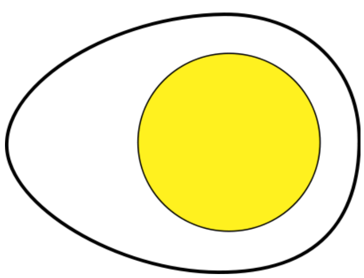
Molecular Gastronomy: The Chemistry of Cooking

We're surrounded by chemistry each and every day but some instances are more obvious than others. Most people recognize that their medicine is the product of chemistry; far fewer would say the same about their lunch. But they should. The flavor of their grilled chicken is the result of complex browning reactions, their salad dressing an emulsion of immiscible liquids, and the texture of their ice cream governed by thermodynamic principles. In this class, you'll learn how to view food and cooking from the standpoint of a chemist and hopefully you come to see why chemistry is useful (and pretty cool!)

Experiment 1: The Perfect Hard-Boiled Egg

First and foremost, chemistry is a science and that means we attempt to answer questions in a methodical and rational way. In this experiment, we'll be answering the question: how do you make the perfect hard-boiled egg? But that's a broad question, so we need to begin by narrowing. What characteristics define a perfect hard-boiled egg? Are you and your neighbors in agreement?

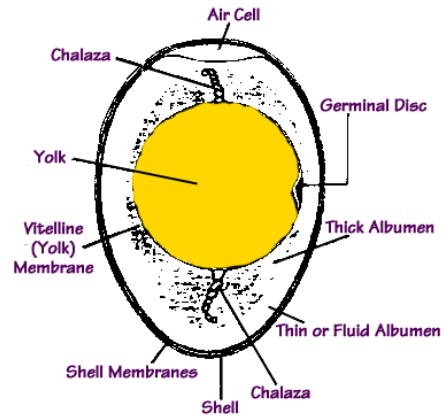


Characteristics of a Perfect Hard-Boiled Egg:

By agreeing on a set of qualities that a perfect hard-boiled egg must have, we've turned a subjective evaluation into an objective one. Now we're ready to investigate how we can achieve these characteristics.

(P.S. Yes, the list of what we consider the characteristics of a perfect hard-boiled egg are on the next few pages but it's no fun if you read them before coming up with your own so DON'T! Plus you might think of something we missed)

1. The Shell Must Not Crack During Cooking



Some common advice to prevent cracking found in cookbooks: add vinegar, salt, or burned matches to the cooking water or avoid the thermal shock associated with placing the egg in boiling water.

Do these suggestions seem reasonable to you? Why or why not?

A more rational approach: cracking is a structural failure so let's begin by examining the structure of an egg. Do you notice any features which could place stress on the egg when cooked and cause the shell to crack? (Hint: what would happen to the air pocket when heated? You might find the equation below helpful)

The ideal gas law

$$PV = nRT$$

P=Pressure
V=Volume
n=Moles
R=Ideal Gas Constant
T=Absolute Temperature

Our solution:

2. The Shell Must Peel Easily

How my hard-boiled eggs usually turn out…

What are some of your methods for peeling hard-boiled eggs nicely?

The chemist's solution: ___________________________

What is an eggshell made of?

Is it possible for us to transform the shell into a substance that is easier to remove? (Hint: think back to acid/base chemistry)

What things do we have in the kitchen that could affect this transformation?

Would this reaction have any negative side effects? How could we avoid them?

Egg De-shelling Demo:
Place the egg in an acidic solution and watch the shell dissolve. Note the formation of bubbles on the shell surface, that's the CO_2

Our Solution:

3. The White Must Not Be Rubbery, Nor the Yolk Sandy

Obviously, this characteristic is determined by how long and at what temperature the egg is cooked. What are the normal guidelines? Why do you think these are so widely used?

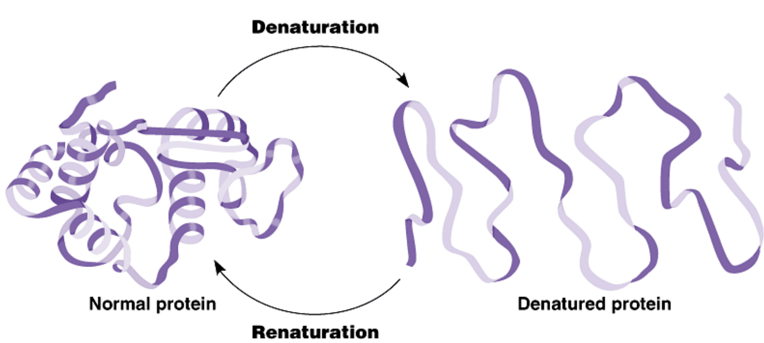
Let's begin by considering the egg white. In order to determine how to properly cook the egg, we need to understand what happens to the egg white when cooked. The white coagulates but why and how?

Egg white composition:
90% water, 10% protein

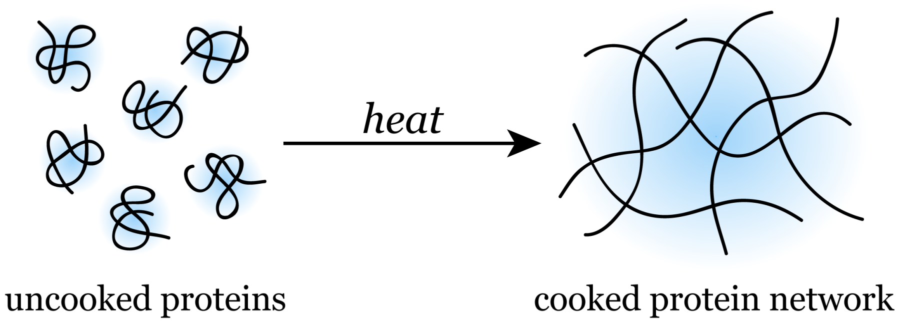
Table 1: Major egg white proteins and selected properties (Mine, Y. et al 1995)

Protein	% protein in egg white	Molecular Weight (kDa)	pI	Denaturation Temperature (°C)
Ovalbumin	54	44.5	4.5	84.0
Ovotransferrin	12	77.7	6.1	61.0
Ovomucoid	11	28.0	4.1	77.0
Ovomucin	3.5	$5.5\text{-}8.8 \times 10^3$	4.5-5.0	Unknown
Lysozyme	3.4	14.3	10.7	75.0

We know what happens to water when heated and that doesn't explain the phenomenon we observe so the proteins must be responsible. What happens to proteins when heated?



How does this explain the transformation from raw to cooked egg? The unfolded proteins link with each other to form a network that traps the water molecules. The components of the egg white can no longer flow. It's a solid!



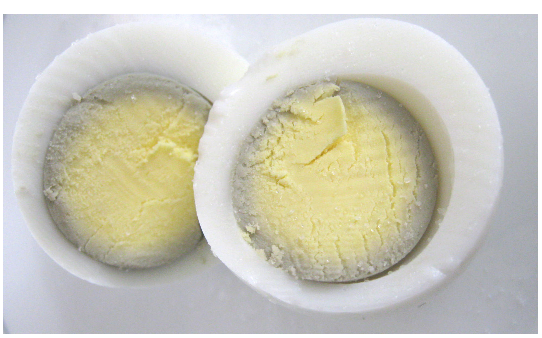
So how does the yolk cook? The same thing happens! Like in the egg white, proteins are denatured by heat, forming a network. However, the yolk has a lower concentration of proteins.

Now how can we use our understanding of how the cooking process works to create a better method? (Hint: the table contains the denaturation temperatures of the proteins in the egg white).

Egg Cooking Demo:
Watch the egg as it cooks and notice how the egg white becomes opaque from the bottom up as the proteins closest to the heat source are denatured first.

Our Solution:

4. The Yolk Must Not Be Greenish, Nor Smell Of Sulfur



What if I don't want green eggs and ham for breakfast this morning? How do I avoid this? First, we'll need to figure out what is causing these undesirable qualities.

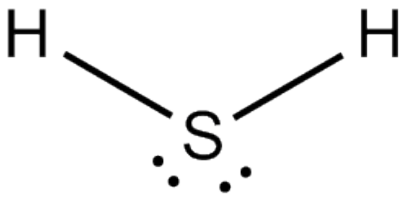
What are the five signs of a chemical reaction?
1.

2.

3.

4.

5.



Dihydrogen sulfide

It looks like a reaction is occurring! Luckily for us, the compound which causes the rotten egg smell is already well-known. It's name is dihydrogen sulfide, and it is one of the products released by burning sulfur.

But could dihydrogen sulfide be responsible for the green color as well? (Hint: One of the standard procedures for producing H_2S in a laboratory is to react ferrous sulfide with a strong acid. Egg yolks contain iron ions.)

Ferrous Sulfide

Test for H_2S:

1. Place a few drops of lead acetate on your filter paper
2. Hold your filter paper over a cooking egg
3. If a dark precipitate forms, H_2S gas is being produced

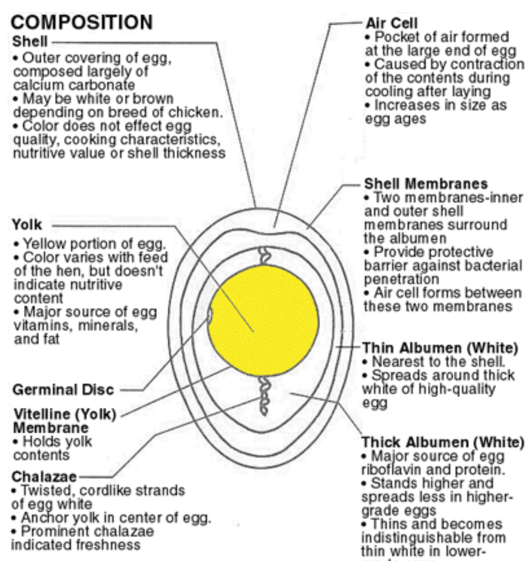
Based on this information, it is reasonable to assume that the production of dihydrogen sulfide is responsible for the bad smell of hard-boiled eggs but we should perform a test to make sure.

Our Solution:

5. The Yolk Must Be Perfectly Centered In the Egg White

To solve this challenge, we will need a better understanding of how the yolk and the egg white interact. First, let's look at the structure of an egg. Do you see any interesting features?

Next, consider the composition of different parts of the egg. How will this affect the position of the yolk in the egg? (Hint: remember that fats are less dense than water)



Now let's check to make sure our deductions are accurate with a few experiments.

Naked Egg Demo: Gently pick up the shell-less egg and hold it up to the light source. Take note of where the yolk is in the egg. Does its position change if the egg's orientation is altered? What affect do the chalaza appear to have?	Density Check: Crack an egg into your beaker. Does the yolk float as we expected it to?	Summarize your findings:

Our Solution:

Now that we know how to make the perfect egg, let's give it a try and see if our analysis was correct!

This lesson was adapted from Hervé This's Building a Meal: From Molecular Gastronomy to Culinary Constructivism, © 2009 Columbia University Press