

The Science of Cooking Eggs

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JUMP TO

[Summary/TLDR](#)

[What happens when eggs are cooked?](#)

[What happens when eggs are beaten?](#)

[What happens when eggs are mixed?](#)

[How do you “un-cook” an egg?](#)

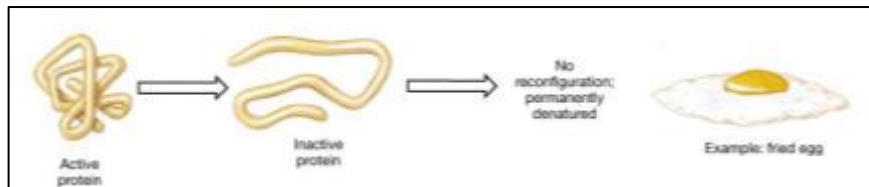
[Appendix](#)

[References](#)

What happens when eggs are cooked?

By Dania Shoab

We often forget how complex the simple things in our daily lives are. A prime example of this is eggs, something nearly everyone eats for breakfast. Eggs may seem just like liquid with a yolk swimming around enclosed in a shell. In reality, they contain complex network of proteins, fats, and water and undergo tremendous changes when heated. In raw eggs, there are several chains of proteins that are composed of numerous amino acids and thousands of water molecules. The proteins are in a very compact form and are held together by weak bonds. Eggs are in a loose, liquid state because of the negative charges found in the proteins that lead to repulsion [1]. Adding heat forces the eggs to become solid, and this is only possible through a complex system of reorganization of molecules all brought on by heat.

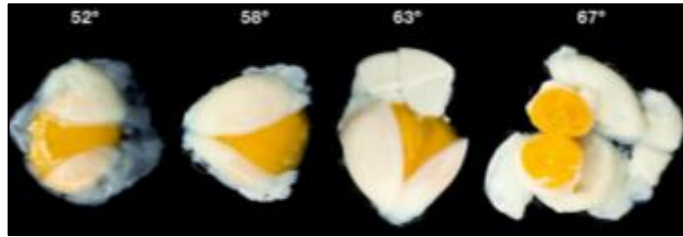


When heat is added, the protein complex will unfold, or denature, allowing changes to take place in the egg [3].

Applying heat to eggs causes the proteins in eggs to interact with the water molecules [1]. As more and more heat is added, the collision of molecules increases very rapidly. This in turn leads

to the weak bonds within the protein globs to break, [the proteins unfold](#), and new bonds to form among proteins, in turn making a complex web of proteins. Since the protein molecules and the water are forced to interact, their numerous bonds cause the egg whites to turn from a near liquid state to a near solid, rubbery state. All the water is now trapped within the network of proteins [2]. Overheating the eggs can cause too much protein unfolding and too many new bonds to form and this is why overcooked eggs become rubbery.

It is interesting to note that the yolks of eggs are different from the whites in raw and cooked forms. The proteins in yolks are not only bound to other proteins, they are also bound



The yolk will appear more solid than the whites while the temperature is increasing due to the fat content [5].

to fat molecules. Fat molecules are nonpolar and carry no charge. The abundance of the fat molecules suppresses the slight negative charge in the proteins [2]. Since there is less of a charge, there is less repulsion; therefore, the yolks of eggs appear to be much more solid than the whites. The yolk of an egg also requires more heat and collisions between

molecules to become as solid as the whites once cooked, yet again due to the abundance of fat molecules. The fat molecules in yolks also serve to hold the proteins together and prevent too much water from escaping. Because of this, the yolks will never be as rubbery as the whites when overheated since the increasing complexity of the protein web in the whites will force out more and more water [4]

Frying sunny-side-up eggs are the quickest and easiest way to enjoy a runny yolk and crispy edges. For the best results while frying an egg, a low to medium heat should be used.



Controlling the heat allows eggs to be fried evenly and prevents them from becoming rubbery [6].

Furthermore, it is a good idea to remove the egg from the pan once the whites appear to have firmed up, as continuous heat will further denature the proteins and remove water. This controlled heating and removal prevents the entire egg from overcooking even after the flame has been turned off. Using fresh eggs is another way to ensure tender sunny-side-up eggs with crispy edges. The whites and yolk are strongest when fresh, preventing them from breaking down and becoming rubbery.



The yolks take longer to solidify, but boiling an egg for too long will discolor the yolk and lead to a rubbery texture [8].

Of course, not everyone likes their eggs the same ways. Some people prefer boiled eggs, others scrambled. Each way of cooking eggs features its own complex set of scientific properties. Boiling eggs, for example, provides an even distribution of heat around the egg. Water will continue to heat up as long as it is on the stove, and this

constant increase in heat is not necessary for the egg to cook through, however. This is because the protein in egg whites go from the raw, liquid state to a solid one at about 145°F. Yet again, the yolks are a different case; they do not become solid until about 150-160°F. Eggs that are boiled at a constant temperature of over 200°F will become rubbery due to the continuation of protein coagulation. The discoloration of the outside of the yolk is also due to excess heat. The yolk is rich in iron while the whites are rich in amino acids. The amino acids contain sulfur that react with the iron of the yolk to form a film of ferrous sulphide on the yolk, and this is the gray discoloration of an otherwise yellow yolk. The prolonged heat will speed up

this reaction. To prevent the yolk from turning gray, plunge the boiled eggs in cold water to stop the iron and sulfur from reacting. So, for the best boiled eggs, the water does not need to be at a continuous, rapid boil [7].



Silky scrambled eggs can be achieved by adding fat and continuously stirring [9].

As mentioned above, the fats in yolk prevent the proteins from falling as far apart as in the whites. Scrambled eggs, a relatively simple method of cooking eggs, actually features a complex relationship between fats and proteins. Many chefs recommend actually adding fat, be it in the form of butter or another egg yolk, to the eggs before scrambling them. The introduction of another fat source allows for the entire mixture to become closer in character to the yolks. Simply put, all the extra fats will prevent more charge between proteins and the loss of water and therefore the scrambled eggs will be smoother like yolks. During the actual cooking portion, using a low heat and stirring constantly will allow the eggs to cook evenly when they are scrambled into small pieces. Large pieces cook best at a higher heat and less stirring to allow for greater coagulation among proteins since excessive proteins would break them apart more, leading to small pieces [4].

The beloved, high-protein breakfast foods we eat on a near regular basis are highly complex. It seems simple to just crack an egg into a hot pan and five minutes later be enjoying a runny yolk and crispy energy. However, there are thousands of protein interactions and a complex reorganization of molecules within the eggs that leads to different types of eggs. The evaporation of water from the protein webs lead to rubbery eggs while the introduction of fats makes them silky and smooth. The complex mechanisms contained within this simple food truly is a testament to the importance of chemistry in our day-to-day lives.

What happens when eggs are beaten?

By Aroog Khaliq

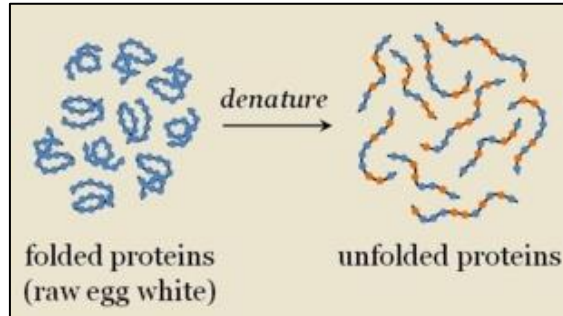


Unlike most French desserts, the recipe for meringue is quite simple [13].

Egg whites are perhaps best known for their role in making meringue. A meringue is a European dessert composed of three main ingredients: egg whites, sugar, and an acid (e.g. lemon juice, cream of tartar, or vinegar) [10]. These ingredients are beaten together from liquid to froth to foam and then baked. The meringue can be piped out and baked into meringue cookies, or added to cake batter to create airy, voluminous cakes like angel food cake. To ensure that the resulting meringue has maximum height and volume, it is important to use eggs that are fresh and cold, because these will naturally be more acidic (lower in pH) than old, warm eggs [11]. When separating the eggs, it is important that no yolks are introduced to the

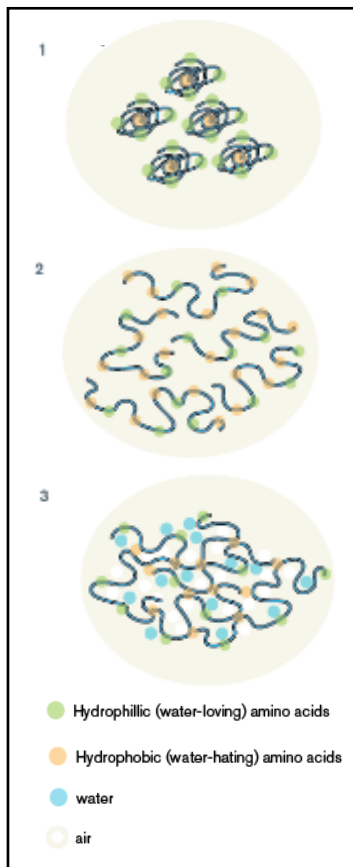
whites because [yolks have high fat content](#), and the main structure of meringue relies on protein and water interactions, which are disrupted by fats [\[12\]](#).

When the egg whites are beaten (by hand with a metal whisk if one is trying to get fit; otherwise, use a hand or stand mixer), the chemical processes that turn them from a clear, snot-like consistency to a foam and eventually a voluminous masterpiece are as follows. The initial beating [denatures](#) the proteins in the egg whites (i.e. makes them lose their secondary, tertiary, or quaternary structure by applying mechanical stress) [\[14\]](#). As mentioned earlier, using fresh, cold eggs adds natural acidity and will likewise denature the egg white proteins, this time by applying chemical stress. After denaturation, beating will cause amino acids to coagulate, or join together, and this causes the liquid to thicken [\[15\]](#). The air that is added in as the egg whites are beaten is covered by these



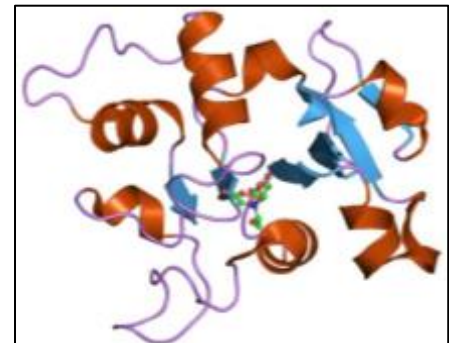
This diagram depicts the process of protein denaturation in egg whites [\[16\]](#).

coagulating proteins, whose joining together involves ionic bonding and/or disulfide bridges (the latter can have a negative effect on the meringue, making it gritty, which is discussed further in the [appendix](#)) and forms bubbles that will make the mixture foam.



A diagram depicting the incorporation of air into egg white proteins on a chemical level [\[19\]](#).

Thus, at a chemical level, making a meringue is only a matter of breaking old bonds between egg white proteins and forming new bonds that allow the proteins to hold air and thereby volumize the mixture. Beyond this bare-bones process, there are other chemical changes can help make a better



The structure of the protein conalbumin (found in egg whites) rendered in 3D [\[18\]](#).

meringue. To increase volume, two processes can be used to slow coagulation and allow more air into the mixture. Adding an acid of some kind to the egg white mixture (e.g. lemon juice, vinegar, or cream of tartar) will slow coagulation by lowering the pH (i.e. increasing the acidity) of the mixture [\[17\]](#). Another tip, which is beloved by French pastry chefs, is to use a copper mixing bowl. This slows coagulation by allowing copper molecules to bind with a protein in the egg whites called conalbumin for support, which raises the temperature needed for coagulation reactions to occur [\[15\]](#). Both of the tips

discussed allow for slower coagulation, more aeration of the foam, and thus a more voluminous meringue.

Finally, it is important to avoid mistakes that can result in a flat meringue and a ruined recipe. First, it is imperative to keep bowls that come into contact with the meringue free of all detergents and fats, and ideally to use metal bowls instead of plastic ones. This is because plastic bowls retain fat molecules better than metal bowls, and as with the danger of getting yolks into the whites, fat molecules interacting with the egg whites will ruin the protein-water interactions that form the foam's structures [12]. It is also important to build stability in the foam; simply adding air to the batter through beating will not retain the structure. After the froth has been created, adding sugar will strengthen the foam's structure because the sugar dissolves into the egg whites. The dissolved sugar adds water to the egg whites' proteins, which increases the stability and elasticity of the mixture. When this egg white and sugar mixture is further beaten, it can be up to eight times as large as a mixture with just egg whites [15]! Lastly, it is imperative that the tips for slowing coagulation mentioned previously (the addition of an acid or usage of a copper bowl) not be used together, so as not to slow down to the point of inhibition. If the pH becomes too low (i.e. the mixture becomes too acidic), the proteins become at risk of being denatured completely, so no foam can form and the meringue is ruined [15].



The three simple ingredients in meringue: egg whites, sugar, and an acid (here, cream of tartar is used) [10].

Thus, to make a proper meringue, various components must be considered. To ensure that denaturation, coagulation, and foam formation reach optimal levels, it is important to begin with fresh, cold eggs. Their low pH will allow chemical denaturation to hasten the denaturation process that begins with beating the eggs. To more efficiently beat the eggs, it is recommended to use a hand or stand mixer, but the process can be done (painfully and painstakingly) by hand with a metal whisk. Removing the egg whites and making sure no fats touch them--whether in the form of contaminants on the bowl or egg yolk fats--will allow the proteins to properly coagulate via ionic bonds and trap air within to create bubbles and thus foam. Volume can be maximized by way of using acids or a copper bowl (be sure to use one or the other of these two tips), and stability can be added to the foam by mixing in sugar. Three simple ingredients--sugar, egg whites, and acid--can thereby make a delicious dessert that exemplifies many important chemical processes such as denaturation, coagulation, and chemical bonding.

What happens when eggs are mixed?

By Andrea Mundakkal

Eggs are useful, and delicious, in many ways and forms. By themselves, eggs can create entrees, appetizers, and [even desserts](#). When eggs are mixed with other ingredients, new recipes are created, and new flavors are discovered, but eggs can also be a very useful tool in

mixtures. In certain mixtures, adding egg yolks will help to keep the mixture together and in uniform. Eggs are an element that is added to allow other ingredients that should not mix naturally, to become mixtures, sauces, and food. The structure of egg yolks contains an important chemical component that makes it a necessity for certain combinations that contain both oil and water, substances that will not mix, to blend and stay mixed. These components within the egg yolks are called emulsifiers. The emulsifiers within an egg yolk are phospholipids, more specifically [lecithins](#),

that are carried and transported by the lipoproteins [\[20\]](#). Phospholipids are a type of lipid that contains hydrophilic water-loving heads and hydrophobic water-fearing tails. Mixtures that contain oil and water will not mix because the polar water molecules will be attracted to other water molecules more than the oil, so these two ingredients will separate into suspensions [\[21\]](#). This attraction is overcome when the egg yolks are added to the mixture because the hydrophilic heads of the lecithins will be attracted to the water, while the hydrophobic tails of the lecithins will be attracted to the oil [\[22\]](#). This causes the oil-water solution to not separate into a layer of oil and a layer of water or to be more concentrated in one ingredient over the other, instead the lecithins allow the mixture to be stable and reduces any surface tension between the two ingredients.

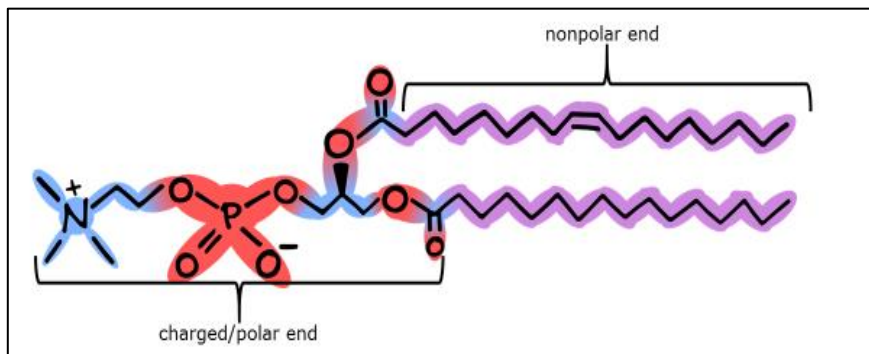


Image of a lecithin, a polypeptide in egg yolk that allows emulsifications to be created [\[21\]](#).

between the amount of lecithins and cholesterol in the egg yolks is important for creating an emulsification. The cholesterol helps to cluster the oil droplets, while the lecithins are used to create the mixture with no separations. The freshest eggs must be used to create an emulsion, because with age the amount of lecithin in the yolks will decline while the cholesterol level stays constant [\[24\]](#). With a greater amount of cholesterol, the oil will be clotted, and the mixture cannot be emulsified. The emulsion becomes less stable, less favorable, and difficult to maintain.

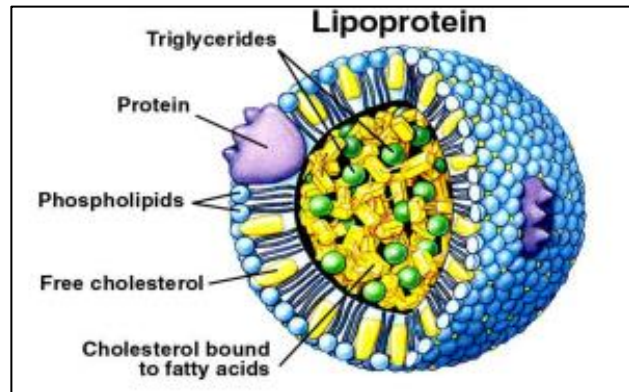


Image of a lipoprotein, containing cholesterol, phospholipids, and triglycerides [\[23\]](#).

Lipids make up thirty-three percent of egg yolks, which includes lecithins, cholesterol, and triglycerides. The balance

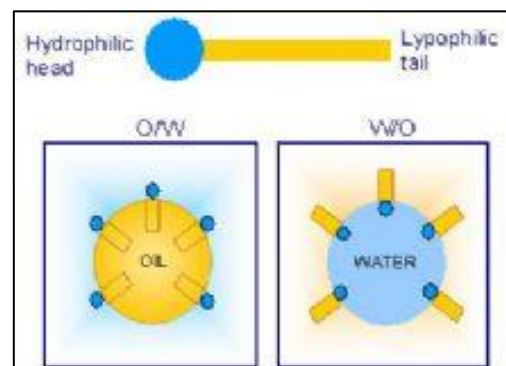


Diagram of an oil-in-water emulsion and a water-in-oil emulsion [\[25\]](#).

When oil and water are mixed, two different mixtures can be made: either an oil-in-water emulsion is created, or a water-in-oil emulsion is created. Although both sound the same, there is a difference that can change the taste of the mixture and how these mixtures are emulsified [25]. An oil-in-water emulsion is when the oil drops are spread throughout the continuous phase of water, and the water-in-oil emulsion is when the water drops are spread throughout the continuous phase of oil. If an ingredient is in the continuous phase this means it will be noticed, distinguished, or tasted more effectively. The type of emulsifier used becomes more specific based on the type of mixtures; egg yolks are only effective emulsifiers in oil-in-water emulsions because the egg yolks are soluble in the continuous phase of water [20]. Whichever ingredient the emulsifier is most soluble in will become the continuous phase in the mixture, therefore the mixture that is created, either an oil-in-water or water-in-oil emulsion, is not affected by the concentrations of both ingredients in the mixture, but instead is affected by what type of emulsifier is added to the mixture.

Factors that will change how effective an emulsion will be include the viscosity, amount of emulsifier, and additives in the emulsion. The viscosity, or thickness, of the emulsion should be high to keep the ingredients in place and to keep the mixture stable. The ratio between the droplets of oil dispersed within the water should be small, so that the emulsifier can keep the mixture stable and evenly distribute the oil within the continuous water phase. Additives added to the mixture can also help to stabilize the emulsion and assists the emulsifiers, egg yolks, to be more productive and useful in the mixture [26].



Example of an emulsification is hollandaise sauce [23].

oily. The egg yolks keep this condiment stable and less concentrated with the oil.

Egg yolks can also be frozen to create better emulsifiers in mixtures. When freezing egg yolks, with the addition of salt or sugar to avert any proteins from freezing, the result will be egg yolks that have become smooth, creamy, and thick. Enzymes are added to these egg yolks to denature the lecithin into lysolecithin. This modified lipid becomes a more effective emulsifier for more food. Examples of food

Examples of emulsifications that use egg yolks as emulsifiers, are mayonnaise, hollandaise sauce and other sauces, salad dressings, and baked goods [27]. In mayonnaise, there is a greater concentration of oil than other ingredients, but the taste of oil does not overpower the other ingredients. This is the result of adding the egg yolks as emulsifiers which makes the oil drops disperse, and the oil no longer stays as the continuous phase, so the taste becomes much less

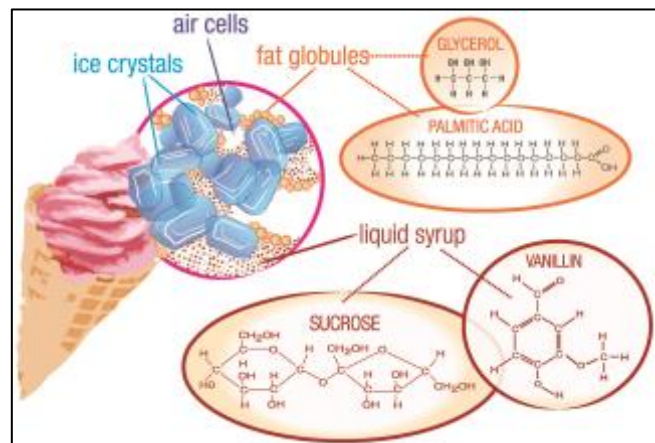


Diagram showing the chemical components of ice cream, and how the egg yolks, the emulsifier, form between the fat globules [28].

that use these lysolecithin emulsifiers includes bread, chocolate, and ice cream [29]. Emulsifiers added to the dough of bread results in bread that has more volume, has a softer crumb, and lasts longer. Emulsifiers added to chocolate allows for the best consistency for the chocolate to be molded and made into different products. The egg yolk emulsifiers are added to ice cream when it is being frozen. The lecithin goes in between fat globules in the ice cream, to keep these globules together, and to entrap the air bubbles, which creates a smooth and firm texture, and helps the ice cream to stay frozen for a longer period [30].

Eggs can be used in different ways to create varied mixtures and food. The yolks in eggs are useful as emulsifiers and can be added into mixtures to make stable and longer lasting combinations of ingredients. There is a strong boundary between oil and water that splits these two ingredients into two, but this boundary can be broken down by using egg yolks. By using these egg yolks that contain the right chemical components to keep these mixtures together, many new recipes and meals are created to be enjoyed.

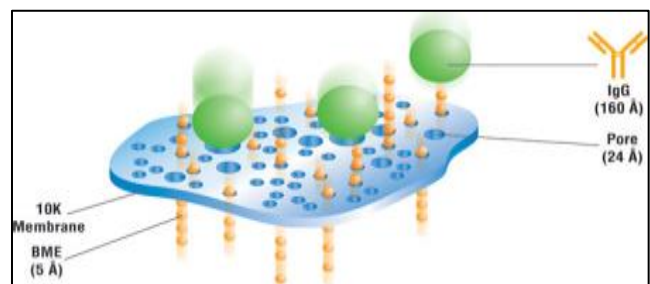
How do you “un-cook” an egg?

By Alex Lambert

The theory behind un-cooking an egg requires that the [proteins that were unfolded while cooking](#) must be refolded back to their original state [31]. A process to fully un-cook eggs with minimal error has not exactly been achieved yet, due to the significant amount of error in the current processes that can be used. Current processes attempt to refold proteins and remove [inclusion bodies](#) and due to the high amount of possible error in these current processes, they have a low recovery yield rate [32].

The process that is used the most is molecular dialysis [32]. [Molecular dialysis](#) is done by using a [semi-permeable membrane](#) to separate the proteins from small contaminations [33]. This process was first created to separate inclusion bodies from *E. coli* samples that were being used for research [34]. When the inclusion bodies were removed, the proteins that were originally unfolded were found to refold correctly in some cases, allow for recover of material. This process does have a low yield of recovery due to the amount of error being placed on chance and would typically take about four days to a week for the process to be completed [32]. This process was then used to un-cook an egg, and was found in most cases to untangle and refold some of the proteins, effectively un-cooking the egg.

Another widely used process to refold proteins and a process that could be used to un-cook an egg is known as [dilution](#). This process is widely used



This diagram depicts a dialysis membrane. The green particles are the macromolecules that are too large to pass through the membrane, while the yellow represent impurities that are being filtered out. In the case of refolding proteins, the green would represent the protein molecules, and the yellow represent the inclusion bodies that are being filtered out [32].

because it is simpler to do, but may have a lower recovery yield than molecular dialysis [33]. Dilution is done by directly diluting the proteins with a refolding buffer to remove contaminations and to reduce intermolecular forces between the protein molecules, allowing the proteins to refold themselves through intramolecular forces [35]. This process is harder to use on eggs, since the entire egg would have to be diluted, and therefore, the egg would not stay whole.

The newest process used does not have a name yet, but in testing, has had the highest recovery yield of all the processes found so far. It is similar to dilution in that the proteins are diluted until they are liquefied. The liquid proteins are then put in a [vortex fluid device](#) which puts enough stress on the proteins that they are then refolded back into their proper shape. This process is being used for cancer research, but was found that it could be used to un-cook an egg. An Australian man was able to un-cook an egg using this process [36].

In each of these processes, the goal is to remove impurities and untangle proteins so they can possibly be refolded back into their original shape to be useful again. These processes are all currently being used to further cancer research [33], and it has been found that due to what these processes are trying to achieve, they can be applied to the problem of un-cooking an egg [31].

Summary/TLDR

Most interactions with the cooking of eggs involve breaking old bonds in egg proteins through denaturation and forming new ones in their stead. When eggs are cooked, heat denatures the proteins and after the proteins bond with water, the eggs solidify and change color. When eggs are beaten, proteins are denatured via stress, and they coagulate around air molecules to create foam, which, when added to an acid and sugar, can be used to create a stable, voluminous meringue. When eggs yolks are combined with other ingredients, an emulsification can be created, and this allows two ingredients that will not naturally mix to stay together and create a new mixture. To un-cook an egg, the proteins must be untangled and refolded to their original shape; this can be done either through molecular dialysis, dilution, or by liquefying proteins and refolding them through stress.

Appendix

Dilution

A process used to refold proteins, which is done by diluting the tangled proteins so they become untangled and will refold themselves.

Disulfide Bridges

A type of bond that forms between sulfur groups on proteins. These bonds are stronger than ionic bonds, and when they form between egg white proteins, they tighten up the structure of the protein bubbles that form around air and water molecules in the foam [17]. This can result in water molecules being pushed out, and will cause the egg whites to become gritty and dry. Without water inside the bubble structures, the egg whites will break down and ruin the meringue. This can be avoided by using the copper bowl trick, because whisking in the

copper bowl will cause copper molecules to break off and bind with the sulfur groups. Another way of avoiding disulfide bridges is by adding an acid to the mixture, because a lowered pH also inhibits this type of bond from forming. Be sure to avoid using these two tips together, or [your meringue will be ruined](#).

Inclusion Bodies

A generic term for any inactive foreign mass that accumulates in or around a molecule or cell.

Intermolecular Forces

Forces that come from interactions between molecules.

Intramolecular Forces

Forces that come from interactions within molecules.

Lecithin

Lecithins are the specific phospholipids found in egg yolks which makes these yolks into useful emulsifiers. Lecithins contain a mixture of different phospholipids including phosphatidyl choline and phosphatidylethanolamine. As phospholipids, the lecithin have a hydrophobic tail and a hydrophilic head, and this means that one side is attracted to water, while the other side is not. As this phospholipid is combined with mixtures that contain water and oil, two substances that do not mix naturally, then these lecithins with the hydrophobic tails and hydrophilic heads, will arrange around the water and oil droplets to create a stable mixture. Lecithins are an important chemical component of the egg yolks that allow emulsifications to be created [\[20\]](#).

Molecular Dialysis

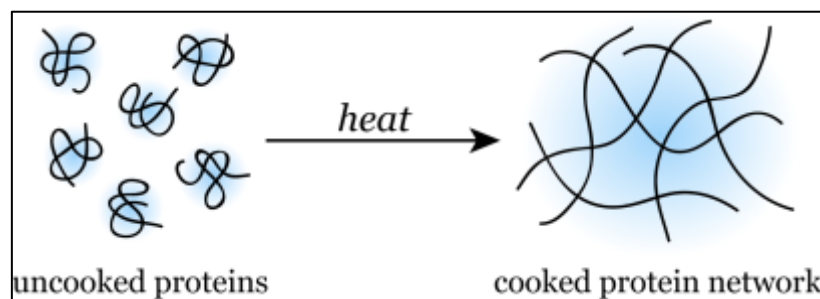
The process of using a semi-permeable membrane to filter out smaller molecules from larger ones.

Protein Structures and Denaturation

Proteins are complex macromolecules made up of thousands of amino acids held by weak bonds [\[38\]](#).

Denaturation occurs when the structure of a protein is altered. Weak bonds hold together proteins, and these bonds can be broken by heat, change in pH, or physical stress, among others. The

unfolded proteins sometimes are permanently denatured, as in eggs. The structure of a protein is related to its function, so an unfolded protein can no longer perform the correct function [\[39\]](#). In the case of adding heat to eggs, once the proteins are denatured they are open to form bonds with other molecules such as water.



Adding heat to proteins unfolds the condensed structure of proteins [\[40\]](#).

Refolding Buffer

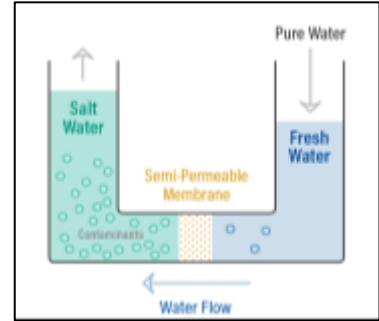
A substance that is used in the process of diluting proteins.

Semi-permeable Membrane

A membrane that allows smaller molecules to pass through openings along the surface of membrane.

Vortex Fluid Device

A device that applies direct stress to a protein to force it to refold into its original shape.



An image explaining how a semi-permeable membrane works [37].

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