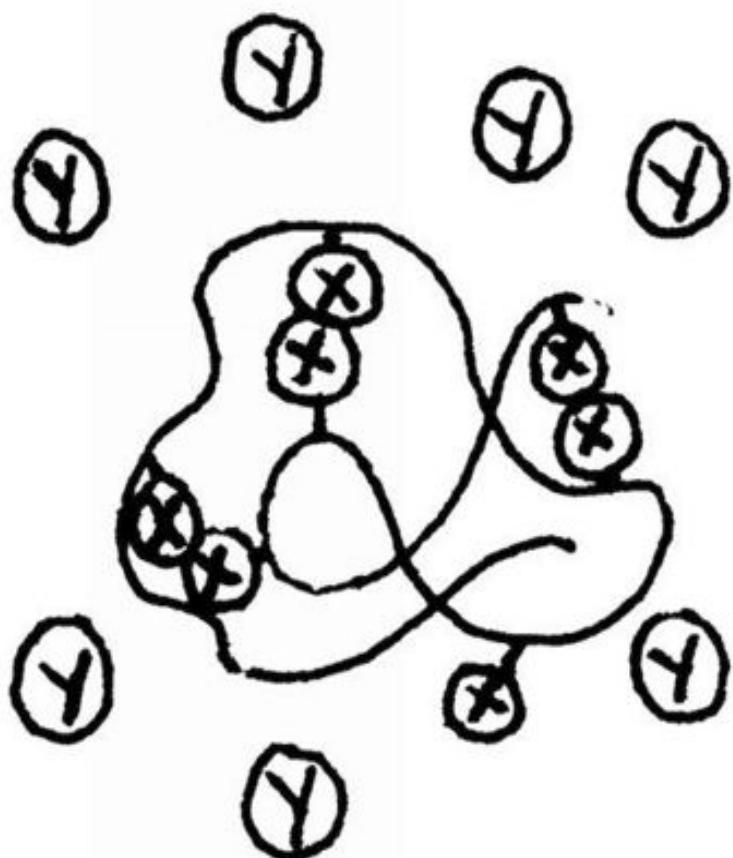
folded protein:  
native, globular



unfolded protein:  
random coil, denatured

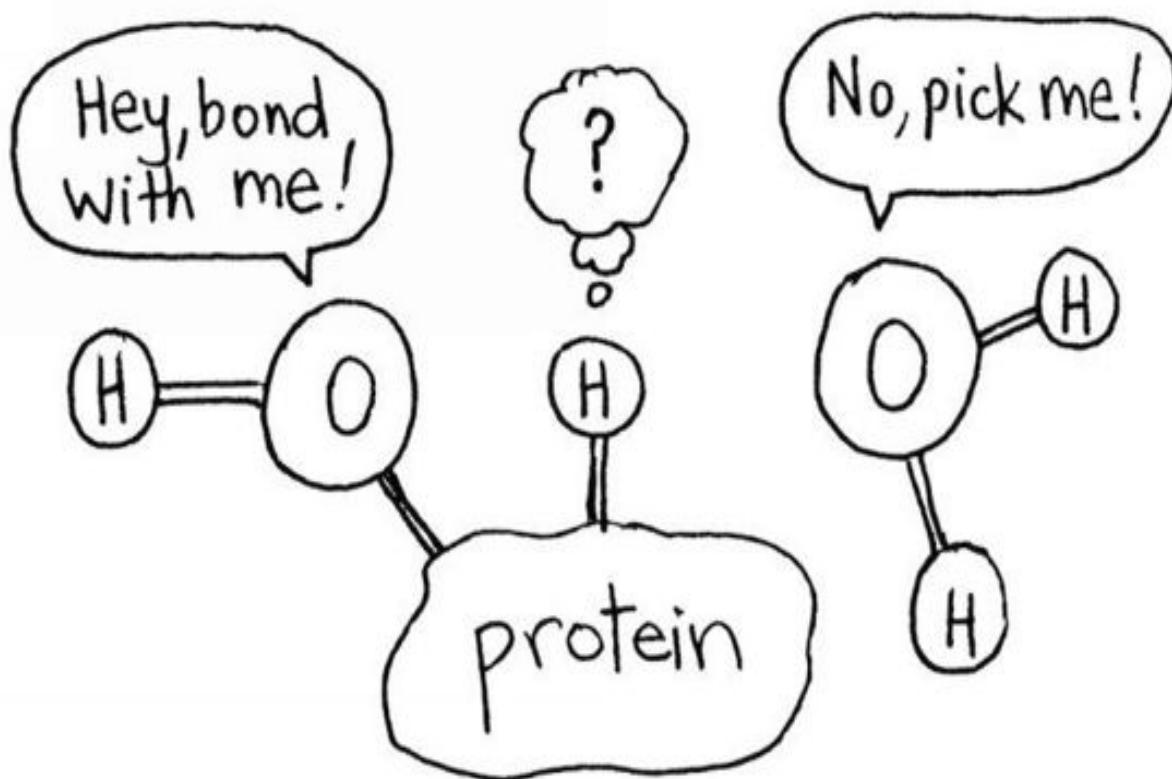
Which conformation a protein adopts depends on the amino acids it contains, the order they are in, and the solvent. In general, in a folded protein, the amino acid units bond to each other more than to the solvent. For example, the amino acids might be able to form many internal hydrogen bonds. Or, there might be many non-polar amino acids. In water, these non-polar, hydrophobic amino acids cluster together. By forming a ball, the protein keeps them in its center, near each other and away from the surrounding water.

In an unfolded protein, the amino acid units bond to the solvent more than to each other. The molecule stretches out, maximizing its contact with the solvent. For example, in water, the amino acids form more hydrogen bonds with water than with each other. In a non-polar solvent, non-polar groups would not need to cluster together in the center of the protein. Also, an unfolded protein is able to rotate more, a disordered state that is energetically favorable.



In the image above, X and Y represent different types of groups that do not bond to each other. The solvent contains Y's. A protein with X groups will fold (top), bonding with itself, not the solvent. When the protein contains Y groups instead, it unfolds and bonds with the solvent (bottom).

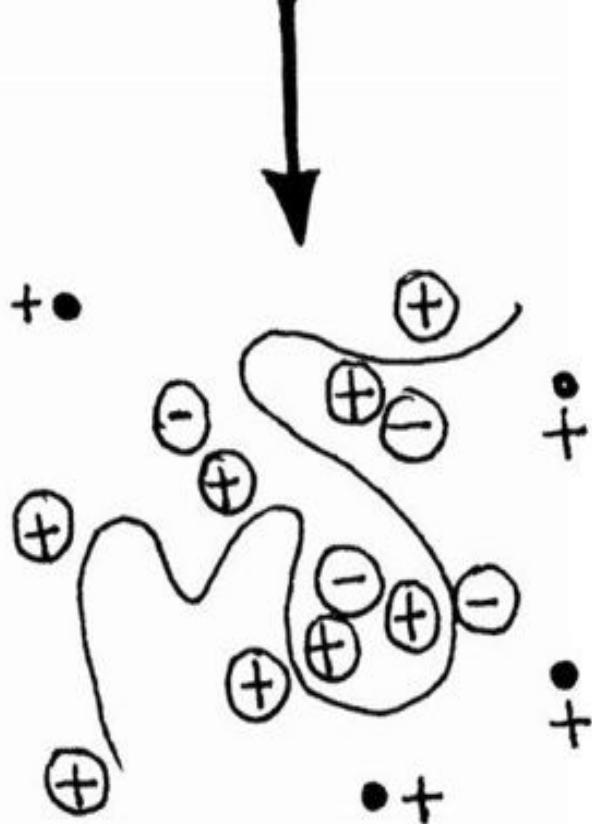
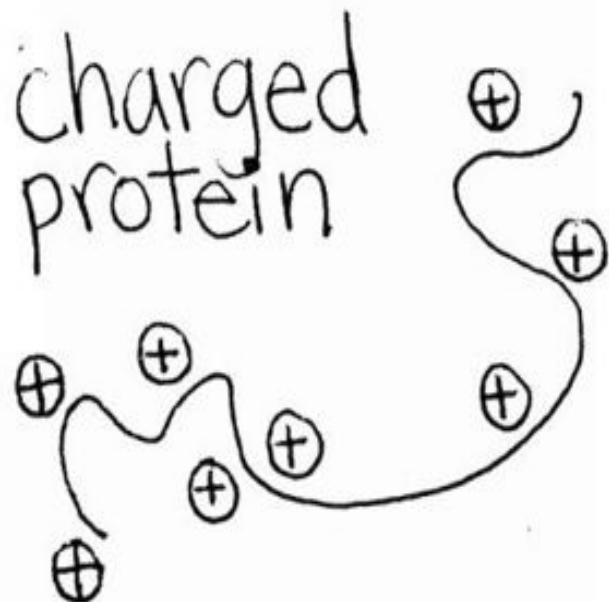
There may be competition between the solvent and the protein molecule for bonding. For example, a protein containing amino acids that can form hydrogen bonds can form internal hydrogen bonds, causing it to fold up. In water, however, the amino acids can also form hydrogen bonds with the water molecules, causing unfolding.



There are different ways to induce conformation change in proteins. The basis of all is either to change the protein directly or to change the solvent in a way that affects the protein. Increasing temperature generally causes proteins to unfold. The increased temperature disorders the solvent and stresses the bonds of a globular protein. Changing the acidity of the solvent provides or removes hydrogen ions that can attach to sites on the protein molecule. This can induce folding or unfolding. Other solvents or chemicals can be added to compete with the internal bonds—polar, hydrogen, and

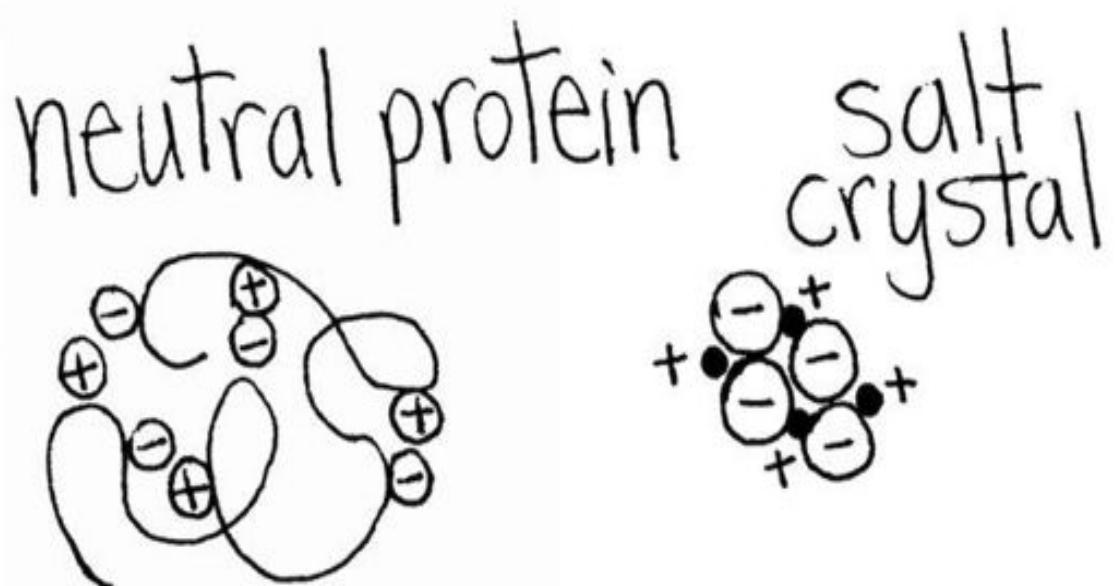
hydrophobic—of the protein and induce unfolding or to promote internal bonding.

Salt is an example of a chemical that can induce changes in protein conformation. The most obvious method is by shielding charges on the protein. In solution, the salt dissolves to positive and negative ions. These ions are attracted to sites of opposite charge on the protein. If the protein contains mostly positive charges, it will be stretched out, with its charges repelling each other (first image, below). The addition of salt will shield these charges, enabling the molecule to tighten (second image, below).

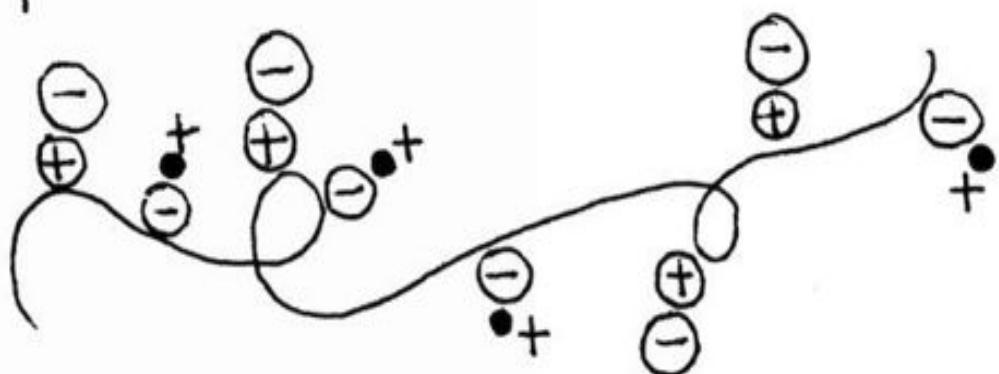


protein tightens

If the protein contains amino acids with both positive and negative charges, there will be internal bonding between the sites. The addition of salt will interrupt this bonding, causing the molecule to stretch out as shown below.



protein stretches



Salt also affects protein structure in more specific ways. Salt ions can react with charged or polar amino acids. If these amino acids are folded inside the protein, the protein may unfold to promote reaction. Also, salt can affect the solvent in ways that indirectly affect the protein.

In summary, the protein-solvent-salt system is a complicated one, with each part affecting the others both directly and indirectly. Each different solvent or salt can induce proteins to fold into a ball or to unfold, and the same solvent or salt can affect different proteins differently.

### Salt, protein, and bread-making

Fortunately, bread-making is just one system: gluten proteins in water with sodium chloride salt. In 1978, A. Maher Galal et al studied dough properties using the acids found in sourdough and sodium chloride. They prepared a control dough, acidic dough, salty dough, and dough with acid and salt. They tested the time it took to mix each dough and the dough's stability. Both properties decreased in the acidic dough, but salt increased the mix time (i.e., made tougher dough) and stabilized the dough. In the dough with both acid and salt, which was similar to actual bread dough, the stabilization was magnified. [15]

The authors hypothesized about the changes in gluten structure that caused these results. At pH's near 5.5, gluten had a small net positive charge because of the amino acids it contained. These positive charges repelled each other, causing the gluten to stretch out. When acid was added, hydrogen ions bonded to the gluten, giving it a bigger positive charge. This further stretched the gluten, weakening and destabilizing it. It also increased hydration because there were more sites available to water molecules and water molecules were more attracted to the charged gluten sites.

If salt was added to dough, salt ions interacted with the charged sites, shielding them. This decreased the repulsion and enabled the gluten to contract. It became tighter and stronger, corresponding to the increase in mix time and stability. There was a decrease in hydration.

When both acid and salt were added, there were opposing effects. The acid created more positive charged sites on the protein, causing it to stretch out. The salt repressed the charged sites, helping the protein aggregate.

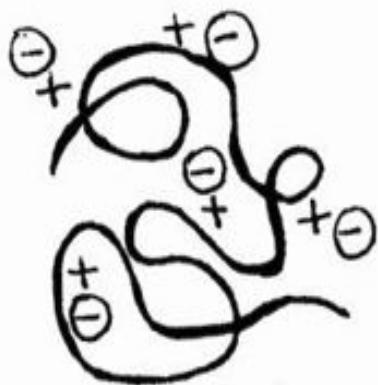
The acid also, in stretching out the molecule, exposed hydrophobic groups. Because the salt had covered the charged sites, preventing them from repelling each other, the hydrophobic groups were able to interact, resulting in even greater dough strength and stability. The acid/salt/dough results are presented in the following diagram.



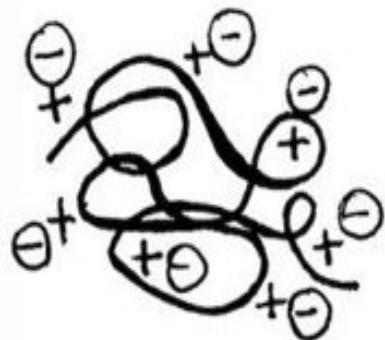
Control



acid



salt



acid and salt

Today, the accepted explanation for the effect of salt on dough strength is that the salt ions shield the gluten's positive charges from each other, enabling the protein molecule to tighten. Research continues on the behavior of salt and proteins in dough, but the hypothesis proposed by Maher Galal et al has not been refuted.

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## 2.11 Miscellaneous

### Sugar added to bread dough

Sugar can be added to bread dough for a few reasons, the main one being to make a sweeter bread. In addition, extra sugar promotes crust browning, as both caramelization and Maillard reactions use sugar. Sugar also is known to postpone the firming of bread associated with staling.

Sugar affects the rate of fermentation reactions. A little sugar, up to three percent, speeds up fermentation. The yeast processes the added sugar first, saving the time it would take to break down starch into sugar. With over three percent sugar, however, the fermentation rate no longer increases. Above six percent, sugar actually decreases the rate. [1] This is because the sugar begins to dehydrate the yeast cells. This effect, called crenation, was described in the previous “Salt and fermentation” section.

### Malt

Malt is a somewhat mysterious optional ingredient in bread. It is basically maltose, the complex sugar involved in fermentation. Two types of malt are available—diastatic and non-diastatic. Diastatic malt contains the enzymes needed to break maltose into the glucose sugars needed by yeast and is the kind appropriate for bread-making.

What exactly does adding malt do? Processing maltose is the rate-limiting step of the fermentation reactions. The yeast must first take in the maltose, the slowest part of the process. The maltose is then broken down to glucose, which happens slowly even in yeasts with lots of maltase to do the job. Overall, this means that the other reactions are stuck waiting for maltose to be processed. There is a bottleneck through which molecules must pass before they can continue being fermented. [2] Adding malt (and malt-processing enzymes) to bread dough widens this bottleneck and allows more fermentation to occur at once.

In addition to its effect on gas production, malt contributes to final crust color. Some people think it adds to the bread’s flavor as well. Malt may be

hard to find in grocery stores, but it can be found in mail-order baking catalogues. Or, flour can be bought with malt already in it.

### Staling

Bread staling is an interesting topic to consider. Bread begins to stale from the moment it finishes baking, and much research has been done both to understand the different aspects of staling and to find ways to postpone them. In my mind, some of the cures for staling are worse than stale bread—adding enzymes, emulsifiers, sugar, lard, or shortening—and I think, why don't people just accept that bread can't be stockpiled in the cabinet?

Staling research often uses recipes for factory-type bread, not artisan bread. For example, an interesting study in 1953 showed that bread actually stale more slowly when its crust is removed. The bread, however, was made with flour, yeast, “arkady” (whatever that is), malt flour, salt, sugar, nonfat dry milk solids, lard, calcium propionate (to stop mold), and water. It was stored in tin containers in a special cabinet. [3] I do not know how relevant this study is to keeping a loaf of sourdough on your kitchen counter.

A basic understanding of staling, however, can contribute to proper storage of your loaf. In addition, the seriousness of staling research has always struck me as comical. There is a pileup of scientific terms used in place of perfectly good common words, for example, “compressing during mastication” in place of “chewing.” Also, I always suspect that interest in the topic is largely driven not by a desire to help people have better bread, but by greedy bread companies’ desire to make more money with a product that lasts longer on the shelf. Therefore I include this section both for information and amusement.

There has never been consensus on the exact definition of “stale” or the best way to measure it. Different parts of staling have been recognized, but they transpire at different rates, so that bread can be stale in one aspect and not in another. Staling includes the following: [4,5,6]

1. The crust becomes tough. It is no longer friable , the scientific term for “crusty.” The loss of friability is caused by the migration of moisture from the middle of the bread outward to the atmosphere, via the crust.
2. Moisture migration also causes dried out bread.

3. The crumb or inside of the bread becomes firm. This happens even when the bread is packaged so that moisture is retained; it is not simply the bread drying out. Firming is sometimes blamed on changes in the starch (see number 5), but this connection has been disputed; the cause of firming remains unknown.

4. The bread loses flavor. This is caused by the loss (over time) of organic molecules to the atmosphere. In addition, components of the flavor may be deactivated, and other unexplained chemical reactions might happen, altering chemical structures that affect flavor. The reappearance of some flavors on heating suggests that flavor compounds might become trapped in starch and released with heating. [7]

5. Starch retrogradation causes an increase in the opaqueness of the crumb (i.e., the insides start to look white) and a decrease in soluble starch. What is retrogradation? During baking, the starch in dough melts. The molecules become less organized and allow water molecules to move near them; some are partially dissolved. As the bread cools, the starch recrystallizes (retrogrades), going back to a solid form. This causes firmness. One part of the starch, amylose, retrogrades quickly, resulting in the original firmness of the bread. The other part, amylopectin, retrogrades more slowly, resulting in added firmness over the next few days. (Some scientists link this with staling firmness and some do not.)

In 1953, Bechtel et al pointed out that staling is defined by consumer acceptance, and consumers do not judge bread with laboratory tests but with feel and taste. [8] Thus, staling studies often include a “sensory perception panel” that performs an “organoleptic evaluation” of bread samples and assigns a “percent freshness” to each.

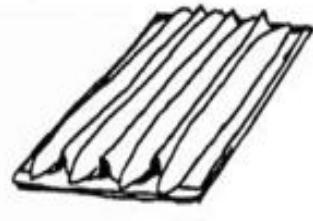
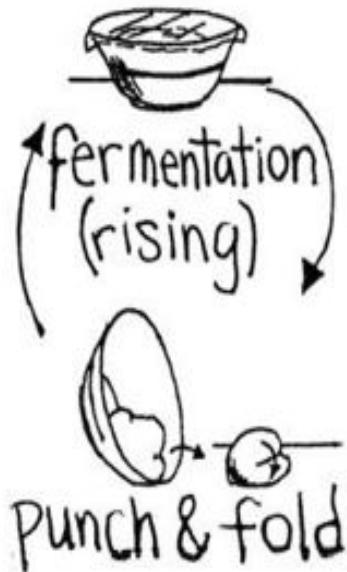
The other factor measured is compressibility, using a “ penetrometer” or a “compressimeter” that squishes a certain size piece of bread with a weight. This is meant to emulate the consumer’s “squeeze test.”

For information on how to battle staling, see the section on storing bread in chapter eight.

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# Chapter 3: Preferments



This chapter explores preferments, starting with the question, what is a preferment? Many people have never heard this term, but using a preferment improves dough drastically, both in flavor and in handling. And once you understand them, using a preferment is easy!

## 3.1 What is a preferment? Why use one?

## 3.2 Poolishes & sponges: what they are, how to mix them

## 3.3 The lifespan of a poolish and how to control it

[3.4 What if a poolish is used too soon/late?](#)

[3.5 Adding a poolish to a straight dough recipe](#)

[3.6 Starters: what they are and how to mix them](#)

[3.7 The lifecycle of starter](#)

[3.8 Notes on creating a sourdough starter](#)

[3.9 Recipe for creating and feeding a sourdough starter](#)

[3.10 How much neglect can starter take?](#)

[3.11 Working with starter using volume measurements](#)

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## **3.1 What is a preferment? Why use one?**

A preferment is a mixture of flour, water, and a rising agent. It is mixed the day before the dough is mixed. Fermentation reactions begin overnight and the preferment rises. It is then added when the dough is mixed. Using a preferment creates both better dough and better bread, as described below. Preferments include the following:

- poolishes and sponges, which are mixtures of flour, water, and yeast that are made one day and used entirely the next
- starters , also called levains , which are mixtures of flour, water, and old starter. The entire starter is not used in the dough— some is saved to make more starter
- old dough, dough saved from the previous day's batch of bread, that has developed flavor overnight.

There are many other names for preferments, but the basic idea is the same.

Making a preferment is an optional step that adds a day onto the bread-making process—so why bother with it? Note that the word “preferment” is made of the parts “pre” and “ferment.” Before the dough is mixed, fermentation and other chemical reactions begin in the preferment. A preferment therefore gives dough a head-start with flavor-producing reactions, creating better-tasting bread. Mixing a preferment also creates a better dough and makes kneading easier. Here is how:

1. Hydration begins. It takes time for water to hydrate the ingredients. Water molecules must work their way into starch granules and move between long protein molecules. Other molecules rely on water to dissolve them or to help them move in the dough. This all begins when a preferment is mixed.
2. Fermentation begins. Once molecules are hydrated, chemical reactions begin. Foremost among the reactions is fermentation, and a longer fermentation time adds flavor to the dough. This is because flavor comes from alcohols, acids, and other fermentation products. A longer

fermentation time allows more of these products to form, resulting in more flavor.

3. Gluten forms. Dough strength is the result of chemical bonds between water and flour protein, i.e., gluten. The bonds form when the flour is mixed with water and then rearrange during kneading. In the end, the best bonds remain, aligned for collective strength. When a preferment is mixed, the protein molecules are hydrated and bonds begin to form. The protein becomes well-hydrated overnight, before kneading occurs.

4. Proteases are activated. Proteases, the enzymes in flour that break the protein chain, are able to move when water is added to flour. They get to work, chewing on the protein and getting it ready to be kneaded.

5. Acidity develops. In general, a more acidic dough requires less mixing.\* [1] Using a preferment allows acid-producing reactions to begin well before kneading. When it is time to knead, the dough is more acidic and easier to mix. [\*Note: No explanation is given for this in the reference. A possible explanation is that proteases work better at acidic pH's and therefore a more acidic dough (5.) is simply enhancing protease activity (4.)]

6. Less yeast is needed. In breads made with yeast, using a poolish enables the baker to use less yeast, which makes the bread taste better.\* A tiny bit of yeast, given a whole evening, can process a large amount of flour. Without a poolish, this flour must be added during the mixing step, and the baker needs to add more yeast to process it in a timely manner. (\*Note: Some people prefer a yeasty flavor. When I write “taste better,” I simply mean there is more bread flavor and less yeast flavor.)

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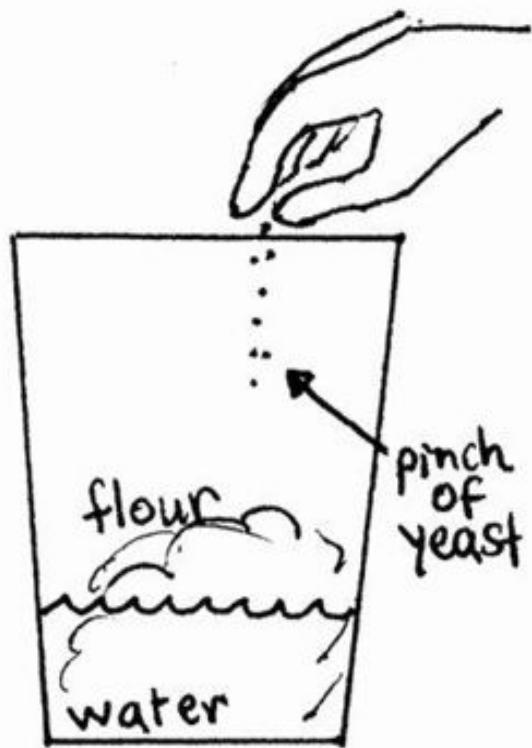
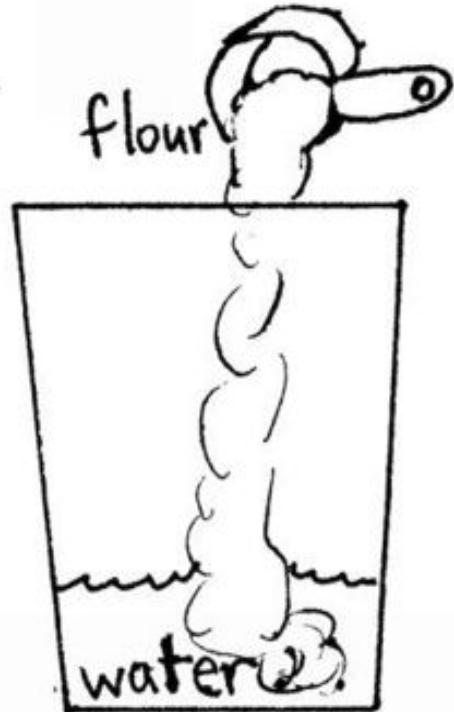
## **3.2 Poolishes & sponges: what they are, how to mix them**

A poolish is a mixture of flour, water, and yeast. Equal weights of flour and water are used, giving a pancake-batter consistency. A sponge is a similar mixture with a higher percentage of flour, giving a dough-like consistency.

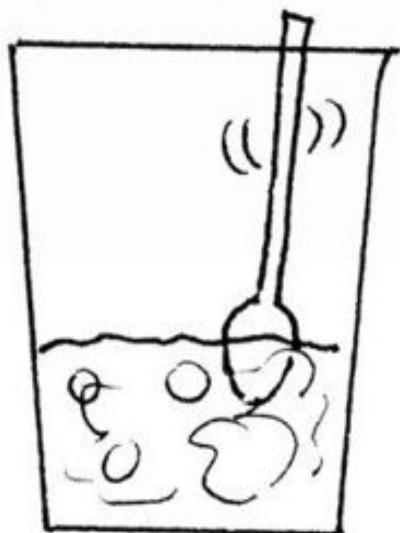
Both poolishes and sponges work well. Why use a poolish versus a sponge? I have made the same bread with each preferment and not seen any obvious difference. Some people believe a more acidic flavor develops in a sponge.

To mix a poolish (or a sponge), use a see-through, covered container. (A see-through container is ideal for monitoring the height and gas content of the poolish.) Make sure the container is big enough—the poolish is going to double or triple in volume. My preference—cheapo plastic containers—is shown in the following pictures.\* (\*Note: Are metal containers bad to use? I have not read this, but since metals often do react with acid, it is probably best to use a plastic container. Another alternative, if you'd like to avoid plastic, is a quart-sized glass canning jar.)

First add water. Then add the flour. Add the yeast on top of the flour and swirl to disperse it into the flour. Use your hand or a spoon to mix the poolish, squashing any flour lumps. At first you will feel stringy flour globs throughout the mixture. When these are gone, you will find smaller lumps to squash. Mix until there is no dry flour left. After mixing, cover the preferment and burp the lid to remove air; otherwise, gas production may cause it to pop off. Mark the starting height of the poolish on the side of the container.



mix till it is  
lump-free

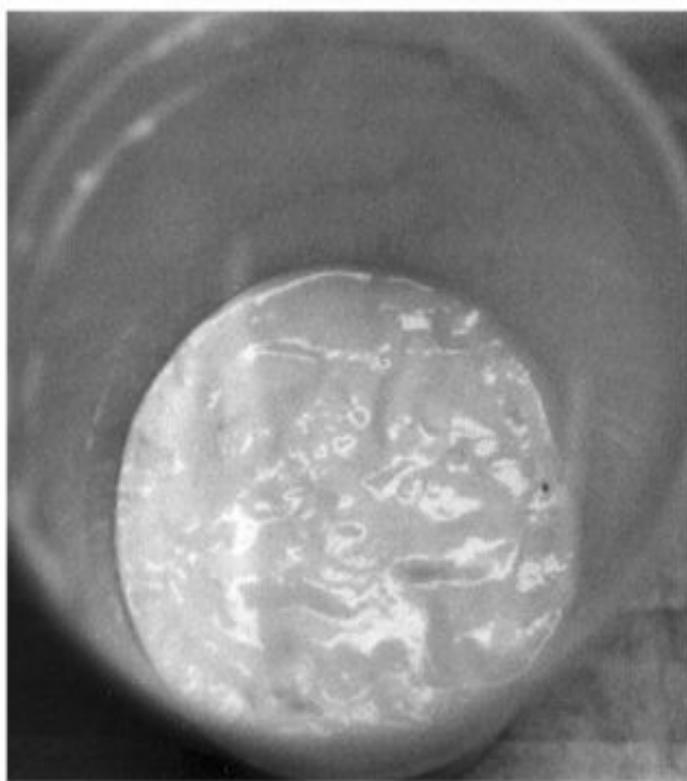


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### **3.3 The lifespan of a poolish and how to control it**

After mixing a poolish, you should see something like this:

1. At first, the poolish is dense inside with a smooth surface. There is plenty of flour available for the yeast to process.



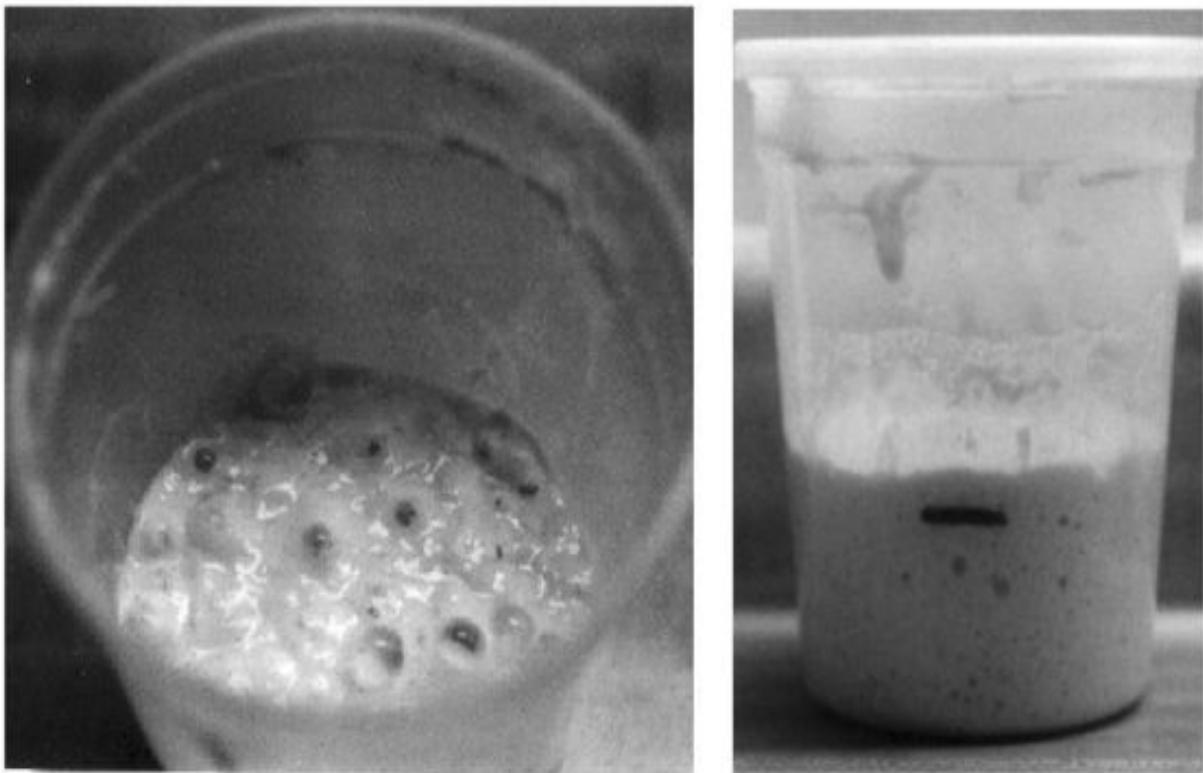
The image above shows the newly mixed poolish with a line marked on the side of the container to show its original height.

2. After a few hours, small bubbles appear on the surface.
3. Gradually, as more fermentation occurs, more and bigger bubbles appear. The poolish grows. The surface may be covered with bubbles, but inside there are still dense spots.
4. The poolish reaches its maximum height. It is full of gas and covered with bubbles; if bumped, it may collapse. It smells fruity. This poolish is ready to be used in dough.



The image above shows the poolish at maximum height.

5. Reactions slow as flour is used up. The poolish starts to lose height and smell more strongly. If bumped, it collapses.



The image above shows the poolish after it has collapsed.

6. The flour supply runs out and the fermentation reactions slow down and stop. The poolish nears its original height. It is flat and bubble-less. The yeast begins to die.

A sponge's lifespan is similar, but its relative dryness gives it a domed shape while rising. Its initially heavy consistency becomes soft and airy.

How can you tell if your poolish is still rising or if it is at its peak and about to fall? Pick up the container and drop it with a thunk on the counter. If it is ready, bubbles will rise to the surface and break. It may collapse. Collapse does not mean it is ruined—the flavor is still there, and it would have collapsed anyway when added to your dough.

Ideally you would watch your poolish rise until it was ready and then use it. Most people's schedules do not allow this, however, so instead you can control the lifespan of the poolish to fit your schedule. It may take a few tries before you are able to predict when your poolish will be ready.

In general a poolish that is slightly below room temperature (20 to 25°C, 65 to 70°F) will be ready to use 12 to 15 hours after it is made. Make the

poolish 12 to 15 hours before you want to mix your dough. When it is time to mix, note if the poolish is ready. If not, you can adjust the poolish's rising time, the amount of yeast used, the water temperature, or the temperature of the poolish's surroundings to make it be ready at the right time the next time you make dough. Here is what to do differently next time:

Was the poolish nowhere near ready?

- Mix it earlier next time to give it more time to rise.
- Use warmer water and place it somewhere warm to rise, like on top of your refrigerator or under a light.
- More yeast can also be used, but remember that one benefit of using a poolish is that you can use less yeast in your dough.

Was the poolish already fallen?

- Mix it later to give it less time to rise.
- Use less yeast.
- Colder water can be used, but do not go below 4.5°C (40°F). Water this cold can damage the yeast.
- Place the poolish somewhere colder—near the air conditioner in the summer, near a drafty door in the winter, or even just on the floor.

If you are able to keep an eye on your poolish while it rises, you can make adjustments after mixing it to keep it on schedule. If it seems like it will not be ready in time, move it to a warmer location. If it is nearing ready and you are not, put it in the refrigerator until you are ready to use it.

Here are some suggestions for scheduling a poolish:

- Make it after dinner and leave it out overnight. Use it the next morning, after about 13 hours.
- Make it before work in the morning and leave it out all day. Use it when you get home, after about 11 hours. This might require using warm water or keeping the poolish somewhere warm to speed it up.
- Make it at night and put it in the fridge. It will begin to rise but slow down as it cools. Pull it out the next morning and leave it out all day. It will continue rising as it warms up. Use it that night.

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## **3.4 What if a poolish is used too soon/late?**

Different bakers have different ideas about when a poolish is ready to use. Intuitively, it seems that a poolish is ready when it reaches maximum volume, as described in the previous section. This is a fine time to use a poolish. I have met bakers who liked to use the poolish early, when it was less gassy, because this produced a less gassy, easy-to-handle dough. The point of using a poolish, however, is to allow for extra fermentation; using the poolish early defeats this purpose. A better solution for gassy dough is to use less yeast in the recipe. Some bakers use a poolish slightly late, presumably to get more flavor.

As always, experimentation will help you decide which method you prefer. As you learn the temperatures and times needed to make a poolish in your kitchen, use the opportunity of having under- and over-ready poolishes to test out which works better in your dough.

What should you do if it is time to mix the dough and your poolish is nowhere near ready? Should you scrap the whole preferment idea and mix a “straight dough” with no preferment? Definitely not—that would be a waste of your time, ingredients, and all the flavor that has developed.

If the poolish is under-ready—it is still rising and does not have many bubbles yet—it may result in dough that is less active and has trouble rising. Add some extra yeast to the recipe to compensate for the under-ready poolish.

If your poolish is over-ready to the point where it is totally flat and smells bad, then you probably should not use it. But if it has recently collapsed it should work fine. If it collapsed several hours ago but still appears to have life in it (i.e., bubbles forming) and smells acceptable, it can still be used. Extra yeast can be used in the recipe to compensate for the loss of activity in the poolish.

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## 3.5 Adding a poolish to a straight dough recipe

A straight dough recipe, with no preferment, can be altered to have a poolish. Mix the poolish with one-third of the recipe's flour, an equal weight of water, and a pinch of yeast. (If you are using volume measurements, you will have to convert to weight and then back.) When you mix the dough, subtract the flour and water already used in the poolish. Only use two-thirds of the recipe's yeast. (Less yeast is needed with a poolish because much of the flour is already processed.) Minor adjustments of the water and yeast can be made after your first attempt at the new recipe.

For example, adding a poolish to the basic bread recipe follows:

Original recipe		
White flour	100%	0.580 kg
Water	70%	0.406 kg
Instant yeast	0.7%	0.004 kg
Salt	2%	0.012 kg

- One-third of the flour is 0.193 kg.
- Make the poolish with this flour, 0.193 kg water, and a pinch of yeast.
- For the final dough, add the poolish to the remaining flour and water. Only use two-thirds of the yeast called for in the original recipe—0.003 kg.

<b>Recipe with poolish added</b>		
Poolish flour	100%	0.193 kg
Rest of flour		0.387 kg
Poolish water	70%	0.193 kg
Rest of water		0.213 kg
Instant yeast	0.5%	0.003 kg
Salt	2%	0.012 kg

This recipe and others using poolishes and sponges are in chapter eight.

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## **3.6 Starters: what they are and how to mix them**

Starter, also called levain , is made with flour, water, and old starter. The old starter contains bacteria and wild yeasts (that is, different kinds of yeast than the one you buy in the store) that perform basically the same function as store-bought baker's yeast—converting the sugars in the flour via fermentation—but with different end products that give distinct flavors to the bread.

Sourdough starter is made with white flour; some of its bacteria produce lactic acid instead of alcohol, which gives bread a sour taste. Rye starter is made with rye flour and has its own set of yeasts and bacteria. It imparts the unique rye taste to bread. Starter can also be made with whole wheat flour or spelt flour.

Where does “old starter” come from in the first place? To create a starter, a mixture of flour and water is left out. The mixture begins to ferment because of bacteria and wild yeasts on the flour and in the air, and the microorganisms that enter the mixture begin to multiply. Every day they must be fed new flour and water; if it is not taken care of, the new starter will die. Eventually, the starter becomes stable, with a strong population of bacteria and yeast that does not need much attention to stay alive.

The longer you keep your starter, the more flavor it will develop, up to a point. Eventually, the starter stabilizes and is pretty much the same from one day to the next. I have no data on the time this takes, but a local bread guru told me that nine months is when maximum flavor is reached. He was referring to a starter that was fed daily; it probably takes longer for a home baker.

People who regularly bake bread with starter keep the old starter in their refrigerator, feeding or refreshing it every one to two weeks. Feeding starter is the same as mixing other preferments: water is measured out and mixed with old starter, flour is added, and it is all mixed until there are no lumps of flour left.

Only a little bit of old starter is used; the rest can be used to make bread or thrown out. Some people have trouble with the idea of throwing out starter. If you tried to save all of it, however, your starter would grow and grow. You would need massive quantities of flour to feed it, and it would quickly get out of hand.

Starter can have different consistencies. Benefits of a soupy starter are it is easier to mix, potentially less messy (a spoon can be used), and it rises faster. [2] I prefer a dough-like starter. It takes more effort to mix, but I am still able to mix it with a spoon. I prefer it rising more slowly because I do not use it regularly. Also, the drier consistency creates a satisfying dome-shape when the starter is ready. For bakers using volume measurements, a dough-like starter matches the consistency of the final product, i.e., dough. Since starter volume is always approximate, dough-like starter makes it easier to get a dough-like dough.

The recipes in this book are for creating a soupy starter and, once it is stable, turning it into a dough-like starter, such as the one pictured below. This way, the starter is easy to mix in the beginning, and the wetness will help the microorganisms take hold, but the starter will be dough-like when it is time to keep it in the fridge and use it in bread.



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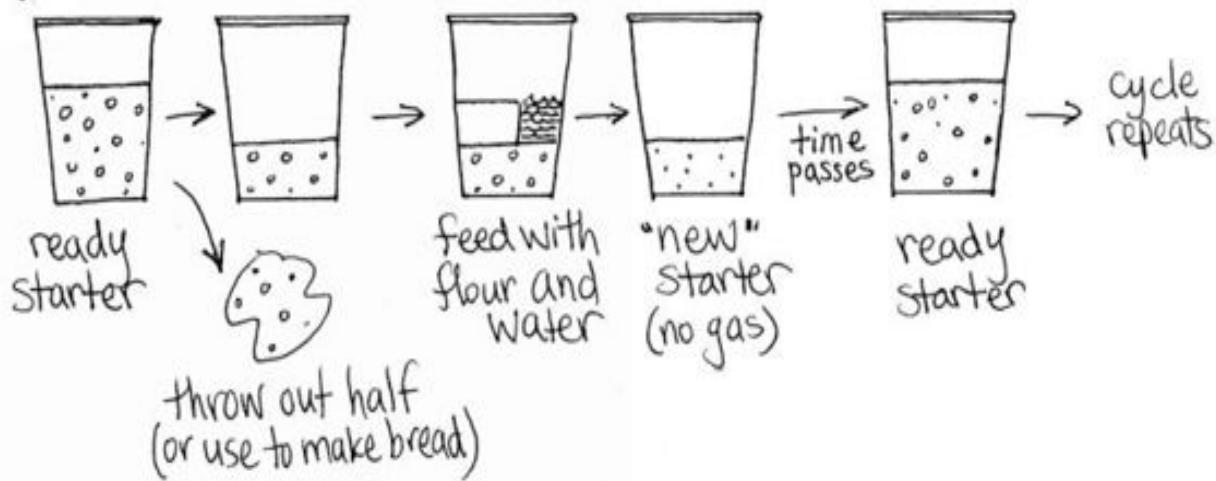
## **3.7 The lifecycle of starter**

The lifecycle of starter can be confusing at first. Many people have trouble understanding when starter is ready to use. Others are bothered by the instructions to throw out half the starter when it is fed. Some situations are presented below to help new bakers understand the process of keeping a starter and when it is ready to use in bread.

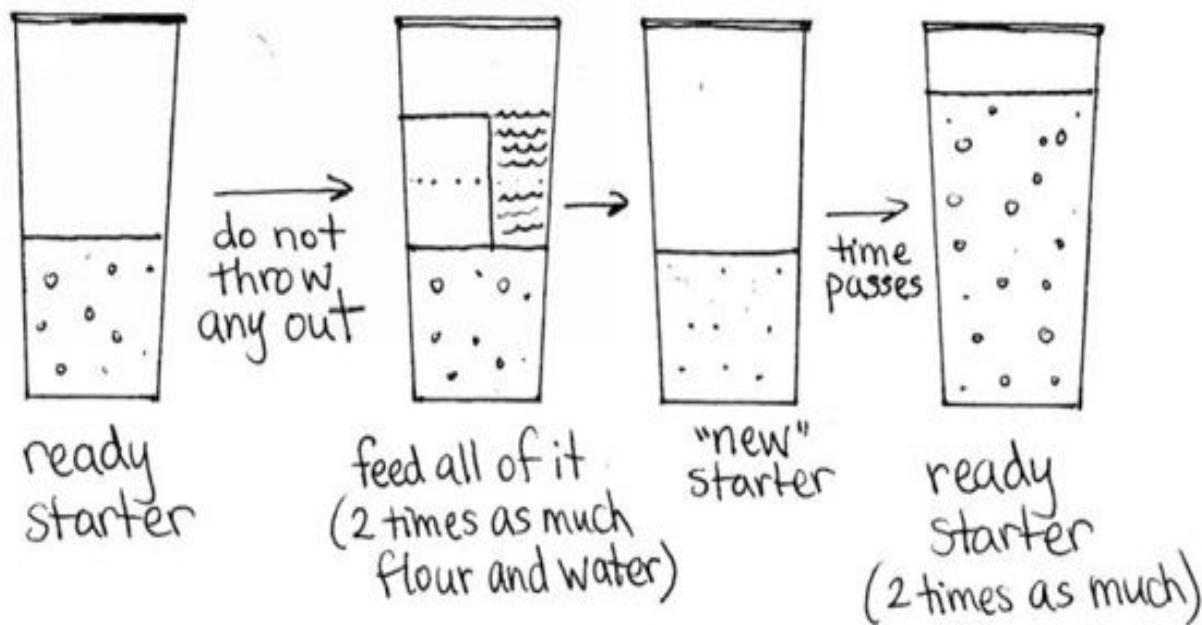
The basic cycle (no refrigerator). Pretend you have no refrigerator. You have a starter culture in a jar on your counter. It rises until it is full of gas, as shown in the picture below; if you do not feed it now, it will fall. You throw out half and feed the rest flour and water. About eight hours later (depending on the temperature and wetness of your starter), it is again “ready” to be fed. This cycle can repeat indefinitely.



If you want to make bread with starter, use it when it is ready—at maximum height and full of gas. This is when it has the most activity and will be able to make bread rise easily. Remember to save some starter for feeding.



Increasing your starter. What if you want to make lots of bread? Your recipe might call for more starter than you have. You can quickly increase your starter by not throwing any away when you feed it. Instead of throwing half away, keep all of it, and feed it twice as much flour and water. (If this does not create enough starter, let it rise and then feed all of it again with four times as much flour and water.)



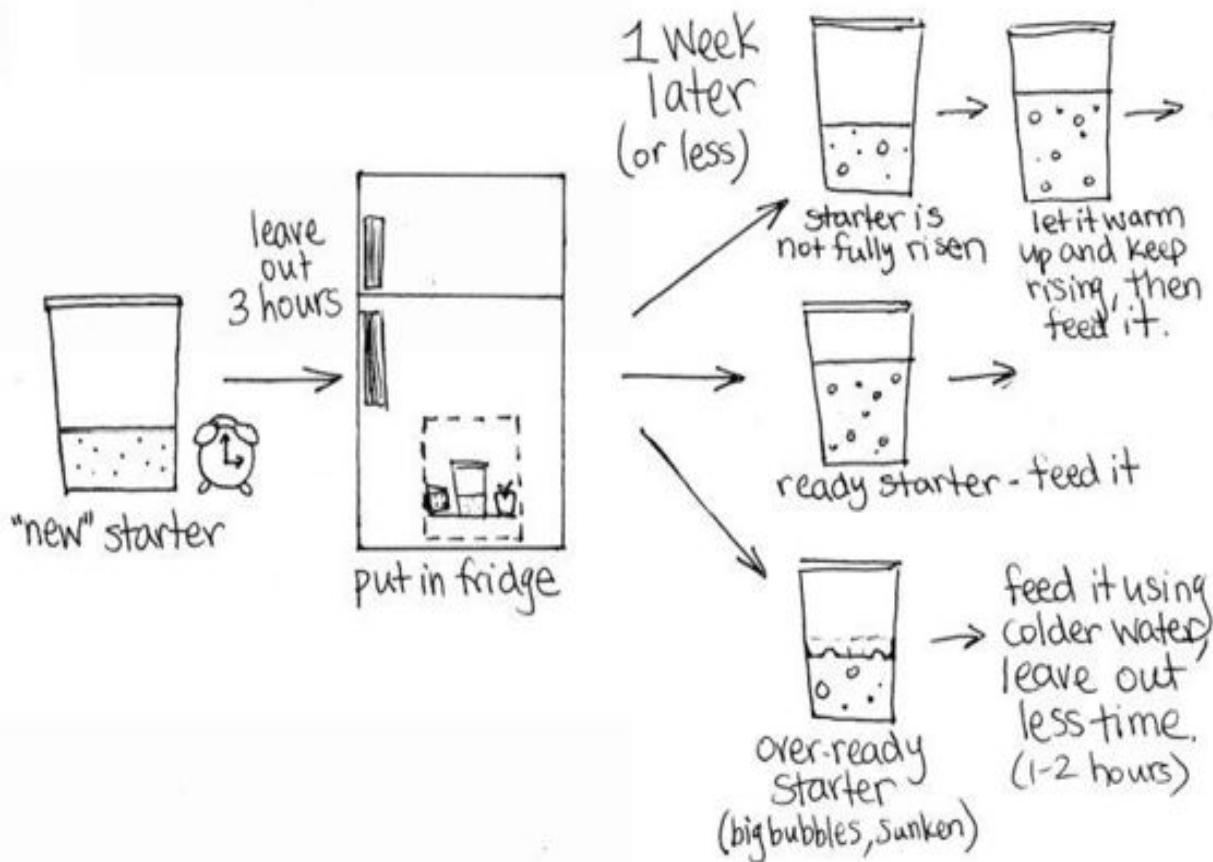
The basic cycle (with refrigerator). Keeping a starter with no refrigerator requires much time and flour. Thankfully we have refrigerators to slow down the fermentation process.

The general rule for maintaining a refrigerated starter is to feed it about once a week. After you feed your starter, cover it and leave it out for two to three hours. This gives the reactions a chance to start. Then put the starter in the bottom, back of your fridge (where it is coldest). As it cools off, the reactions will slow down and (in a 40°F fridge) stop.

The next week, pull it out and look at it. Is it ready to be fed? If it seems too dense and small, let it warm up and see if it continues rising. (In general, err on the side of letting it be over-ready.) When it is ready (or if it does not rise any more), feed it. Leave it out for two to three hours and return it to the refrigerator.

If your starter always seems over-ready (i.e., it does not continue to rise when pulled out of the fridge), check your fridge temperature to make sure it is 40°F. Try leaving the starter out for only one to two hours after feeding, or use colder water to feed it.

When you feed your starter, you can always use the throw-away starter to make bread. What if you feed your starter every Saturday morning, but you want to make bread on Wednesday night? Plan ahead to have starter ready when you mix your dough by pulling it out of the fridge on Wednesday afternoon. After using some in dough, feed some to keep for next time.



Preparing your starter for bread-making. Starter fed a day ago is more active than starter fed a week ago. After a week, the microorganisms have gotten low on food—some have died. Bread made with old starter might have trouble rising and might produce bread with less volume.

Give your starter an extra feeding the day before you use it in bread. This will result in a strong, well-fed population of bacteria. I prefer to do the extra feeding about eight hours before I make dough and leave the starter out to rise; this way, the microorganisms can multiply without the interference of the cold of the refrigerator, and I am sure of having a good population when I mix my dough.

[Return to start of Chapter 3](#)

## 3.8 Notes on creating a sourdough starter

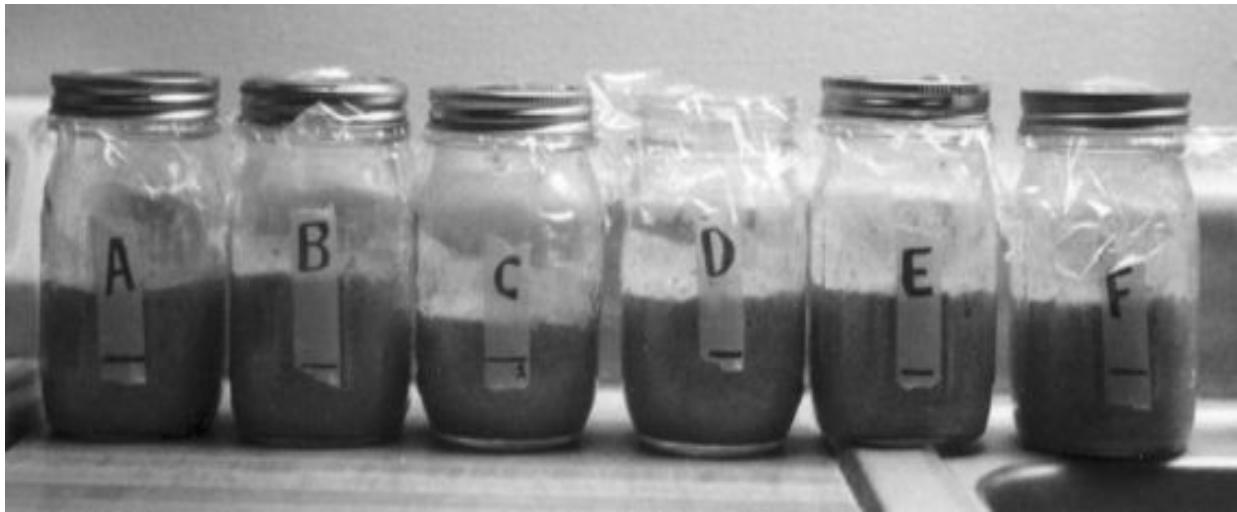
There are many recipes for creating a sourdough starter. Theoretically, leaving out a flour-water mixture should work, but in reality, the desirable microorganisms have trouble taking hold. Some recipes use orange juice or grapes to provide extra sugar to help the organisms survive.

The recipe in this book uses rye flour to help the process get going. The feedings start with rye flour and move into white flour. The starter will be soupy at first, making it easier to mix and providing a wet environment for the microorganisms. Once the creation process is complete, the starter will be maintained at a dough-like consistency.

My first attempts to create a sourdough starter failed; as soon as I switched to white flour, the mixture stopped rising and a layer of liquid separated at the top. It smelled like nail polish remover. I tried different recipes, different flours, different containers. I worried about the temperature of my apartment—never below 80°F in the summer. When I finally had a potential success, a weekend trip to the beach interfered. I took my starter along, feeding it by a garbage can on the boardwalk after dark. Pedestrians eyed me warily. In the end, the hot car ride was too much for it.

I tried a controlled experiment to assess the importance of different factors—could starter be created with tap water? Is there a difference between using all-purpose flour and using bread flour? How important is covering the starter—are “bad” bacteria getting in if it is open? Many recipes for creating a starter involve feeding it every 24 hours. In a hot kitchen like mine, is it better to feed your starter at its maximum height instead of waiting 24 hours?

I immediately noticed a difference in the starter made with tap water—it did not rise as much as the others. All-purpose flour seemed to work just as well as bread flour. The uncovered starter seemed to have more trouble than the others. Feeding the starter as soon as it doubled, instead of waiting 24 hours each time, did not seem to help. In addition, I decided a slower transition from rye flour to white flour would increase the chances of success.



The image above shows the starter experiment: A, control. B, bread flour instead of all-purpose flour. C, tap water instead of bottled water. D, uncovered. E, an instant switch to all-purpose flour from rye flour, instead of a slow transition. F, fed whenever it reaches maximum height, instead of waiting 24 hours each time.

Two changes helped me achieve my first successful starter creation. A friend suggested cleaning my container and tools with baking soda after cleaning with dish soap. Soap can leave a residue that harms the growing bacteria; baking soda washes this away. In addition, the hot summer ended and my kitchen temperature dropped to 70 degrees. This seemed to work well with a 24-hour feeding schedule.

My second successful starter creation was in the middle of winter—now my apartment never got above 60 degrees. I kept the new starter on the counter under a lamp that I always left on. I saw bubbles forming, but it was going very slowly and never rising much. This changed when I put the starter in the cabinet over the lamp, which, I had realized, was warmer inside. After that, the starter came to life.

My third success was again in the summer. This time, after a week at 80 degrees, I made an ice bath for the starter to sit in—basically my cooking pot with ice water in it, as shown below. I put the whole setup on the floor where it was cooler. Throughout the day, I dropped ice cubes into the bath, keeping the temperature down.



I concluded that a starter can be created with many recipes under many conditions. The main secret is cleanliness—clean your container, your mixing spoon, your measuring cups, your hands, plus anything else that is going to come in contact with the starter. After you have cleaned them, clean them again with baking soda and water to remove any soapy residue or greasy films that might linger. Use your hands, not a sponge that may have grease in it.

In addition, pay attention to the temperature of the starter's surroundings. Small changes, like a lamp over the starter in winter or putting it on the floor in summer, can help the starter out without altering the room temperature.



The image above shows the setup for creating a sourdough starter—bottled water, rye flour, a container cleaned with baking soda, a scale (or clean measuring cups), and a clean spoon.

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## 3.9 Recipe for creating and feeding a sourdough starter

- You will feed your starter every 24 hours. Pick a time of day when you will be home consistently, like dinnertime.
- Ideally the room temperature should be about 70 to 75°F, but this can vary. If your house is cold, put the starter under a lamp.
- Use bottled water at room temperature (about 70°F).
- Use a container big enough that the starter can double in size. A see-through container is important for monitoring the starter's height. Mark the original height on the side for comparison. I re-use the same container until I cannot stand the messiness and then switch to a clean one.
- A loose-fitting lid is important because gas will be produced—a sealed container might burst open. I use plastic wrap and a rubber band.
- If you do not have a scale, you will have to approximate when you measure your starter. This is fine—I did not have a scale the first time I created a starter. To help you approximate, each day's recipe calls for half of the starter created the previous day. The other half is discarded.

[how to do recipe?]

### Day 1

rye flour	0.116 kg	0.252 lb	1 cup
water	0.120 kg	0.264 lb	½ cup

Day 2      Do nothing!

Day 3      The starter should have increased in volume. Usually a big, encouraging increase is seen with rye flour. The starter may collapse before it is time to feed it.

starter	0.118 kg	0.260 lb	half
rye flour	0.029 kg	0.064 lb	¼ cup
white flour	0.029 kg	0.064 lb	¼ cup
water	0.060 kg	0.132 lb	¼ cup

Day 4 Again you should have a big increase in volume, and the starter may be collapsed by the time you feed it.

starter	0.118 kg	0.260 lb	half
rye flour	0.015 kg	0.033 lb	⅛ cup
white flour	0.044 kg	0.097 lb	⅜ cup
water	0.060 kg	0.132 lb	¼ cup

Day 5 With less rye flour, the starter might have trouble rising. Look for bubbles—a sign of life. Repeat the day 4 feeding until the starter begins to rise regularly.

starter	0.118 kg	0.260 lb	half
rye flour	0.015 kg	0.033 lb	⅛ cup
white flour	0.044 kg	0.097 lb	⅜ cup
water	0.060 kg	0.132 lb	¼ cup

Day 6 Again, is the starter rising? Did it rise until it was doubled in height? Check your starter often—sometimes it rises in the first few hours and then falls, so if you feed it before bed, by morning it will seem as if it never rose at all.

Keep feeding as you did on days four and five until your starter is rising regularly. This might take a few days—it took a week for me in the wintertime. Keep looking for bubbles. You should see more and more—the starter might look like a milkshake. Liquid might separate at the top. It is

going badly if the starter smells sharp, like nail polish remover. A good starter smell is fruity—mine always smells like apples. When your starter is ready, move on to day 7.

Day 7 When you observe your starter rising to double its original height (or almost), stop using rye flour and feed it only white flour.

starter	0.118 kg	0.260 lb	half
white flour	0.057 kg	0.125 lb	½ cup
water	0.060 kg	0.132 lb	¼ cup

Day 8 Did the starter rise? It will have more trouble with its new diet of only white flour. Repeat the day 7 recipe until it is rising happily and you feel like it is stable.

Day 9 Let us say your starter seems fine. Every time you feed it, it starts to rise in 5 to 6 hours. Now you can change to a drier, more dough-like recipe. This is exciting because the drier starter will rise more easily, with a domed shape that flattens out as it nears maximum height. This drier recipe is the one you will follow when you keep your starter in the refrigerator and feed it once a week.

starter	0.118 kg	0.260 lb	half
white flour	0.100 kg	0.219 lb	⅔ cup
water	0.060 kg	0.132 lb	¼ cup

Day 10 Your dough-like starter should rise within a few hours after mixing. You can keep feeding it and leaving it out for a few days to watch it. (Note that “half” of the starter now equals 0.139 kg. This number will eventually stop changing.)

At this point your starter is “created.” It should be strong enough to keep in a cold refrigerator and feed once a week and also strong enough to make dough rise. If you are worried that it is not strong enough, keep following the daily, room temperature feeding schedule. When you are ready to let go, switch to a weekly, refrigerated feeding schedule.

The recipe for maintaining a dough-like starter is

starter	0.160 kg	0.352 lb	half
white flour	0.100 kg	0.220 lb	$\frac{7}{8}$ cup
water	0.060 kg	0.132 lb	$\frac{1}{4}$ cup

Leave the newly-fed starter out for two to three hours at room temperature, then put it at the back of the fridge.

Pictures of a summertime (i.e., hot) starter creation follow. Your starter might look different; these are just to give you an idea of what to expect.

Day 1. Initial mixture.

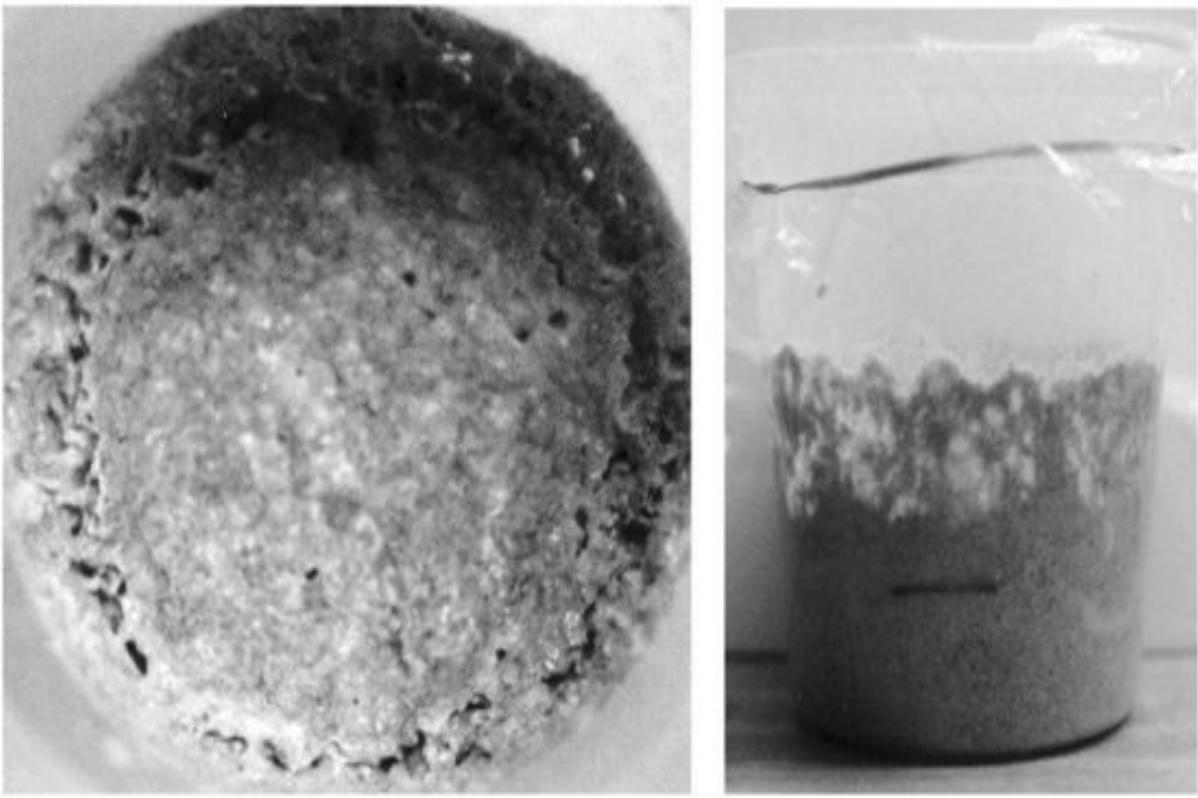


Day 3. Well-risen starter, before day 3 feeding.

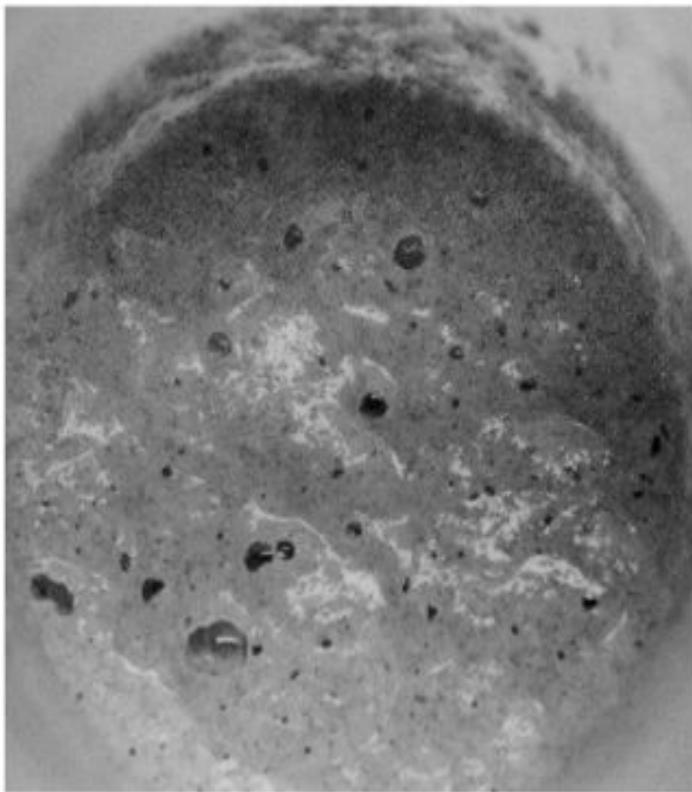


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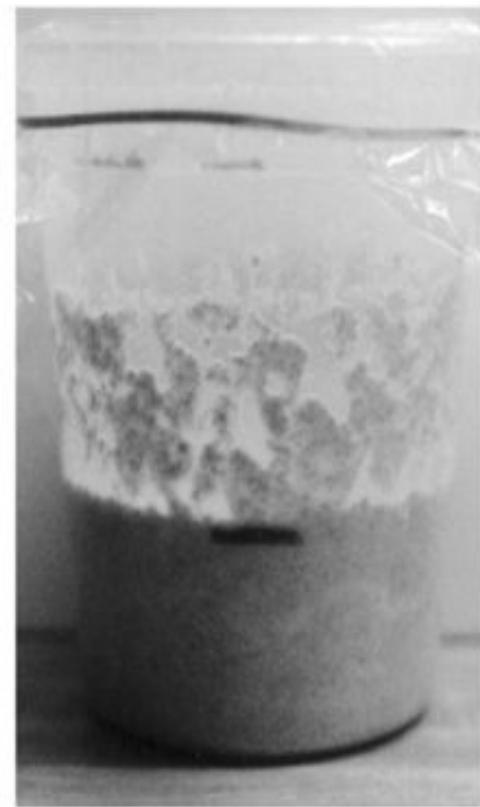
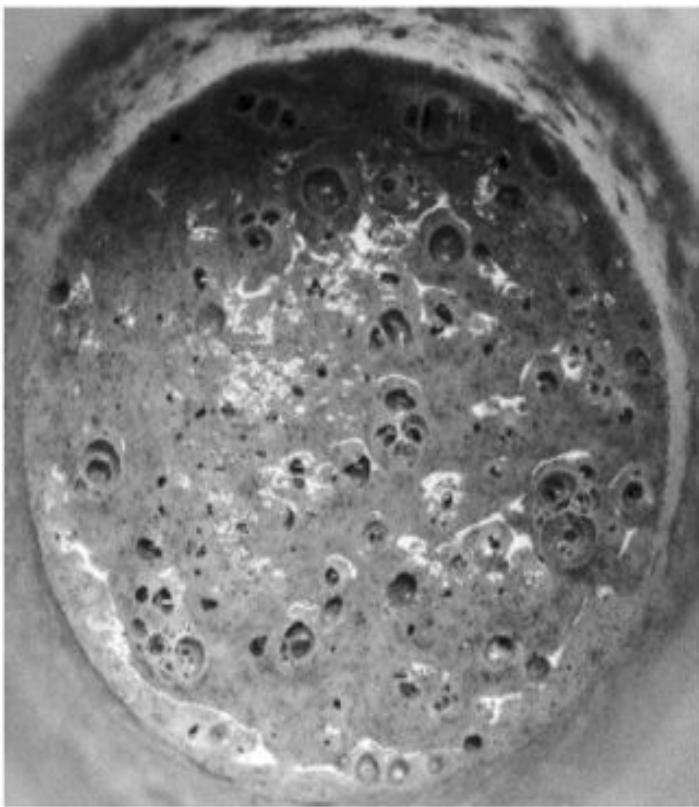
Day 3. Well-risen starter falls when container is bumped.



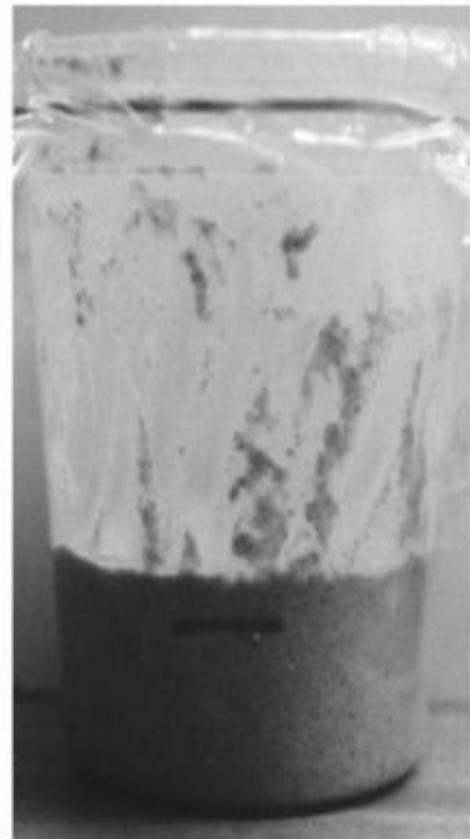
Day 3-4. 12 hours after day 3 feeding, starter has already risen and has begun falling.



Day 4. By feeding time, starter has fallen back to original height.



Day 4-5. 12 hours after day 4 feeding, starter has risen a little.



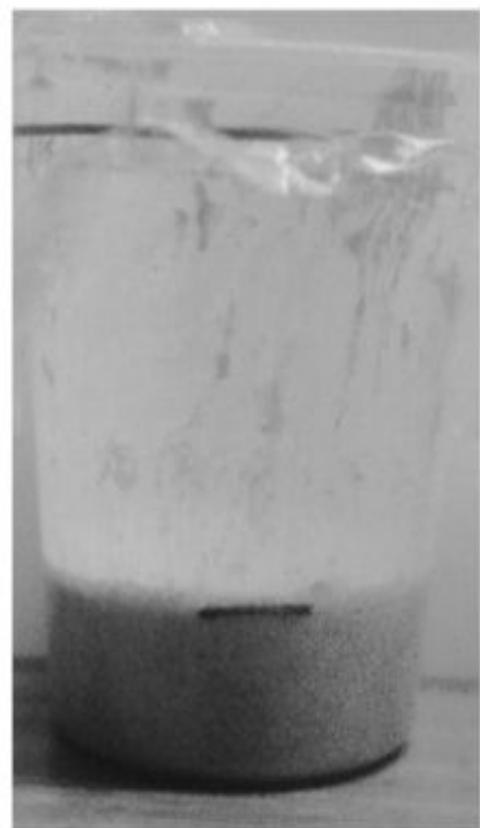
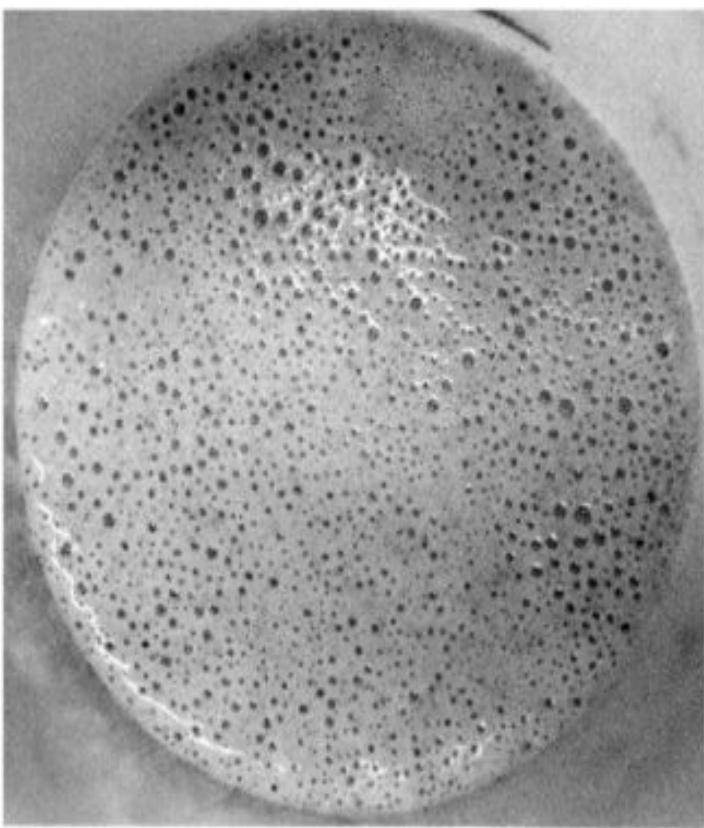
Day 5. Starter has the look of a milkshake and a sharp smell.



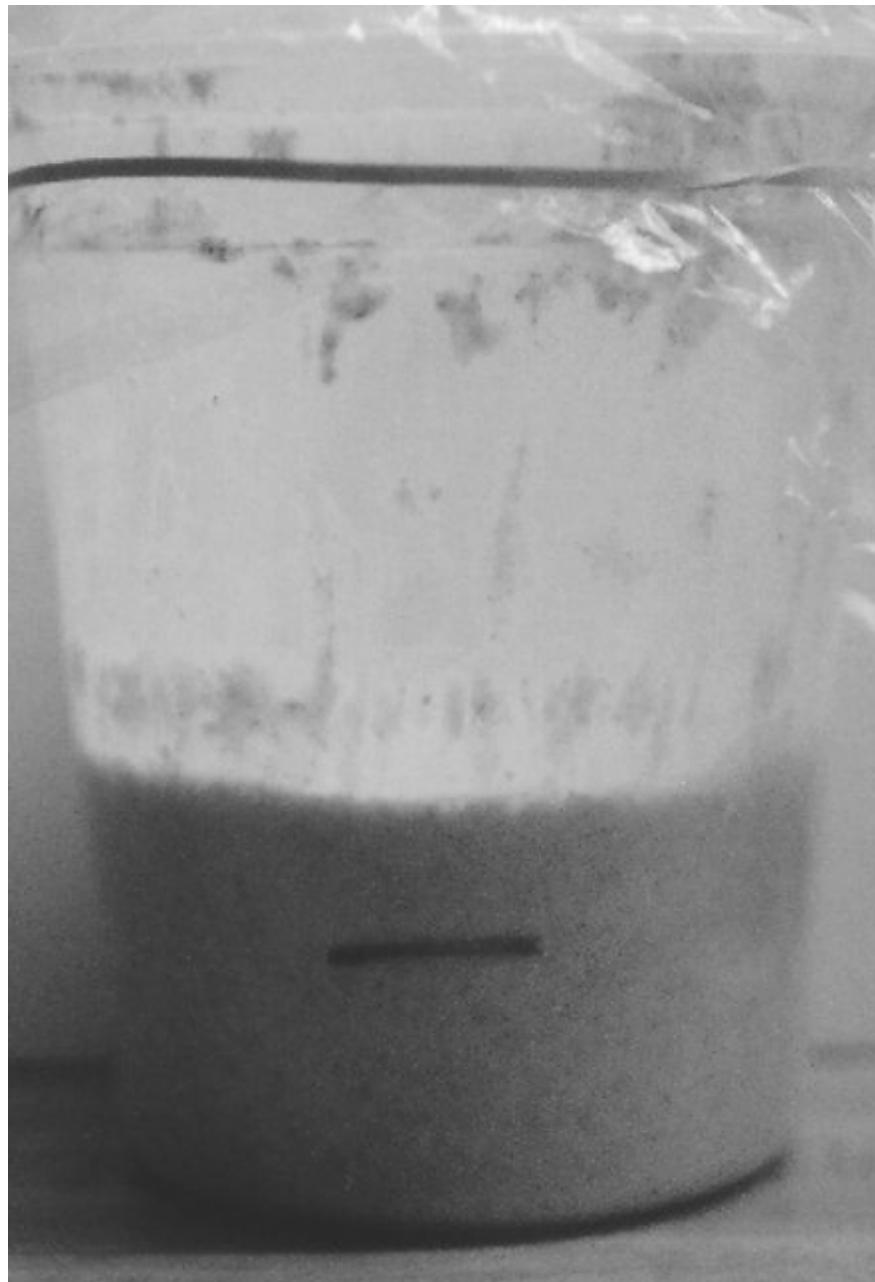
Day 5-6. 12 hours after day 5 feeding, starter is bubbly and rising.



Day 6. By feeding time, starter has risen and fallen.



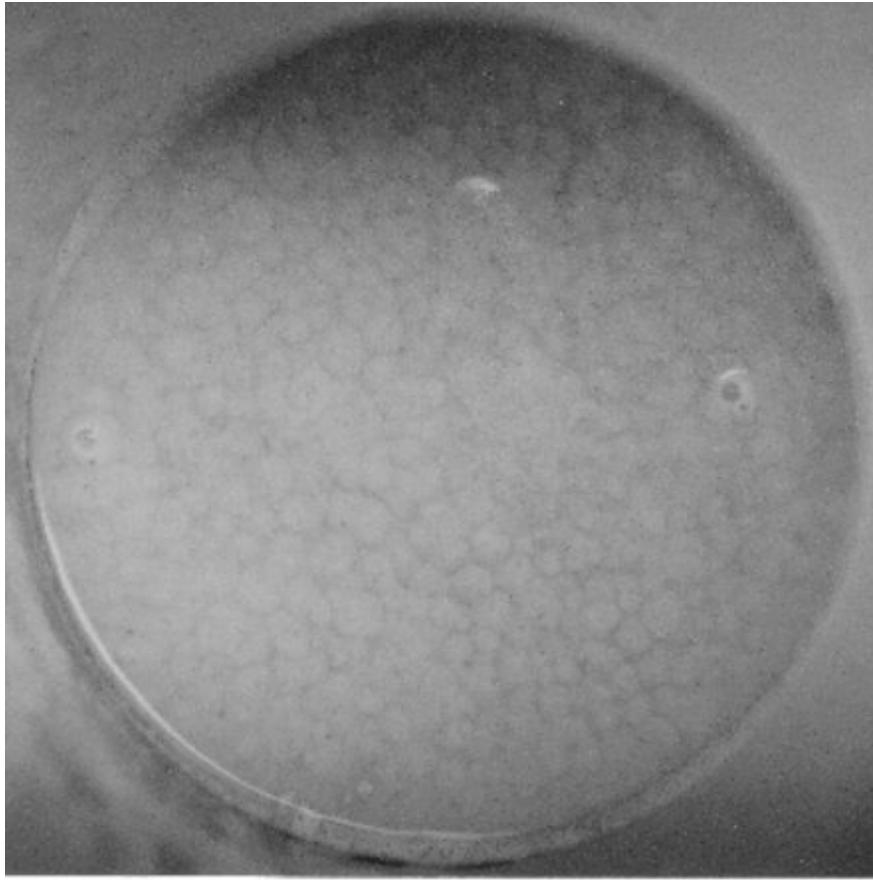
Day 6-7. 6 hours after day 6 feeding, starter has already risen and is falling.



Day 6-7. 12 hours after day 6 feeding, starter has completely fallen.

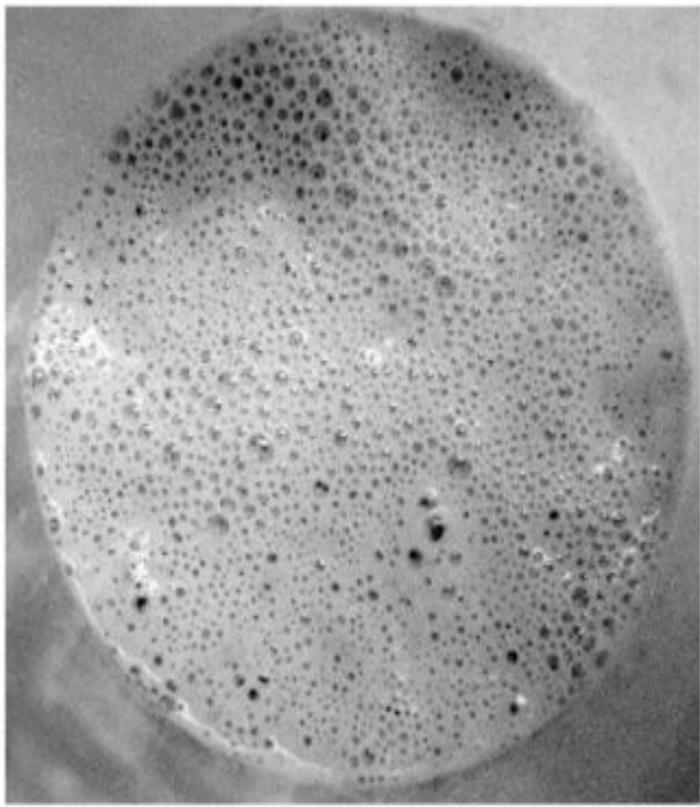


Day 8. Starter has no bubbles. It looks clumpy under a clear layer of liquid. It smells sharp but not awful. Bubbles rise when I drop it on the counter, indicating life.

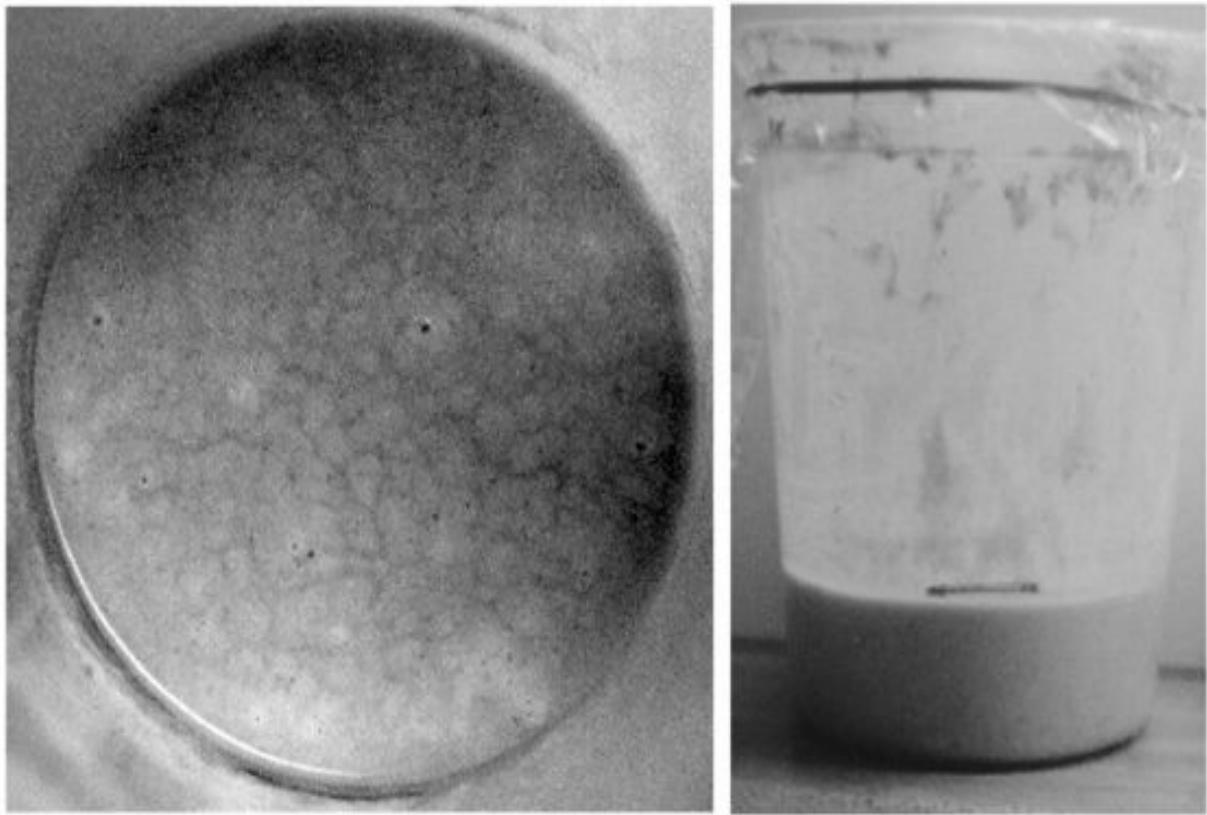


At this point, the starter is rising quickly (after only six to twelve hours) and is full of bubbles. It has fallen by feeding time; without periodic checks, you might think it never rose. The day 7 feeding is all white flour. This slows the starter down—it does not rise, it starts to smell bad, and it loses its bubbly milkshake appearance. I decide to use an ice bath (described previously) since my apartment is so hot.

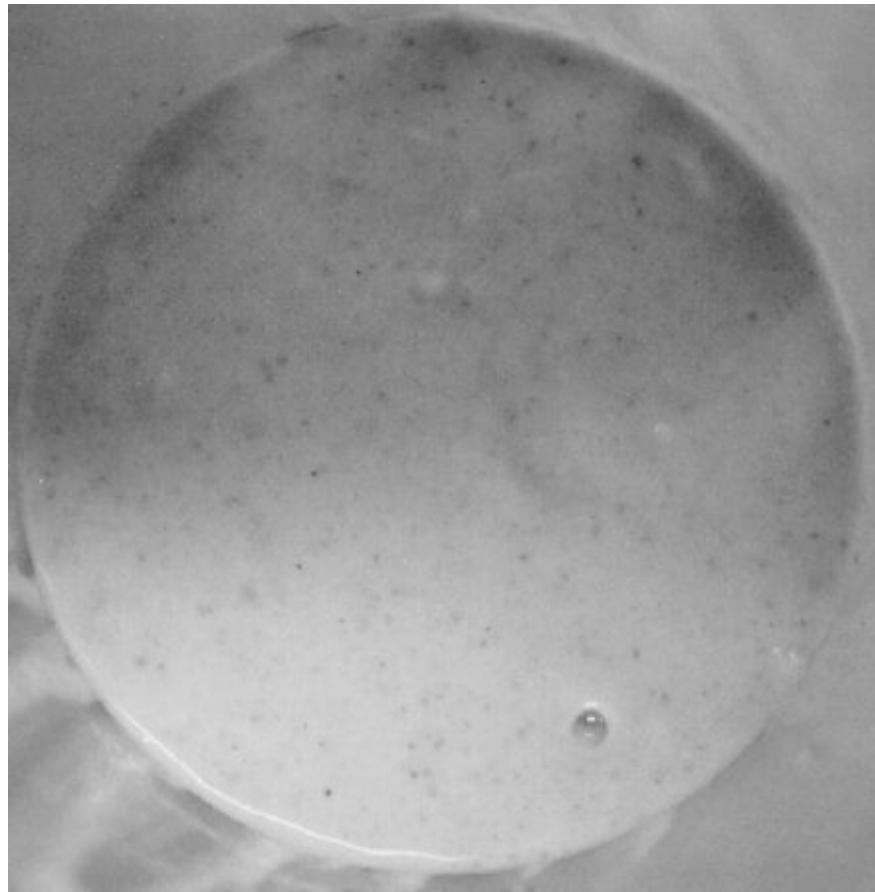
Day 8. 3 hours after day 8 feeding, starter is rising and again has bubbles on top.



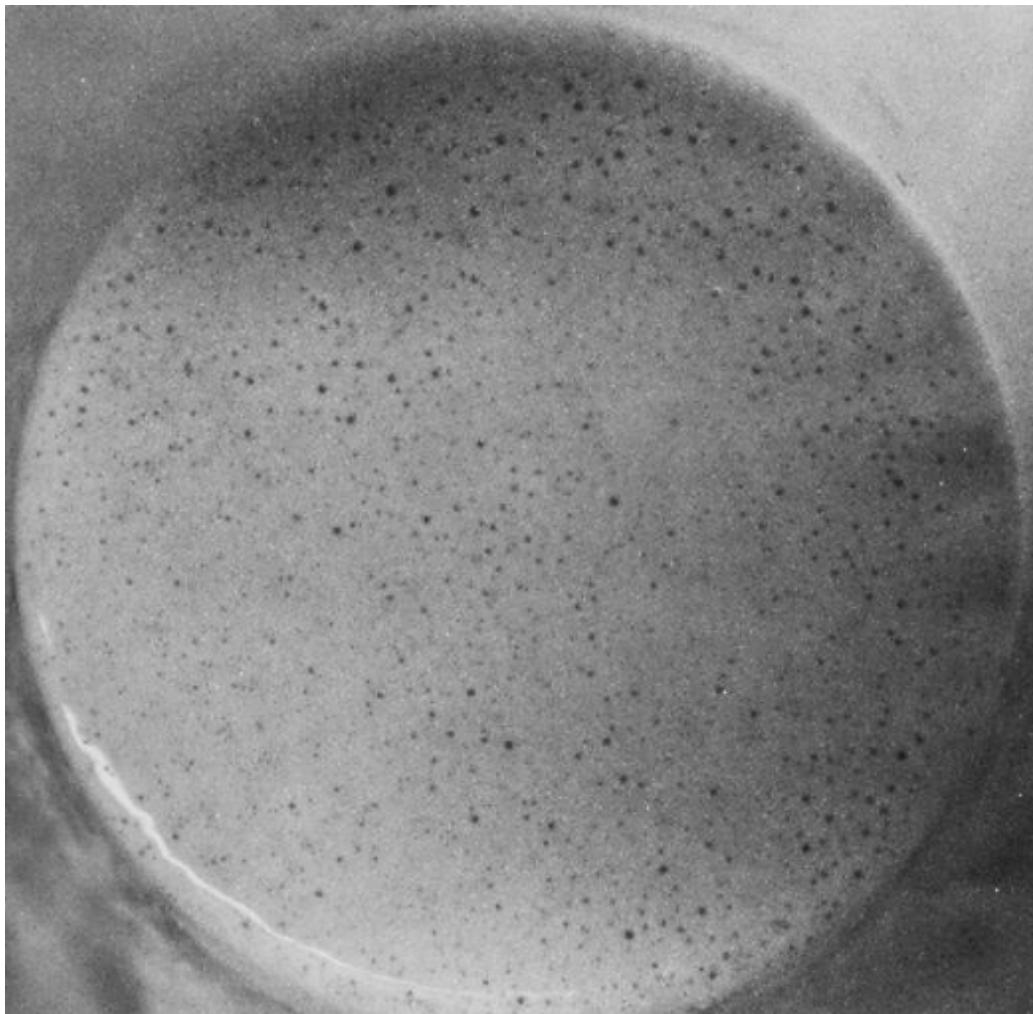
Day 9. By feeding time, starter is again clumpy and separated. Smell is okay.



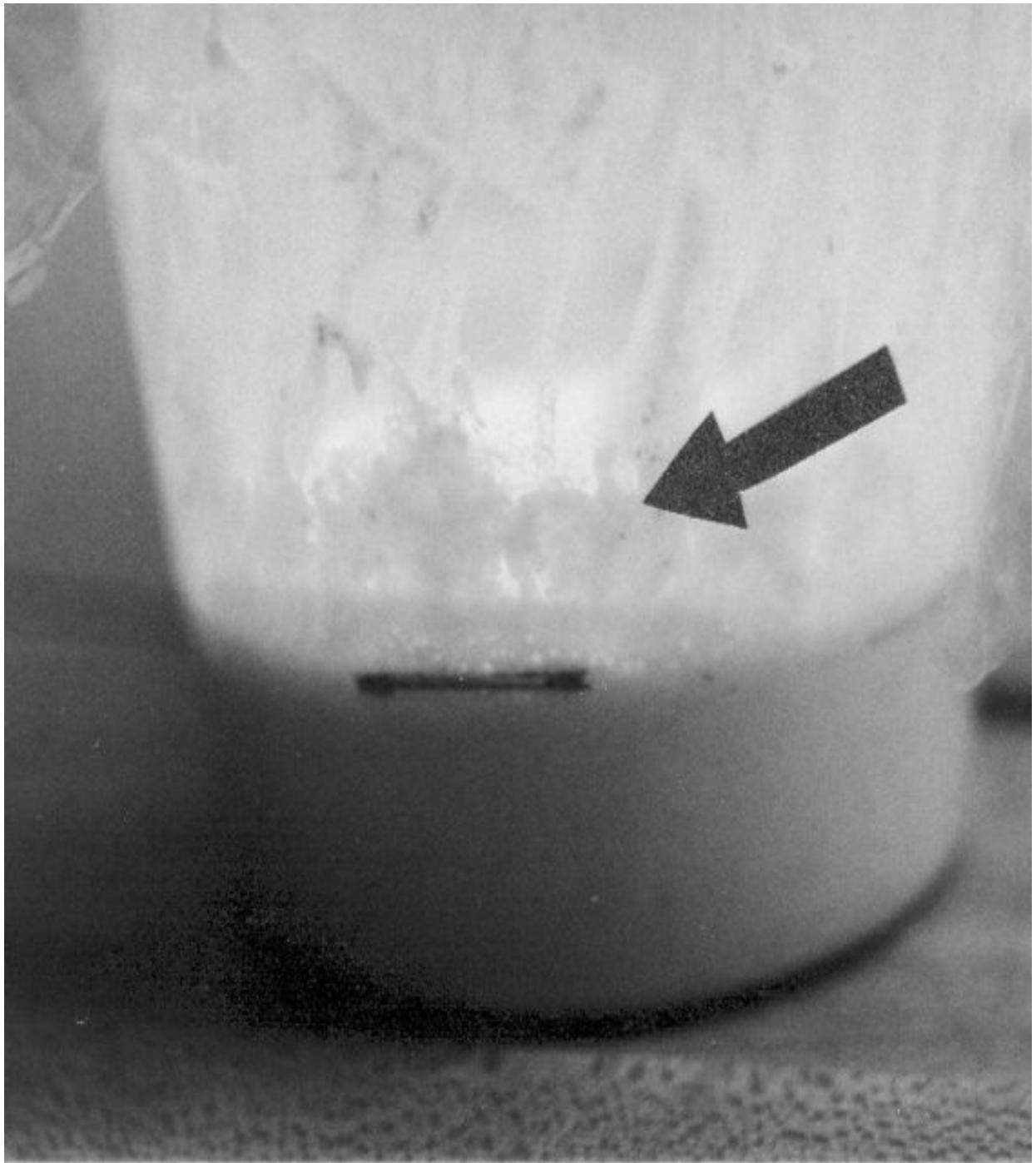
Day 9. A bubble forms immediately after feeding.



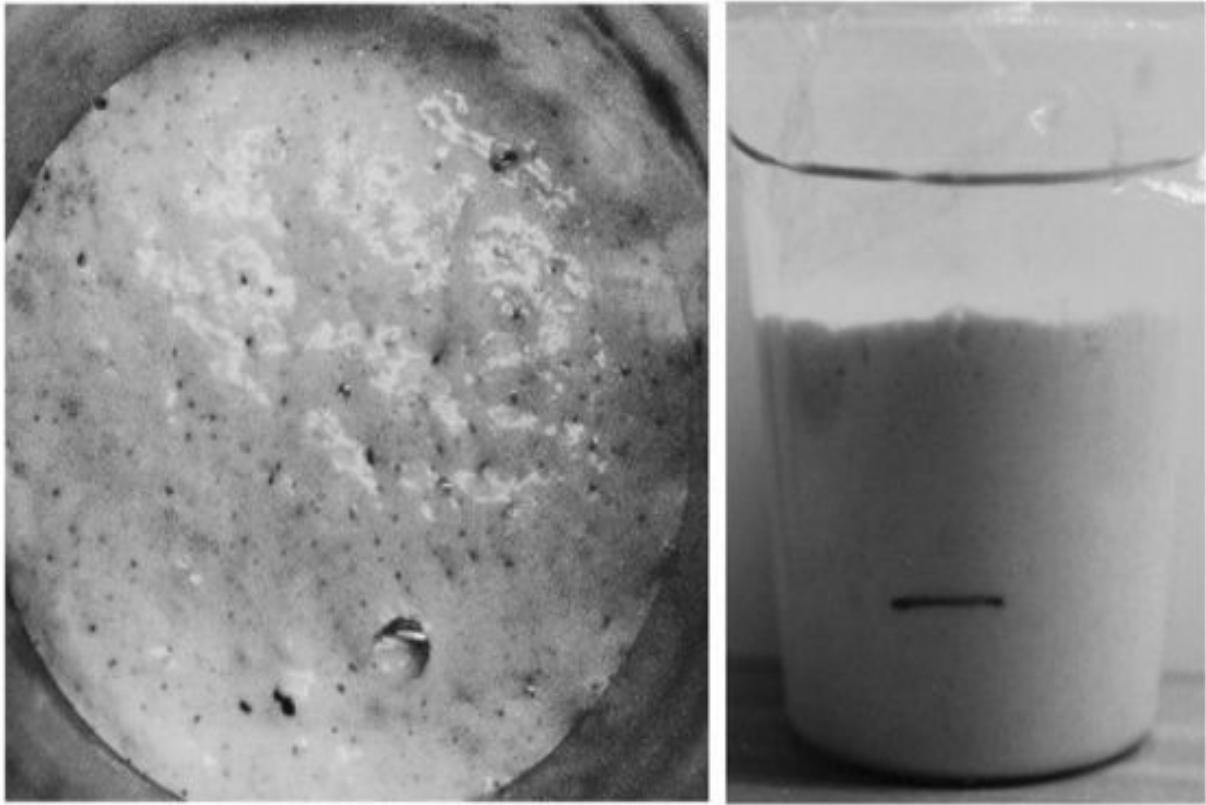
Day 10. By feeding time, starter has risen and fallen, but there are tiny bubbles (not clumps).



Arrow indicates residue line at maximum height to which starter rose before day 10 feeding. Look for signs like this to indicate that starter rose.



Switch to a drier recipe. 4 hours after feeding, starter is full of gas and more than double in height!



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## **3.10 How much neglect can starter take?**

Just how many weeks can your starter sit in the back of the fridge, lonely and forgotten, before it is dead? The microorganisms will not die all at once; the life remaining in your starter decreases gradually. Even after several weeks, there will be life lurking in your starter that can be salvaged.

If your starter gets “sick” from a lack of attention, there are fewer microorganisms than usual—bread made with such starter has trouble rising. To nurse your starter back to health, you need to feed it a few times, letting it rise between feedings. (You must let it rise between feedings; otherwise, you simply dilute the microorganism population each time you feed it.) If possible, let it sit out after feeding instead of using the fridge; the warmer temperatures will help it. Use a higher proportion of starter at first, since some of the starter microorganisms are dead. Even a starter that smells bad can be salvaged by feeding it a few times.

Can starter be frozen? The microorganisms would “halt” in the freezer, not growing, dying, or needing to be fed. I tried it with success. I froze starter that had been rising for several hours—this way, there were lots of bacteria in it when it froze. When it defrosted, it appeared lifeless. I fed it once, using twice as much starter as usual (because, I assumed, the population had been decimated by the freezer.) It barely rose at all, but I could tell gas was produced because the lid of the container poofed outward. After 24 hours, I fed it again, again using twice the starter called for in the recipe. I waited another 24 hours and this time, it rose higher. After a third feeding, it was back to normal.

My frozen starter experiment only lasted ten days. A longer time in the freezer might kill the starter completely. For best results, the freezer temperature should be constant (so the starter freezes once and stays frozen).\* (\*Note: An explanation of how yeast and bacteria survive freezing is given in the “Storing dough” section of chapter eight.)

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## 3.11 Working with starter using volume measurements

Recipes with starter use weight measurements, not volume. A volume of starter is meaningless, since it changes constantly as gas is produced. It also depends on the temperature of the starter and its surroundings. (On a hotter day, a gas bubble will take up more space, because the gas molecules are more active.)

Having a scale is not necessary, however, for making bread with starter. During starter creation, the recipe uses half of the previous day's starter; this can be approximated. The weekly starter feeding recipe always creates the same amount of starter and uses half of this amount each week.

In a recipe, a certain weight of starter is needed. If you know the weight of the starter you maintain, you can approximate how much is needed for your recipe. Another way to approximate the weight of the starter is to compare it to a known weight. For example, using the conversion tables, you know that 1 cup of flour equals about 0.11 kg:

$$1 \text{ cup} \times \frac{112 \text{ g}}{1 \text{ cup}} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.11 \text{ kg}$$

The sourdough recipe in chapter eight calls for 0.107 kg of starter. This is approximately the same weight as one cup of flour. You need to know what 0.107 kg feels like. Hold a bowl with one cup of flour in one hand and a similar bowl with starter in the other. When the weights feel about the same, you know you have about 0.107 kg of starter.\* (\*Note: Incidentally, 0.107 kg is also one third of the starter created with the weekly feeding recipe given in this book.)

If the amount of starter you use is slightly off, it is okay—simply adjust the water to make the dough feel right, as described in the next chapter on mixing dough. Different starters have different consistencies anyway. Even

with a scale, you may need to adjust the water in a recipe for it to work with your starter.

[Return to start of Chapter 3](#)

[1] Hoseney, R.C. Principles of Cereal Science and Technology . St. Paul, MN: American Association of Cereal Chemists, Inc., 1986 222; and 64.

[2] Wing, Daniel and Alan Scott. The Bread Builders . White River Junction, Vermont: Chelsea Green Publishing Company, 1999 9.

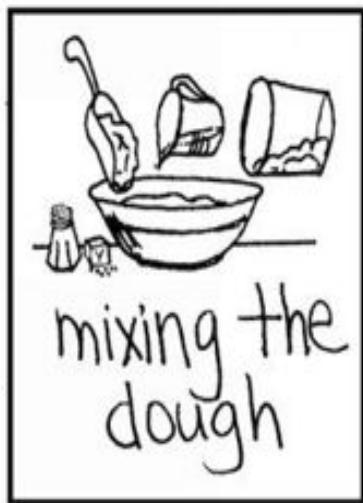


Happy poolish, Carrboro, NC, 2002

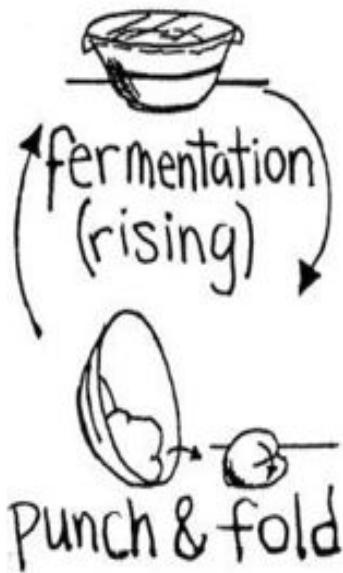
# Chapter 4: Mixing the Dough



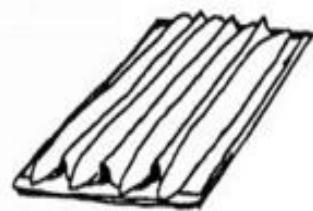
mixing a  
preferment



mixing the  
dough



shaping



proofing  
(rising)



baking

Mixing the dough is where bread-making gets exciting—once the dough is mixed, all the chemical reactions begin going full swing. These reactions were discussed in chapter two. Understanding how they relate to the mixing process will make you more comfortable with your dough. You will know what is going on inside, why you are kneading, and what to look for as your dough develops. Dough chemistry is reviewed in the overview of this chapter. Practical aspects of mixing dough follow.

## 4.1 Overview of mixing the dough

[4.2 Mixing dough by hand](#)

[4.3 How to tell when dough is “done”](#)

[4.4 Adding special ingredients to your dough](#)

[4.5 What to do with dough after it is mixed](#)

[4.6 Mixing dough with a machine](#)

[4.7 Bread production data sheet](#)

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## 4.1 Overview of mixing the dough

The mixing step is an important chance for the baker to get the dough started on the right track. Poorly-mixed dough might be salvaged later in the process, but everything proceeds more easily if the dough is well-mixed in the first place. Dough characteristics to consider are the strength (or toughness) imparted to the dough during mixing and the temperature of the dough after mixing.

Mixing consists of first combining the ingredients (flour, rising agent(s), water, and salt) and second, kneading them into dough that is strong but flexible. An optional rest period called an autolyse (pronounced “auto-lease”) can be used before kneading to help the dough develop; this is described later in this chapter. When the ingredients are combined, molecules interact and chemical reactions begin; kneading furthers these interactions by dispersing ingredients, incorporating air bubbles, and breaking bonds.

The important dough chemistry occurring during mixing includes the following:

1. Starch granules are hydrated and starch molecules are able to move about.
2. Starch enzymes are able to move and begin converting starch into sugars.
3. Sugar is able to move about and is absorbed by yeast and bacteria cells.
4. Fermentation of sugar begins, producing carbon dioxide ( $\text{CO}_2$ ) molecules that go into solution, i.e., they are dissolved in the wet dough.
5. Dissolved  $\text{CO}_2$  affects the pH of the dough, making it more and more acidic as more  $\text{CO}_2$  is produced.
6. When the dough is saturated with  $\text{CO}_2$ ,  $\text{CO}_2$  molecules move from the dough into air bubbles as  $\text{CO}_2$  gas.
7. Fermentation produces alcohol and other organic molecules that contribute to the final flavor of the bread.
8. Water causes changes in the structure and bonding of flour proteins; together, water molecules and protein molecules form gluten.

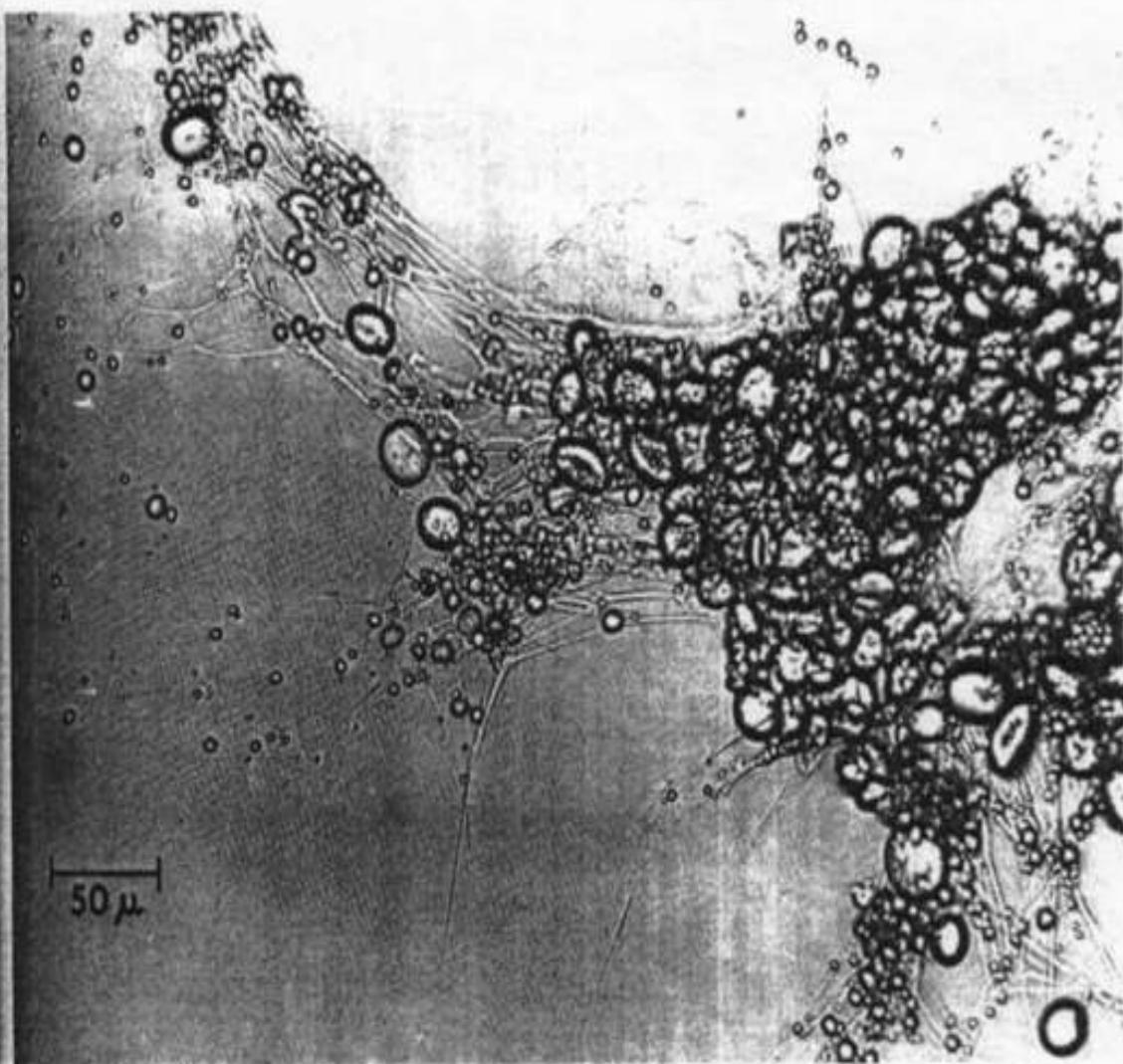
9. Acids and alcohols in the dough denature or unravel protein molecules, making them more amenable to aligning during kneading.

10. Protein enzymes begin to move and break the protein chains, making them easier to knead.

11. A gluten network is developed through kneading.

In spite of much research, there is still uncertainty and disagreement on details of the chemistry of dough. An overview of the possibilities, however, gives you a good sense of what your actions are accomplishing.

[Return to start of Chapter 4](#)



## Starch granules and protein strands in wet flour.

From J.E. Bernardin and D.D. Kasarda, Cereal Chemistry 50 (1973) 529-536, used courtesy of the American Association of Cereal Chemists.

## 4.2 Mixing dough by hand

Do not let mixing dough by hand intimidate you. It does take energy to get the dough adequately kneaded, but even a half-hearted attempt will produce bread that tastes good. It might look lopsided or small and dense, but it will still be bread. You can improve it with practice. Do not worry about doing things perfectly the first time.

The Basic Bread recipe introduced in chapter one is a good place to begin. Its simplicity will help you focus on the process. A summary of the process described in the next few pages is as follows:

Step 1. Incorporate ingredients: Measure flour into a bowl. Add yeast and mix to disperse it. Add water. Mix with your hands until no flour lumps are left.

Step 2. Autolyse. Cover dough and wait 20 to 30 minutes.

Step 3. Add salt and start kneading. Work on a surface at a comfortable height. Find the kneading method that works for you.

Step 4. Assess the dough: If it is too wet it will not hold together. If it is too dry it will be very tough to knead. Add flour or water in small increments and keep kneading.

Step 5. Do a window test to determine done-ness.

Step 1. First comes the incorporation step. Begin by measuring out your flour. Measure out your yeast and mix it into the flour.\* Next add water. Then just mix! The point is to get rid of the dry lumps of flour—squish them between your fingers. Your hands are going to get gloppy. A bowl-scraper or stiff rubber spatula will help you keep the ingredients together, not stuck to the bowl. (\*Note: Instant yeast can be added directly to flour. Technically, active dry yeast should be activated first with some of the water from the recipe. It is so much easier to mix it directly into the flour, however, that you may want to try it and see if it works with your brand of yeast. Fresh yeast can be added to flour or later to the dough.)

In general, pay attention to your dough, not just the recipe. If the dough seems too wet or dry, as described in the following pages, then fix it by

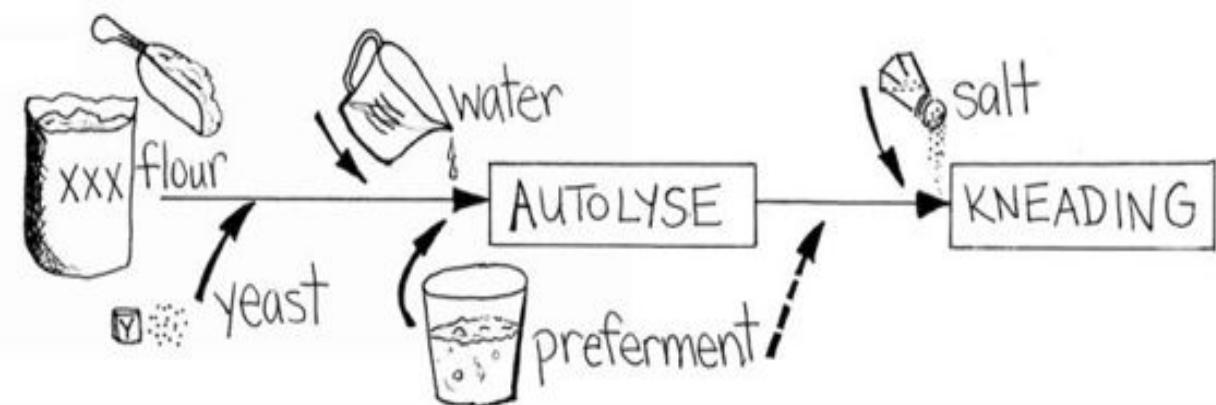
adding flour or water. As a beginner, however, be patient if the dough seems too wet. You must get used to sticky hands. Wetter dough is harder to work with, but it tends to make better bread. When you begin mixing, you might think, “This recipe can’t be right!” Resist adding extra flour; give the process a chance. If the dough is indeed too wet, you can fix it later during kneading.

Step 2. Once you get the ingredients incorporated, stop and let the dough sit for 20 to 30 minutes. Cover it with plastic wrap. This is the autolyse step. During the autolyse, the flour becomes hydrated. Water molecules work their way into starch granules and surround proteins. Dough usually feels less sticky after the autolyse.

The chemical reactions begin, and the pH of the dough begins to fall. This affects the dough in two ways. First, the alcohol and acids produced by fermentation alter the structure of proteins, causing them to uncoil and stretch out. This makes them more like the protein in finished dough. [1] Second, proteases go to work, breaking protein bonds. (Remember that the proteases work better at a low pH, but before the dough is fully mixed and before salt is added.) When kneading begins, the gluten will be ready to form new bonds; a gluten network will develop with less kneading. Your dough will reach a “final state” more easily.

If you are using a recipe with a preferment, it can be added before or after the autolyse. Preferments are already hydrated; their reactions have started and their enzymes have been at work, so they do not need to be autolysed. It may be easier to incorporate your ingredients, however, if you include the preferment at the start. Also, the preferment will be more acidic than the newly-incorporated dough and can therefore lower the dough’s pH and help protease activity.

Step 3. After the autolyse, flatten your dough and sprinkle the salt evenly over it. Mash the salt in with your fingers. Kneading will distribute it throughout the dough.



Now it is time to knead. Start with clean, dough-free hands. Transfer the dough onto a table, a countertop, or some other clean surface, at a comfortable height. (I work on my cutting board, on top of a towel to hold it still.) As mentioned before, kneading dough is a way to strengthen it by breaking the gluten and allowing it to reform in a network. Any form of pushing, pulling, smacking, or cutting will work. Since you have to do it for awhile, find motions that are comfortable for you.

A traditional kneading method (shown below) involves pushing your lump of dough with the heel of your hand (or hands). Between pushes, fold and rotate the dough so the entire dough ball is kneaded. Watch your dough as you knead to make sure the entire dough ball is being kneaded.



Kneading dough requires a balance of energy (it is work!) and care (do not maul your dough). Use the force of your whole body behind your arms. Keep your energy up and knead quickly; think of it as a workout. If you do not start to sweat, you are not properly kneading the dough. On the other hand, you are trying to build a network of gluten in the dough. If the dough is constantly ripping, you are hindering the growth of this network. Also, kneading adds heat to the dough. Make your motions efficient; touch the dough as little as possible. If you get tired, rest for a brief period and then keep going.

Instead of watching the clock, I use a CD to keep time. I now have a favorite dough-mixing CD: *The Sinners of Daughters* by the Charlotte, NC band The Talk. Since they are a slightly punk rock band, the songs are all fast-paced (and full of curse words—be warned!) I have found that if I knead in time to the music for the whole CD, my dough will be well-kneaded.

Flouring the surface is not recommended because this adds flour to the dough and dries it out. A bench-scraper (pictured below) in one hand can be used to keep the dough ball together and off the table. Kneading quickly also helps. As you knead, the dough should begin to stick more to itself. Once a layer of dough has covered your palm, the rest of the dough may stop sticking to you. Leaving the layer of dough on your palm will make kneading easier. On the other hand, if you notice small bits of dried dough getting into your dough from your hands, you should wash them.

Step 4. If the dough is too dry, it will be stiff and hard to knead. If the dough is too wet, it will have trouble holding together. An easy way to add water or flour is to wet or flour your hands and then keep kneading. This adds a little at a time, giving you control over how much you add. Adding flour to sticky dough can be addictive—be careful not to overdo it! While a layer of dough on your palm can help, gummy dough hands increase sticking—try washing your hands to see if it helps. Hot dough also sticks more—try putting your dough (and the kneading surface, if possible) in the freezer for two minutes; then continue kneading.

An alternative kneading method is to hold one corner of your dough, slap it out onto the table, and then fold it back into a lump. Repeated slapping and folding accomplishes the kneading. (This is loud and less meditative, but could be therapeutic in its own way.)

A different method entirely involves flattening your dough into an oval with your hands and using your thumbs to “cut” it, making many cuts up the length of the oval. The dough is then folded back together, turned 90°, flattened into a new oval, and cut again. This method accomplishes the same restructuring of the gluten; however, it requires extremely strong thumbs. An adaptation is to use a bench-scraper to cut the dough. Place your dough on a flat, sturdy surface. Press it into an oval. Use your blade to cut several horizontal lines into the dough. Fold the top down, turn it sideways and cut more horizontal lines. Scoop up the dough and mush it together (with a traditional kneading motion) until you cannot see the lines any more. Then cut it again. These methods are shown below.



There is not one correct way to knead dough. Find a method you enjoy.\*  
(\*Note: Step 5, assessing the dough to decide if it is finished, is described below.)

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## **4.3 How to tell when dough is “done”**

There are two characteristics to consider when assessing if your dough is mixed enough. One is how strong the dough feels, i.e., how much force is needed to pull on it or how much the dough resists when you stretch it. The other is flexibility—can you stretch it without ripping it?

When you begin, the dough is weak—soft and slack. The gluten is not developed. Although it may be flexible, it is not ready.

When kneading begins, the dough becomes stronger. It requires more force to stretch the dough. This strength corresponds to the formation of the gluten network. The presence of more, better bonds makes the dough harder to pull on. The dough is not flexible, however; it rips easily when you try to stretch it. This indicates that the gluten has not rearranged to its “best” formation yet.

After much kneading, this toughness decreases. The dough becomes more flexible but still feels strong, not floppy. When the dough is stretched, it does not rip.

The window test can be used to answer the question, “Is it done?” “Pulling a window” means stretching dough thinly enough that light passes through it without ripping it. Dough in the tough, under-kneaded state will rip before a window is formed.



Dough that is done will easily form a good-sized window that either does not rip or lasts more than a few seconds before ripping.



The goal is a smooth, even window. When the dough is under-kneaded, you might see thick strands of gluten or overlapping sheets running in different directions in the window. When the dough becomes more well-kneaded, a window will form that is devoid of these thick places.

Can you quit early? Beginning kneaders (and others!) often have trouble reaching the “window stage.” It is hard to get dough to the point of optimum flexibility reached so easily with a mixer. If you are getting tired, you can stop kneading and still make bread. Folding (discussed in chapter five) can be used to add strength to under-kneaded dough. Under-kneaded dough might rise more slowly, or not as much, producing smaller, denser bread.

You may feel like you did the best you could and it was not enough. Do not be discouraged; it will get easier. Becoming comfortable with dough will make your motions more effective, and you will become a more efficient kneader, able to finish your dough before you tire out.

What about over-kneading? When dough reaches an over-mixed state, the gluten appears to break down suddenly. The dough loses its structure and becomes a gloppy mess. (A discussion of the science behind over-mixing is in the “Gluten structure” section of chapter two.) If you are mixing by hand, there is little chance of over-mixing your dough. With a machine, it still takes awhile. If you are worried about it, let your mixer mix some test dough while you time it. See how long it takes to over-mix.

Would you ever want to mix the dough extra? In general, dough does not need extra kneading. Kneading after you reach the window-pulling stage makes the dough stronger, possibly too strong. Instead of adding strength this way, wait and see if the dough needs strength—if your dough feels too floppy and relaxed, you can add strength when you fold and shape the dough. Extra mixing forces extra air into the dough, and the oxygen in the air lessens the dough’s flavor. Continued mixing can also overheat dough and cause it to rise too quickly.

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## **4.4 Adding special ingredients to your dough**

Special ingredients should be added to dough during the initial incorporation step only if they will not interfere with the formation of the gluten. Small or smooth ingredients (like small seeds, spices, honey or apple sauce) can be safely added in the beginning of the process, along with the water. Larger ingredients (like potato chunks, nuts, raisins, or olives) should be added after the dough is kneaded but before it rises.

To add ingredients to finished dough, flatten the dough out and sprinkle on the chunky ingredient (say, olives). Then continue kneading with a traditional hand motion, working the olives in. At first, the dough will separate into chunks of dough surrounded by olives. Knead until the olives are not falling out and the dough comes together; the olives will be part of the dough, not a separate entity amid chunks of solid, olive-less dough. Keep in mind that the olives are breaking up the gluten, so you want to incorporate them as quickly as possible.

Grains can be added at the beginning or end. Softer ones, like oats, are okay during kneading, but harder ones, like wheat berries, should go in at the end. Since grains absorb water, mixing them in dough dries it out. Using wetter dough to compensate, however, makes handling difficult. To avoid this problem, soak grains overnight and drain them before adding them to the dough.

Some suggestions of special ingredients are listed in the “Make your own recipe” section in chapter eight.

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## **4.5 What to do with dough after it is mixed**

After your dough is mixed, it needs to rise before it can be shaped. Details on this rising time, referred to as the fermentation step of bread-making, are given in the next chapter. For now, you just need to know where to put your dough.

The dough should be kept covered so it does not dry out. If it dries out, a skin will form across the top. This will prevent it from rising properly. Later when you shape it, there will be dried-dough-skin-bits in your dough. Use a bowl covered with plastic wrap or a Tupperware-style plastic container with a tight-fitting lid. Make sure the bowl is big enough to accommodate the dough after it expands. Oil or grease your container so that the dough will not stick to it.

Place the container somewhere that is 70 to 80°F, if possible. If your house is cold, you can use a lamp over your dough to generate heat. Also try exhaust heat sources like the bottom of the refrigerator or near a stove that has been used recently. It is usually warm over the pilot light on a gas stove. If your house is very hot, keep the dough on the floor.

Commercial bakeries put dough inside proofing boxes that have built-in temperature control. Proofing boxes can consistently keep the dough at the optimal 70 to 80°F. They can also produce steam, creating a moist environment that helps dough rise and prevents it from drying out.

You can make a less fancy proof box with a large plastic container with lid—the kind used to store things in closets. Get one big enough that the whole bowl of dough can be placed inside, along with a bowl of boiled water. An optional thermometer inside the box will help you monitor the box's temperature. Periodically boil more water and add it to the water in your proof box to keep the temperature and humidity up.

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## 4.6 Mixing dough with a machine

If kneading dough by hand is not for you, there are several mixing machine options. A kitchen mixer with a dough hook (which simulates kneading motions) is one option.\* This is probably the best way to simulate hand mixing. Another option is a food processor with dough blades—the cutting blades seem a little extreme, but it works. A third option is a bread machine; it can be used to knead the dough, which can then be removed so that the rest of the process can be done by hand. (Do not buy a bread machine solely for mixing dough. I suggest it only because many potential bread makers already have bread machines.) (\*Note: There is a new spiral-style dough hook on the market that works much better than the original crooked-C-style dough hook.)

Because of increased friction, machine-mixing adds more heat to dough than hand-mixing. Use colder water to compensate for this. This is especially true of dough made in a food processor with blades. You may need to stop mixing and cool the dough periodically—put it in the freezer for a minute or hand knead it briefly on a cold surface.

How long to mix depends on your dough—what kind and how much. To determine mix time, stop the mixer every few minutes and do a window test. When the dough feels strong but enables you to stretch out a window, it is done. Keep track of how long it mixed as a guideline for next time.

Dough can be over-mixed (and ruined) in a mixer. Scientists have theorized that over-mixing is a total disruption of the structure of gluten that occurs when too much strain develops. The usual methods of relieving the strain are not fast enough, so covalent bonds break. [2,3] One study, described in the “Gluten structure” section of chapter two, relates the build-up of strain to reactions between the dough and oxygen introduced into the dough during mixing. This strain builds during mixing until it can only be relieved by dough breakdown (over-mixing.) [4]

A common problem is a mixer bowl too big for the amount of dough being mixed. The dough gets stuck on the hook and goes in circles, not actually

being kneaded. Use high speed to try to fling the dough off the hook. Another solution is to mix two loaves at once, better filling the bowl.

As mentioned above, mixers create more friction than hand-kneading, increasing the final temperature of the dough. Colder water should be used to compensate for this. If you want to be more exact, keep track of the water temperature used and adjust it for next time after you know the final dough temperature.

Adjusting water temperature is enough, but some bakers want to get more detailed. Other factors affecting dough temperature are the temperatures of other ingredients, the room temperature, and the kind of dough. A discussion of how to take these factors into account was confusing many readers; but I did not want to delete the information. I have therefore included the discussion as a giant footnote.\*

[\*Giant footnote: The following equation calculates what water temperature to use in your dough based on several factors. “T” stands for temperature. Average the flour temperature with preferment temperature if necessary.

$$\text{water T} = (3 \times \text{desired final T}) - (\text{flour T}) - (\text{room T}) - (\text{friction factor})$$

The friction factor of a dough is a number that describes the heat added to the dough while it mixes due to friction. Different doughs have different friction factors—in general, grainy doughs and whole wheat doughs have higher friction factors. Very wet doughs might have a friction factor of zero—mixing does not heat them much at all.

The friction factor is a guideline; it developed as bakers tried to mix dough at a certain temperature. You find it by trial and error. The first time you mix a dough, start with a median value for the friction factor—maybe 20. Once you see the final dough temperature, adjust the friction factor for next time. For example, your dough was five degrees too hot. If you had used a friction factor of 25 instead of 20, your dough would have been about five degrees colder.]

A sample “Bread Production Data” sheet is provided in the following section for bread bakers who like taking notes. Some of the items on this sheet are discussed in the previous footnote. The most important items on the sheet are noted in bold lettering.

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## 4.7 BREAD PRODUCTION DATA

Date \_\_\_\_\_

Type of dough \_\_\_\_\_

Desired final dough temperature \_\_\_\_\_

Friction factor \_\_\_\_\_

Room temperature \_\_\_\_\_

Flour/preferment temperature \_\_\_\_\_

Water temperature \_\_\_\_\_

Autolyse time \_\_\_\_\_

Length/Speed of mix \_\_\_\_\_

Final dough temperature \_\_\_\_\_

Time at end of mix \_\_\_\_\_

Approximate fold time (based on previous experience) \_\_\_\_\_

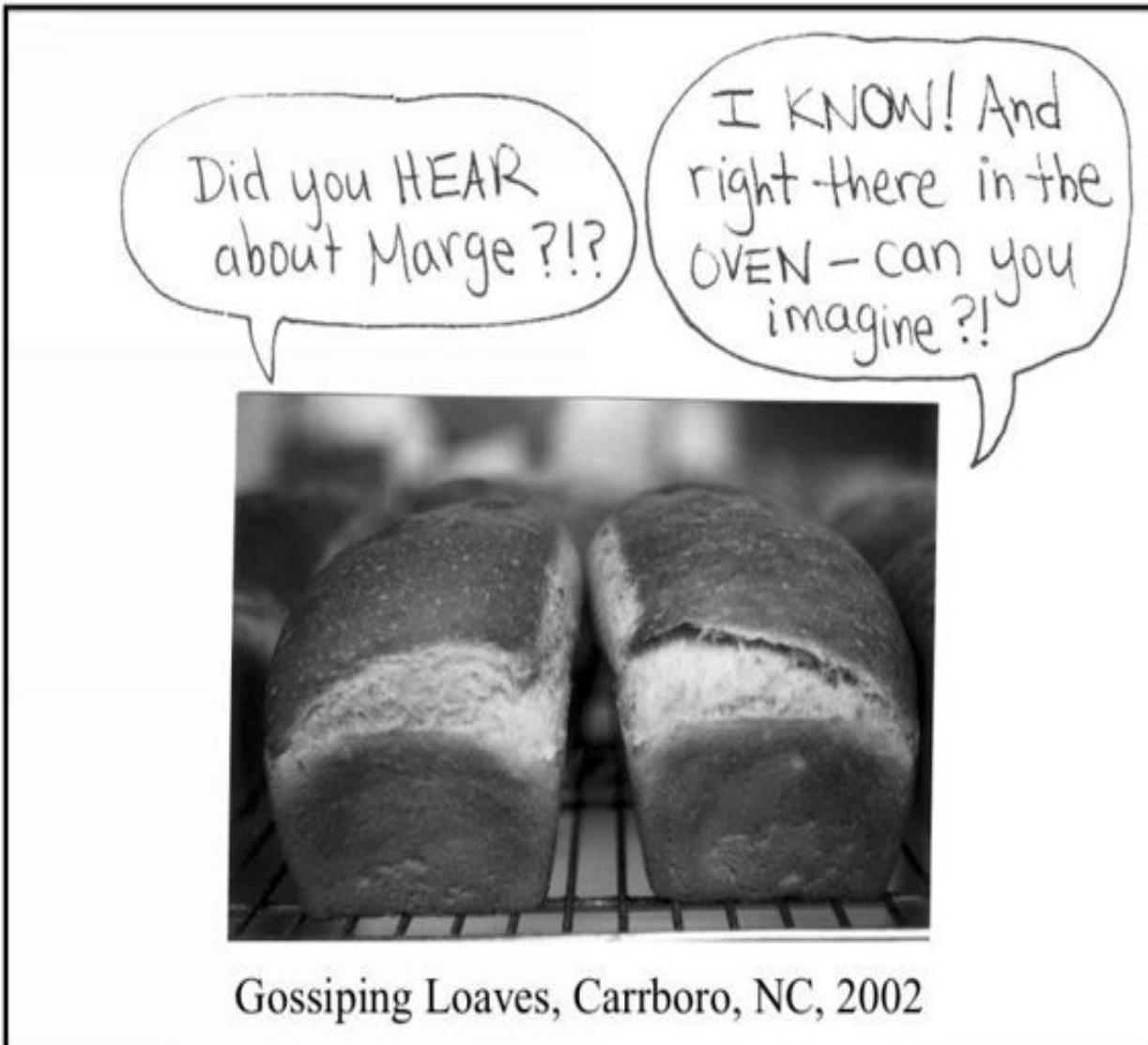
Actual fold time \_\_\_\_\_

Approximate shape time (based on previous experience) \_\_\_\_\_

Actual shape time \_\_\_\_\_

Notes:

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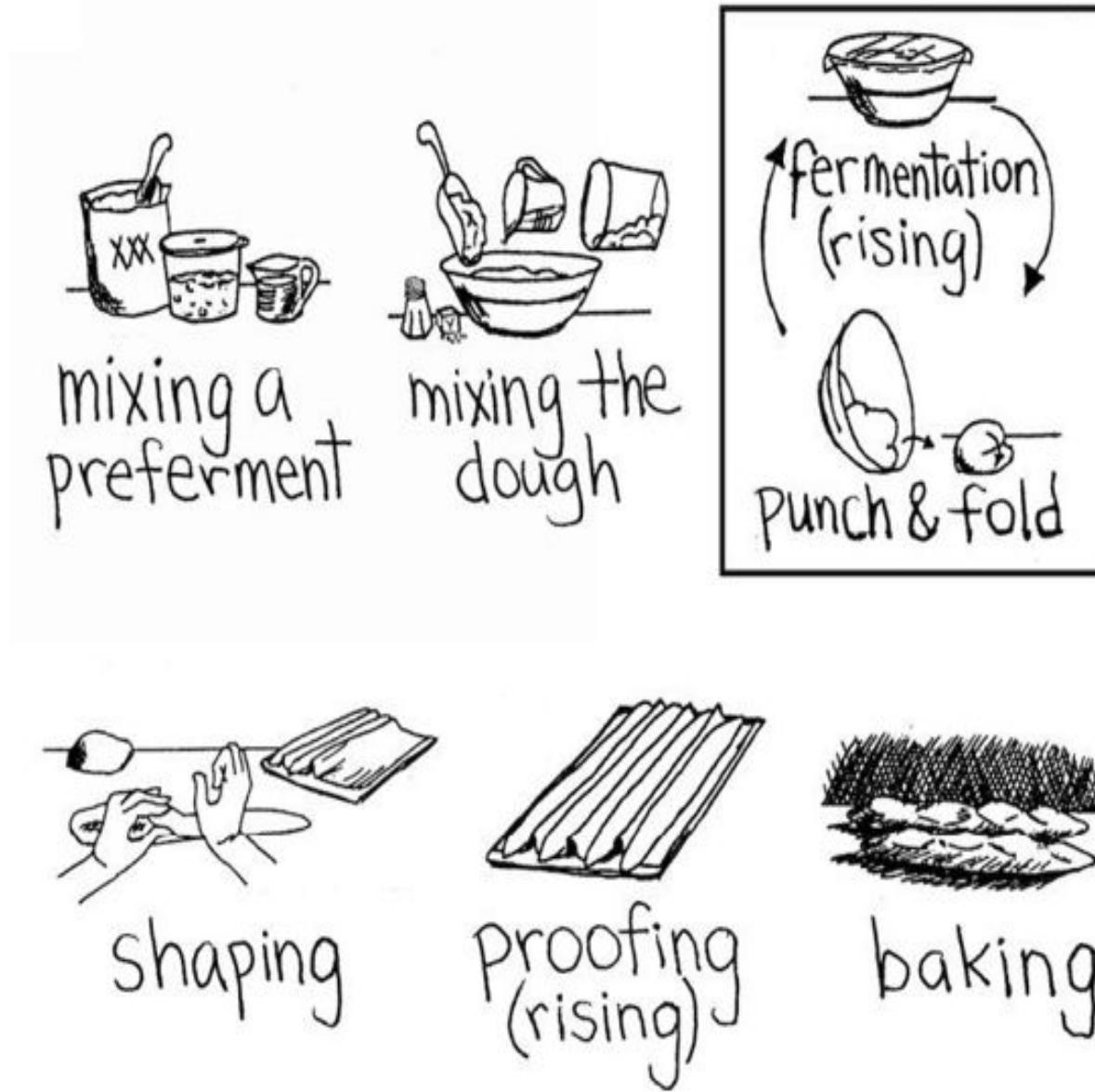
[1] Maloney, D.H. and J.J. Foy. "Yeast fermentations." *Handbook of Dough Fermentations*. New York: Marcel Dekker, Inc., 2003 55.

[2] Belton, P.S. "On the elasticity of wheat gluten." *Journal of Cereal Science* 29 (1999) 103-107.

[3] Schofield, J.D. "Flour proteins: structure and functionality in baked products." *Chemistry and Physics of Baking*. London: The Royal Society of Chemistry, 1986.

[4] Hoseney, R.C. *Principles of Cereal Science and Technology*. St. Paul, Minnesota: American Association of Cereal Chemists, Inc., 1986 217-218.

# Chapter 5: Fermentation



Chapter five describes the details of fermentation, the time between mixing and shaping the dough. It may seem like not much is happening—after all, watching dough rise is comparable to watching grass grow. But attention to a few points can make a big difference in your final bread.

## 5.1 Overview of fermentation

## 5.2 When is dough fully risen and how to control it

[5.3 Approximating fermentation time with dough temperature](#)

[5.4 Punching and folding dough—why and how](#)

[5.5 How many times can dough be punched and folded?](#)

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## 5.1 Overview of fermentation

Fermentation, or rising, is the time between mixing and shaping the dough. (This is not the only time fermentation happens. Fermentation occurs throughout the process, beginning when the preferment is mixed and continuing until the yeast or starter bacteria die in the oven.)

It seems like the baker has little to do while the dough rises—this is your chance to rest and let the yeast do the work! There are steps you can take, however, to improve your bread. These are described in the following sections and summarized in the following list:

1. Place your dough in a container or bowl large enough to allow expansion and covered with a lid or plastic wrap to keep it moist.\* When dough dries out, a hard skin forms which prevents it from expanding further. (\*Note: A towel or a damp towel can also be used. I hesitated to write this because it might not be enough in drier climates.)
2. Be patient: shape your dough when it is fully-risen and ready to be shaped, as described in the next section. During fermentation, the growth of gas bubbles in the dough stretches the gluten; subsequently, the gluten is softer and stretches more easily. This allows the dough to rise properly later in the process. If dough is shaped early, the gluten has not been properly stretched and will be too strong. The dough will not rise well the second time.
3. Also be attentive—there is an interval of time during which the dough is ready. The size of this interval depends on the type of dough and “how fast it is moving”—faster-rising dough has a smaller interval. On a hot day, all doughs ferment faster and have a smaller interval.
4. Understand the factors that affect fermentation time and use them to try to control your dough .
5. Punchdown and fold your dough once or twice during fermentation. Punching down the dough releases the gas built up inside, allowing the rising process to start over and thus doubling the fermentation time and increasing the flavor. Folding also functions as an additional bit of kneading—it strengthens the dough by further developing the

gluten network, helps make the temperature uniform throughout, and redistributes un-reacted sugars, helping them to encounter yeast.

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A challah for everyone, Carrboro, NC, 2002

## 5.2 When is dough fully risen and how to control it

How can you tell when your dough is fully risen? Many recipes advise waiting until “the dough doubles in volume.” This is ambiguous and difficult to practice. Short of submersing the dough in a bathtub and measuring the water displaced, accurate volume measurement is difficult.

To know when dough is ready to be folded or shaped, touch it. Consider how springy the dough is—does it bounce back when you push on it? If it is very springy, then it is not ready. Springy-ness may be easy to identify, but alone it is not enough. A strong dough may remain springy even when it is ready. Also consider how gassy the dough is—it will be full of gas when it is ready.

Begin by touching the dough when it is first mixed—when you are sure it is not ready. It feels dense—barely any gas has been produced. If you press it with the pads of your fingers, it resists and you leave no dent. (If you poke aggressively enough, you can make a hole in anything. Use the pads of your fingers and press firmly but gently.) The dough has not softened or relaxed; if you tried to shape it, it would resist, pulling back to its original shape and resulting in an ugly loaf.

With time, gas production increases. A dough may be gassy on the surface but still have a dense center. The gas pushes against the dough, trapped inside. On the edges, there is less dough resisting the gas so the dough expands more rapidly. Inside, gas is also being produced, but it must build up enough pressure to expand against the mass of dough surrounding it.

As the dough rises, it becomes less springy. Pressing on the dough gets easier and leaves deeper indentations. When the dough is ready, there is equal gas throughout—in the center and at the edges. When pressed, it feels full of air. As a beginner, try pushing your fingers deep into the dough to see what it feels like inside. Your fingers will crush the expanded gluten structure and release gas; the holes will remain visible afterwards.

If you wait too long, the dough becomes extremely gassy and soft. It is hard to impart strength to this dough or control it during shaping (i.e., your baguettes will be floppy and uneven.) Also, after shaping, the dough needs to rise one more time before baking. This step, called proofing , is discussed in chapter seven. Without proper proofing, bread is small and dense. The yeast need sugar as food to produce gas during proofing. If you wait too long before shaping your dough, the yeast's food supply may run low, leaving little food to make the dough rise a final time.

There are many ways to control the time dough needs to rise fully. The best way is to alter the dough when it is mixed. If a dough rises too slowly (i.e., two hours pass and it has not risen much), increase the yeast or starter percentage or use warmer water the next time.\* For a longer fermentation time that allows more flavor to develop, cut some yeast or starter or use colder water. [\*Note: The suggestions made here for controlling dough's rising time are for a dough that was fully kneaded and is still rising slowly. Dough that is not fully kneaded may rise slowly even if it has enough yeast and warm enough water was used to make it. Also, a very cold room (below 60°F) can hinder rising even if the dough was well-mixed with plenty of yeast and warm enough water.]

After the dough is mixed, the fermentation time is controlled by the temperature of the surroundings. If you are in a hurry, place the dough near the warm oven, a heater, or a light bulb (turned on). If you have an unexpected errand to run, put the dough down on the floor, near a drafty door, or even in the fridge to slow down the process.

Some kinds of dough simply take longer to rise, like whole wheat or spelt. These doughs benefit from extra folds to build their strength, resulting in bigger baked loaves.

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## 5.3 Approximating fermentation time with dough temperature

It is not always practical for a baker to sit and watch his or her dough rise. As a guideline, so that bakers do not have to check their dough every five minutes, approximate fermentation times are established. They are based on the dough being a certain temperature. (For example, when my French dough is 75°F, it rises for about one hour and is ready to be folded. After a second hour it is usually ready to be shaped.)

Recipes might suggest an approximate fermentation time, or you can establish one the first time you make dough by taking the dough's temperature and then watching until it is ready, noting how long it takes. The fermentation time will vary with the room temperature, with humidity, and with other dough characteristics; use your value only as a guideline.

To take dough's temperature requires a thermometer with a probe, either a digital model or a simple old-fashioned dial one. To get an accurate reading, push the probe into your dough and wait until the temperature stops changing. This may take a minute because the temperature of the metal probe is adjusting to match the dough temperature. Once the probe temperature is constant, take the temperature reading in a new place on the dough.

If the dough temperature is higher or lower than expected, adjust the approximate fermentation time. Warmer dough will need less time while colder dough will need more time. If you want to be exact, use the following equation to approximate changes in fermentation time:

$$\text{Minutes to add or subtract} = (0.08) \times (\text{°C off from expected temperature}) \times (\text{minutes in normal fermentation}).$$

For example, French dough that is 75°F sits for about two hours (120 minutes) before shaping, with one fold in the middle of that time. If your French dough comes out at 72°F, it is going to need to sit for longer than two hours. Note that 1°C = ~2°F. Since the dough is off by 3°F, the equation gives us

Minutes to add =  $(0.08) \times (1.5^{\circ}\text{C}) \times (120 \text{ min}) = 14.4 \text{ min.}$

Therefore, French dough at 72°F rises for about two hours fifteen minutes, with one fold in the middle.

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Over-ready dough, Carrboro, NC,  
2002

## 5.4 Punching and folding dough—why and how

Punching and folding dough is a unique opportunity to give your dough a boost—some help in the right direction. Punching removes gas from the dough and gives it a chance to rise again. This increases the fermentation time, allowing more flavor to develop.

Gas that remains is dispersed throughout the dough in smaller bubbles. This is important because gas produced in the dough is not able to form its own, new bubbles—it can only move into pre-existing bubbles.\* Punching subdivides bubbles, creating more tiny bubbles where gas can go and thus helping the dough rise. These new bubbles also allow the dough to rise evenly, with a good, even internal structure. Without punching, the dough might end up with only a few, gaping holes inside it. The resulting bread would also contain big holes, resulting in a sticky mess if you tried to make a peanut butter sandwich with it. (\*Note: This is because the pressure in a bubble must balance with the pressure on the bubble from the outside in order for it to survive. The internal pressure is related to the bubble's size. Before the bubble exists, the outside pressure seems infinite, so yeast cannot simply produce a new bubble of CO<sub>2</sub>. Once a bubble exists, however, gas can enter it and make it grow. This is discussed further in the section “Gas retention” in chapter two.)

Punching and folding redistributes the yeast or bacteria, exposing them to new areas of flour. This enables more fermentation to occur and helps the dough keep rising steadily.

Folding adds strength to the dough by stretching it. The strands of gluten become stretched more tightly. Any remaining weak bonds break and better bonds are able to form. This is a final chance for the gluten structure to rearrange into its best state. This is especially important for beginners who may not knead their dough adequately.

Finally, punching and folding can be used to manage your time. If your dough is nearly ready to shape, but you no longer have time, you can

postpone baking: punch and fold the dough and put it in the fridge. It will start to rise, but as it chills, the reactions will slow down. Later, when you are ready to bake, pull out the dough. It will warm up and begin to rise again, and you can continue where you left off.

To punch dough, either put it on a counter and slap it to remove the gas, or punch it with your fist right in the bowl. To fold dough, hold the bulk of the dough with one hand, grab an edge with the other hand, and pull the edge, stretching the dough enough that it resists you but not so much that it begins ripping. Fold it over the bulk of the dough. Repeat this process with the opposite side of the dough and then with the adjacent sides. Finally, flip the folded dough upside-down so the smooth surface faces up. Folding dough (below, top) and flipping the folded dough smooth-side-up (below, bottom) are shown below.



Punching and folding are usually done together, but if your dough was well-mixed and feels strong enough, punch it down without folding. This way you are eliminating the gas, enabling the dough to rise again, without adding strength to an already tough dough.

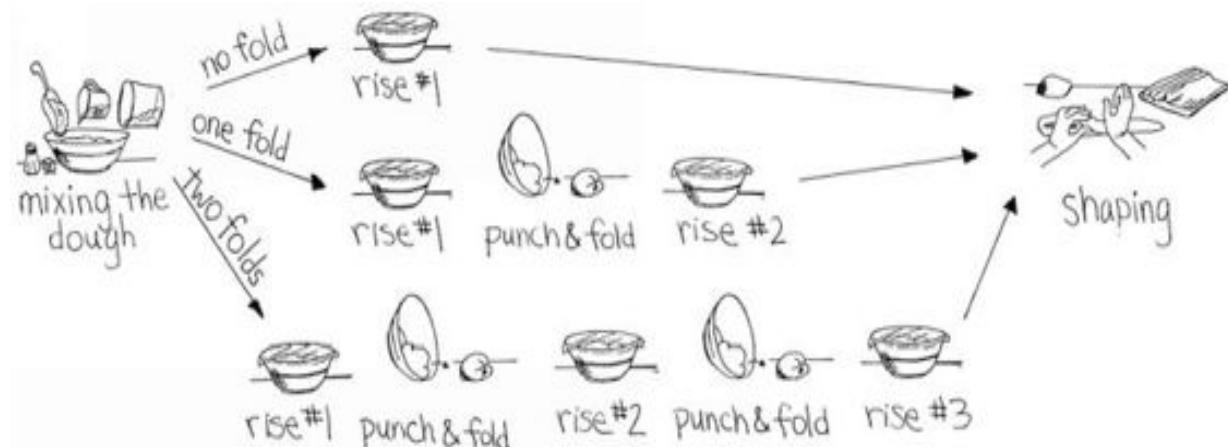
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## 5.5 How many times can dough be punched and folded?

If punching and folding dough adds flavor to bread, why not do it ten times? At some point, all of the flour is processed and the yeast does not have any sugars left for food. When this happens, fermentation is over and no more gas is produced. The dough stops rising. Dough baked at this point still makes tasty bread. It will be small, dense bread, and some bakers might scoff at it, but it will taste good.

Somewhere between zero and infinity is the number of times dough can be punched down and folded before it stops rising. Generally, zero, one, or two folds are used. If you would like to try more, it is an easy experiment—just keep folding each time the dough is ready, and note the point at which the dough starts to rise more slowly.

How many times should dough be folded? This is a matter of personal preference. If you have time to wait before baking your dough, and it seems to be rising easily, then more punches and folds will increase the flavor of your bread. If you know that your dough is weak or was not fully kneaded, using two folds will add strength, helping it become bigger bread. If you just want the bread to be done, or if it is rising very slowly and you do not want to wait a second time, than making bread without punches or folds makes sense.



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# Chapter 6: Dough Shaping



When it comes to shaping dough into baguettes and batards, there is only so much you can learn from pictures. Skill at shaping comes with practice! The techniques described in chapter six will get you off to a good start, however, describing both what to do and what not to do when you are shaping dough.

## 6.1 Overview of shaping the dough

## 6.2 Things to watch for when shaping

## 6.3 The basic motions of shaping

[6.4 The pre-shape](#)

[6.5 The steps of shaping: Boules](#)

[6.6 The steps of shaping: Batards](#)

[6.7 The steps of shaping: Baguettes](#)

[6.8 Common baguette problems](#)

[6.9 The effect of your attitude](#)

[6.10 What to do with your shaped dough](#)

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## 6.1 Overview of shaping the dough

When the dough is ready—full of gas, soft, and relaxed—it is cut into pieces (if necessary) and shaped. A good work surface such as a counter helps immensely. I use my cutting board with a towel underneath it, to hold it still.

The most obvious purpose to shaping is to make different styles of bread. There are other less obvious but equally important reasons for shaping dough:

1. Removegas. Shaping removes excess gas from the dough, which will rise again before baking. This extends the fermentation time and allows more flavor to develop. Removing gas adequately before a final rise also eliminates gaping holes in the final bread.
2. Disperse gas bubbles. The gas that remains is dispersed into small bubbles throughout the dough. These bubbles are available for new CO<sub>2</sub> molecules to enter. (Remember that to become gaseous, CO<sub>2</sub> molecules in the dough need bubbles to enter.) The population of bubbles allows the dough to rise with an even internal structure.
3. Create an even loaf. Shaping creates a smooth outer layer that will become the crust. The tightness of this outer skin forces the dough to rise evenly, resulting in a good internal structure—i.e., no giant holes or dense spots. In the oven, when the dough expands rapidly, it will expand evenly. Dough that is not well-shaped might expand lopsidedly or burst out on one side during baking.
4. Add strength. Shaping is the final chance to add strength to the dough. During shaping, the dough can be pulled tighter and tighter. Dough with a tight outer surface will take longer to rise, since more gas must be produced inside to push against the tight dough. This increases the fermentation time. In addition, tightly shaped dough will hold up better than floppy dough in the oven, producing taller, rounder bread.

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## 6.2 Things to watch for when shaping

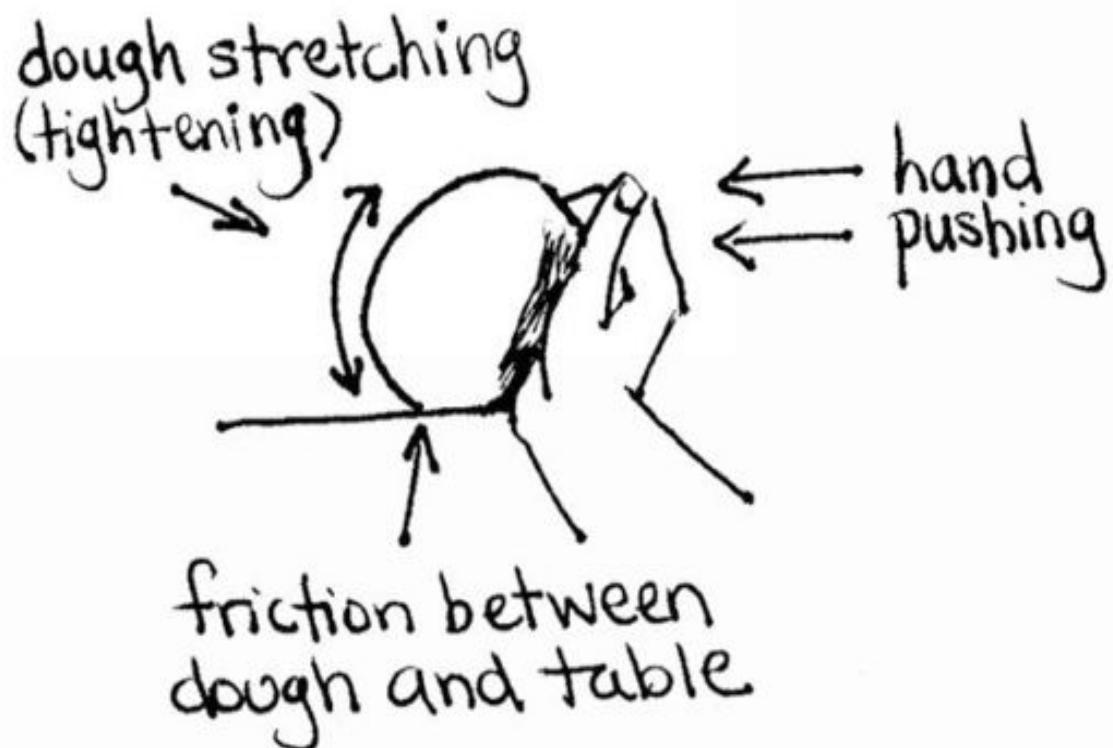
There are many fine points to shaping dough; a few basics are presented here. It is hard to remember them all at once, but go over them whenever you shape dough and try to make them a habit. They will help with shaping, but the only way to get truly comfortable with shaping is practice.

1. First, it is important to touch the dough as little as possible. Over-handling increases the temperature of the dough. It may rip the gluten, making the dough sticky and floppy. Many people make nice shapes and then ruin them because they do not stop when they should—this is commonly the cause of the impossibly-long baguette.
2. Manage your flour. The general tendency is to sprinkle an ample coating of flour on the table. While shaping on an un-floured surface might result in dough sticking to the surface, too much flour eliminates the dough-table friction entirely. This friction is used in the shaping process. Flour your hands well, but refrain from over-flouring the table.
3. With each fold of the process, remember that you are adding strength to the piece of dough. Fold meaningfully, not weakly. Make each fold count.
4. As you make folds, you will be moving the gas around, pushing it to the edges of the dough, where it will be removed. Learn where the gas is in the dough. Watch that you do not trap a pocket of gas in the middle of your shape.
5. Finally, the dough is going to pass through many stages before it is finished. With each step, strength is added, gas is eliminated, or the dough is adjusted for evenness. Focus on these steps and not on the final product —each step of the process is important for creating a good final shape. Do not try to rush your dough straight into the final shape, bypassing these important steps; the result will be an ugly loaf. The journey is as important as the destination!

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## **6.3 The basic motions of shaping**

A basic skill used repeatedly during shaping is using the friction between the table and the dough to add strength to the dough. The motion is illustrated below. To do it, place your hand on the table and slowly push on your dough. The dough should stick to the table on the side opposite your hand. Because the dough sticks, its outer surface is stretched more tightly; this is an increase in strength.



Keeping your hand in contact with the table and pushing slowly will help you learn this motion correctly. No matter how many times I tell students this, they still do not do it. Keep your hand on the table, and push slowly . Simply rolling the dough back and forth does not add strength. These actions are shown below: creating good friction with the table (top) versus simply rolling and mashing the dough (bottom). The dough should not be moving across the table as you tighten it; it should be stuck to the table and stretching.



If your surface is too floury and you cannot find good friction, simply use both hands to cup the dough, stretching it across its top, as shown below.



Different people have different shaping techniques; the guidelines presented here are just one method. This method breaks the process of shaping a loaf into steps to show where strength is added, where gas is eliminated, and how to keep the dough even.

Three basic shapes, pictured below, are discussed in the following sections—the boule or round (middle), the batard (right), and the baguette (left and behind).



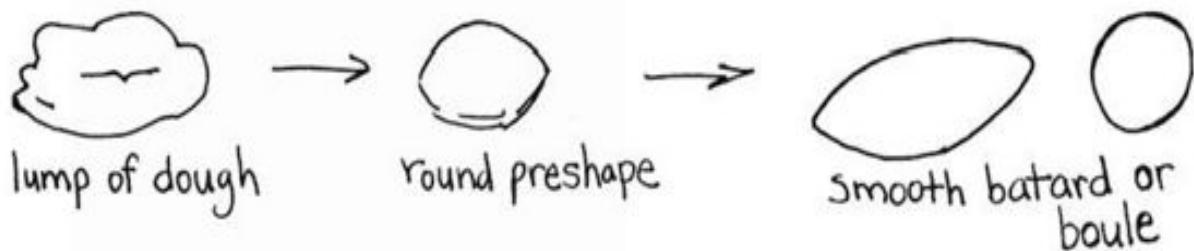
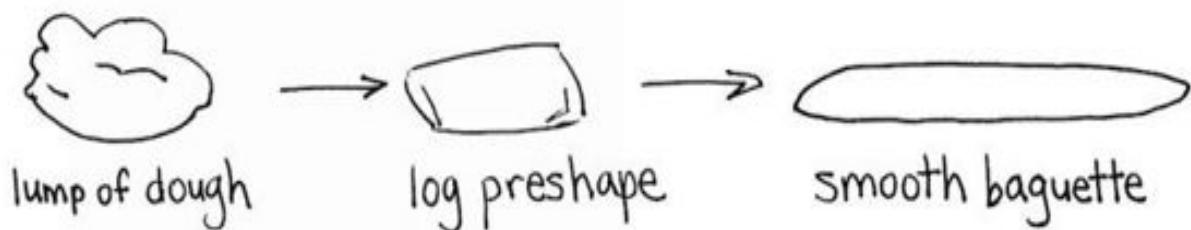
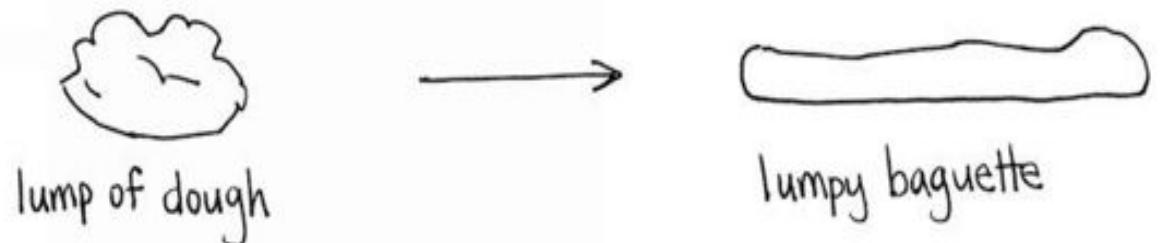
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## 6.4 The pre-shape

Dough can be pre-shaped to make the final shaping easier. The pre-shape is a stepping stone partway to the final shape. It creates a symmetric piece of dough with a smooth outer surface, both of which contribute to a good final shape. Pre-shaping also extends the shaping step by giving the baker another chance to remove gas from the dough and add strength. Dough that tends to flatten out in the oven can be pre-shaped for extra strength, resulting in taller bread.

The shape of your pre-shape depends on the final shape you plan to make:

- a boule is pre-shaped as a round ball
- a batard is pre-shaped as a round ball
- a baguette is pre-shaped as a log



To obtain a round pre-shape, smack the gas out of the lump of dough with your whole, flat hand. Fold the edges up and turn the dough over to reveal the smooth underside. Tuck the sides under a little bit, tightening the smooth top. Do not overdo it—the pre-shape should not be super-tight. The images below show these steps: (top to bottom) tucking up the corners, flipping the dough smooth-side-up, the basic round shape, and tightening the round by stretching the top of it with two hands.



To obtain a log pre-shape, smack the gas out of the lump of dough and then roll the dough up, tucking the edges in to produce a smooth log. Further tucking along the length of the log will help make it smooth. You can also try the tightening technique described in the last section, using the friction between the dough and the table to stretch the dough. The images below show these steps: (top to bottom) rolling up the dough, the general log shape, tightening the log by stretching the top of it with the hands, and tightening the log using its friction with the table.



The log should be even or fatter in the middle, but never thinner in the middle or at one end. The so-called “barbell” pre-shape (thinner in the middle) results in a baguette with a thin middle that is impossible to fix. The “baseball bat” (thinner at one end) is not as bad as the barbell but still makes subsequent shaping difficult. Two good, even pre-shapes (left) and two bad, uneven pre-shapes (right) are shown below.



This is just a pre-shape; minimum handling is necessary . The shape does not have to look perfect and should not be made very tightly. If you are touching the dough too much, it may begin to rip.

After pre-shaping, place the dough on a floured surface and cover with plastic wrap. Having just been pre-shaped, it should feel slightly springy when poked. It needs to sit until it relaxes, flattening out and softening. Dough that has been pre-shaped more tightly will take longer to relax. Dough in a colder environment will also take longer.

When the dough is ready to shape, it will feel relatively soft. Shaped too early, the dough will contract when you try to work it. Shaping will be difficult and forced, and an uneven loaf may result. Shaped too late, the

dough will be floppy and hard to control. Again the final result may be uneven.

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## 6.5 The steps of shaping: boules

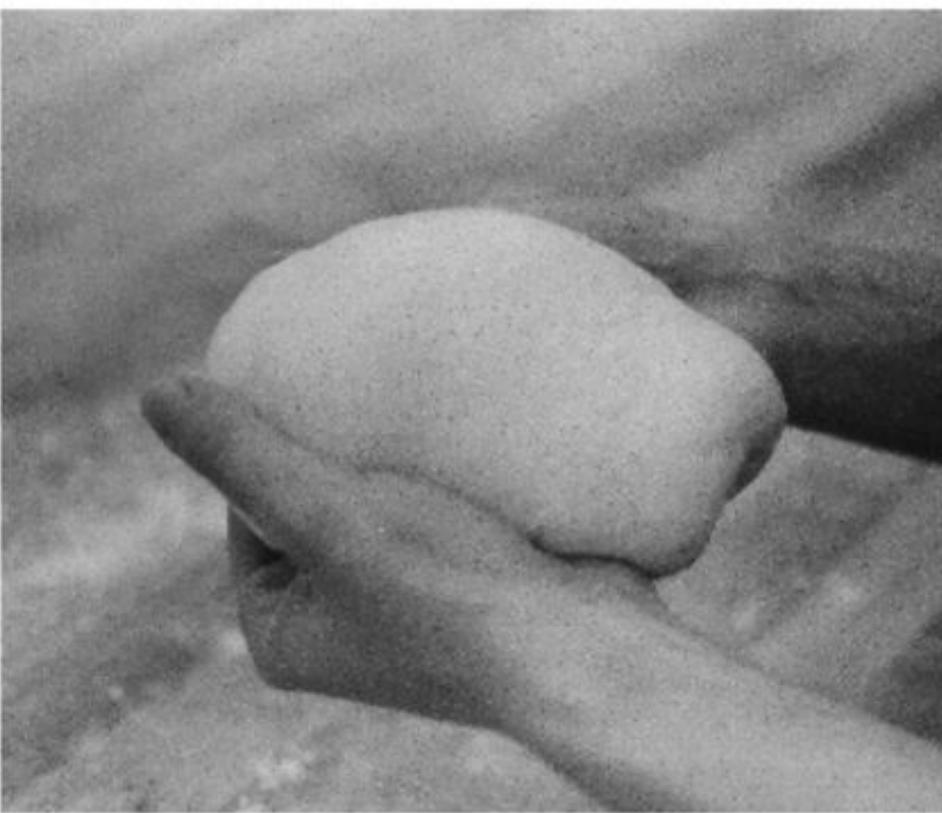
1. Start with a lump of dough or a pre-shaped round, placed smooth side down. Flatten it out by smacking it with your flat hand. You want to get all the gas out of it. Do not pat it lightly or poke it with your fingers. Do not pull on it with both hands or try to stretch it. Just flatten it without missing any spots. Degassing the dough using the flat of your hand is shown below.



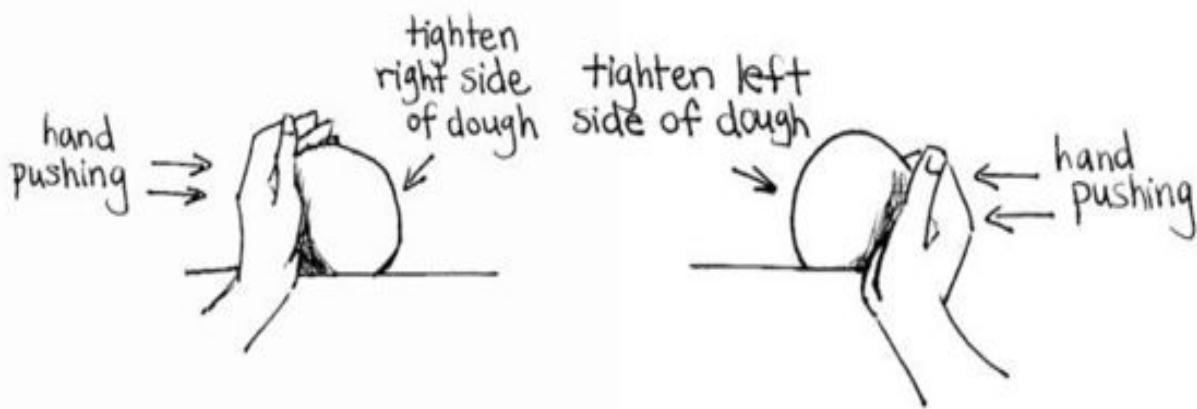
What not to do is shown below: just poking at the dough will not get the gas out (top), and stretching the dough will rip the gluten (bottom).



2. Fold up the four “corners” of the dough. Pick it up, turn it over, and continue to tuck under the edges. This is shown below.



3. The dough is now approximately ball-shaped and you can begin “rounding it” or tightening it. Place the dough smooth-side-up, put a hand on each side, and slowly push it back and forth, stretching each side (opposite your hand). Work your way around the ball, so that you push on all sides of it. This is shown below. Do not rush or spin the dough around; the side-to-side motion is what is important, not how fast you can do it. You are adding strength to the dough by stretching it. This strength should be even over the surface of the ball.



Continue with this motion until you have a relatively tight dough ball. The ball should be tight enough to stand on its own and not flatten out. If you over-shape the dough, it will start to rip. Try to shape it with as little handling as possible. If you have warm, humid hands, they might rip the dough; flour your hands (not the table) to protect the dough.

A well-shaped dough ball is shown below:



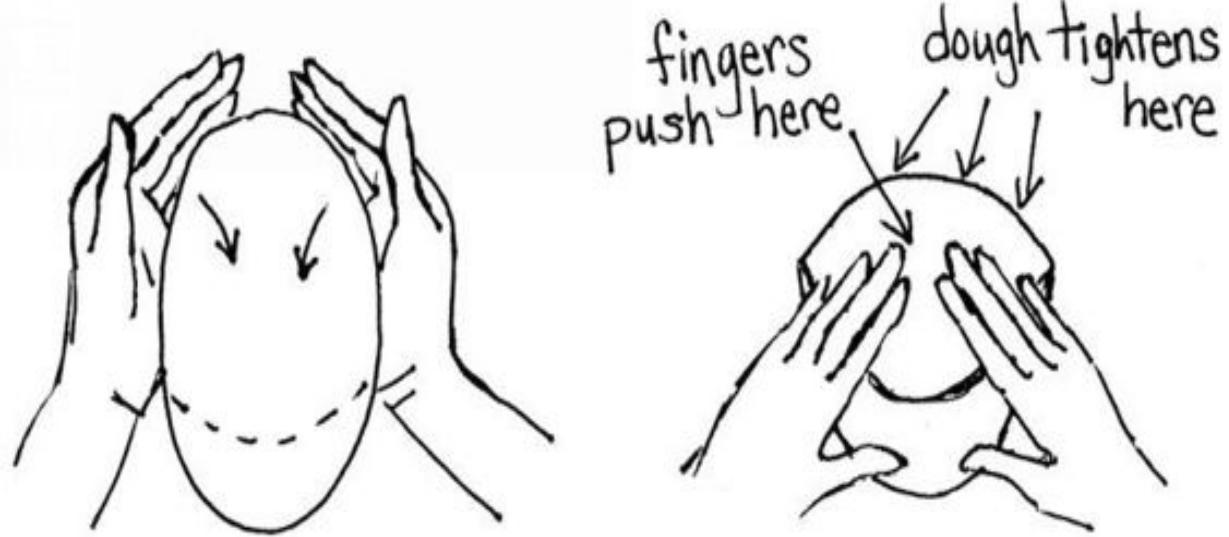
A flat dough ball that needs to be shaped more tightly (top) and an over-shaped dough ball that is starting to rip (bottom) are shown below.



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## **6.6 The steps of shaping: batards**

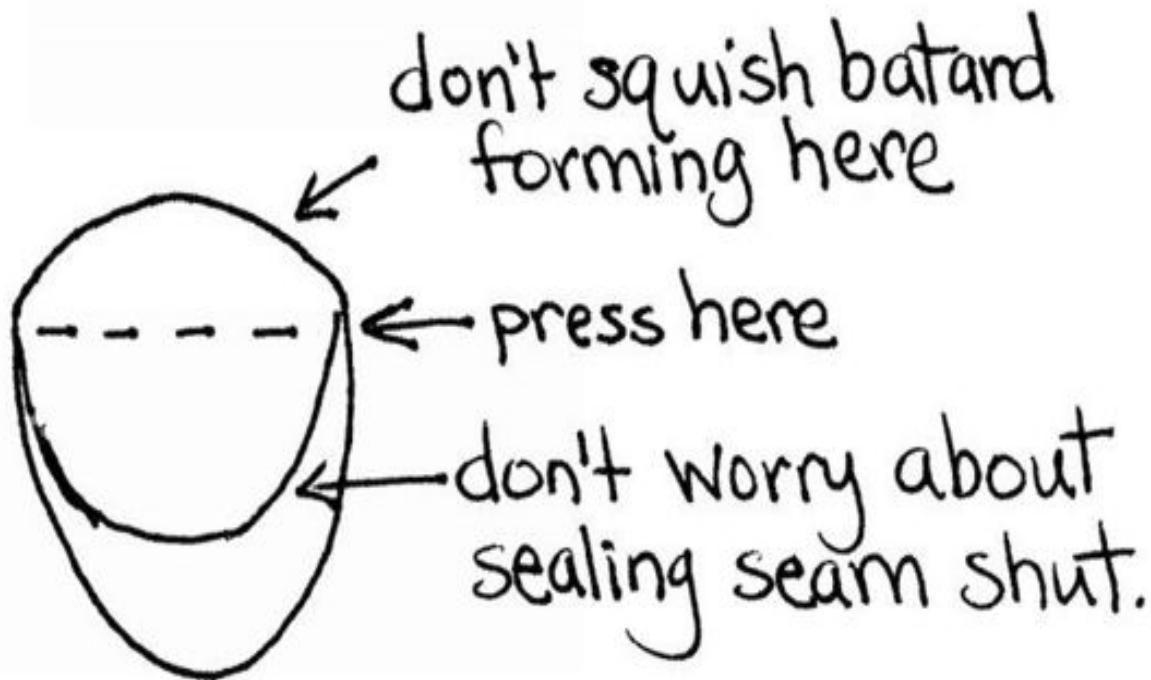
1. Start with a pre-shaped round. Put the smooth side down on a lightly-floured table. This will become the smooth outer surface of your bread. Flatten the dough by smacking it with your flat hand. Stretch it slightly to get an oval shape.
2. Position the dough vertically—this is anti-intuitive, since you will be making a horizontal shape. Fold the top third of the oval down and in. Use your hands at angles—picture a triangle between your hands. Do not just flop the dough over; push on it to tighten the outside of the fold. The first fold is shown below.



What not to do: pulling the dough outward instead of folding over and in will move dough towards the ends of the batard, resulting in the “barbell batard” with fat ends and a skinny middle. Once the middle is too thin, it is nearly impossible to fix! This is shown below.



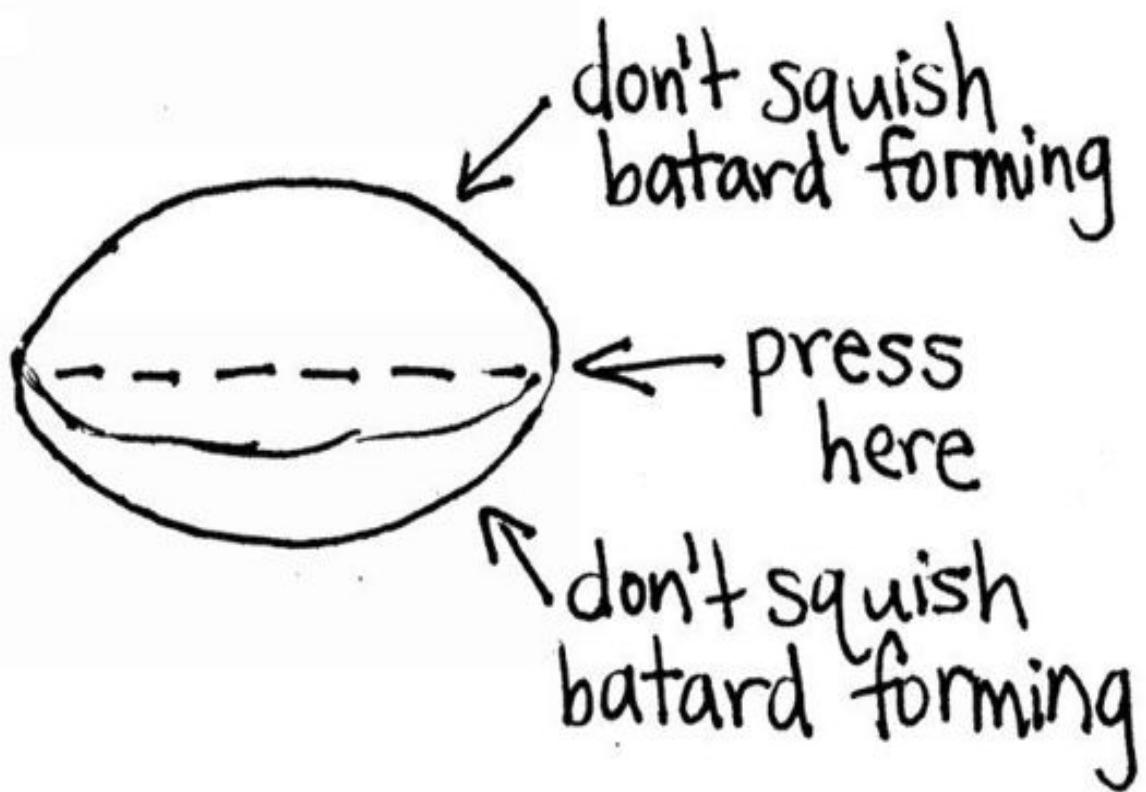
3. Press the fold shut with the heel of your hand. (Do not just poke at it with your fingers.) Use only three or four strokes. This step forces any remaining gas to move to the edges of the dough. Place your strokes close enough to the edge to be effective at moving the gas there, without being so close as to squash the shape that is forming. Do not worry about sealing the seam shut. This is shown below.



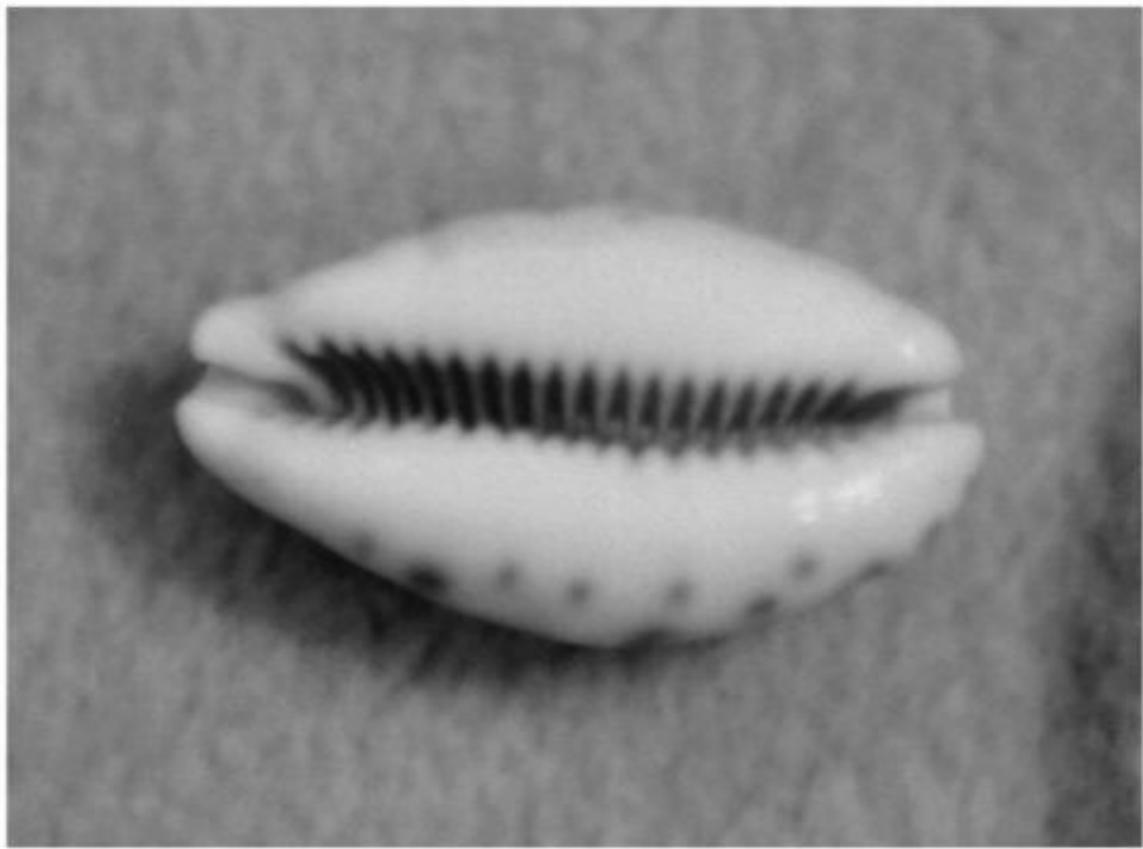
4. Without stretching it, rotate the dough 180 degrees and repeat steps 2 and 3: first, fold the dough. Again, picture a triangle between your hands and fold down and in, not out. The second fold of shaping a batard is shown below.



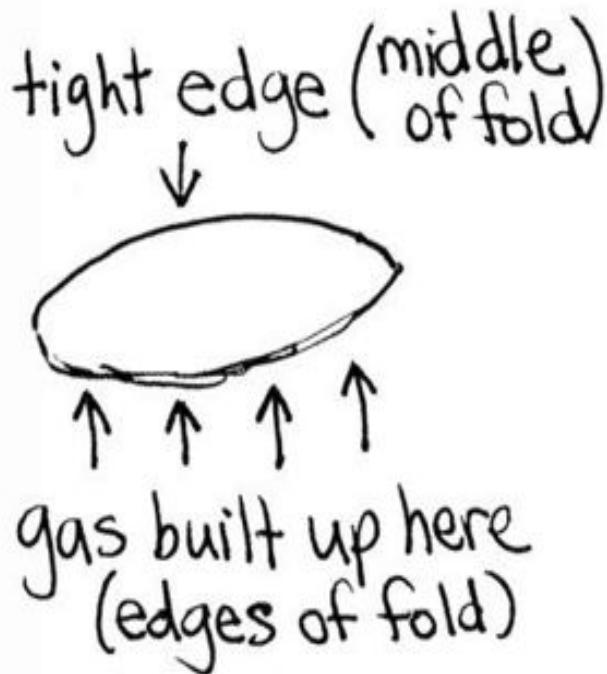
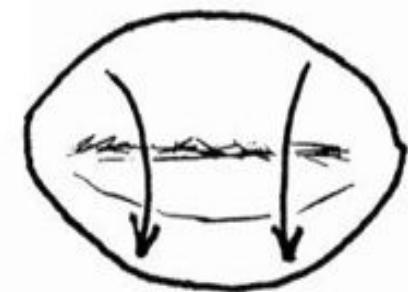
Next, press down the middle of the dough with the heel of your hand. Avoid squishing the edges where the shape of the batard is forming. This is shown below.



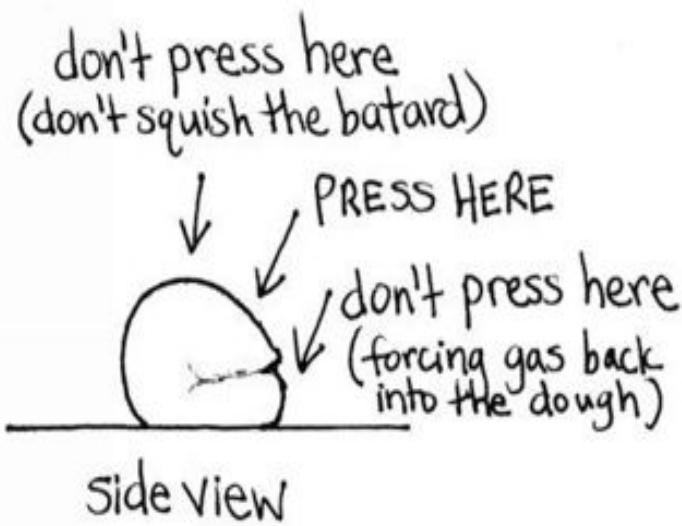
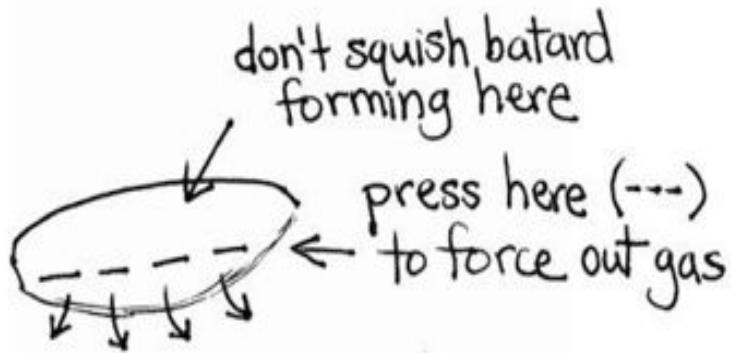
At this point, the dough (below, top image) makes me think of a cowry shell (bottom image). It has a trench down its middle, with gas built up along the edges. It can be shorter than the final batard; making it longer later on is very easy, but there is no way to make it shorter if it gets too long.



5. Use both hands to fold the dough in half, bringing together the two edges where gas has built up from the first two folds. You are tightening the outside edge of the dough—make sure it feels tight. Fold slightly inward as you did before. The third fold is shown below.



6. Press the seam shut with the heel of your hand. Do not push right on the seam—this will force air back into the loaf. Focus on forcing out the gas that has built up along the edges. On the other hand, do not flatten the batard shape you just created. Find the place in between where your pressing is not hurting the shape but is effectively eliminating gas. This is shown below.



7. Stop to examine your batard. Turn it smooth-side-up, with the seam down. Is it even? Is it tight enough? Use the friction between the dough and the table to continue shaping.

For example, this batard has too much dough on its left side:



Pushing on this dough, using the friction with the table to stretch it, spreads out the dough until both sides match:



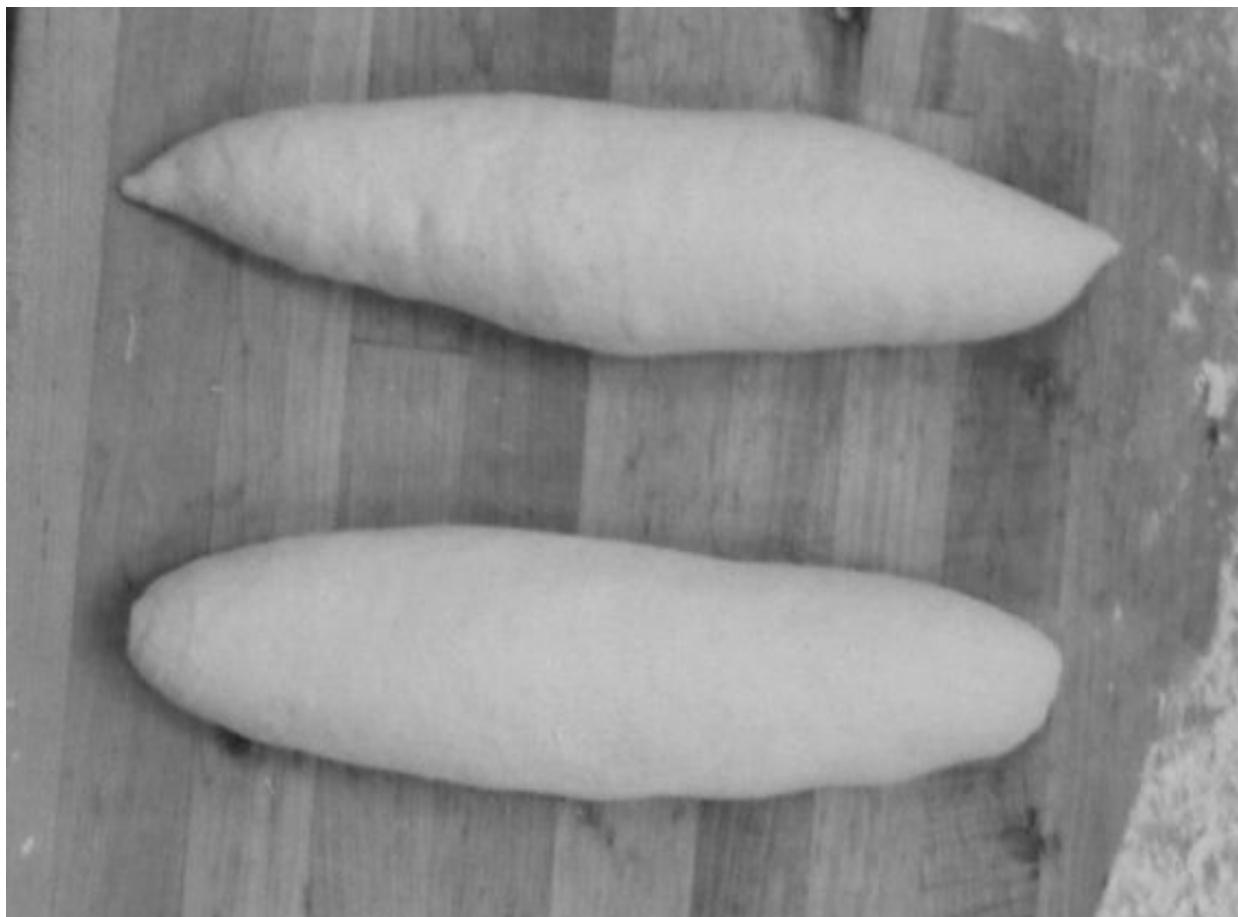
Fixing an uneven batard is not an easy step; keeping your batard symmetric from the beginning is much easier.

If the batard is even but soft and weak, add strength down the whole length of it. Pull the batard towards you with both hands, stretching the dough and adding strength on the near side. Or use both thumbs to push the batard

away, adding strength on the far side. Remember to keep your hands on the table, pushing the dough, not rolling it. Using the friction between the dough and the table to tighten the outer surface of the batard is shown below.



8. Use both hands to lengthen the batard (if necessary!) by rolling it on the table. Push harder on the ends to make them pointy. (The correctness of pointy batard ends is subjective. Pointy ends are favored by people who like crust. Those who like rounded ends view pointy ends as a waste of bread, and potentially dangerous, if sharp enough.) Finished batards, with pointy and rounded ends, are pictured below.



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## 6.7 The steps of shaping: baguettes

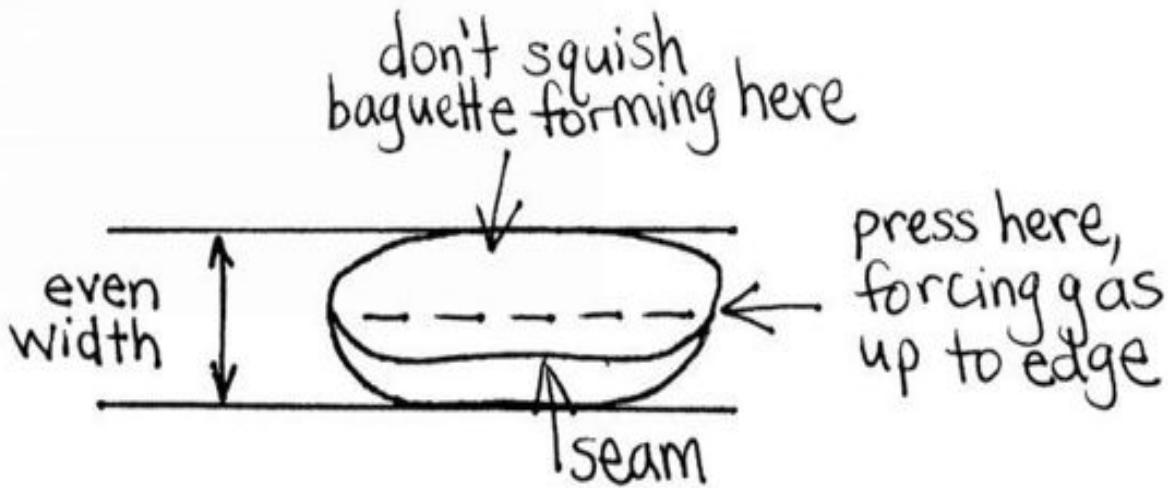
1. Start with a pre-shaped log. Put the smooth side down on a lightly-floured table in a horizontal position. This side will become the outside of your loaf. Flatten the dough by smacking it with your whole hand. Do not try to make it longer by stretching it. Getting your baguette long enough will not be a problem.

2. Fold over the top third of the oval. Focus on keeping the width of the dough even along its whole length. (This will give you an even baguette.) The first fold is shown below.



3. Press the fold shut with the heel of your hand. Use only three or four strokes. This step forces any remaining gas to move to the edges of the dough. Place your strokes close enough to the edge to be effective at moving the gas there, without being so close as to squash the shape that is forming. Do not worry about sealing the seam shut.

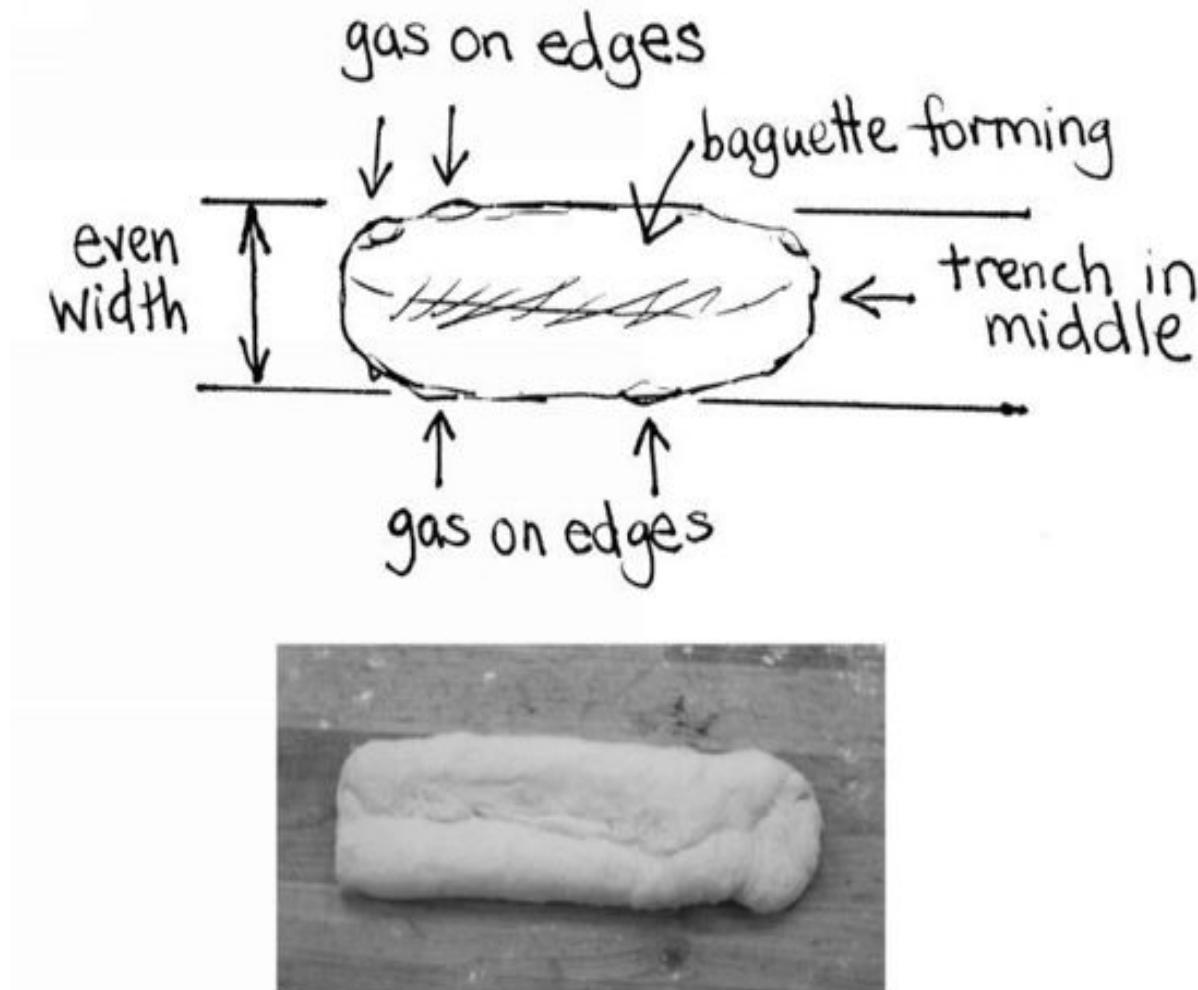
Pressing shut the baguette after the first fold is shown below.



4. Without stretching it, rotate the dough 180 degrees and repeat steps 2 and 3: fold the baguette a second time and press it shut down the middle of the dough, preserving the baguette forming on either side. The second fold and pressing shut the dough after the second fold are shown below.

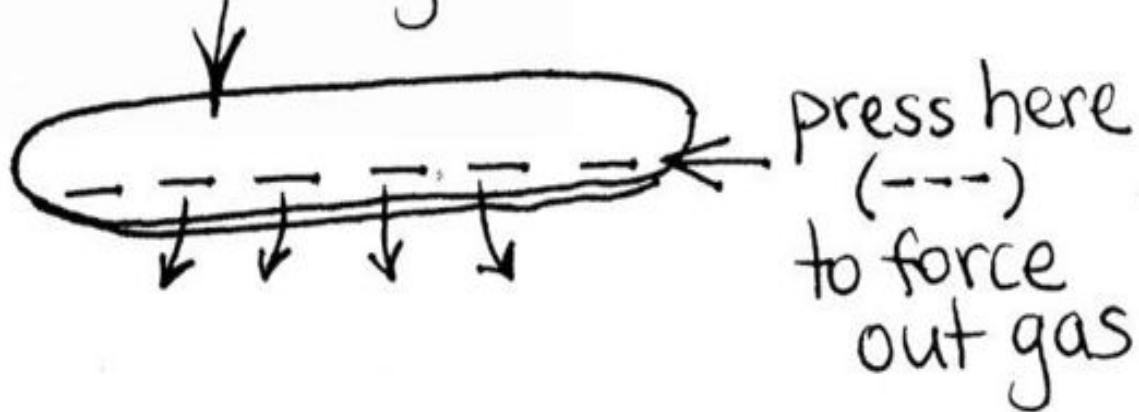


At this point, your dough has a trench down its middle, with gas built up along the edges. It should be even. Do not worry if it is much shorter than a baguette should be. The dough after the second fold is shown below.

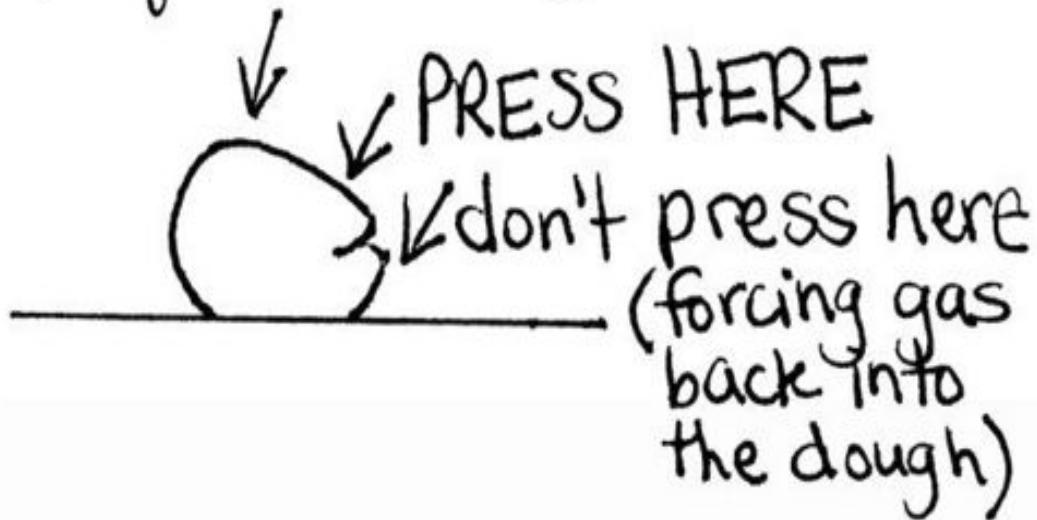


- 
5. Fold the dough in half and press the seam shut. You are tightening the outside edge of the dough, lining up the edges where the gas has built up, and eliminating the gas. Remember, you do not want to push right on the seam and force gas back in, but you also do not want to destroy the baguette shape that is forming. Find the place in between. This is shown in the diagrams below.

don't squish baguette  
forming here



don't press here  
(don't squish the baguette)



Two methods are suggested for this step:

Method 1. Moving from right to left, use your left hand to fold the dough over and your right hand to press the seam shut. Your left thumb presses out the backside of the baguette (opposite the new seam). You should hear gas bubbles popping. Focus on pushing the gas out; sealing the seam will happen. (If you are left-handed, using the opposite hands may be more comfortable.) This is shown below.



Method 2. Starting in the middle, fold the dough over down its whole length. Then use the heel of your hand to press the seam shut. This method helps produce a symmetric baguette; however, it is a lot of dough to handle all at once. This is shown below.



6. Stop to examine your baguette. Turn it smooth-side-up, seam down. Is it uneven? Too soft? Do not worry about making it longer—make it even first! Use the friction between the dough and the table to continue shaping.

For example, this baguette has too much dough on its left end:



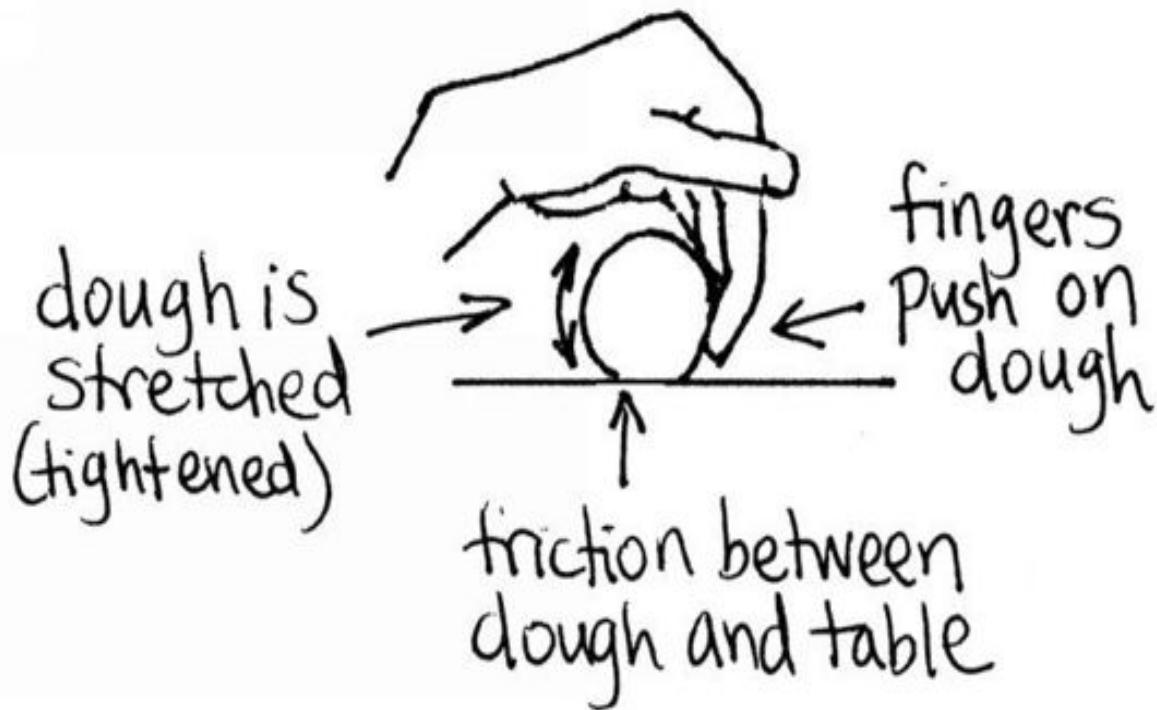
Pushing on the excess dough using the friction with the table stretches the baguette, spreading out the dough:



If the baguette feels soft and weak, use the friction to add strength down the whole length of it. Use both hands to pull the baguette towards you, starting in the middle and working towards the edges, as shown below.



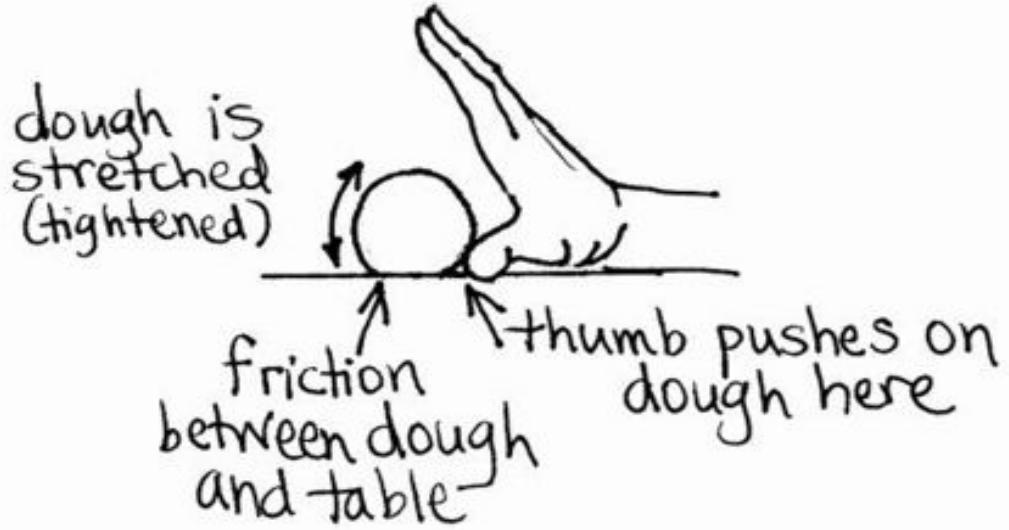
Or, pull with one hand curled over the baguette, as shown below.



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This adds strength or tightens the dough on the near side of the baguette. Remember to keep your hands on the table to prevent you from simply rolling the dough in an unproductive way.

Use both thumbs to push the baguette away from you, adding strength on the far side. Again, keep your thumbs on the table as you push to do this step correctly. Two-handed and one-handed methods of this step are shown below.



If your baguette is very soft, you can roll it upside down and fold it an extra time. This will tighten the entire baguette.

8. Use both hands to lengthen the baguette (if necessary!) by lightly rolling it on the table. Push harder on the ends to taper them. Finished baguettes are shown below.



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## 6.8 Common baguette problems

There are certain shaping problems I see repeatedly. If your baguette has one of these problems, listed below, here is what to fix the next time you shape. (Remember, you can still bake and eat an ugly baguette!)

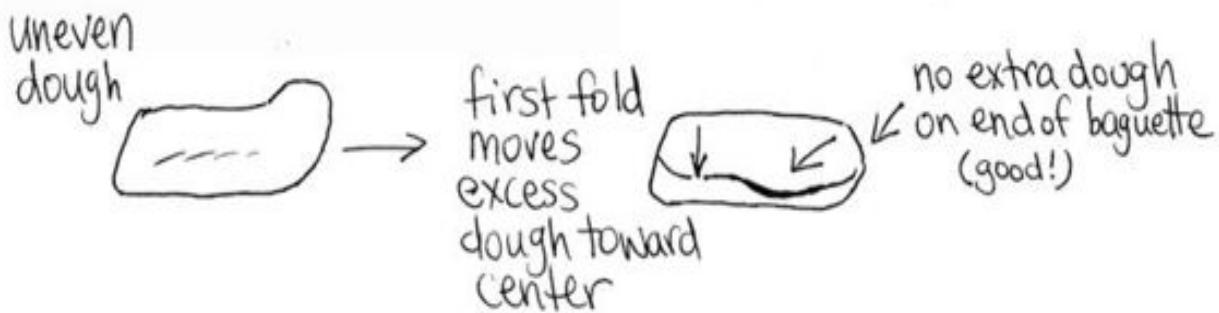
- The floppy baguette. If your baguette feels soft or flattens out against the table, it needs more strength. Focus on pulling the dough tighter each time you fold it. You can also try to add strength to the finished baguette using the friction between the dough and the table.

A very floppy baguette can be salvaged by adding an extra fold—turn it on its back and fold it one more time, stretching the backside of the dough until it is taut. The baguette will get longer—if it becomes impossibly long, you can chop it in half and braid the halves or make two ficelles (thin baguettes).

You can also make the dough stronger next time—mix it longer, fold it tighter, or shape it sooner.

- The bubbly baguette. If your baguette has lots of bubbles in it, you have not done a good job removing the gas. Either pound more gas out in the beginning or, more importantly, pay attention to where you are pressing on the dough after each fold. Make sure you are not pressing on the very edge of the dough, forcing built-up gas back into the dough. Look for “missed spots,” big gas bubbles, after you press. Make sure you are pressing gas out of the whole length of the baguette. Use the heel of your hand and press firmly, do not just press with a thumb or poke with your fingers.
- The baseball bat. If your baguette is uneven, you may force dough to one side during the shaping process. I often “mush left” as I make the final seal, ending up with the majority of dough on the left side. Keep your dough even throughout the process. When you are pressing down, make sure you are not pushing to one side.

In addition, make sure the dough is even at the start. If it is not, correct it as you start shaping:



- The barbell baguette. It is almost impossible to fix a baguette that is fat on the ends and thin in the middle. The first possible cause is a barbell pre-shape. A second cause is dough being inadvertently stretched when it is moved. This usually happens one of two places: when the dough is being rotated between folds, or during a fold, if the shaper pulls outward as he folds. A good fold (top) versus a fold with an outward pull (bottom) is shown below.



- The mauled, ripped-up baguette. Ripping is the result of over-handling. Try to shape your dough with minimum handling. When the baguette is formed, stop. Do not keep rolling it around. Use a bench-scraper or stiff spatula to separate the baguette from the table if it sticks. Keep flour on your hands if they are clammy so they will not stick to the dough.
- The peapod baguette. If your baguette is lumpy, it is probably because you pressed on the newly-formed baguette as you tried to press gas out. This happens when people press with their hand angled across the baguette, instead of flat to it. Keep an eye on where the baguette shape is forming and do not smash it. The peapod baguette, dough (top) and baked bread (bottom), is shown below.



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## 6.9 The effect of your attitude

Cultivating the proper attitude can do a lot to help your shaping technique. You must be confident and firm, in control of the dough, without being dominating and aggressive towards it.

For example, when you are pounding gas out of your dough, you need to use firm strokes to be effective. A timid baker pats at the dough, failing to eliminate gas. The overly-aggressive baker pounds the dough to death, heating it up and stretching it out in the process. It only takes a few strokes to get the gas out, but they should be firm ones.

This general trend extends through the rest of the process as well. With each fold, a timid baker does not fold tightly enough or move gas to the edges effectively. The over-aggressive baker is in a hurry, constantly touching the dough as if he or she does not trust the process to add enough strength or eliminate the gas. In the end, the timid baker will have a floppy baguette, while the aggressive baker will have an uneven, over-handled baguette.

What is your shaping technique saying about you?



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## **6.10 What to do with your shaped dough**

Shaped dough needs to rise (or proof) before it is baked. Where you leave your dough depends on how you will be baking it. Some possibilities are listed below:

- A simple baking method is to bake bread on a cookie sheet or other flat pan. You can grease or flour the pan or line it with parchment paper (that can go in the oven) and then put your shaped dough on the pan to proof.
- Another simple method is to bake in a bread pan, which will result in the familiar square-bottomed loaf of bread. This method is useful for doughs that are softer and flatten out while baking. A short, fat batard-shaped piece of dough fits in a bread pan. Grease the pan before putting the dough in to proof. This is shown below.



- Baking on a pizza stone has benefits described in the next chapter. If you bake on a stone, you must pre-heat the stone with your oven. Proof your dough on a surface from which it can easily be removed when it is time to transfer it to the pizza stone. If you proof it on parchment paper on a cutting board or sheet pan, you can move the whole piece of paper onto the stone when it is time to bake. An alternative is to proof it on a floured linen (not furry) towel. White flour works fine, or a grittier flour (corn meal, rice flour, semolina flour) can be used to give your bread a rustic-looking bottom. The towel can be folded to support the edges of the rising loaf, as shown in the picture below.



- Dough that is weaker and flattens out during proofing can be put smooth-side-down in a floured basket (called a banneton) to rise. The basket helps the dough hold its shape. It is then turned out smooth-side-up onto a stone or pan for baking. The spiral pattern of the basket adds a decorative touch to

the loaf. Willow baskets, while aesthetically pleasing, are expensive and hard to maintain. Cheaper, washer-friendly plastic ones work just as well. Dough rising in a banneton is shown below.



- A small bowl with steep sides works well in place of a basket. Line the bowl with a linen towel and sprinkle flour onto it before placing your dough in the bowl. This is shown below.



However your dough proofs, keep it covered. If it dries out, a hard skin will form, preventing it from rising. It will not be able to expand in the oven. If you cover it with plastic wrap, leave the wrap loose enough that the dough can rise. A poofed-up plastic bag around the whole pan, board, basket, or bowl works, too.

Place your dough somewhere appropriately warm or cool—in a cold house, put it near a warm spot on the stove or under a lamp. In warm, humid weather, if it is rising too fast, turn off nearby lights or put it near the floor. Preheat your oven early, especially if you are using a pizza stone.

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# Chapter 7: Proofing and Baking



At last, it is time to put the dough into the oven! This final step of the bread-making process entails much more than opening and closing the oven door. Baking the dough at the correct time and having a hot enough oven are key to getting the biggest loaf possible. Scoring the dough and using steam also enable the loaf to expand, in addition to producing other effects. Baking is the baker's last and perhaps greatest chance to create an aesthetically pleasing loaf of bread.

[7.1 Overview of the proofing and baking steps](#)

[7.2 When is dough ready to go into the oven?](#)

[7.3 What happens to dough in the oven](#)

[7.4 Modifications to improve your oven for baking](#)

[7.5 The purpose of scoring \(cutting\) dough](#)

[7.6 Scoring patterns](#)

[7.7 Steaming dough: why and how](#)

[7.8 Getting your dough into the oven](#)

[7.9 When is bread done baking?](#)

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## 7.1 Overview of the proofing and baking steps

The final steps of bread-making seem simple enough—let the dough rise one final time (this is called proofing) and then put it into the hot oven to bake. There is a lot to take into account, however, if you want your loaf to turn out well. Consider the following:

1. Gascontent. The dough must rise the proper amount to maximize the final bread size and produce an even interior. Baked too soon, with not enough gas bubbles inside, the bread will be small and dense. Baked too late, it will be so full of gas that it will collapse in the oven.
2. Proper oven heat. Once in the oven, the dough expands rapidly in the first ten minutes, a occurrence called oven spring; proper heat is essential. The home oven can be modified to maximize the effects of oven spring.
3. Scoring. Dough should be scored (cut) before it enters the oven. The purpose is not only to create decorative designs on the bread, but also to maximize expansion and encourage even growth by controlling the position and depth of the cuts.
4. Steaming. Steaming the dough as it enters the oven is important for maximizing dough expansion and for obtaining a crispy, well-browned crust. Creating steam in a home oven requires a bit of improvisation.
5. Bake time. After the initial expansion, other changes occur in the dough as it becomes bread. The most obvious is the gelating of the starch; the bread must be baked long enough to reach the temperature at which this solidification occurs. Baked too long, however, it will begin to dry out, if not burn. It must be baked the proper amount and then cooled properly before storing.

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## 7.2 When is dough ready to go into the oven?

There are two dough properties to check when determining if your dough is ready to go into the oven: its strength and its gas content. (Size can also be used, but this is not always an easy determination to make.) To examine the dough's strength, poke it gently with your finger—does it bounce back or did you leave a dent? Compare the strength to how it felt when it was first shaped. With time, the dough relaxes. It should get easier to press. A dent indicates that it is ready to be baked.

Strength alone should not be used, however. Some doughs are stronger than others and remain strong until the end—they will always spring back when poked. And some people are aggressive pokers who will always leave a dent. To examine the dough's gas content, gently pick it up. Does it feel denser in the middle? Gas first expands the loaf's outer edges, where there is less resistance to expansion, but the middle may still be dense. When baked, the loaf should be filled with gas throughout, giving it a delicate airy feel when bounced in your hands.

A good way to learn about proof times is to watch a loaf rise until it over-proofs—it will become so gassy and fragile that it collapses. Poke it periodically as it rises and remember how it feels just before it over-proofs so you can recognize it next time. If you prepare more than one loaf, you can bake one when you think it is ready and wait on the other. Could you have waited another 30 minutes? See how the second loaf feels after rising for 30 more minutes. If the loaf collapses, you can still bake it—it may look odd but will taste fine.

The dough should be baked when it is ready, not after a set amount of time. To give you an idea of how long proofing takes, however, an approximate proof time for properly kneaded, folded, well-shaped basic white bread that had a long enough fermentation time is an hour.

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## 7.3 What happens to dough in the oven

The heat in the oven affects the dough in many ways. Initially, there is significant expansion, called oven spring. Most oven spring occurs in the first ten minutes that the bread is in the oven. Many factors contribute to oven spring:

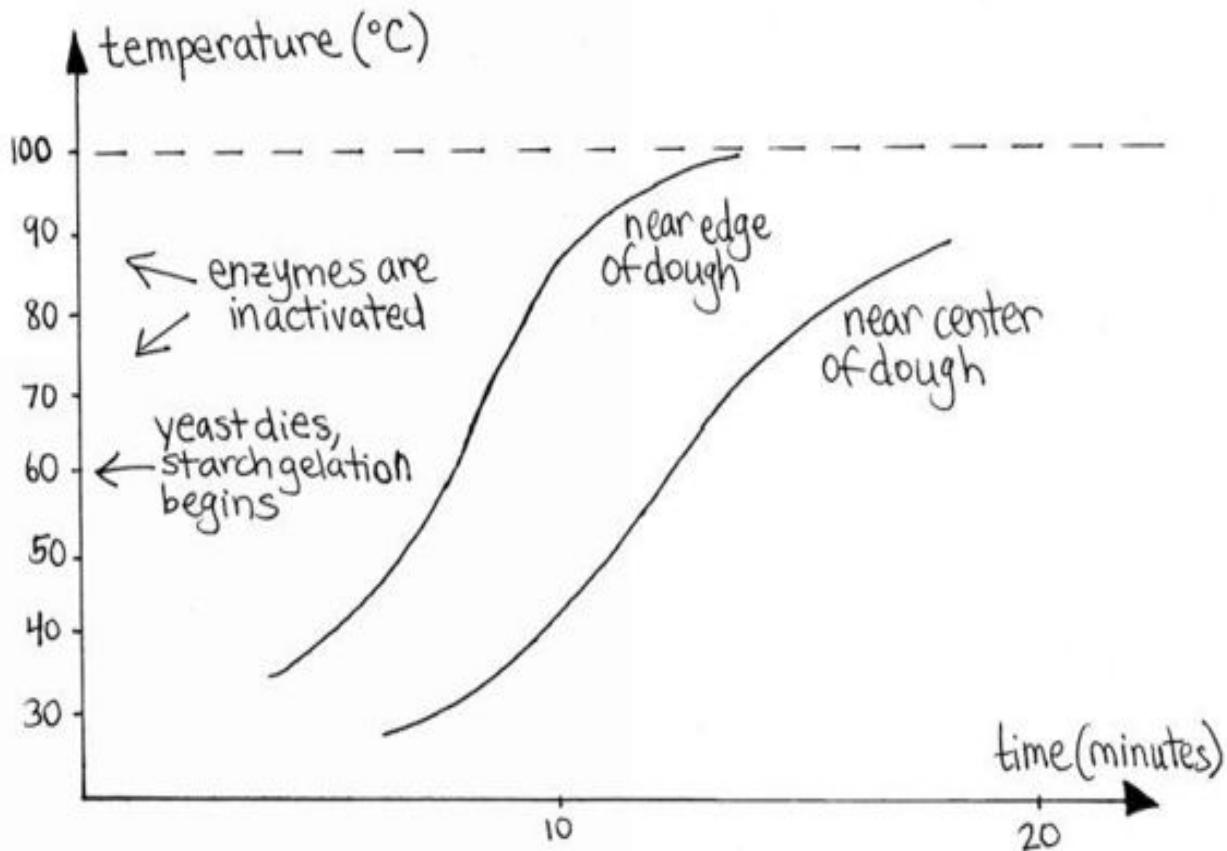
- Chemical reactions speed up. Enzymes work faster. Fermentation reactions produce a final burst of CO<sub>2</sub>. More gas means more expansion of the dough.
- Many molecules are present in the dough in aqueous (dissolved) or liquid form. The oven's heat vaporizes them. The solubility of CO<sub>2</sub> decreases as temperature increases, so in the oven, dissolved CO<sub>2</sub> comes out of solution. Alcohol and water both vaporize at hotter temperatures. Again, more gas means more dough expansion.
- Gases expand as they heat. The bubbles of CO<sub>2</sub> expand, pushing the dough out. Other gases, such as water vapor and ethanol, also expand. [1,2]

It takes time for heat to reach the center of the loaf, and a denser lump of dough will transfer heat more slowly. Partly this is a simple matter of heat transfer through the dough. In addition, water molecules at the dough's surface absorb heat and evaporate, cooling the surface and making less heat available for transfer to the center.

A properly proofed loaf has gas throughout that transfers the heat relatively quickly, so heat is able to reach the center of the loaf quickly, allowing gas at the center to participate in oven spring. If a loaf is not fully proofed when it enters the oven, the dense center has less gas available for expansion, and heat infiltrates the loaf more slowly, resulting in less oven spring. The center of the bread will be very dense, maybe even uncooked. Thus proper proof time is important for full loaf volume.

After the initial phase, oven spring ends and the dough begins to solidify. The starch gelates\* by absorbing nearby water molecules, some of which were being “held” by proteins. This begins around 60°C (~140°F) and increases to temperatures around 80°C (~180°F), giving the bread the structure it needs. The gluten proteins denature, or come apart. The yeast

dies around  $60^{\circ}\text{C}$  ( $\sim 140^{\circ}\text{F}$ ), and enzymes are inactivated. Gases in the dough, such as  $\text{CO}_2$ , water vapor, and ethanol, rupture their bubbles and escape to the atmosphere. This is important because if they did not escape, they would condense on cooling and the bread would collapse. Some organic molecules remain, contributing to the final bread's flavor. The plot below shows these aspects of baking as dough temperature increases. [3] [\*Note: The word "gelatinizes" is often used, but according to Harold McGee in *On Food and Cooking* this is a misnomer. The starch is forming a gel ("gelating") not turning into gelatin ("gelatinizing.")]



The outside of the loaf is the hottest part—the crust temperature might be as high as  $180^{\circ}\text{C}$  ( $360^{\circ}\text{F}$ ). [4] The enzyme-driven reactions that convert starch into sugars and break proteins into amino acids increase with heat, so they increase most near the dough surface. The extra sugars and amino acids produce the flavor and color of the crust by caramelization and Maillard reactions, described in chapter two. These begin around  $165^{\circ}\text{C}$  ( $330^{\circ}\text{F}$ ) and  $120^{\circ}\text{C}$  ( $250^{\circ}\text{F}$ ), respectively, temperatures off the top of the chart shown above.

Because dough is an aqueous system, its temperature cannot exceed 100°C (212°F) unless it dries out. This is because when dough temperatures do get that high, water molecules absorb the heat and evaporate, taking the heat away from the dough and cooling the system back to below 100°C. (This is the same way sweat works to keep our bodies cool—by absorbing heat and evaporating with it.) The center of the dough never exceeds 100°C, as shown in the plot above. The outer surface of the dough is the only part that dries out and reaches higher temperatures. This happens towards the end of the bake, and the crust rapidly becomes brown. [5,6]

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Arizmendi Bakery, San Francisco, CA, 2003

## 7.4 Modifications to improve your oven for baking

Two things make commercial bakeries' ovens superior to a home oven—their ability to retain heat and their ability to steam dough after the door is closed. (Steaming dough will be discussed in the next section.) One type of commercial oven is a hearth oven, where bread is baked on a slab of concrete or stone. This oven barely loses any heat when its door is open in contrast to a home oven where most of the heat escapes. Any heat lost from a hearth oven is quickly replaced by heat emanating from the oven floor. Other commercial ovens are designed to reheat quickly.

It is important to have your oven at a hot enough temperature (460°F for basic bread) when the dough enters in order to maximize oven spring. There are several ways to help a home oven reheat quickly once the dough is in.\* (\*Note: All ovens heat by convection, the transfer of heat from the hot coil or flame through the air to the food. So-called “convection ovens” increase the rate of this heat transfer with fans, helping the oven reheat quickly.)

- Put the dough in and close the door as fast as possible.
- Pre-heat the oven too hot: to 500°F instead of 460°F, for example. This way, some of the heat lost will not matter. Once the door is closed, turn the oven down to 460°F.
- Bake on a pizza stone. You must pre-heat the stone to the baking temperature with the oven. This will take longer, but the stone then becomes a source of heat, helping to reheat the oven once the dough is in. A second pizza stone above the bread will radiate even more heat; just make sure there is room on the sides of the oven for air to circulate.
- Pre-heat some other object with the oven and leave it in to radiate heat during baking. (Pick an oven-safe object: an old cast iron pan is one suggestion. My mom used to heat up rocks from the beach for our beds in the winter, to keep our feet warm, and they never exploded in the oven.)

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## **7.5 The purpose of scoring (cutting) dough**

Dough is scored or cut just before it goes into the oven. This is after it has proofed, when it is again full of gas.

Scoring dough has many purposes. The most obvious is to create patterns on the final bread. Equally important, the cut mark increases the exposed surface area and creates a weak spot in the outer skin of the dough. This helps the dough expand, producing bigger bread. If the dough is not cut, it might rip open in another place—where there is a weak spot on the surface or a big bubble inside, or near the base where the dough touches the pan.

This is illustrated in the pictures below: in both pictures, the bread on the left was scored before baking while the bread on the right was not. The scored dough opened up more, resulting in bigger bread. In the first image, the un-scored dough ripped open on the top.



In the second image, the un-scored dough ripped open on the sides.



While it is true that ugly bread still tastes good, there is something horrific about badly ripped bread:



A scene from "Night of the Living Bread."



"Hellraiser IV: The Starter Returns."

Professional bakers use a lame, a razor-on-a-stick, shown below, to help them cut quickly and identically when they have dozens of loaves going into the oven at once.



A serrated bread knife is a good substitute for a lame. Use deliberate, quick motions to achieve good cuts. Hesitation causes the lame or knife to drag through the dough, creating an ugly, uneven cut. It may take some time for this motion (shown below) to feel natural. Sacrifice some dough and practice scoring it over and over.



Scissors are used to make fun bread patterns. Snip the dough wherever you want an ear, tail, or tooth and create breads like bunny rolls and monster batards, shown below.



Even cuts—even placement over the loaf and cut to the same depth—help the bread expand evenly. Dough will expand in the direction of cuts. To demonstrate this, make “the volcano”: cut a tiny “x” in the top of a round loaf. In the oven, the loaf will expand unevenly, with the gas moving towards the tiny cut to escape. The result is the volcano-shaped loaf, (below left). A bigger “x” over the surface of the loaf results in a rounder bread (right). Traditional scoring patterns make even cuts over the surface of the dough; remember this when you make up your own patterns.



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The depth of cuts also controls the expansion of the dough. Deeper cuts allow the dough to open more. Cut too deeply, however, the dough is not able to support itself and flattens out. A balance is needed.

If your dough is under-proofed (not yet ready to go in the oven) but you need to bake it anyway (because the dinner guests are arriving, for example), cut it deeply. Dough that is well-proofed (nearing over-proofed) might collapse, so cut it very shallowly or not at all. Strong dough can be cut more deeply than weak dough at any stage of readiness.

The following photos show the same bread with different cut-depths (uncut, cut slightly, and cut deeply), baked at different stages of readiness (almost over-proofed, well-proofed, and under-proofed). Two views of the same loaves are shown. These loaves are described below.



The top row was almost over-proofed. The loaves were huge and full of gas when they entered the oven, but the dough felt weak—it caved in when poked, leaving a big hole. Uncut (left) the loaf managed to support itself, resulting in a big loaf of bread. Cut slightly (middle) or deeply (right) the loaf collapsed.

The middle row was well-proofed. The loaves were big and full of gas when baked, but the dough still had strength—although poking it left a depression, it did not cause a hole. Uncut (left) the loaf ripped; cut slightly (middle), the loaf still ripped, but only a little. (This ripping is more apparent in the picture on the previous page.) Cut deeply (right) the loaf did not rip. All three loaves are big, with the one that was deeply cut and better able to open up (right) slightly bigger.

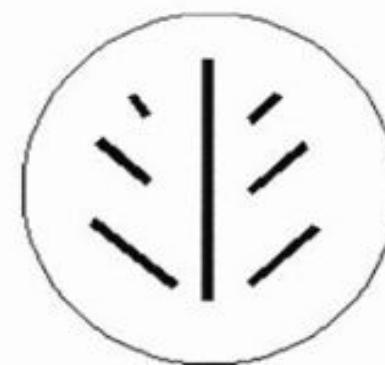
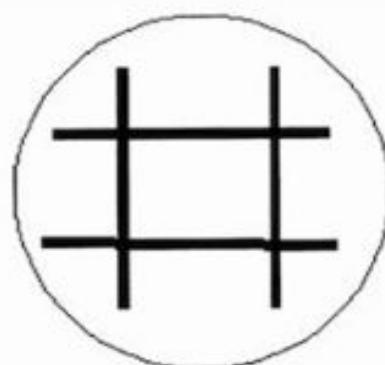
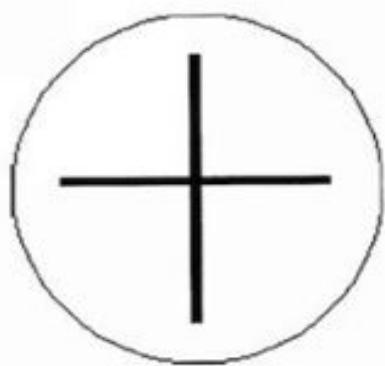
The bottom row was under-proofed. Uncut (left) the loaf ripped open in a grotesque fashion. Cut slightly (middle) the loaf ripped less. Cut deeply (right) the loaf did not rip. All three loaves are smaller than the more-proofed loaves above them.

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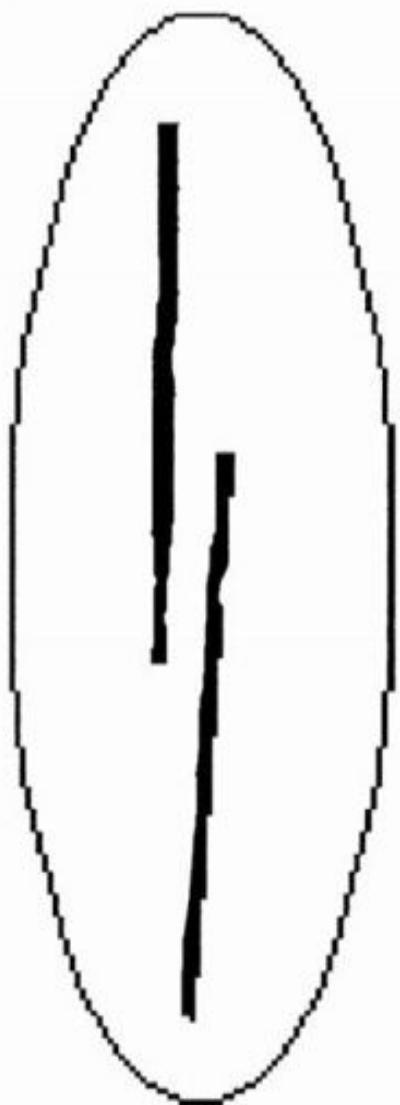
## **7.6 Scoring patterns**

Some scoring patterns and the resulting bread are shown below.

Rounds:



Batard:



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With batards (shown above) and baguettes (shown below), hold the blade flat, slicing the dough at an angle. This allows the cut to open with an upper lip that darkens in the oven. Note how the cuts run parallel to the baguette, overlapping each other, on the left baguette below. Cutting lines across the dough (right baguette) does not produce the desired pattern.



An epibaguette (below) can be made with a pair of scissors as shown below: starting at one end, snip triangles in the baguette, being careful not to cut all the way through. Move the triangles to alternating sides of the baguette.



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## 7.7 Steaming dough: why and how

Dough is steamed just before it enters the oven for two reasons: to increase loaf size and produce a good crust.

Steam increases loaf size by slowing the formation of the crust, allowing maximum dough expansion to occur. The outer surface is where the dough heats up fastest—once it dries out and crust begins to form, the dough will not be able to expand any further. Steam condenses on the relatively cool dough, creating a layer of water on the surface. At first, this provides a burst of heat to the dough; the water vapor contained energy that is released as heat when the vapor condenses. Subsequently, the water layer cools the surface by evaporation. This slows crust formation, creating time for heat to reach the center of the loaf and promote expansion.

Steaming dough also results in a better crust—thicker, browner, and shinier. Remember that the hotter dough near the surface results in more chemical reactions, producing the sugars and amino acids needed for browning. At a high enough temperature, the enzymes facilitating these reactions are killed. Steam's cooling effect on the surface of the dough provides the moist, not-too-hot climate needed to keep enzymes working. More steam creates a thicker layer of water and allows more reaction to occur; this results in more sugars and amino acids available for browning reactions and therefore makes a thicker crust.

There are many ways you can steam your dough before putting it in the oven. An obvious method, spraying the oven with water from a spray bottle, does not do much. Below are some suggestions I have heard over the years.\*

- Wet your hands and use them to coat the surface of the dough with water. More water will make a thicker crust.
- Use a brush or spray bottle to apply a coat of water to the surface of the dough.
- Place an oven-safe cup of water in the oven a few minutes before the dough goes in. Put another cup of water in with the dough. Remove any remaining water after fifteen minutes to allow the crust to become crispier. If

the water is evaporating too fast, use more water or ice water in the oven to create longer-lasting steam.

- Heat a cast iron pan with the oven. Ten minutes before the dough goes in, carefully pour a cup of water onto the pan. Repeat this when the dough goes into the oven.

(\*Note: spraying water onto the oven light can break it. Dripping water onto the oven window can break it.)

One final suggestion is to bake in a cloche or a casserole dish. A cloche is a pottery-like dish with a lid. A casserole dish that you might already have in your kitchen is a pretty good substitute for a cloche. Pre-heat the dish with the oven, carefully put the loaf inside, cover it, and return it to the oven. The hot dish gives off heat on all sides of the dough and keeps moisture in so a good crust develops. Towards the end of the bake, remove the lid or place the loaf on the oven rack to allow the crust to become crispier.

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Grain storage bin, Sheridan, WY, 2003

## 7.8 Getting your dough into the oven

Getting your dough into the oven will probably be awkward the first few times you do it. There is a lot to remember—you may carefully handle your pizza stone and put in a cup of water for steam, shutting the door only to realize you forgot to score the loaf. Do it enough times, though, and you will get a procedure down.

Here is a sample method to help you get started:

- The covered dough rises on a baking sheet; it is full of gas.
- The oven is preheated to 500°F.
- Uncover the dough and score it with a knife.
- Wet your hands and wipe them over the surface of the dough.
- Open the oven, put the baking sheet in, and close the door quickly.
- Turn the oven temperature down to 460°F and set a timer.

If you have a pizza stone to bake on, follow these instructions:

- The covered dough rises on a floured towel; it is full of gas.
- The oven is preheated to 460°F with the pizza stone inside.
- Uncover the dough, score it with a knife, and steam it (for example, wet your hands and wipe them over the dough).
- Open the oven door. Carefully pull out the rack with the pizza stone on it.
- Pick up the dough and transfer it to the stone.\*
- Add a metal cup of water to the oven for more steam.
- Push the rack back in, close the door quickly, and set a timer.
- Remove the cup with any leftover water after fifteen minutes.

(\*Note: For a more professional touch, put your dough on a low-friction surface, like a cutting board sprinkled with cornmeal. Position the cutting board over the pizza stone and pull it away quickly, so that the dough drops onto the stone. This method keeps your fingers clear of the hot pizza stone.)

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## 7.9 When is bread done baking?

Artisan breads such as sourdoughs and French breads generally bake around 450°F or a little higher. An approximate time is 20 minutes for a thinner bread (like a baguette) and 25 to 30 minutes for a fatter bread with more dough inside (like a batard or boule). A dough with added sugar or honey will bake at a lower temperature, maybe 350°F for 30 to 35 minutes.

When you take the bread out, thump the bottom with your finger—if it is baked, it should echo a bit as if it is hollow inside. If it does not echo, it is still doughy inside and needs to bake more.

Some bakers take the bread's temperature, looking for 180 to 200°F to indicate it is done inside. This temperature is near the top of the baking plot shown previously; at temperatures this high, starch gelation is well underway.

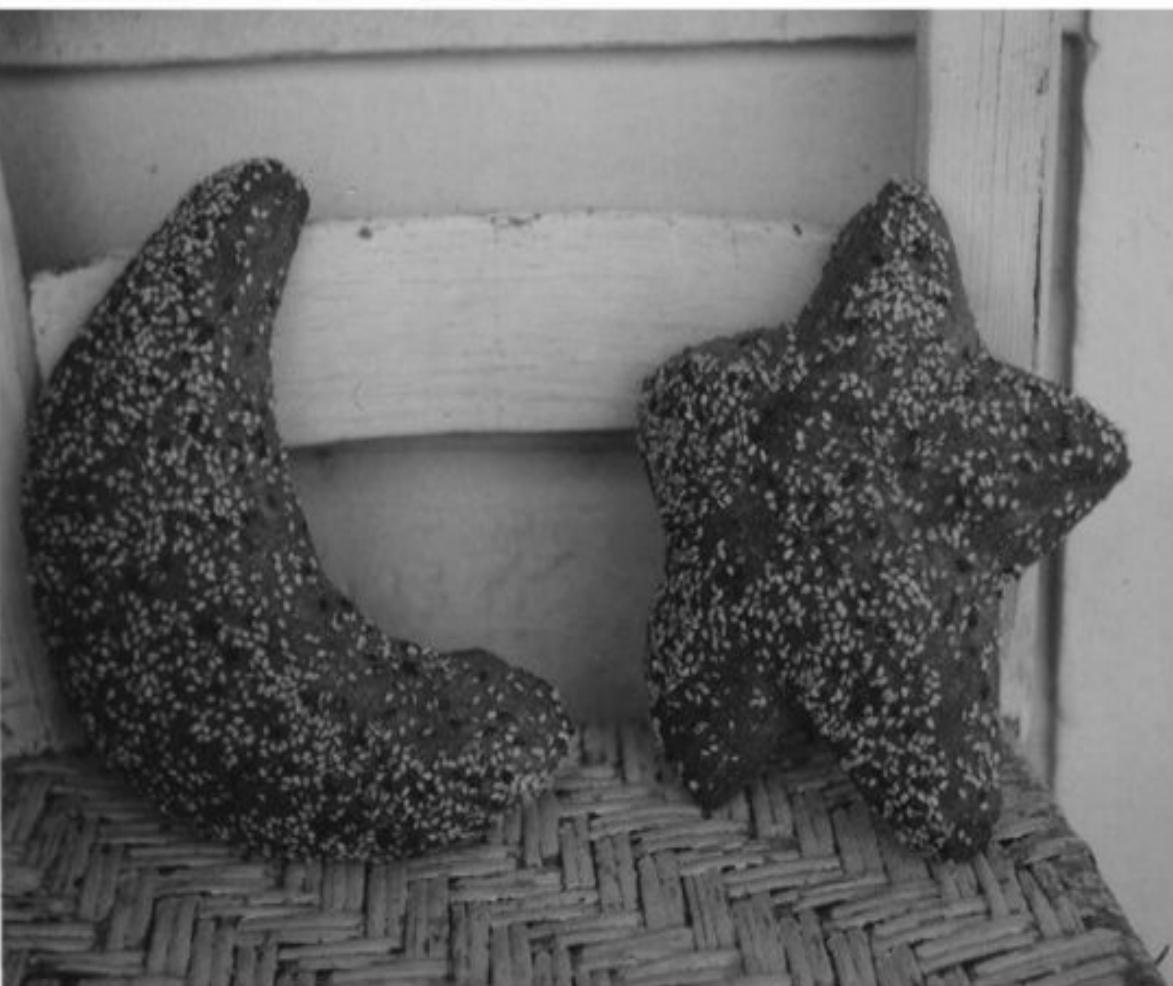
To take your bread's temperature, jab your thermometer probe into it and wait, allowing the probe to equilibrate with the hot temperature. Then repeat the measurement in a new spot or push the probe further into the bread to take an accurate reading. Taking the bread's temperature produces neat little vampire holes in your crust.

If the oven is too hot, the loaf will brown too quickly without cooking inside. If the oven is not hot enough, the loaf will cook and begin to dry out inside without turning brown. (Improper steam can also result in a loaf that will not turn brown no matter how long it stays in the oven.)

If the loaf is getting too brown, but you suspect it is not cooked inside, leave it in the oven and turn the temperature down or cover it with foil. Keep notes for next time—if it browned too fast, use a slightly cooler temperature next time. If it took forever to cook, then use a hotter temperature.

Let your bread cool on a rack so that air can circulate around it. Otherwise it might get soggy on the bottom. Some bakers advocate letting bread cool before it is eaten. It may be hard to slice when warm, and some flavors are more noticeable when the bread is cool. Warm bread has its own merits, however. The choice is yours.

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Moon and star bread, Carrboro, NC, 2002

[1] Moore, W.R. and R.C. Hoseney. "The leavening of bread dough." *Cereal Foods World* 30 (1985) 791-792.

[2] Burhans, M.E. and J. Clapp. "A microscopic study of bread and dough." *Cereal Chemistry* 19 (1942) 196-216; in particular see page 214.

[3] Based on the plot in Drapron, R. and B. Godon. "Role of enzymes in baking." *Enzymes and their Role in Cereal Technology*. St. Paul, MN: American Association of Cereal Chemists, Inc., 1987 284-288.

- [4] Maloney, D.H. and J.J. Foy. "Yeast fermentations." *Handbook of Dough Fermentations*. New York: Marcel Dekker, Inc., 2003 54.
- [5] Maloney, D.H. and J.J. Foy (2003) 54.
- [6] Hoseney, R.C. *Principles of Cereal Science and Technology*. St. Paul, Minnesota: American Association of Cereal Chemists, Inc., 1986 232.

# **Chapter 8: Recipes, Storage, and Troubleshooting**

[8.1 Recipe: French bread made with a poolish](#)

[8.2 Recipe: Ciabatta made with a poolish](#)

[8.3 Recipe: Sourdough bread made with starter](#)

[8.4 Recipe: Whole wheat bread made with a sponge](#)

[8.5 Recipe: Lazy Baker's Bread \(now known as No-Knead Bread\)](#)

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## **8.1 Recipe: French bread made with a poolish**

This recipe for French bread is simply the basic bread recipe with a poolish added. This recipe was consistent throughout the winter, but when I mixed it on a rainy day in April the dough was too sticky! I had to dip my hands in flour ten times during kneading to make the dough stop ripping and come together. For humid weather, reduce the water to 67% or 0.389 kg. Keeping the poolish the same, the water needed in the dough recipe becomes 0.196 kg, 0.43 lb, or  $\frac{7}{8}$  cup.

<b>Total recipe</b>			
White flour	100%	0.580 kg	1.28 lb
Water	70%	0.406 kg	0.89 lb
Instant yeast	0.5%	0.003 kg	0.11 oz
Salt	2%	0.012 kg	0.42 oz
<b>Total</b>		<b>1.001 kg</b>	<b>2.20 lb</b>

- Mix the poolish 12 to 15 hours before you plan to mix your dough. Use 50 to 60°F water—warmer if your house is cold, cooler if your house is warm. The final temperature of the poolish should be between 65 and 70°F.

<b>Poolish</b>			
White flour	0.193 kg	0.42 lb	1¾ cup
Water	0.193 kg	0.42 lb	⅔ cup
Instant yeast	a pinch	a pinch	a pinch
<b>Total</b>	<b>0.386 kg</b>	<b>0.84 lb</b>	

- Cover the poolish and keep it at room temperature.
- When the poolish is ready, mix the dough. Use 65 to 70°F water.

<b>Dough</b>			
White flour	0.387 kg	0.85 lb	3½ cup
Poolish	0.386 kg	0.84 lb	all of it
Water	0.213 kg	0.47 lb	1 cup
Instant yeast	0.003 kg	0.11 oz	¾ tsp
Salt	0.012 kg	0.42 oz	2 tsp (1¾ is okay, too)
<b>Total</b>	<b>1.001 kg</b>	<b>2.20 lb</b>	

- When the dough is adequately kneaded, put it in an oiled, covered bowl and let it rise.
- When it is fully risen (about one hour), punch it down, fold it, and let it rise again.
- When it is again fully risen, cut it into two pieces and shape them into batards.
- Preheat your oven to 460°F. If you are baking on a stone, preheat it with the oven.
- Place the batards on a surface to rise. This can be an oiled or floured baking sheet or a cutting board covered with a floured linen towel. This is

shown below (top). Cover the batards so they do not dry out. I use a towel on my Tupperware cake holder because it has a convenient lid.

- Let the batards proof until they are soft and full of gas (below, bottom); poking them leaves a dent.



- Score the batards and steam them. Quickly put them in the oven, either on their baking sheet or by transferring them to the pizza stone.
- Bake for 25 to 30 minutes. The crust should turn brown.
- Cool on a rack so that air can circulate below the bread.

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## 8.2 Recipe: Ciabatta made with a poolish

This recipe makes a wetter dough than the basic bread recipe. It includes a small amount of whole wheat flour. Also, the method of fermentation is different: it uses less yeast and a longer fermentation time involving the refrigerator.

Total recipe			
White flour	90%	0.522 kg	1.15 lb
Wheat flour	10%	0.058 kg	0.13 lb
Water	73%	0.423 kg	0.93 lb
Instant yeast	0.25%	0.0015 kg	0.05 oz
Salt	2%	0.012 kg	0.42 oz
<b>Total</b>		<b>~1 kg</b>	<b>~2.2 lb</b>

- Mix the poolish 12 to 15 hours before you plan to mix your dough. Use 50 to 60°F water, warmer if your house is cold, cooler if your house is warm. The final temperature of the poolish should be 65 to 70°F.

Poolish			
White flour	0.193 kg	0.42 lb	1¾ cup
Water	0.193 kg	0.42 lb	⅜ cup
Instant yeast	a pinch	a pinch	a pinch
<b>Total</b>	<b>0.386 kg</b>	<b>0.84 lb</b>	

- Cover the poolish and keep it at room temperature.

- When the poolish is ready, mix the dough. Use 65 to 70°F water.

Dough			
White flour	0.329 kg	0.72 lb	3 cup
Wheat flour	0.058 kg	0.13 lb	½ cup
Poolish	0.386 kg	0.84 lb	all of it
Water	0.230 kg	0.51 lb	1 cup
Instant yeast	0.0015 kg	0.05 oz	⅓ tsp
Salt	0.012 kg	0.42 oz	2 tsp (1¾ is okay, too)
<b>Total</b>	<b>~1 kg</b>	<b>~2.2 lb</b>	

- When the dough is adequately kneaded, put it in a well-oiled , covered bowl and let it rise.
- When it is fully risen (about one hour), punch it down and fold it.
- Put the dough, covered, in the refrigerator to rise again overnight.
- The next day (~18 hours later), pull out the dough. It may be fully risen. If not, let it warm up and continue rising.
- When it is again fully risen, transfer it to a floured surface. Spread it out so that it has an even thickness everywhere (below, top). Use a stiff blade such as a bench-scraper or a spatula to cut it into two pieces (below, bottom).



- Preheat your oven to 460°F. If you are baking on a stone, preheat it with the oven.
- Place the ciabatte on a floured linen on a cutting board to rise (shown below). They are top-side-down and will be flipped before baking, so scraps of dough can be added on top of them.



- Cover the ciabatte so they do not dry out. I use my cake holder as a mini proof box (below, top). A poofed-up plastic bag works, too (below, bottom).



- Let the ciabatte proof. With such a wet dough, it may be hard to tell when they are ready. They will stay flat, but they should fill with gas.
- Flour the up side of the loaves (preferably with cornmeal or semolina flour) and flip them over onto the baking sheet. If you are using a pizza stone, flip them onto another surface for now. There is no reason to score a flat ciabatta loaf.
- Steaming floury loaves can be tricky. A cup of water in the oven works better than wetting the dough outside the oven, which tends to sop up the flour. If you must steam the dough before putting it into the oven, using a wet brush or spray bottle will be less messy than using your wet hands. However, ciabatta is such a wet dough that steaming is unnecessary.
- Quickly put the loaves into the oven on the baking sheet or by transferring them to the pizza stone.
- Bake for 20 to 25 minutes. The crust (under the flour) should turn brown.
- Cool on a rack so that air can circulate below the bread.

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## 8.3 Recipe: Sourdough bread made with starter

This recipe is similar to the French bread and ciabatta recipes but uses sourdough starter instead of yeast and a poolish. There is also a small amount of whole wheat flour included. The loaves, after shaping, proof overnight in the refrigerator to allow more sour flavor to develop.

Total recipe				
White flour	94%	0.479 kg	1.05 lb	4¼ cup
Wheat flour	6%	0.031 kg	0.07 lb	¼ cup
Starter	21%	0.107 kg	0.24 lb	*
Water	64%	0.326 kg	0.72 lb	1½ cup
Salt	2.25%	0.011 kg	0.39 oz	1½ tsp
<b>Total</b>		<b>~1 kg</b>	<b>~2 lb</b>	

(\*Note: If you are using the starter feeding recipe from this book, you are maintaining 0.320 kg starter. The value needed for this recipe, 0.107 kg, is one third of that.)

- Check your starter ahead of time. If possible, feed it 8 to 10 hours before mixing the dough and leave it out to rise. It should be fully risen when it is used to make dough.
- Mix the dough. Use 60 to 65°F water.
- When the dough is adequately kneaded, put it in an oiled, covered bowl and let it rise (shown below).



- When it is fully risen (about two hours), punch it down and fold it.
- After it rises again (about two more hours), cut it in half and shape it into boules, batards, or baguettes.
- Place the loaves on a floured surface to rise. This can be the baking sheet on which they will be baked or a linen towel on a cutting board. I use a floured linen towel on my 9x13 Tupperware cake holder (shown below) because it has a convenient, tight-fitting lid. Cornmeal is preferable to white flour and will give the loaves a rustic-looking bottom.



- Cover or wrap the loaves so they do not dry out. This is especially important for loaves spending a night in the refrigerator. I covered the proofing dough shown above with plastic wrap and with the cake holder's lid. The plastic wrap should cover the dough well but not so tightly that the dough cannot expand.
- Place the loaves in the refrigerator overnight.
- The next day, preheat your oven to 460°F. If you are baking on a stone, preheat it with the oven.
- Pull the loaves out and let them continue to proof until they are full of gas and poking leaves a dent.
- Score and steam the loaves. Quickly put them into the oven, either on their baking sheet or by transferring them to the pizza stone.
- Bake for 25 to 30 minutes. The crust should turn brown.
- Cool on a rack so that air can circulate below the bread.

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## 8.4 Recipe: Whole wheat bread made with a sponge

This is a basic bread recipe using whole wheat flour. It has more water and less yeast than the white flour recipe.

Total recipe			
Whole wheat flour	100%	0.374 kg	0.82 lb
Wheat bran	5%	0.019 kg	0.04 lb
Water	75%	0.280 kg	0.62 lb
Instant yeast	0.5%	0.002 kg	0.07 oz
Salt	2%	0.007 kg	0.26 oz
<b>Total</b>	<b>182.5%</b>	<b>0.682 kg</b>	<b>1.50 lb</b>

- Mix the sponge 12 to 15 hours before you plan to mix your dough. Use 50 to 55°F water, warmer if your house is cold, cooler if your house is warm. The final temperature should be about 65°F.

Sponge			
Whole wheat flour	0.187 kg	0.41 lb	1½ cup
Water	0.140 kg	0.31 lb	⅔ cup
Instant yeast	a pinch	a pinch	a pinch
<b>Total</b>	<b>0.327 kg</b>	<b>0.72 lb</b>	

- Cover the sponge and keep it at room temperature. When it is ready (shown below), mix the dough with 60 to 65°F water.



Dough			
Whole wheat flour	0.187 kg	0.41 lb	1½ cup
Wheat bran	0.019 kg	0.04 lb	~⅙ cup
Sponge	0.327 kg	0.72 lb	all of it
Water	0.140 kg	0.31 lb	⅔ cup
Instant yeast	0.002 kg	0.07 oz	½ tsp
Salt	0.007 kg	0.26 oz	2 tsp
<b>Total</b>	<b>0.682 kg</b>	<b>1.50 lb</b>	

- When the dough is adequately kneaded, put it in a covered bowl and let it rise. When it is fully risen (about one hour), punch it down, fold it, and let it rise again.

- When it is again fully risen, shape it into a boule.
- Preheat your oven to 460°F with your pizza stone if applicable.
- Place the loaf smooth-side-down in a floured basket or a floured, towel-lined bowl to rise (below, top). The container should be big enough to allow dough expansion but small enough that the sides of the container support the loaf. Cover it so it does not dry out.
- Let the loaf proof until it is soft and full of gas; poking it leaves a dent (below, bottom).



- Flip the loaf out of its basket or bowl onto a baking sheet or other surface and score it. Steaming the floury loaf may be difficult—a cup of water in the oven will work better than trying to wet the loaf. If you must wet the loaf, using a wet brush or spray bottle will be less messy than using your hands. Quickly put the loaf into the oven on the baking sheet or by transferring it to the stone.
- Bake for 25 to 30 minutes. The crust should turn brown.
- Cool on a rack so that air can circulate below the bread.

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## 8.5 Lazy Baker's Bread

Someone gave me a method for making bread without kneading. I tried it out and was surprised by the results, pictured below. While you might not want to serve this bread to your in-laws, it would work fine if you wanted some fresh, homemade bread and were feeling pretty lazy.



Use the basic bread recipe and follow these instructions:

- Incorporate the ingredients until there are no dry spots.
- Let the dough sit for 30 to 60 minutes.
- Fold the dough tightly.
- Put it, covered, in the refrigerator overnight.
- The next day, pull out the dough and fold it again.

- Divide it into pieces of the correct size and shape them. I shaped mine as a boule. In retrospect, having support for the dough (a bread pan or basket) would probably produce bigger bread.
  - Let the dough proof and bake it as usual (steam, hot oven, etc.) Scoring is not necessary.

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## 8.6 Make your own recipe

Starting with the basic bread recipe in chapter one, you can easily make your own recipe. It will take at least three tries to get it right. The first time you make it, you will adjust the hydration to get a workable dough. The second time you will adjust the yeast content to get the dough rising in a timely manner. Then you can fine-tune your recipe. You may need a few extra tries to get it working smoothly.

Make a list of the ingredients you want in your own bread. Some suggestions follow:

- grains and seeds (wheat berries, oats, a mix of grains, sunflower seeds, caraway seeds, fennel seeds)
- sweeteners (apple sauce, maple syrup, honey, brown sugar)
- herbs (rosemary, basil, dill)
- fruits and veggies (tiny chunks of apple or pear; dried figs, apricots, raisins, currants, or cherries; olives; corn kernels; onions, potatoes, or tomatoes roasted in olive oil)
- nuts
- cheese
- different types of flour (extra bran, rye, semolina, spelt).

Decide if the ingredients should be added before kneading or after. Remember that chunkier items that break up the gluten should be added after.

Think about whether these ingredients will require more or less water or not. For example, adding bran will require more water while adding honey will require less. Soak grains overnight (drain them before use) to make them less “disruptive” to the dough’s hydration. Measure out a tentative amount of water for your new recipe but do not add it all. You may not need it all, or you may need more.

Incorporate the ingredients using most of the water. Let the new dough autolyse, and then begin kneading. At this point, you may decide to add

more water. Keep track of the final amount of water used. In addition, judge the overall wetness of the final dough and decide if you need a little more or less water next time.

Watch how your dough rises and alter the amount of yeast for next time if necessary. Remember that a wet dough may have trouble rising even if there is enough yeast. Finish the process as you would for any other dough—let it rise, fold it, let it rise again, shape it, proof it, and finally bake it. In general, basic breads bake at 460°F. Breads with extra sweeteners bake at lower temperatures, near 350°F.

The second time you make your dough, you know approximately how much water to use. The amount can still be fine tuned. In addition, alter the amount of yeast based on how your dough rose last time. Remember that temperatures are playing a role in rising-time—was it cold that first day?—and also that if your first attempt was too wet, it may have had trouble rising for that reason. Is there anything else you want to change about your bread—perhaps make it sweeter or more grainy? Try it now.

The third time you make your recipe, you have the numbers for water and yeast from last time. As is true any time you make bread, minor adjustments can still be made, but your basic recipe is complete.

I created Nutty New England Oat Bread with the directions above; it is the basic white bread recipe with walnuts, maple syrup, and oats added:



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## 8.7 Storing dough

Dough can be frozen for later use. After mixing your dough, shape it into a ball, seal it in a plastic bag, and put it in the freezer. When you want to use it, pull it out and let it thaw. As it warms up, the reactions will begin again and it will begin to rise.

How do yeast survive the freezer? As the temperature falls, water outside of the yeast cells turns to ice first. The water inside then flows out as it tries to balance the vapor pressure inside and outside of the cells. The yeast cells are essentially dried out but still able to be revived. [1]

If the yeast is cooled too quickly, ice crystals will form inside the yeast cells before the water has time to leave, and the crystals will kill the yeast. Also, at temperatures close to or below  $-35^{\circ}\text{C}$  ( $-31^{\circ}\text{F}$ ) the yeast freeze and are killed.

The method is not perfect. Some yeast may be killed, so the dough might not rise as well after freezing. If you experience this problem, add extra yeast when you mix the dough to counteract this.

The dough seems to rise better if it is frozen before fermentation occurs—that is, right after you mix it, before it rises. Putting it in the freezer quickly and keeping the freezer temperature constant prevent fermentation from happening. Sometimes the consistency of the dough upon thawing is not ideal—ice crystals that form when the dough freezes take water away from the dough's proteins, and when it thaws, the water does not automatically return to the protein. [2]

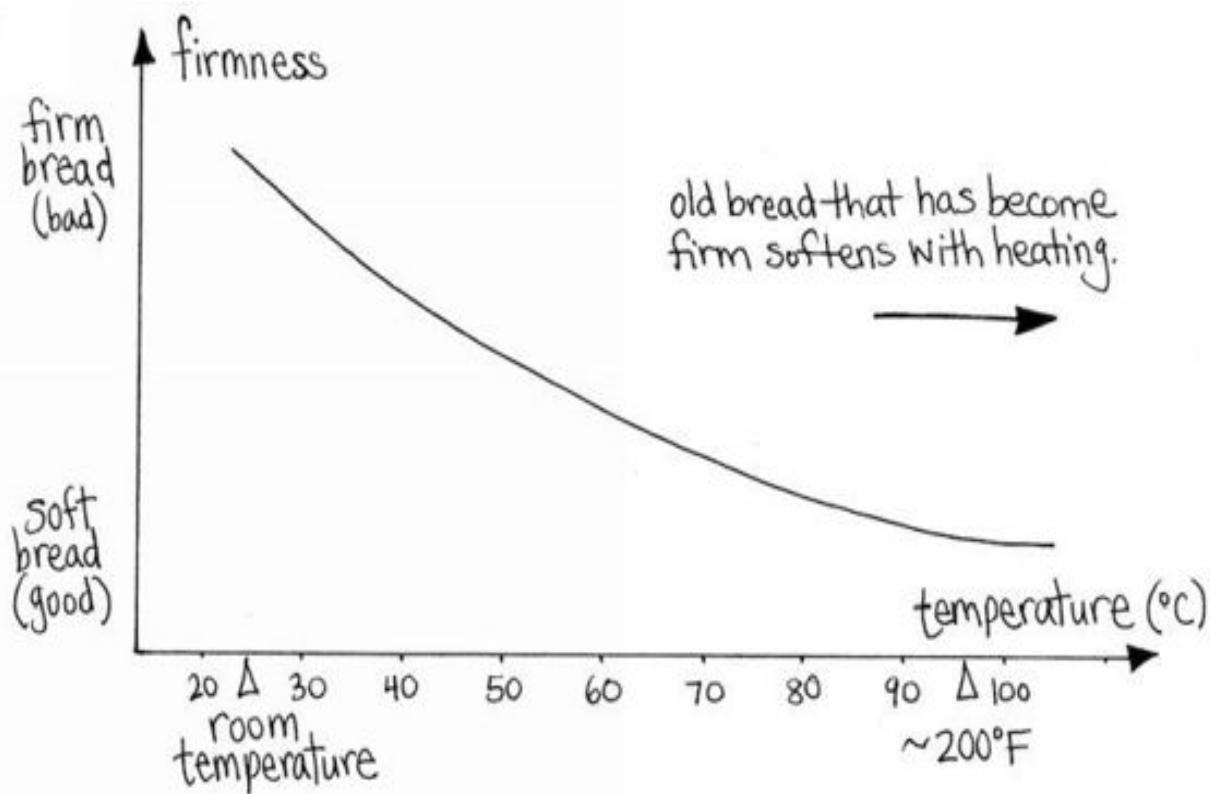
Still, freezing dough can save the home baker much time, as dough kneaded one day can be split in two and baked off on two separate occasions. Freezing also provides a means of producing fresh bread on days when there may not be time or space for kneading, such as the holidays.

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## 8.8 Storing bread

From experience, any bread-eater knows that storing bread in a paper bag maintains crustiness but lets the bread dry out. Some breads become too tough to eat within a day or two. Storing bread in a plastic bag, on the other hand, prevents it from drying out, but woe to the crust!

The surrounding temperature also plays a role in staling: starch retrogradation, one aspect of staling, happens faster at lower temperatures, such as those you might find in a refrigerator. Below freezing, however, retrogradation (and staling) practically stop. Another useful fact is that some aspects of staling can be reversed by heating. The starch crystals melt around  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ), and the bread continues to soften up to about  $100^{\circ}\text{C}$  ( $\sim 200^{\circ}\text{F}$ ), as shown in the plot: [3]



To sum up: bread left out or stored in paper will stay crusty but become firm and dry. There is no cure for dry bread. If you can eat your bread soon enough, however, a paper bag may be the right choice for you. Bread stored in plastic will retain its moisture but become firm and lose its crustiness. It

can be softened and “re-crusted” in the oven, although the result is not exactly like the original bread.

To keep bread longer, freeze it. If all you want is toast for breakfast, slice your bread, double-bag it in plastic, and put it in the freezer. Every morning, pull out a frozen slice and put it in the toaster for a few minutes. Without a toaster, a slice will still defrost fairly quickly.

To recreate fresh-baked bread, keep your loaf (or some chunk of it) whole. Double-bag it and put it in the freezer. When you want to eat it, pull it out and defrost it completely; this may take a few hours depending on the room temperature. Heat the oven to 300°F. Put the bread in (right on the oven rack) for ten minutes for a large loaf, less for smaller loaves. If the bread has been cut, cover the open side with foil to prevent the crumb from drying out. When you take the bread out, it will be crusty on the outside and soft in the middle, just like new.

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Wheat harvest, Washington, 2003

## 8.9 Trouble-shooting

Some common problems with bread and possible causes and cures are listed below.

The dough did not rise well.

- The yeast was old and less active. Buy new yeast.
- The dough was too wet. Decrease the water in the recipe by one to two percent. (Note, however, that wet dough results in bread with bigger holes.)
- The dough was too cold. Use warmer water and keep the dough in a warmer location while it rises.
- The dough was not fully kneaded. Knead for longer and use the folding technique described in chapter five.

The bread did not expand in the oven.

- The oven temperature was not high enough. Use a thermometer to check its accuracy. Use the oven modifications described in chapter seven.
- The dough had dried out during proofing and could not expand. Keep it covered and check it periodically. Wet it if it starts to dry out.
- The dough dried out too quickly once it was in the oven. Use more steam as described in chapter seven.

The bread tastes odd—bland and unpleasant.

- The most likely explanation is that you forgot the salt!

The bread is very dense in the middle or even doughy.

- The dough was not fully proofed when it was baked. Wait longer before baking to allow it to rise more.
- The dough was not fully proofed in spite of a long proof time because the yeast was not active enough. Check the activity of your yeast or buy new yeast.
- The dough was not fully proofed in spite of a long proof time because the yeast ran out of sugars to ferment. The dough was unable to rise the final

time before entering the oven. If your dough rose very quickly after kneading but failed to rise after shaping, try using less yeast or shaping the dough sooner, before all the yeast-food is used up.

- The dough was not fully proofed in spite of a long proof time because it was too cold. Keep the proofing dough somewhere warm.

The bread collapses in the oven.

- The dough had over-proofed. It had not collapsed yet when you baked it, but it was so big and poofy that it could not maintain its shape once in the oven. Bake the dough sooner or use less yeast, colder dough, or a colder environment during proofing to slow down its rising.

The loaf rises too high over the top of the pan.

- The pan is too small. Use a bigger pan or less dough.

The insides are full of gaping holes.

- You did not get enough gas out during shaping. You did not shape the dough tightly enough. Be more careful to remove gas and make tight folds when you shape the loaf as described in chapter six.

The bread is badly ripped on the sides.

- The dough was under-proofed. Let it rise longer before baking it.
- The dough was scored too shallowly or not enough. Score the dough more deeply and all over its surface.

The crust is too soft.

- For harder crust, use more steam at the start of the bake, but make sure there is none left for the last 10 minutes.

The crust is too hard.

- For softer crust, use steam throughout the bake. A cup of ice water or a big enough cup of water will provide steam for the entire bake time.

The crust is too pale but the bread is done inside. (If you keep baking it, it will start to dry out.)

- There was not proper steam. Use more steam. You can also brush the dough with beaten egg or malt syrup instead of steaming it to get a browner

crust.

- The oven temperature was too low. Use a thermometer to check its accuracy. A higher temperature should brown the crust in time.

The crust is too dark but the bread is not done inside. (If you keep baking it, it will burn.)

- The oven temperature was too high. Use a thermometer to check its accuracy. A lower temperature should brown the crust more slowly, giving the middle time to bake.
- You can try to keep baking the middle of the dark loaf without further browning by using a low oven temperature.

A loaf baked in a pan has a brown top but pale sides and bottom.

- The pan is removing the heat from the dough. Try taking the loaf out of the pan for the last ten minutes of its bake time and putting it directly on the oven rack.

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New wheat and old wheat, South Dakota  
(early June) and Washington (late July), 2003



- [1] Oura, E., H. Suomalainen, and R. Viskari. "Breadmaking." Chapter 4 in Economic Microbiology Volume 7 : Fermented Foods . London, New York: Academic Press, 1982 102.
- [2] Hoseney, R.C. Principles of Cereal Science and Technology . St. Paul, Minnesota: American Association of Cereal Chemists, 1986 238.
- [3] Based on a plot in Hoseney, R.C. (1986) 235.

# **Conclusion**

Bread has a history of both sustaining great empires and inciting revolution. What can bread accomplish in our society? Artisan bread, whether made at home or in a small bakery, represents a return from the world of machine-laden mass production. It is concerned with flavor and texture, not maximizing profits for a distant corporation. Flavor must develop during a long fermentation, not be added in the form of sugar or vinegar. Bread must be sold locally and daily, not pumped full of shortening, sugars, or other preservatives and shipped across the country to sit on supermarket shelves.

Authentic artisan bread cannot be corrupted. It cannot be co-opted by the greedy. It is a gift for everyone. Slow down your busy life. Breathe deeply and exercise your arms. Learn to be more patient. Get in touch with your food. Teach your children how to knead. Eat healthily. In other words, make bread!

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Ciabatta, Carrboro, NC, 2002

# Bibliography

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Literary bread books. A few favorite bread-related books follow. These are not recipe books.

- Wing, Daniel and Alan Scott. *The Bread Builders: Hearth Loaves and Masonry Ovens*. White River Junction, Vermont: Chelsea Green Publishing Company, 1999.

This book explores a few topics (starter, grains, flours, dough) in a science-oriented way, ending with several chapters about bread ovens and how to build one.

- Seligson, Susan. *Going With the Grain: A Wandering Bread Lover Takes a Bite Out of Life*. New York: Simon and Schuster, 2002.

This is a collection of bread stories from the author's travels. For example, in the first chapter, she is in the ancient marketplace of Fès, Morocco. She watches in wonder as dough is carried to the bakeries and bread is sent back home. Each family gets the correct loaf even though they all look the same. With much effort she overcomes the language barrier and gains entry to a bakery to discover how.

- Sheraton, Mimi. *The Bialy Eaters: The Story of a Bread and a Lost World*. New York: Broadway, 2000.

This was not my favorite book to read, but the premise is so neat I felt I should mention it. The author travels to Bialystok, Poland, the birthplace of the bialy (a roll filled with onions and poppy seeds), only to find a town that was destroyed by the Holocaust. She then searches the globe for former Bialystok residents who can tell her about the bialy.

Bread history. Here are two detailed histories of bread-making and two articles that describe the research done to learn about ancient bread-making techniques.

- Jacob, H.E. *Six Thousand Years of Bread: Its Holy and Unholy History*, 1<sup>st</sup> edition. Garden City, New York: Doubleday, Doran, and Co., Inc., 1944.

This book contains a lot of information, but there are no references in the text. There is now a third edition by Globe Pequot Press.

- Wirtz, R.L. “Grain, baking, and sourdough bread: a brief historical panorama.” Chapter 1 in *Handbook of Dough Fermentations*. New York: Marcel Dekker, Inc., 2003.

This chapter is fully referenced.

- Roberts, D. “Rediscovering Egypt’s bread-baking technology.” *National Geographic* (January 1995) 32-35.
- Samuel, D. “Investigation of ancient Egyptian baking and brewing methods by correlative microscopy.” *Science* 273 (1996) 488-490.

Cool old stuff. If you are near a university library, you may have access to a lot of old journals and books. Here are three that I found:

- Cohn, E.J. and L.J. Henderson. “The physical chemistry of bread making.” *Science* 48 (1918) 501-505.
- Johnston, J.F. *The Chemistry of Common Life*. New York: D. Appleton and Co., 1857.
- Anonymous. “Gluten of wheat.” *Annals of Philosophy* 15 (January-June 1820) 390-391.

Places to start reading about science. Encyclopedias have a low-tech blurb about bread-making. Food encyclopedias give more details. The problem is that many of these contain information about the bread-making industry—they assume the bread recipe has sugar and shortening in it and that it will all be processed in a machine.

Another source is food chemistry or science books with a chapter about bread-making. I found many of these to be spotty in the information they gave. One that I enjoyed is

- Charley, H. *Food Science*. New York: The Ronald Press Co., 1970.

Two others with good sections on starches and sugars, proteins, and other science basics are the following:

- Barham, P. *The Science of Cooking*. Berlin: Springer-Verlag, 2001.

- McGee, H. *On Food and Cooking: The Science and Lore of the Kitchen*. New York: Scribner, 2004.

A good reference for many aspects of science is textbooks—chemistry, biology, and particularly microbiology. Try looking up sugar, protein, yeast, or fermentation. Remember that bread-making yeast is only one kind—general information on all yeast is often contradictory and confusing.

Another warning: any information specifically about bread-making should be read with a grain of salt. Standards at commercial bakeries have led to many faulty ideas, such as “Bread bakers desire as much oxygen in the dough as possible for a fast fermentation.”

There are many high-tech baking books. They are usually too expensive to buy, but you may find one at a university library or through inter-library loan. I find them to be confusing and full of information that relates to commercial baking (similar to the encyclopedia entries.) One that I grew attached to, although I only understood it after doing the rest of my research, is the following:

- Hoseney, R.C. *Principles of Cereal Science and Technology*. St. Paul, Minnesota: American Association of Cereal Chemists, 1986.

Finally, there are scientific journal articles. A few, like *Science*, may be found at the public library. Others may be found at university libraries, but some are pretty obscure. I had the most luck at NC State University, which has an agricultural school and carries the cereal science journals.

Start with a review, an article that sums up the research done on a topic. While reviews are excellent sources of both information and references to research papers, keep in mind that the scientists writing them often have the hidden agenda of getting you to read all their previous papers. They often cite several of their own works but ignore relevant work by others. I have even come across references that had little if anything to do with the topic!

Two reviews that I found helpful follow:

- Pomeranz, Y., K.F. Finney, and R.C. Hoseney. “Molecular approach to bread making.” *Science* 167 (1970) 944-949.
- Autio, K. and T. Laurikainen. “Relationships between flour/dough microstructure and dough handling and baking properties.” *Trends in Food*

Science and Technology 8 (1997) 181-185.

More detailed science research. Papers are listed below under subject headings for various aspects of bread science. The subjects follow the order of chapter two.

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- Drapron, R. and B. Godon. "Role of enzymes in baking." Chapter 10 in Enzymes and Their Role in Cereal Technology . St. Paul, Minnesota: American Association of Cereal Chemists, 1987.
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### Yeasts and bacteria.

- Sugihara, T.F., L. Kline, and M.W. Miller. "Microorganisms of the San Francisco sour dough bread process." Applied Microbiology 21 (1971) 456-458. See 459-465 for part 2.
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### Water and protein.

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Bread as a model of polar molecules with and without an applied magnetic field (above and below, respectively),  
Carrboro, NC, 2001



# Appendix: Units and Conversion Factors

## Units of weight

1 kilogram (kg) = 1000 grams (g)

1 pound (lb) = 16 ounces (oz)

1 oz = 28.35 g

1 g = 0.035 oz

1 lb = 0.454 kg

1 kg = 2.2 lb

## Units of volume

1 quart = 2 pints = 4 cups

1 liter (L) = 1000 milliliters (mL)

1 cup (c) = 16 tablespoons

1 tablespoon (Tbsp) = 3 teaspoons (tsp)

1 c = ~250 mL

## Conversions between weight and volume

Sifted flour: \* 0.112 kg = 4 oz = 1 c; 0.007 kg = 0.25 oz = 1 Tbsp

(\*Note: This value worked for white flour (both all purpose and bread), whole wheat flour, rye flour, and spelt flour. The flour was very fluffy! If you use this value, it is very important that the flour be sifted before measuring to avoid using packed flour, which would result in more flour than is desired. Even sifted flour can become packed if it is scooped with the measuring cup. A good technique, which can be used even if you do not own a sifter (like me!) is to ladle flour into your measuring cup one spoonful at a time. This avoids the scooping motion that can pack the flour into the bottom of the measuring cup. An alternative that may be easier is to scoop four normally and use the conversion of 1 cup = 0.135 kg, which is more flour per scoop.)

Water: 0.224 kg = 8 oz = 1 c; 0.014 kg = ½ oz = 1 Tbsp

Instant yeast: \* 0.004 kg = 0.15 oz = 1 tsp

(\*Note: Active dry yeast has about the same values as instant yeast. One “single-serve” package of dry yeast is 2 1/4 tsp.)

Fresh yeast: 0.007 kg = 0.25 oz = 1 tsp

Salt: 0.006 kg = 0.21 oz = 1 tsp

Wheat bran: 0.069 kg = 2.40 oz = 1 c

Semolina flour: 0.168 kg = 6 oz = 1 c

Oats: 0.099 kg = 3.45 oz = 1 c

Honey: 0.026 kg = 0.92 oz = 1 Tbsp

Sunflower seeds: 0.147 kg = 5.17 oz = 1 c

Conversion between temperature scales

Fahrenheit to Celsius:  $^{\circ}\text{C} = \frac{5}{9} (\text{ }^{\circ}\text{F} - 32)$

Celsius to Fahrenheit:  $\text{ }^{\circ}\text{F} = \frac{9}{5} (\text{ }^{\circ}\text{C}) + 32$

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Green wheat, South Dakota, 2003

# Glossary

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**Active dry yeast** Yeast that has been almost totally dehydrated. It needs to be activated before use. It is convenient for storage but may contain a chemical that is harmful to dough.

**All-purpose flour** Flour with about 10.5 percent protein content. It is suitable for bread-making, although a higher percentage of protein may be desired.

**Alpha helix ( $\alpha$ -helix)** A common secondary structure of protein consisting of loops stabilized by hydrogen bonds.

**Alveograph** A dough-testing machine that simulates fermentation by blowing a bubble with dough and measures the dough's properties.

**Amine** A molecule based on the small  $\text{NH}_3$  molecule. The H's may be replaced by bigger groups.

**Amino acid** A molecule that contains certain groups of atoms—one with nitrogen, one with carbon and oxygen, and one that changes. It is the building block of proteins.

**Amino group** The part of an amino acid that contains nitrogen and hydrogen atoms. In general, a group containing an amine.

**Amylase** The enzyme that converts starch to sugar. Alpha-amylase breaks starch into pieces, and beta-amylase breaks maltose units off the end of starch chains.

**Amylopectin** A form of starch that has branched chains.

**Amylose** A form of starch that is a straight chain.

**AP flour** See all-purpose flour.

**Auto-digestion** This is used to refer to the action of proteases in dough because the dough appears to be breaking itself up or digesting itself.

**Autolyse** A rest period for dough after incorporating ingredients but before adding salt and kneading. The word comes from autolysis, or “self-

breaking.” I believe the term refers to the action of proteases breaking protein chains, so that the dough is effectively “breaking itself.” Another explanation, from *The Bread Builders*, is that yeast and bacteria cells break up upon dying in a toxic medium, releasing proteases and other chemicals that affect gluten. I am not sure why this would occur in dough during the autolyse.

Autolysis See autolyse.

Bacteria A one-celled, prokaryotic organism.

Baguette A long, thin loaf of bread.

Baker’s percent A convenient method for listing ingredient amounts in a recipe, in which flour weight is set at 100% and the weights of other ingredients are relative.

Baker’s yeast Certain strains of the species *Saccharomyces cerevisiae*. They are used in baking because they have the necessary enzymes (invertase and maltase) and perform well converting starch into CO<sub>2</sub> under bread-making conditions.

Banneton A basket to hold proofing dough.

Batard An oval-shaped bread. The word is French for “bastard”; the batard is not quite a boule or a baguette.

Beta sheet ( $\beta$ -sheet, a.k.a.  $\beta$ -pleated sheet) A common secondary structure in protein: a flat, wavy, double-wide protein chain stabilized by hydrogen bonds.

Beta turn ( $\beta$ -turn, a.k.a.  $\beta$ -fold) A common secondary structure in protein: a fold in the protein chain, secured in place by a hydrogen bond.

Bilayer See lipid bilayer.

Boule A round bread.

Bran The outer coating of the wheat kernel, included in whole wheat flour.

Bread flour Flour with a higher protein content than AP flour. Often it has too much protein for home baking.

Budding The main method of reproduction for yeast.

**Calorimetry** The science of measuring heat flow.

**Caramelization** Reactions of sugar molecules on heating that produce flavor molecules and a brown color.

**Carbonyl-amine reactions** See Maillard reactions.

**Carbonyl group** A chemical group containing a carbon atom double bonded to an oxygen atom.

**Carboxyl group** The part of an amino acid that contains carbon and oxygen atoms. In general, a group containing carbon and oxygen atoms in a characteristic arrangement.

**Chromatography** A technique for separating components of a sample that involves a stationary phase and a mobile phase. There are many kinds of chromatography. For example, a sample poured into a vertical column will be pulled through by gravity. Its components can be separated by filling the column with a substance that attracts different components with different amounts of force, slowing them more or less as they pass through. Separate components exit the column.

**Cloche** A lidded clay container for baking dough, similar to a casserole dish.

**Colloid** A suspension of tiny particles in a medium. A system of protein molecules in water is an example.

**Commercial yeast** Yeast produced in a processing plant and sold in a store, as opposed to the natural yeasts in a starter. See also baker's yeast.

**Covalent bond** A bond in which two atoms share electrons.

**Crenation** In biology, this refers to the dehydration of cells because of salt or sugar in their surroundings.

**Crumb** The inside of bread, i.e., not the crust.

**Degas** To remove the gas from dough, usually by hitting it.

**Denature** To unfold or to cause to unfold.

**Diastatic** Containing diastase, a certain amylase.

**Dipeptide** Two amino acids bonded by a peptide bond.

Dipole-dipole bond (a.k.a. dipole-dipole attraction) The attraction between the opposite charges of polar molecules.

Disaccharide Any complex sugar with two rings.

Disulfide bond (S—S) A covalent bond between two sulfur atoms.

Elasticity (of dough) Stretchiness.

Electrophoresis A technique for separating components of a substance based on their speeds of migration through a substrate when an electric field is applied.

Entropy The science word for disorder or randomness. It can contribute to the stability of systems.

Enzyme A molecule (usually a protein) that enables a specific chemical reaction to happen or speeds up its occurrence.

Eukaryote A slightly complex one-celled organism.

Extensibility The ability to extend (stretch) without ripping.

Extensigraph A dough-testing machine that stretches dough and measures its resistance.

Farinograph A dough-testing machine that mixes dough and measures its resistance during mixing.

Fat A lipid consisting of an alcohol molecule attached to three fatty acid molecules.

Fatty acid A non-polar chain with oxygen atoms at one end.

Feed (starter) See refresh.

Fermentation 1. A general term for the process in bread-making by which microorganisms turn sugar into CO<sub>2</sub> and alcohol. 2. The reactions that turn one glucose molecule into two CO<sub>2</sub> molecules and two ethanol molecules, done by yeast in the absence of oxygen. 3. The step of the bread-making process after mixing, when the dough is rising before being punched down or shaped.

Fibrous (conformation of protein) Stretched out or chain-like.

First rise See fermentation (3).

**Folding** A final stretching of rising dough that adds strength. It accompanies punching.

**Forming** See shaping.

**Free energy** A measure of the stability of systems, incorporating both energy and entropy.

**Friction factor** A number that describes the heat added to dough during mixing due to friction.

**Fructose**  $C_6H_{12}O_6$ , a simple sugar that cyclizes into a five membered ring.

**Gas cells** The pockets of carbon dioxide in dough.

**Gelate** To turn into a gel.

**Gelatinize** To turn into gelatin or to become gelatinous. This is often used (improperly) in place of gelate.

**Gliadin** One of the flour proteins that helps form gluten. Gliadins are shorter chains, responsible for the extensibility of gluten.

**Globular (conformation of protein)** Ball-like.

**Glucose**  $C_6H_{12}O_6$ , a simple sugar that cyclizes into a six-membered ring.

**Gluten** A strong, elastic substance composed of flour protein molecules and water.

**Glutenin** One of the flour proteins that helps form gluten. Glutenins are long chains, responsible for the elasticity of gluten.

**Hydrate** To combine chemically with water.

**Hydration** The water content of a dough. This can also refer to the act of hydrating.

**Hydrogen bond** A bond between an electronegative atom (a strong electron-sucker—usually oxygen or nitrogen) and a hydrogen atom that is bonded to an electronegative atom. The bond is the attraction between the opposing partial charges these atoms carry.

**Hydrophobic bonding** The association of non-polar, hydrophobic parts of molecules based on their desire to avoid a polar solvent or polar parts of the molecules.

**Instant yeast** A partially dehydrated form of yeast that does not need to be activated before use. It is convenient and works well for bread-making.

**Invertase** The enzyme that breaks sucrose into glucose and fructose. It is found in many kinds of yeast.

**Ionic bond** A bond in which a positive ion and a negative ion stick together because of the attraction between opposite charges.

**Kneading** Mixing of the dough after the ingredients are incorporated.

Kneading develops the gluten network and makes the dough stronger and more flexible.

**Lactic acid bacteria** Bacteria that produce lactic acid during fermentation. This usually refers to the bacteria in starter.

**Lame** A razor blade on a stick used for scoring dough.

**Leaven** To raise (for example, yeast leavens dough). Also, leaven is another word for levain, or starter.

**Leavening agent** See rising agent.

**Levain** See starter.

**Lipid** A substance that is insoluble in water but soluble in non-polar, organic solvents. Lipids include fats.

**Lipid bilayer** Two sheets of phospholipids with their non-polar tails in the middle and their polar heads facing out. It often forms when the phospholipids are in a polar solvent.

**Lipoprotein** A substance containing both lipid and protein.

**London dispersion force** See Van der Waals force.

**Maillard reactions** Reactions between sugars and amino acids that produce flavor molecules and a brown color.

**Malt** Essentially maltose. Malt is added to bread dough to help fermentation proceed steadily.

**Maltase** The enzyme that breaks maltose into glucoses. It is found in many kinds of yeast.

**Maltose** A complex sugar made of two glucose rings.

Maltozymase See zymase.

Mixing (of dough) The step of the bread-making process in which ingredients are incorporated together and kneaded.

Molding See shaping.

Native (conformation of protein) See globular.

Nuclear magnetic resonance (NMR) A technique that measures the response of a sample to a magnetic field and identifies components of the sample by recognizing characteristics of the response.

Old dough Leftover dough that is used in a future batch of bread to add flavor.

Osmosis The diffusion of solvent (usually water) through a membrane (like the cell membrane of yeast).

Oven spring The expansion of dough in the oven due to increased production of potentially gaseous molecules, evaporation of molecules from solution into gas form, and expansion of gases on heating.

Over-proof To allow shaped dough to rise too long. It will not expand well in the oven and may collapse.

Oxidation In dough, oxidation usually refers to the reaction of sulfhydryl groups ( $-SH$ ) with oxygen to form a disulfide bond ( $S-S$ ). In general, oxidation is a reaction in which the atom loses electron, so named because atoms usually lose electrons when they react with oxygen. There are rules for counting the electrons assigned to each atom.

Parchment Paper that can go into the oven. It is useful for moving shaped dough from one surface to another because the dough does not have to be peeled off it before baking.

Peel A flat board on a stick that bakers use for removing bread from the oven.

Peptide bond A bond between the carbon of one amino acid and the nitrogen of another. A water molecule is lost when it forms.

pH A measure of acidity. The pH scale runs from one (very acidic) to fourteen (the opposite of acidic). A median pH value of seven corresponds

to a neutral substance, like water. Dough can develop a mildly acidic pH of five to six.

**Phospholipid** A lipid consisting of an alcohol molecule attached to two fatty acids and one phosphate group, a group of atoms that includes a phosphorus atom. Phospholipids are known for having a polar head and a non-polar tail.

**Plasticity** Another word for extensibility.

**Polar molecule** A molecule with permanent partial positive and negative charges resulting from different atoms' abilities to hold onto electrons. For example, in a water molecule ( $H_2O$ ), the oxygen atom has some negative charge while the hydrogen atoms have some positive charge.

**Polypeptide** A chain of amino acids.

**Polysaccharide** A chain of sugar rings.

**Poolish** A soupy pre ferment containing yeast and equal weights of flour and water.

**Pre ferment** A dough-like mixture made a day before bread is made to increase the length of fermentation and allow ingredients to hydrate and react.

**Pre-shape** To shape dough into a round or oval in preparation for further shaping. Pre-shaping creates a symmetric piece of dough with a smooth outer surface, making the final shaping easier, and adds strength.

**Primary structure (of protein)** The order of the amino acids in a protein chain.

**Prokaryote** A very simple one-celled organism.

**Proof** The final rise for bread dough before baking.

**Proof box** A box in which shaped dough is put to rise. Usually it is heated and has humidity control, but a large plastic box with a tight-fitting lid can be used at home.

**Protease** An enzyme that cuts peptide bonds between amino acids, resulting in shorter protein chains.

**Punching** Knocking the gas out of rising dough during the fermentation step, enabling the dough to rise again and doubling the fermentation time. See also folding.

**R group** (a.k.a. side chain) The unique part of an amino acid. There are 20 common R groups.

**Random coil** See fibrous.

**Refresh (starter)** To mix old starter with flour and water, giving the microorganisms new food.

**Respiration** The reactions that turn one glucose molecule and six O<sub>2</sub> molecules into six CO<sub>2</sub> molecules and six water molecules, done by yeast when oxygen is present.

**Retrogradation** See starch retrogradation.

**Rising agent** The ingredient that makes bread rise. Examples include yeast and starter.

**Saccharomyces cerevisiae** See baker's yeast.

**Score** To cut. In bread-making this refers to cutting the top of dough just prior to baking.

**Secondary structure (of protein)** The arrangement of a protein chain based on attraction and repulsions between its amino acids.

**Shaping** The step in bread-making in which risen dough is degassed and folded into a final shape or form.

**Side chain** See R group.

**Slash** See score.

**Sourdough starter** See starter.

**Spelt** A cousin of wheat that makes bread well. It is often preferred by people with sensitivities to wheat.

**Sponge** A doughy preferment containing yeast, flour, and water.

**Starch** A polysaccharide made of glucose rings.

**Starch gelatinization** Often improperly used in place of starch gelation.

**Starch gelation** The gelling or solidifying of hydrated starch as dough bakes.

**Starch retrogradation** The partial recrystallization of starch in bread crumb. The previously melted starch returns to a solid, ordered form.

**Starter** A pre ferment of flour and water inhabited by a population of bacteria and yeasts that are able to perform fermentation and thus make bread dough rise.

**Steam** In bread-making, to wet the surface of the dough prior to putting it in the oven.

**Straight dough** A dough made with no pre ferment.

**Strength (of dough)** The toughness and elasticity of the dough. Strength is initially determined by how much gluten structure develops during mixing and how much this structure relaxes as gas bubbles in the rising dough push on it. Strength can be added by folding or shaping the dough, which stretches relaxed dough to make it tight again.

**Strong (dough)** A dough that is tough and hard to stretch.

**Sucrose** A complex sugar made of one glucose ring and one fructose ring.

**Sulfhydryl group (—SH)** A sulfur atom bonded to a hydrogen atom.

**Tertiary structure (of protein)** The overall shape of a protein molecule, in a range between fibrous and globular. It depends on the character of both the protein and its solvent.

**Thermometer** A device for measuring temperature.

**Van der Waals forces** Temporary forces between non-polar molecules. Temporary, small charges occur on molecules as their electrons swish around, and these can induce opposing charges in neighboring molecules, which are then attracted to the original charges.

**Weak (dough)** A dough that is soft and stretches easily.

**Wild yeast** This usually refers to yeasts in bread-making that are not baker's yeast.

**Window test** A test to see if dough is fully mixed. If the dough can be stretched until it is translucent (forming a "window") without ripping, it is

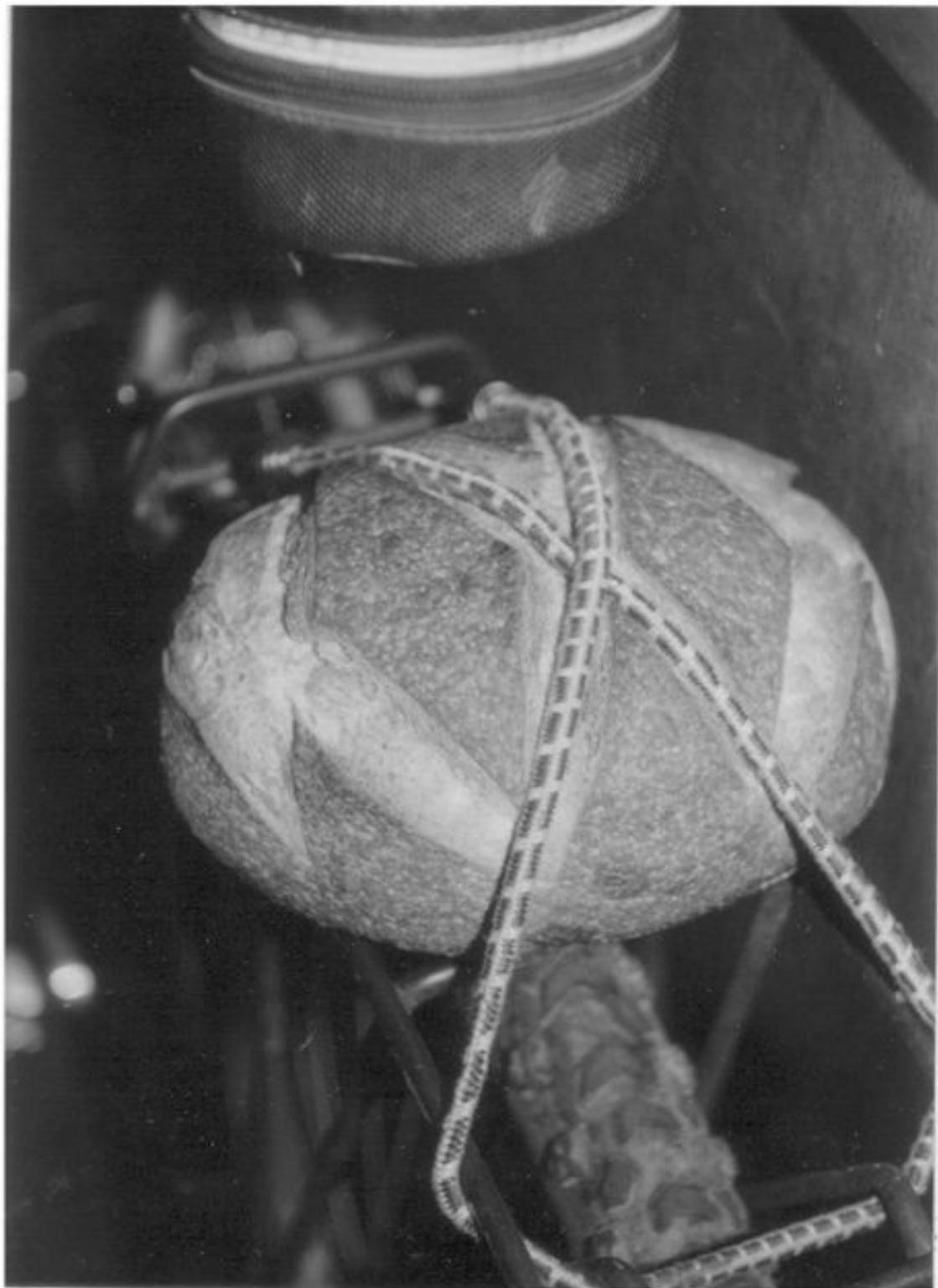
fully mixed.

X-ray diffraction A technique for determining structure by shining X-rays at a sample and obtaining a diffraction pattern from which interatomic spaces can be determined.

Yeast A one-celled, eukaryotic organism. Baker's yeast is one kind. There are wild yeasts in the air around us.

Zymase The original name for the enzyme system that processes maltose into fermentation products.

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Sourdough on my bike rack, Carrboro, NC, 2002

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Photo by Maria Mauceri

Emily Jane Buehler lives and works in Hillsborough and Carrboro, North Carolina. She received her PhD in chemistry from the University of North Carolina in Chapel Hill in 2001. She then began baking bread at Weaver Street Market, a cooperative natural foods store. In 2002, she began teaching bread-making classes and hosting a monthly “Community Oven Night.” Her interactions with the bread-making public led to the desire to write this book. Learn more about her on her website, [www.emilybuehler.com](http://www.emilybuehler.com).

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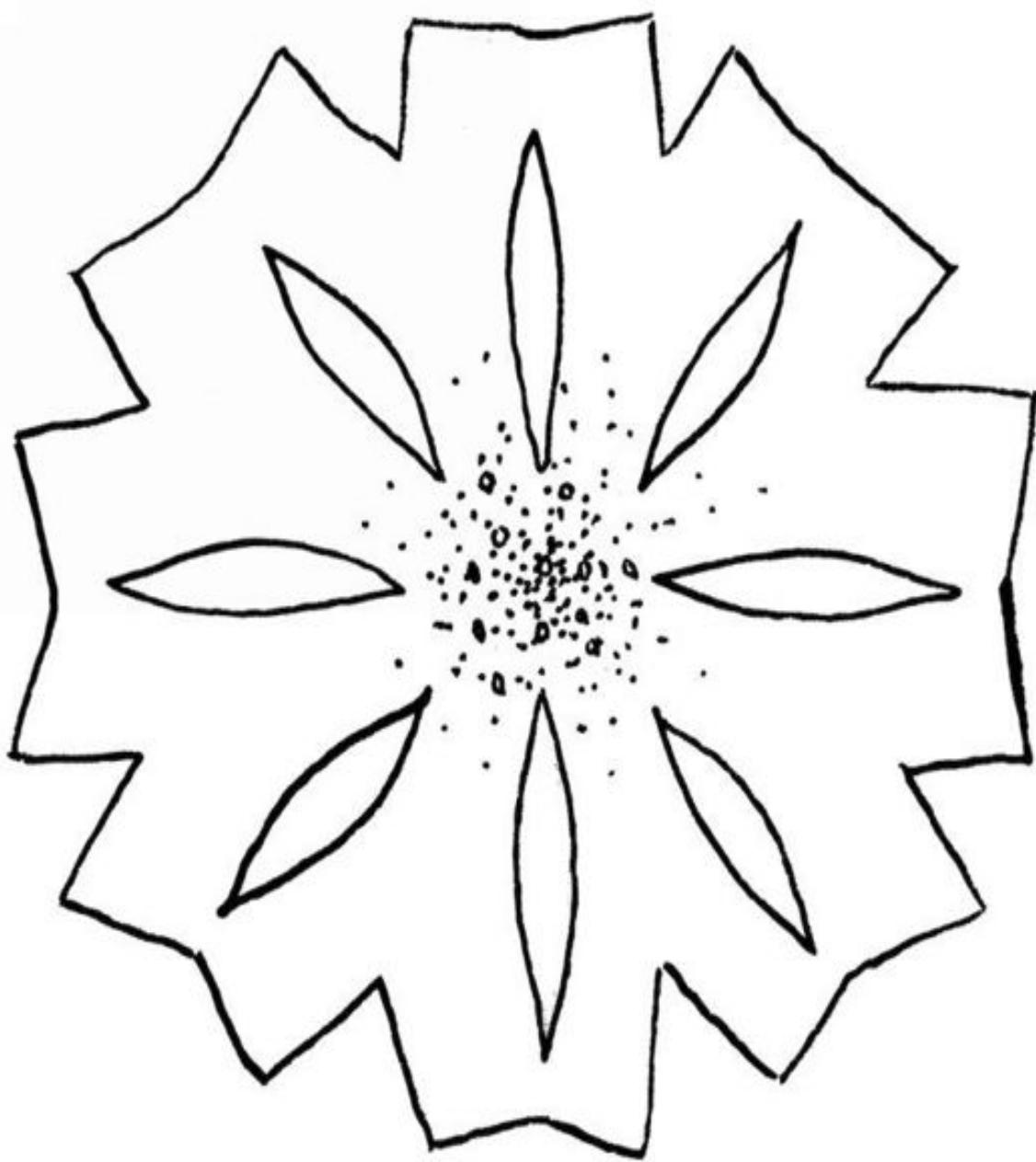
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