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# EXPERIMENTAL COOKERY

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# EXPERIMENTAL COOKERY

*From the Chemical and Physical Standpoint*

BY

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WITH A LABORATORY OUTLINE

*SECOND EDITION*

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TO  
ELIZABETH MILLER KOCH  
*with*  
*acknowledgment of help,*  
*inspiration, and encouragement*



## CONTENTS

CHAPTER	PAGE
I. THE RELATION OF COOKERY TO COLLOID CHEMISTRY . . . .	1
II. SUGAR COOKERY . . . . .	31
III. FREEZING . . . . .	83
IV. FRUITS AND VEGETABLES . . . . .	103
V. JELLY . . . . .	152
VI. GELATIN . . . . .	178
VII. MEAT . . . . .	194
VIII. EMULSIONS . . . . .	266
IX. MILK AND CHEESE . . . . .	293
X. EGG COOKERY . . . . .	323
XI. FLOUR AND BREAD . . . . .	391
XII. BATTERS AND DOUGHS . . . . .	447
XIII. FATS AND OILS . . . . .	542
INDEX . . . . .	585



## INTRODUCTION

The principal function of this volume is to present our newer knowledge of food preparation and cookery processes from a chemical and physical basis, particularly that of colloid chemistry. In doing this, many results secured from experimental work along these lines at Iowa State College have been included. A condensed arrangement of the data on cookery, which are found in widely scattered sources, has been included also.

Many of the sciences serve as a foundation or basis for food preparation. Inorganic, organic, physical, and plant chemistry, as well as physics and other sciences, are necessary for an adequate understanding of many processes in food preparation. But the subject matter herein covered is perhaps more closely related to physical chemistry and the branch of physical chemistry known as colloid chemistry. In fact, so many of the ingredients used in food preparation are colloidal in nature that food preparation may be classed as one field of applied colloid chemistry. As a phase of colloid chemistry it offers a vast field for exploration, for although commercially prepared foods have been studied extensively the problems in connection with their preparation are far from completed. Work along other lines of cookery has hardly started. Some of the older work on cookery needs to be repeated and explained in the light of newer interpretations of science.

Because the majority of home economics students have had no opportunity to take even an elementary course in physical or colloid chemistry, it becomes necessary to present a simple outline and explanation of colloid chemistry in its relation to food preparation. Since this is the foundation material for this treatise it seems logical to present it first. But to many persons this is the newest and perhaps the most difficult subject matter in relation to food preparation. Therefore, it is probably better for the student to commence with the chapters on sugar cookery, freezing, and fruits and vegetables, referring only to the few paragraphs in Chapter I needed to understand some of the factors of sugar cookery and freezing. A fundamental understanding of sugar cookery and freezing preparation processes is based largely upon the portion of physical chemistry dealing with solutions, vapor pressure, the boiling point, and the freezing point. This material is outlined in these chapters. But to present the material on colloid chemistry in such a manner in every chapter would lead to many repetitions and make the book unduly long. Hence this material is summarized in Chapter I, although the author realized that it would probably be necessary to review or to present portions of this chapter in connection with subsequent ones.

Many contradictory observations are often made in cookery. This is to be expected, particularly when the materials used are in a colloidal state. Unless the constituents of food products are present in the same amount, and, even if present in the same proportion, if the colloidal particles are not the same size, if the previous treatment, including the thermal and mechanical treatment and the time element, is not exactly duplicated, then even an elementary knowledge of colloid chemistry leads one to expect different results in finished products, because of variation of these different factors. It is not possible to control all these factors. For instance, the variation in ash content of flour, eggs, milk, meat, fruits, and vegetables is nearly always beyond our control. But the necessity for a detailed description of the technic and method followed in reporting results is obvious. Detailed directions in writing the laboratory outline are essential or the technics followed may vary so much that the results are worthless for comparisons. It is of course understood that adequate explanations cannot be offered for all cookery processes. In some instances it is necessary to determine the results time after time and let the theory fit the laboratory facts. In other cases the explanations offered will need to be changed, modified, or replaced by data obtained from future investigations.

In starting the laboratory work the author asks her students to assume the attitude that every result obtained is right. If it is not as expected, what are the reasons? For example, a burned, charred product results from certain procedures. If, when students have used the same proportions, the same ingredients, and tried to follow the same technic, the individual results differ, what are the possible interpretations for the divergence? In the same manner the reported results of other investigators are taken as correct. If the students' laboratory results do not always agree with reported results, interest comes in comparing methods used, the ingredients used, their proportion, and the technic followed, to find explanations for agreement or disagreement.

It is hoped that this volume will fill a need for a textbook for discussion material for food-preparation courses in colleges and as a reference work for teachers of secondary schools. It is also hoped that the reference to and summary of articles in the literature will create an interest on the part of the student to read and interpret them for herself.

Food-preparation study in colleges may include courses designated as experimental cookery. The material in this book may be given in such courses. The manual "Food Preparation Studies" by Child-Niles-Kolshorn will also be an aid in these courses.

To some the term experimental cookery implies only a method of presenting material. Such is not the use of the expression in this volume. It is used to designate a certain field of subject matter relating to food preparation. The laboratory outline included in this volume is arranged to present this subject matter as far as possible.



What constitutes or should constitute experimental-cookery courses cannot be answered fully at the present time. They are of necessity rapidly developing and changing. The author believes that eventually they will have the same relation to food-preparation courses that those in animal feeding have to nutrition courses.

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# EXPERIMENTAL COOKERY

## CHAPTER I

### THE RELATION OF COOKERY TO COLLOID CHEMISTRY

The early lines of food work cannot be expressed better than in the words of Ostwald (1922). "Scientific study of the field still contents itself with chapters on analysis and the recognition of adulterants, but chapters dealing with the preparation of food are hardly started. Much as every one would like to obtain better food for less money, study of such questions is regarded as menial and best left to the cook. A scientific study of the preparation of food is considered as only amusing even in scientific circles." Later Ostwald remarks that the chapters that are missing in food preparation are the ones to which colloid chemistry may be applied.

Since so many phases of food preparation are based on colloid chemistry it seems necessary to include in this book a chapter on its relation to cookery. It is a short and brief outline. As such, it can be used as an introduction or as a summary or for both introduction and summary of the work on food preparation, although the subsequent chapters have been written with the idea that at least portions of this chapter will be used in connection with each of them.

Thomas Graham's contributions constitute the foundations of colloid chemistry. His most important results were published between 1861 and 1864. But it is only since the publications of von Weimarn and of Ostwald in 1906 and 1907 that rapid development has been made in colloid chemistry, and it is an even shorter time since the most extensive applications of it have been made to food preparation. Graham used the terms crystalloids and colloids to apply to definite materials. Crystalloids were dialyzable through parchment membrane, whereas colloids were not dialyzable. The terms are now misleading, for we know that any crystalloid can, by a definite treatment and the selection of the right medium, be brought into the colloidal state. Many of the so-called colloids can be crystallized. The term colloidal state indicates that the material is dispersed in another substance, so that it is preferable to speak of colloidal systems rather than colloids. Colloidal systems differ from molecular ones in the size of the dispersed particles. This difference in size of the particles gives different physical properties to the system.

Bancroft states that "adopting the very flexible definition that a phase

## 2 RELATION OF COOKERY TO COLLOID CHEMISTRY

is called colloidal when it is sufficiently finely divided, colloid chemistry is the chemistry of bubbles, drops, grains, filaments, and films, because in each of these cases at least one dimension of the phase is very small. This is not a truly scientific classification because a bubble has a film round it, and a film may be considered as made up of coalescing drops or grains." A knowledge of colloid chemistry is necessary to have a real understanding of processes and methods used in a large number of industries and occupations. Bancroft gives a list of 60 such occupations, which include: "cream, butter, cheese, and casein products; cooking and washing."

### Classification of Substances Based upon the Degree of Dispersion in Solution

**Solutions and suspensions.** When a solid substance is added to a liquid one of three types of mixtures may be formed. (1) A true solution, which is a homogeneous mixture. (2) A colloidal solution, which appears to be homogeneous. The dispersed particles have a size of  $1\text{ m}\mu$  to  $0.1\mu$  and can be separated by a sufficiently fine filter. (3) A suspension in which the dispersed particles are greater than  $0.1\mu$ . The dispersed particles can be separated from the liquid by filtration or sedimentation. Gortner states, "Inasmuch as fine suspensions possess, to a large degree, certain characteristic properties of colloidal systems, there has been a general tendency of recent years to raise the upper limit to  $0.5\mu$ ," instead of  $0.1\mu$ . It should be understood that the above classification is an arbitrary one and that in nature there are no abrupt transitions. There can be no definite division made between true and colloidal solutions for the transition is gradual. There are some colloidal solutions known in which the dispersed particles are less than  $1\text{ m}\mu$ . There is also no line of demarcation between colloidal solutions and suspensions.

In true solutions the dispersed phase consists of particles of molecular or ionic size, whereas the colloidal solutions contain particles of larger size, and the suspension contains particles large enough for mechanical separation. The smaller the particles with a definite quantity of material the more dispersed the substance; the larger the particles the less dispersed. A true solution can be reproduced if the temperature, pressure, and concentration are known, since the degree of dispersion is constant. But in colloidal solutions it is necessary to know the degree of dispersion as well as the temperature, pressure, and concentration to reproduce the system. The properties of solutions like gelatin also depend upon the method of preparation and their previous history; the properties of a true solution are independent of the method of preparation or their previous history. The systems whose properties are dependent upon their previous history are said to show hysteresis.

Colloidal systems are heterogeneous, so that it is necessary to distinguish which is the dispersed phase and which is the dispersing medium. Some of

the terms used are dispersed phase and dispersing medium · discontinuous phase and continuous phase; internal phase and external phase; and micelles and intermicellar liquid. The usage of the last group appears to be increasing at the present time.

TABLE 1  
CHARACTERISTIC DIFFERENCES OF

True solutions	Colloidal solutions	Suspensions
In molecular subdivision	In colloidal subdivision	In mechanical subdivision
Particles are not visible with ultra-microscope	Refracted light of particles is visible with ultra-microscope	Particles visible with ordinary microscope or naked eye
Particles less than $1\ \mu$	Particles from $1\ \mu$ to $0.1\ \mu$	Particles greater than $0.1\ \mu$
Formation of gels is not characteristic	Formation of gels is characteristic	Formation of gels is not characteristic
Transparent	Transparent	Generally opaque
Particles pass through parchment membranes	Particles or micelles pass through high-grade filter paper, but not parchment	Particles do not pass through high-grade filter paper
Intense kinetic movement	Less kinetic movement, more Brownian movement	Little movement
Systems show high osmotic pressure	Systems show low osmotic pressure	Systems show no measurable osmotic pressure

Particles of colloidal size may be in a gaseous, liquid, or a solid state. These micelles may be dispersed in solids, liquids, or gases; and if systems are classified according to the dispersed and dispersing medium there may be a

- solid in a solid, ruby glass;
- liquid in a solid, opals;
- gas in a solid, pumice;
- solid in a liquid, gold sol;
- liquid in a liquid, lyophilic colloids;
- gas in a liquid, whipped cream;
- solid in a gas, smoke;
- liquid in a gas, fog.

Sometimes the classification of colloidal systems is based on the dispersed phase only, and this is designated as a solid, liquid, or a gas, according to the material dispersed. Gortner adds emulsions to the above eight systems to be considered in colloidal systems.

**Dispersion of substances.** It is possible to change particles from molecular size to suspension particles and *vice versa*. Ostwald states that "it may be accomplished either through the dispersion of nondispersed or coarsely dispersed substances, or through the condensation of molecularly dispersed systems. To these ends not only chemical but mechanical, electrical and other kinds of energy may be used." Water passes from the molecular through the colloidal and into the suspension state in freezing. Von Weimarn states that all crystalline substances pass through a colloidal zone in going into solution and in crystallizing from solution, for during crystallization the size of the particles increases, passing from molecular, through colloidal, to suspension dimensions. This emphasizes the fact that, within each group or class of substances, there may be a wide variation in the degree of dispersion. This dispersion, as in crystallization, may pass through molecular, colloidal, and suspension zones, whereas with other substances there may be wide degrees of dispersion of the substance within one zone. The properties of the systems vary with the size and degree of dispersion of their particles, which affect the results obtained in cookery. The properties of colloidal particles approaching molecular dispersion are different from those of particles approaching the suspension zone. One illustration will be mentioned. The gluten particles of flour have colloidal dimensions. According to Gortner and Doherty, not all gluten particles from different flours are the same size. The gluten particles in pastry flour are more dispersed or of smaller size than those in bread flour. This is one reason for the different results obtained in baked foods when bread flour is used instead of pastry flour. The properties and baking qualities of different flours vary with the size of the gluten particles.

Particles approaching the limits of the size of one zone may show properties of two zones. Thus sugar has a high molecular weight and in cookery shows both molecular and colloidal properties as if it belonged to an in-between group. In gelatin dishes with a definite concentration it increases the stiffness of the gel; in custards it acts like a protective colloid.

### Increasing and Lessening the Degree of Dispersion of Substances in Food Preparation

In food preparation many of the methods used and many of the ingredients added to foods bring about increased or decreased dispersion.

**Heat.** Increasing the temperature may bring about a greater or a lesser degree of dispersion. The heating of water increases its dispersion. The dispersion of fat globules in milk is increased by the application of heat to



the milk, but when proteins are coagulated by heat the degree of dispersion is decreased.

**Mechanical dispersion.** Beating of a food is a mechanical means of bringing about a greater or a lesser degree of dispersion. In cookery, stirring may bring about more uniform distribution of particles in a food, like white sauce. But even this may prevent lumping or clumping and thus is a means of bringing about dispersion, just as beating a curdled custard is a mechanical means of bringing about a greater degree of dispersion of a suspension, but although it reduces the size of the curds it does not reduce them enough to change the suspension to the colloidal state. Homogenization of milk or cream is a mechanical means of increasing the dispersion of fat particles. Beating an egg white is a mechanical means of lessening the degree of dispersion, as it brings about partial coagulation of the egg white in the cell walls surrounding the air bubbles.

**Dispersion by acids.** The addition or the development of acid in preparation of food may be a chemical means of bringing about a greater or a lesser degree of dispersion. For instance, the development of acid during the fermentation of bread brings about greater dispersion of the gluten. The addition of acid to whole egg tends to curdle the egg or bring about a lessened degree of dispersion. If a large enough quantity of acid is added, the degree of dispersion may be increased after passing through a zone of lesser dispersion. The explanation of the different effects of acid on the gluten and on the egg proteins depends upon the isoelectric point of the gluten and the egg protein and the degree of acidity developed. This will be considered later.

**Dispersion by alkalies.** The addition of alkalies may also tend to bring about a greater or a lesser degree of dispersion. In quick breads and cakes the addition of soda in excess of the amount required to neutralize the acidity of the mixture may bring about increased dispersion of the gluten particles, which results in a definite grain or crumb.

The different methods of bringing about a lesser or a greater degree of dispersion are applicable to all food products. In some cases the effect may be modified by other factors. It is interesting to trace these through different classes of food products. If alkali is taken as an example, its effects on some foods may be cited. The alkalies, hydroxides of ammonia, sodium, and potassium or their basic salts are the ones considered. Calcium and magnesium salts may have different effects.

Sucrose is little affected by alkalies if they are not stronger than those ordinarily used in cookery. But when alkalies are added to the monosaccharid sugars they bring about decomposition. The sugar in solution is in the molecular state, and the alkalies cause increased dispersion, even though the sugar and its decomposition products both remain in molecular dispersion. The properties of the decomposition products are different from those of the original sugar.

Vegetables and fruits are softened by the addition of alkalies during

cooking, and they may become mushy and disintegrate. This is probably due to the greater dispersion of the cellulose and pectic substances. In dried legumes, alkalis may also increase the disintegration of some of the protein.

Milk is prevented from curdling or coagulating by the addition of alkali. Curdling is a lessened dispersion of the milk protein, casein. The addition of alkalis to eggs elevates the temperature for coagulation. Alkalis added to doughs cause a greater degree of dispersion of the gluten, which results in a dough that is runny and sticky to handle. In larger quantities the baking quality of the flour is partially destroyed. Alkalis added to gelatin tend to prevent its setting, and they may cause greater dispersion in emulsions.

**Dispersion by enzymes.** Enzymes may also cause an increased or lessened degree of dispersion in foods. The clotting of milk upon the addition of rennin is an example of lessened dispersion, but the proteinase enzyme in flour increases the dispersion of the gluten.

### Classification and Properties of Colloids Based upon Physico-Chemical Relationships in Liquids

Each colloidal solution as well as each true solution has its own peculiar properties. These depend upon the nature of the particles in solution and the dispersing medium. But a large group of colloidal systems may have similar properties, and for convenience they are classified in a group or subdivision. The classification of colloidal systems into groups is not always satisfactory, for there is no distinct line of demarcation between the different subdivisions. Ostwald, Freundlich, Gortner, and Buchanan and Fulmer give excellent discussions of the properties of colloidal systems which are of interest to those concerned with food preparation.

**Suspensoids and emulsoids.** One basis for classification of colloidal systems is the nature of the dispersed phase. In a suspensoid the dispersed particles are in a solid state. In an emulsoid the dispersed particles are in a liquid state. Many authorities classify suspensoids and lyophobic, emulsoids and lyophilic, as being coextensive, but Freundlich states that this is incorrect, for there are many emulsoids with lyophobic properties.

**Reversible and irreversible colloids.** If after a colloidal solution is evaporated, a sol is reformed upon the addition of water, the colloid is classified as a reversible colloid. Gelatin and dried egg white are examples of this type of colloid. An irreversible colloid does not spontaneously form a sol with the addition of water, after water has been evaporated. Reversible and hydrophilic colloids are coextensive; irreversible and hydrophobic colloids belong to similar groups.

**Sols and gels.** Colloidal solutions are also classified upon the basis of their consistency. Those which are apparently solutions are called sols. Those with a jelly-like consistency are called gels. The consistency of fruit jelly or a gelatin dessert is that of a typical gel. There is no distinct line

of separation between sols and gels, nor on the other hand, according to Jordan Lloyd, between gels and curds. The classification of gels on the basis of consistency includes many gels that do not have similar properties. Some gels are formed from sols by coagulation. Custard is an example of this type. A starch gel is formed by gelatinization of the starch during cooking. Gelatin, agar-agar, and soaps form sols above certain temperatures and gels at lower temperatures. Such gels are called reversible. The sol-gel transformation is brought about gradually, there being no definite melting or setting temperature. The change from a sol to a gel by cooling is termed gelation and is a distinct process from that of coagulation. Temperature, time, concentration, and the presence of electrolytes or non-electrolytes are factors in gel formation. There are various theories regarding gel structure, but space does not permit considering them here. It may be added that there is a similarity between crystallization and gelation. Jordan Lloyd states that "gelation is a process closely parallel to crystallization and is accompanied in most cases by evolution of heat." One other factor of similarity is that with rapid cooling a finer structure of the micelles is obtained.

**Swelling of colloidal gels.** Freundlich designates the gels that may imbibe a liquid and give it up as turgescible, and those which do not swell as non-turgescible. The imbibition of water is known as turgescence; the giving up of water is designated as deturgescence. The term hydration is used to indicate imbibition of water by the micelles; solvation is the general term used for all liquid dispersion mediums. The lyophilic colloids are characterized by their affinity for their dispersion mediums. Whether the micelles of gelatin, agar-agar, etc., actually act as a solvent for the intermicellar liquid, or whether the liquid is attracted and bound, probably by electrical forces, to the surface of the micelle in the form of a shell is still a disputed question. The amount of water that can be held by many of the micelles in the form of a shell around the particle is relatively enormous. As the concentration of the micelles is increased, the viscosity of the solution increases, owing to a larger portion of the dispersion liquid being bound. A concentration of 0.75 per cent of pectin micelles gives a fruit jelly of good texture. Increasing their concentration gives a stiffer jelly. The molecules of the dispersion medium are probably oriented in a definite manner around the micelle, for the volume of a gelatin gel is less than the combined volume of the dry gelatin and the water.

The ability of the micelles to take up and hold water is important in food preparation. The thickening of a cup of milk by an egg in a custard is due to the ability of the egg proteins to bind the liquid. The thickening power of starches is due to the swelling of the starch granules during heating. The ability of proteins, starches, etc., to imbibe water is very great. A pressure of 2500 atmospheres is required to prevent the swelling of starch when it is heated in water. Gortner defines imbibition pressure as "the pressure against which such a colloid will imbibe a liquid, or conversely the

pressure which is required to force the dispersions medium out of a gel. Imbibition pressures should not be confused with osmotic pressure, and in many instances they assume values greatly in excess of values obtainable by osmotic pressure. If a sheet of dried gelatin is placed in a saturated solution of sodium chloride, water will be withdrawn by imbibition forces against the osmotic pressure of the sodium chloride solution, and sodium chloride will crystallize out in the solution."

The micelles possess either a positive or a negative charge. When the electrical forces holding the bound water to the micelle are neutralized, as may happen when electrolytes are added under suitable conditions, the bound water is released and the viscosity of the system decreases. When a custard is curdled the bound water is set free. The ability of muscle fibers to hold water during cooking prevents drying of the meat to a great extent.

**Effect of added substances upon swelling of gels.** The addition of such substances as acids, alkalis, mineral salts, and sugar may increase or inhibit the degree of swelling. Many such combinations are made in cookery. Lemon juice and vinegar may be added for flavor. Soda, salt, and baking powder may be added to foods. Different proportions of mineral salts are found in foods, and the proportion may vary in the same food owing to many causes. In general, the addition of acids or alkalis increases the swelling of colloidal gels. With acids, this usually continues until a maximum is reached at  $pH$  3.0 to 2.5, when imbibition is decreased with greater acidity. With alkalis the maximum swelling is about  $pH$  10.5, though gluten gels are likely to disintegrate when they become as alkaline as this. Sometimes the addition of acids or alkalis lessens hydration. This depends upon the  $pH$  of the substance when the acid or alkali is added. In general, salts lessen the degree of swelling even in the presence of acids or alkalis.

**Syneresis.** After gels are allowed to stand protected against evaporation for a number of hours there is a tendency for the gel to separate into two phases. A liquid may squeeze out of the gel. A typical example is the separation of the whey from the curd in clabbered milk. It is also noticed in some jellies, cranberry jelly in particular. This separation into a more solid and a more liquid part may take a long time in the case of some food gels, a shorter time in others. In syneresis the liquid part contains a large proportion of the solvent, a smaller proportion of the solid. The more solid part has a high concentration of the solid, a lower one of the solvent.

**Hydrophilic and hydrophobic colloids.** The terms lyophilic and lyophobic include all dispersing mediums whereas hydrophilic and hydrophobic indicate that the dispersing medium is water. Hydrophilic means "water loving"; hydrophobic means "water hating." The lyophilic colloids belong to the liquid dispersed in liquid systems, though as pointed out by Gortner and by Fischer this terminology is not strictly accurate, for the dispersed phase and dispersing medium are more or less soluble in each other. Thus, with gelatin and water, hydration occurs or the two are

mutually more or less soluble in each other. The chief differences between hydrophilic and hydrophobic colloids are their degree of hydration and their reaction to electrolytes. The particles of a hydrophilic colloid require the addition of a large quantity of an electrolyte to bring about coagulation, whereas the hydrophobic colloids are sensitive to, and coagulated by, very small quantities of electrolytes. Gelatin, agar-agar, starch, and protein solutions belong to the hydrophilic group; the metal sols belong to the hydrophobic group. There is no distinct line between the hydrophilic and hydrophobic colloids. Even the particles of the rather typical hydrophilic colloids are not hydrated to the same extent. Thus an agar-agar sol is more strongly hydrated than a gelatin one. Another way of expressing this is to say that about 1 per cent of agar-agar will form a stiff gel, but more than 1 per cent of gelatin is required for a stiff gel.

**The charge on colloidal particles.** That the micelles possess either a negative or a positive charge is agreed, though the origin of the charge is still disputed. For aqueous solutions the charge is most easily explained on the basis of adsorbed ions. The charge may also come from ionization of the micelle, or by electrification by contact with the dispersing medium, in the same manner that a glass rod becomes charged when rubbed with fur. If the charge on the micelles is reduced to practically zero, the colloidal system becomes unstable. The electrical charge is one important factor in the stabilization of sols. One example in foods is the casein of milk. When the electrical charge of casein reaches zero, the protein flocculates and is precipitated. Kruyt cites it as an example of a protein sol that is not sufficiently hydrated to be stabilized by hydration alone, so that it can exist when negatively or positively charged, but not when the charge is neutralized.

Freundlich uses the term electrokinetic phenomena to designate certain electrical properties of colloidal systems. He also states that these electrokinetic phenomena are closely associated with the physical properties of interfacial tension, adsorption, colloidal stability, mutual precipitation, and flocculation.

The theories that have been advanced to explain electrokinetic phenomena are based upon the double-layer theory of Helmholtz. This theory is that the micelle is surrounded by a double layer of ions, the inner layer, which may be negative or positive, being closely adsorbed by the micelle, and the outer layer, consisting of ions of opposite charge from those of the inner layer, lying close to the micelles in the intermicellar liquid. If the inner layer of ions is negative, the micelle is negatively charged, the outer layer being positively charged. As the colloid passes through its isoelectric point the charge of each double layer is reversed.

**Effect of electrolytes upon hydrophobic colloids.** When a hydrophobic colloid is coagulated by an electrolyte its electric charge is removed. The amount of electrolyte required depends upon several factors: (1) The manner of adding. More electrolyte is required if it is added in

small portions than if added all at once. (2) The valence of the ion bringing about the coagulation. Coagulation is brought about by the ion having the opposite charge to that of the colloid. As a general rule, the precipitating effect is increased with an increase of valence of the ion bringing about the coagulation. There are exceptions to this rule, as some monovalent ions have greater effect in bringing about coagulation than some polyvalent ions. (3) Concentration of the electrolyte. In many cases there are zones in which a definite concentration of the electrolyte brings about maximum coagulation. Higher or lower concentrations are not so effective or may not bring about coagulation. This is illustrated later in egg cookery. High concentrations of ferric or aluminum chloride do not bring about coagulation of distilled-water custards but small concentrations cause coagulation. (4) The concentration of the colloid also affects the amount of electrolyte required for coagulation. (5) A definite time may be required, depending upon the concentration of the protein and electrolyte.

**Effect of electrolytes upon hydrophilic colloids.** The effect of electrolytes upon hydrophilic colloids is varied. Kruyt states that the hydrophilic colloids are stabilized by two factors, the electric charge and the strong hydration of the particles, and after the hydrophilic colloid is dehydrated it is as sensitive to electrolytes as the hydrophobic colloids. Dehydration of the hydrophilic colloids may be brought about by different means. Some proteins may be dehydrated by heating. Alcohol may be used to dehydrate hydrophilic colloids, and tannins may also bring about dehydration. This dehydration by heating or other means is called denaturation. If an egg white is dialyzed and the electrolytes removed it is not coagulated when heated. But the addition of electrolytes to the heated dialyzed egg white brings about coagulation. Kruyt states that if small quantities of electrolytes are added to a starch or agar-agar sol the electric charge is removed but the colloidal particles do not precipitate. If alcohol, a dehydrating agent, is added to the above starch or agar-agar sol, coagulation occurs. It is immaterial in which order the two stability factors, the electric charge and hydration, are removed. The removal of one has no evident effect, but the removal of both factors causes coagulation. The term denaturation will be used in later references to indicate sensitization of hydrophilic colloids to electrolytes. The term denotes whatever changes are brought about during dehydration of the colloid.

The action of electrolytes upon proteins is given as follows by Buchanan and Fulmer.

“1. Those electrolytes which bring about a reversible precipitation in high concentration. These include the salts of the alkalis, K, Na,  $\text{NH}_4$ , Li and possibly Mg. Ammonium sulphate is commonly used in ‘salting out’ of proteins. The precipitate so formed will be redissolved on dilution, i.e., the process is reversible.

“When the protein is on the alkaline side of its isoelectric point (i.e.,



negatively charged), the order of effectiveness of the salt is on the basis of cations:  $\text{Li} > \text{K} > \text{Na} > \text{NH}_4 > \text{Mg}$  and of anions, citrate  $>$  tartrate  $>$   $\text{SO}_4 >$  acetate  $>$   $\text{Cl} >$   $\text{NO}_3 >$   $\text{ClO}_3 >$   $\text{I} >$   $\text{SCN}$ .

"2. Those electrolytes which bring about an irreversible precipitation in concentrated solutions. These include the salts of alkaline earths, Sr, Ba, Ca, and possibly Mg.

"The order of effectiveness for negatively charged protein is  $\text{Ba} >$   $\text{Ca} >$   $\text{Sr}$  and acetate  $>$   $\text{Cl} >$   $\text{NO}_3 >$   $\text{Br} >$   $\text{I} >$   $\text{SCN}$  with the reverse order for the positively charged protein.

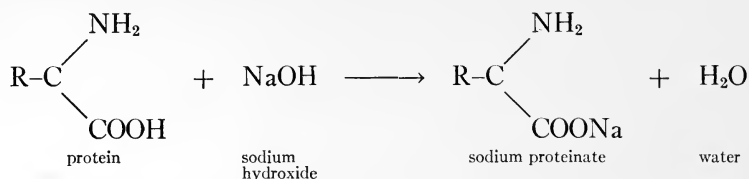
"3. Those electrolytes which in low concentrations bring about an irreversible precipitation. These include the salts of the heavy metals such as Ag, Hg, Fe, Cu. An interesting characteristic of this group is the fact that two optimal zones may be found. For instance, copper sulphate solutions precipitate albumin in concentrations from  $0.001 N$  —  $1 N$ , in higher concentrations the precipitate redissolves, a precipitate appearing again at a concentration of  $6 N$ . Zinc salts show maximal precipitation at  $0.01 N$  —  $0.5 N$  and again at  $4 N$ ."

**Protective and denaturing colloids.** A substance that tends to prevent coagulation of micelles is designated as a protector; if it is in the colloidal state it is called a protective colloid. Sometimes small amounts of a colloid sensitize instead of protecting. The latter are sometimes called denaturing colloids.

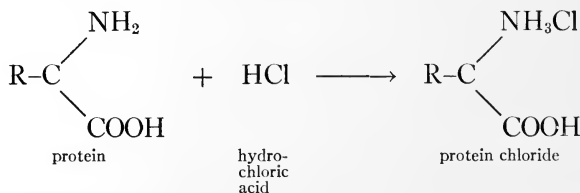
**Amphoteric colloids.** Substances that combine with either acids or bases are known as amphoteric substances. Proteins belong to this group. They are composed of amino acids. The amino acids contain amine ( $-\text{NH}_2$ ), and carboxyl ( $-\text{COOH}$ ), groups. The  $-\text{NH}_2$  groups combine with acids; the  $-\text{COOH}$  groups combine with alkalies. Most of the  $-\text{NH}_2$  and  $-\text{COOH}$  groups are linked or bound in forming the protein molecule, but some are free, and combinations with acids and bases are formed with these free groups.

**Isoelectric point.** At a definite acidity or  $p\text{H}$  for each protein, there is a point called the isoelectric point. The  $p\text{H}$  of different proteins at the isoelectric point varies because of the different amino-acid content of each protein, which results in a larger or smaller number of  $-\text{NH}_2$  or  $-\text{COOH}$  groups. At the isoelectric point the protein is combined with neither anions nor cations or else it is combined with both equally, for the charge is neutral. Thus at the isoelectric point in a cataphoresis experiment the protein does not migrate to either the anode or cathode. At the isoelectric point certain characteristic properties of the protein are at a minimal, i.e., it is most easily precipitated by electrolytes, is least soluble, shows the least viscosity, is also less dispersed, and least stable as a colloidal solution. Other minimum points at higher acidity or alkalinity than the isoelectric point are not considered in this discussion, for they are found less frequently in food preparation.

**Combinations of proteins with alkalis.** At a  $pH$  above its isoelectric point the protein combines with alkalis to form such salts as sodium proteinate, calcium proteinate, etc.



**Combination of proteins with acids.** At a  $pH$  below the isoelectric point or on the acid side the protein combines with acids to form salts such as protein chlorides. Here the effect is additive and similar to the addition of hydrochloric acid to ammonia to form ammonium chloride.



**Combinations of proteins with acids or alkalis in food preparation.** Many combinations of proteins with acids or alkalis are formed in food preparation. Most alkaline salts of the proteins are soluble. Some of the acid salts are soluble; others are difficultly soluble. Casein, the protein present in milk in the largest quantity, has a  $pH$  of 4.7 at its isoelectric point. Casein in sweet milk is found as an alkaline salt. Fresh milk has a  $pH$  of 6 to 7. If an acid is added to the milk the casein will be precipitated when the reaction of the milk reaches the isoelectric point of the casein,  $pH$  4.7. This occurs in natural souring by the formation of lactic acid in the milk. Familiar examples of combinations of acid with milk are the addition of lemon juice to milk for sherbet or the addition of tomatoes to milk for cream of tomato soup. If enough acid is added to lower the reaction of the milk below the isoelectric point of the casein, an acid salt is formed. If this salt is soluble, the curds of casein will dissolve. This change of the protein from an alkaline to an acid salt often occurs in making mayonnaise and other salad dressings. The addition of a small amount of acid to egg yolk will curdle it, but upon the addition of a little more acid the curd may dissolve.

**Stoichiometrical combination.** Stoichiometrical combination means that the reaction between compounds is carried out according to the laws of valence. Loeb and others working with dilute solutions of proteins, acids, alkalis, and salts showed that proteins combine with acids and alkalis in stoichiometrical relationship. But Hoffman and Gortner have shown that proteins in stronger concentrations of acids or alkalis adsorb

acid or alkali. This means that owing to the surface area and the physical property of adsorption the proteins can combine with larger quantities of acids or alkalies than is possible in stoichiometrical combination alone.

### Boundary Phenomena

Because of the size of micelles, surface phenomena assume an important place in colloidal reactions. Surface tension, the formation of foams, interfacial tension, adsorption, formation of surface skins, orientation of molecules, cohesion, and adhesion all have application in food preparation. Different authorities use a different terminology to designate the chemical and physico-chemical processes taking place at the interface between two phases. Kruyt calls them boundary phenomena, Freundlich designates them as capillary chemistry, and other authorities use other terms.

Total surface area increases in proportion to the increase in number and decrease in size of the micelles. Molecular systems have proportionally a greater surface area than colloidal ones, but, on account of the small size of the particles, other forces have a greater effect than surface ones in molecular systems.

Freundlich states that "The subject of capillary chemistry may be divided into natural subdivisions, according to the nature of the interfaces which separate the various possible pairs of phases. We can distinguish the following interfaces: liquid/gaseous, liquid/liquid, solid/gaseous, solid/liquid, solid/solid. Because of the complete rigidity of the interface between two solids, the section relating to this pair drops out."

**Surface tension.** Arbitrarily, surface tension refers to the tension of a liquid/gas interface. Liquids like gases possess kinetic energy, but unlike gases they have a surface or a boundary layer. This boundary layer gives a liquid certain properties that gases do not have. Surface tension is the result of the inherent property of a fluid to tend to form a minimum surface under all conditions. The minimum surface for a given volume is in the form of a sphere; hence, when free to do so liquids assume a spherical shape. Small drops of water falling on a dusty surface or a waxy leaf tend to form in drops. Large drops are flattened by gravity. When drops of water fall on a surface like clean glass, they spread and wetting occurs. The forces acting between the clean glass and the liquid prevent the liquid assuming a spherical shape.

The molecules in the interior of a homogeneous liquid do not exhibit any surface-tension phenomena in relation to one another since they are subjected to a balanced attraction. That is, they are equally attracted by other molecules on all sides. But the surface film is in a state of tension due to the unbalanced attractions of the molecules at the surface. The molecules are attracted only downward and sideways. Whereas the molecules in the interior of the liquid are evidently arranged at random, those in the surface are oriented or arranged in a definite and orderly manner. Freundlich

states that it is only a step to conceive that this tendency to form a minimum surface resides in a membrane. Kruyt speaks of a boundary layer. The tension of this membrane is the so-called surface tension of the liquid. Surface tension is defined by Buchanan and Fulmer as "the amount of work required to produce a new surface of unit area at constant temperature." To enlarge the surface of the liquid requires work. The amount of work expended to enlarge a surface multiplied by the area increased is termed free surface energy. The amount of work to enlarge a surface is greater with increased surface tension. Just as the surface area of a liquid tends to assume a minimum surface through its inherent surface tension, so free energy tends to assume a minimum value. The free surface energy is decreased (1) by reducing the surface area or (2) by reducing the surface tension. Hence, small drops of liquid will unite with large drops if they are within the same space so that they are connected by their vapor, thus reducing the surface area.

Water has a high surface tension. Surface tension is measured in dynes per centimeter. The surface tension of water at 18°C. is 73.0; that of ethyl alcohol, methyl alcohol, and chloroform at 20°C. is 21.7, 23.0, and 26.7, respectively. The surface tension of mercury at 15°C. is 436.0. Surface tension decreases with increase in temperature, becoming zero at the critical temperature.

**The surface tension of solutions.** When a substance is dissolved in a pure liquid the surface tension of the solution may not be changed, it may be raised, or it may be lowered. The substances that scarcely change the surface tension or elevate it slightly include the aqueous solutions of most electrolytes and some organic compounds. Sugar increases the surface tension of water. Freundlich calls these substances capillary-inactive or surface-inactive. The group of substances that lower surface tension includes in aqueous solutions many organic compounds such as aldehydes, fatty acids, fats, acetone, amines, alcohols, tannins, saponins, and proteins. Freundlich calls this group of substances capillary-active or surface-active. If a substance lowers or increases the surface tension, the effect is always increased with its concentration. Surface tension can be lowered tremendously, but it can be raised to only a slight extent. If a substance lowers the surface tension its concentration is greater in the boundary layer than in the bulk of the liquid; and, conversely, if the substance raises the surface tension the concentration is less in the boundary layer.

Substances like the fatty acids, formic, acetic, propionic, and butyric, etc., that belong to a homologous series, show an increased lowering of the surface tension as the series is ascended, if they are kept at the same concentration. This regularity of increase with such a series is known as Traube's rule.

**Formation of foams. Absorption at liquid/gaseous interfaces.** A foam is a dispersed gaseous phase, the dispersing medium often being a liquid. The solutions of substances that lower surface tension are apt to

froth. Freundlich states that the formation of a foam is a complicated phenomenon. "Whilst in most other colloidal structures the particles of the disperse phase are of colloidal minuteness, this is by no means essential or even usual, in the case of foams. On the other hand the dispersion medium is often of colloidal fineness, that is, the gas bubbles are separated from one another by liquid films, having a thickness of only a few  $m\mu$ . Hence in a foam the surface of a liquid has been enormously extended, which is in opposition to the tendency of surface tension to make the surface a minimum. For this reason a liquid must fulfil a number of special conditions. In the first place the surface tension of the liquid must be small, for otherwise its tendency to reduce the surface would be too powerful." A second condition for the production of stable foams is that the vapor pressure shall be small, for substances with high vapor pressure evaporate rapidly. The surface films must not coalesce readily. These conditions are fulfilled by aqueous solutions of capillary-active substances, and especially by sols of many colloids, like soaps, saponins, tannins, and proteins. Freundlich states that in protein solutions a third influence plays a part, for they have the property of forming thin "pellicles" or surface skins on the boundary layer, which tend to prevent evaporation. Since the substance that lowers surface tension of the liquid is found in greater concentration in the foam, if the foam is continually removed as it is formed, the greater portion of the protein or other substance is removed. This is applied in the following and similar ways. In making sorghum molasses, in order to have a delicate-flavored product, one must have "a good boil" and remove the scum forming on the surface. In this way, tannins, which would increase the bitterness of the sorghum, proteins, and other substances are removed.

Rahn has shown analytically the results of the application of "the law of Gibbs and Thomson which states that substances which cause a depression of surface tension will accumulate in the surface. In a gelatin solution, there is more gelatin in the very surface layer than in the center of the solution." In a milk foam the concentration of protein is greater in the foam than in the solution. The analytical results of Rahn are given in Table 2.

Rahn states that "If protein is concentrated on the surface it has a tendency to become solid, but all proteins do not behave alike. Some solidify rapidly, others slowly, and some do not solidify at all. Quite often, this solidification is irreversible, and the protein, when put back into the solution, will not dissolve again." When milk foams, solid walls form around the air bubbles and, when the foam settles, these walls of protein can be seen with the aid of a microscope.

**Interfacial tension of liquids/liquids.** When two non-miscible liquids are poured together, one liquid forms a layer on top of the other, thus making a liquid/liquid boundary. The less the solubility of the two liquids in each other, the greater their interfacial tension; but most liquids

TABLE 2  
COMPOSITION OF SKIMMED MILK AND ITS FOAM (*Rahn*)

Constituent of the milk	Average of 9 experiments with intensely foaming skimmed milk		Average of 6 experiments with slightly foaming skimmed milk	
	Liquid part %	Foam %	Liquid %	Foam %
Protein . . . . .	3.09	3.51	3.01	3.24
Fat and lactose . . . . .	4.85	4.73	4.92	4.92
Ash . . . . .	0.75	0.78	0.74	0.76
Total solids . . . . .	8.69	9.02	8.67	8.92
Protein increase in the foam . . . . .		13.6		7.6

are not completely insoluble in each other. Just as a substance may concentrate at a liquid/gaseous interface, so likewise those substances which decrease interfacial tension tend to concentrate at a liquid/liquid or a liquid/solid interface. With the addition of a third substance soluble in water, Traube's rule holds, but if it is more soluble in the second liquid then the lowering of the interfacial tension is small and Traube's rule scarcely applies.

**Adsorption.** Adsorption has been defined as the concentration of a substance at an interface. The increased concentration at the interface is designated as positive adsorption; a decrease in the boundary layer is called negative adsorption. The amount adsorbed depends on the concentration of the material being adsorbed and the extent of the surface at which it can be adsorbed. The importance of surface reactions or phenomena cannot be over-emphasized in food preparation. Lowering of interfacial tension aids in the forming of emulsions. Fat is strongly adsorbed by sugar crystals, and when the two are mixed this aids in distributing the fat throughout the batter.

Bancroft states that peptization is always due to adsorption. Since peptization occurs frequently in food preparation, additional mention should be made of it here in connection with adsorption. Bancroft states that theoretically there are three possibilities when adsorption occurs at a surface. (1) If an adsorbed film has a low surface tension on the water side and a high one on the other side, it will tend to scrunch up and to peptize the solid as internal phase. (2) If the reverse is true, the solid will tend to form the external phase. (3) If the two surface tensions are equal, neither will pre-

vail. Many instances of peptization might be mentioned. There is the prevention of coagulation by heat of peptizing action of sugar on egg protein. There is the peptizing action of soda on flour proteins with increasing tenderness of the product. This occurs in the chocolate cake known as devil's food when excess soda is used.

**The interfacial tension of solids/liquids.** Adsorption is very pronounced at the interface between these two phases. Just as small drops of a liquid will unite through their vapor to form larger drops, thus reducing the free surface energy and their surface area, so small crystals in a supersaturated solution will unite to form larger crystals. Small crystals have a greater solubility than large crystals. They also have a greater surface area than the large ones per unit mass, thus a greater surface energy. Since surface energy tends to a minimum, equilibrium can be reached only by establishment of larger crystals in the solution. A discussion of the growth of crystals in fondant and similar candies during storage is given later.

**Formation of surface skins.** Bechhold states that one characteristic of colloidal systems is the forming of a surface skin. This may be similar to the formation of a boundary layer in a liquid. Staining solutions form a scum on the surface that must be removed by straining before using. In food preparation this surface skin may be due to a change, as coagulation of a portion of the egg by beating or coagulation of proteins by heating. Whatever the cause, beaten eggs and egg yolks form surface skins after standing a short time, which is not entirely due to a drying of the surface. Boiled milk forms a pronounced skin during heating and after cooling.

**Orientation of molecules.** The molecules at an interface do not lie at random but are oriented or arranged in a definite manner. The arrangement assumed depends partly upon the arrangement of the atoms in the molecule. Molecules of ethane ( $\text{CH}_3\text{CH}_3$ ), butane, and pentane are symmetrical, i.e., in each molecule the two ends are identical. In acetic acid ( $\text{CH}_3\text{COOH}$ ) the two ends of the molecule are unsymmetrical. In ethane the two ends would behave the same at an interface, but this would not hold for acetic acid. The ( $\text{CH}_3$ ) group is called a non-polar group; the ( $\text{COOH}$ ) group, a polar one. At the air/water interface polar groups always orient away from the air and towards the water, for water has pronounced polar characteristics. "Like attracts like" is a rule that all students of organic chemistry have learned. In general, the polar liquids are miscible, but slightly polar liquids are relatively insoluble in polar liquids. A substance like acetic acid, containing a short hydrocarbon chain and a polar group, is completely miscible with water, for the ( $\text{COOH}$ ) group is attracted to the water so strongly that the hydrocarbon chain is also dragged into the water. When two ( $\text{CH}_3$ ) groups are attached to the ( $\text{COOH}$ ) group, the solubility is lessened, and with increasing length of the hydrocarbon chain solubility in water progressively decreases. Thus the possession of a polar group confers upon the substance a certain solubility in water, and the possession of a non-polar group may confer upon it a

greater solubility in some other solvent. Orientation occurs at the interface of two liquids, such as emulsions. Polar groups are those containing oxygen, nitrogen, sulfur, or iodine. Thus substances containing (COOH), (CHO), or (NH<sub>2</sub>) groups, or double bonds, contain polar groups. Polarity is based upon the concept that some parts of a molecule may have gained while other parts may have lost one or more electrons. This results in differences in charges at a small distance apart. The polar groups or polar substances are reactive; the non-polar groups or substances are more inert.

**Cohesion.** Cohesion refers to the property of a substance whereby the particles of a body are united throughout the mass. The particles as a unit resist being torn apart.

**Adhesion.** Adhesion refers to the attraction whereby the surface of a substance sticks to the adjacent surface of another substance. Drops of water adhere to glass, and the dough adheres to the sides of the container in which it is placed. Pans for sponge and angel cakes are not greased, so that the adhesion of the cake mixture to the sides of the pan will aid expansion of the cake.

### Coagulation of Proteins

The term denaturation is used more frequently than coagulation by scientific investigators at the present time to denote certain changes in proteins. Definite characteristics of the proteins are changed when they are coagulated, among which is loss of solubility in water and dilute salt solutions. In some instances and under certain conditions the coagulation process may be reversible.

**Manner in which denaturation may be brought about.** Coagulation of proteins may be brought about by a variety of processes. In cookery one of the principal means of coagulation is heat. But in addition to heat the action of acids, alkalies, salts, alcohol, mechanical agitation, radiation, and ultra-sonic vibrations may denature the protein and convert it from a soluble into an insoluble form.

**Some changes in the proteins during denaturation.** All investigators agree that denaturation is brought about in two steps. The first step is a preliminary alteration of the protein or denaturation. The second is a physical change which leads to coagulation or aggregation. Clayton in discussing "Foods as Colloid Systems" reviews some of the theories of protein denaturation. "Hydrolysis has been frequently reported as the cause of denaturation, but present views incline to the idea of some structural rearrangement within the molecule. Thus, the refractive index increases during heat denaturation, whilst X-ray diffraction patterns lead to the view that coagulation is accompanied by the elimination of water between NH<sub>2</sub> and COOH groups. . . . Cubin holds that denaturation is the distortion or opening up of the protein unit, whilst flocculation is the



process following this and rendered possible by it. Interaction of  $\text{NH}_2$  and  $\text{COOH}$  groups situated on contiguous colloid units leads to aggregation and, hence, coagulation."

No matter how denaturation is brought about, the denatured product has sulfur atoms, the combination of which differs from those in the native protein. Mirsky and Anson have shown that in native egg albumin no sulfhydryl (SH) and disulfide (S-S) groups are detectable by certain methods. But in completely coagulated protein the number of SH and S-S groups detectable is the same as in hydrolyzed protein. These workers have also shown that in partially coagulated protein when the soluble and insoluble fractions are separated the soluble portion contains no detectable SH or S-S groups, but the insoluble fraction has the number of reactive SH and S-S groups characteristic of the completely denatured protein. In the interfacial coagulation of a protein, i.e., when a film of insoluble protein forms at the surface of a protein solution, SH and S-S groups appear, the number being the same as that found in the hydrolyzed protein. Also when the proteins are denatured by ultra-violet light, by acids, or by other means the SH and S-S groups appear. From these results they conclude that the formation of insoluble proteins and increase in detectable SH and S-S groups are closely linked phenomena; that denaturation is a definite chemical reaction; and that a given protein molecule is either completely native or completely denatured.

In a later paper Mirsky and Anson report that the number of detectable SH and S-S groups in different proteins varies with the  $p\text{H}$  and the temperature. To illustrate, native hemoglobin had no detectable SH groups at  $p\text{H}$  6.8. But with increase of  $p\text{H}$  the SH groups become detectable in increasing numbers up to  $p\text{H}$  9.6. But native egg albumin showed no detectable group at  $p\text{H}$  6.8 or  $p\text{H}$  9.6. However, denatured hemoglobin had detectable groups at  $p\text{H}$  6.8 and still more at  $p\text{H}$  9.6. They found that intact, unhydrolyzed proteins possess in addition to SH groups other reducing groups which can be oxidized by ferricyanide. The number and activity of these groups vary from protein to protein. They are probably contained in the tyrosine and tryptophane component of proteins. "It can now be seen that the activation of SH and S-S groups in protein denaturation is part of a more general process."

**Heat coagulation.** As has been indicated heat coagulation of proteins is used in preparation of food products, and, fortunately for the mental equilibrium of the cook, heat coagulation of proteins is ordinarily not reversible. Otherwise, many cooked dishes would, with certain treatment, revert to their original uncooked consistency.

Some of the changes occurring during heat coagulation of the proteins have been indicated. But these are not the only factors playing a rôle in the process. Electrolytes have some rôle in heat coagulation of proteins. This is shown in the work with distilled water egg custards. It has been shown that, if the mineral content of egg white is lowered through dialysis,

coagulation does not occur on heating. The effect of electrolytes in heat coagulation may be brought about either by chemical reaction or by adsorption. If the effect of salts is brought about by adsorption, the salts must be very strongly adsorbed and almost impossible to remove from the aggregated protein by washing the protein, for the process is usually irreversible. Any theory of heat coagulation of the proteins must not only explain how the proteins are rendered insoluble by heat but the effect of other factors. That the heat coagulation of proteins is influenced by electrolytes, sugar, temperature, time, the reaction of the solution, and the presence of water and other factors is evident when the cooking of eggs, custards, salad dressings, cheese and egg dishes, baked products, and meat is observed. The effect of some of these factors can be determined in the laboratory; but the understanding of the manner of their action is lacking in many instances and awaits explanation by the colloid chemist or bio-chemist.

Bancroft and Rutzler have reported that heat-coagulated egg white may be peptized by dextrose and certain salts. They showed that the coagulated and re-peptized egg-white sols are identical with the original solution by immuno-biological tests for species specificity and isoelectric point measurements. Because of the similarity of the reversed protein to the original protein they believe that coagulation is a colloidal reaction which is due to a physical rather than a chemical change.

**Interfacial denaturation.** Proteins are also denatured at interfaces, typical examples being the insoluble portion of beaten egg white, and froth or foam on milk. When egg white or milk foams are allowed to remain undisturbed, they gradually collapse and the wrinkled membranes, skin, or films may be observed through the microscope. Mention has already been made that protein can be recovered from a solution by removing the foam. Denaturation of protein solution occurs by shaking and in some instances spontaneously, an example being the membrane formed at the interface of an air/protein solution when no agitation has occurred.

Neurath and Bull state that both heat and surface denaturation processes involve an unfolding of the peptide chains which in the natural state are curled up in the interior of the molecule and become stretched out when the molecule comes in contact with the surface of the bulk of the solution. The polar groups of the protein molecule, the amino, carboxyl, the OH groups of the hydroxy acids, the sulfur-containing groups, and the peptide linkages, have an affinity for water; whereas the non-polar or lyophobic groups, the hydrocarbon residues, tend to be repelled by water. Thinking that an interaction between the amino and carboxyl groups during heat denaturation might diminish the lyophobic or polar properties of natural protein, whereas an unfolding of the peptide chains by surface denaturation might expose lyophobic groups to the surface, which in the native state are buried in the interior, Neurath and Bull measured the volume contraction of native, heat-denatured, and surface-denatured pro-

teins. They found that the native protein had the lowest density, heat-denatured ones were intermediate, and the surface-denatured protein had the highest density.

This membrane-forming property of protein through denaturation is important in food preparation, in all products in which beaten egg white is used, in emulsions, and wherever interfacial reactions occur.

Membranes form readily on the surface of protoplasm and play important parts in cell functions. The presence of calcium has been shown to stiffen the surface membranes in some instances, whereas sodium and potassium in the absence of calcium tend to soften and dissolve the membrane.

This suggests that salts may also have some influence in surface denaturation and that the salts of flour, egg, and milk used in cooked products may modify the denaturation at surfaces.

Clayton states that high concentrations of sugar in egg white will prevent surface denaturation, which of course has application in making angel cakes, meringues, and sweetened soufflés.

### Peptization of Proteins

Peptization is the reverse process of coagulation. It increases dispersion and solubility.

**Means of bringing about peptization.** Peptization may be brought about by chemical, electrical, and mechanical means or by enzymes. Freundlich states that the hydroxyl ion is generally a very effective peptizer. Other peptizing ions used in food preparation are the citrate, acetate, and tartrate ions. Peptization brought about by adsorption has been mentioned.

**Peptization of proteins.** The results of Gortner, Hoffman, and Sinclair show that different salts added to wheat proteins in varying amounts to give the same  $pH$ , or in equivalent concentrations, cause peptization and solution of varying amounts of the proteins. Both cations and anions form a lyotropic series. They found the anions arranged in the following order of increasing peptization:  $F < SO_4 < Cl < tartrate < Br < I$ ; and for the cations the following order of increasing peptization:  $Na < K < Li < Ba < Sr < Mg < Ca$ . Most of their salt solution extracts of flour had a  $pH$  of 5.0 to 6.0. This would be on the acid side of the isoelectric point of the flour proteins, and they would be positively charged. When the solubility of wheat proteins is increased, the tenderness of the resulting bread is increased.

Freundlich states that hydrophobic colloids and also solids may be peptized by suitable electrolytes, but the process does not take place spontaneously. It is necessary to divide up mechanically the liquid or solid mass very finely, in order that the charging action of the peptizing ion may be effective. In some liquids it is often sufficient to divide them by energetic stirring.

“Salting-out” of hydrophilic colloids occurs at high concentrations. But

at lower concentrations electrolytes frequently bring about peptization. Freundlich states that this has been investigated particularly in some proteins or mixtures of proteins, it being found clearly in the case of globulins. Some globulins remain in solution only in the range of their isoelectric point because of the peptizing effect of electrolytes.

Both the concentration of the electrolyte and its valence affect the extent of peptization. In general, the peptizing action is increased with increasing valence. For example, there is little peptization with the chlorine ion, the sulfate ion peptizes in higher concentrations, and the citrate ion brings about peptization with low concentrations.

### Bound and Free Water

Water plays a very important rôle in both plant and animal life as a solvent for sugars, electrolytes, etc., and thus in the translocation of food material and metabolism products. But in addition to being a solvent water forms part of the inmost structural portion of the cell. For example, from muscle tissue, although it is composed of more than 65 per cent of water, even with considerable pressure only a few drops of liquid can be pressed. Part of this water is free water, for it contains the dissolved salts, proteins, and other materials. But as the period after death increases, changes occur in the tissue, and greater amounts of liquid can be obtained with pressure. This water, held by the colloidal micelles so that it forms an intimate part of the material, is designated as bound water.

Not only cells of plants and animal tissues, but starches, proteins of flour, gelatin, eggs, and other complex compounds such as lecithin have the capacity to bind water, giving the product certain characteristics. The free water is designated as that portion of the water in which solutes such as sucrose and salt can be dissolved. The bound water is that portion which is held so tightly that not even sucrose will dissolve in it. The density of bound water is so great that some investigators state it is equivalent to having a pressure of 10 thousand atmospheres on it. From this and other properties bound water is often considered as solid water. Bound water has a very low dielectric constant. Burns states, "All the physiological colloids have the property of taking in relatively large quantities of water even against enormous pressures, and of holding this water against even strenuous methods of removal. This 'bound' water stored in the micropores is under considerable compression, so much so that its density and all its physical properties are altered."

The compression of the bound water in bulk is probably due to orientation and packing of the water molecules around the micelles. It has no appreciable vapor pressure and freezes with difficulty or forms such small ice crystals that the biological structure is not injured.

Bound water often requires the application of heat and suction to drive it off. Burns says, "An alumina gel cannot be dried by heating it for 2 or 3

days at 500°C., yet some relationship does exist between the 'free' and 'bound' water. Under certain conditions as yet undefined, bound water may become free again, and the reverse." The greater power of some samples of meat to retain moisture and yet appear firm and less juicy than other samples cooked under the same conditions is known. Ostwald states that pork can be distinguished from other meats by the fact that its water-holding capacity suffers the least change when cooked or dried. In his work with angel cake Barmore speaks of the crumb of cake baked at higher oven temperatures as containing as much moisture but apparently binding the water more securely for it appears more dry.

### Fluidity, Viscosity, and Plasticity of Colloidal Systems

**Fluidity and viscosity.** Bingham uses the term fluidity to express the opposite of viscosity. A fluid like water yields readily to any force that tends to change its form, whereas a viscous substance shows some resistance to flow. Viscosity is one of the important properties of colloidal systems. As a general rule, the lyophobic colloids show a viscosity but little greater than that of the dispersion medium, the viscosity increasing only slightly with increasing concentration of the micelles. But the lyophilic colloids may show very high viscosities or even plasticity with very low concentrations of the micelles.

Bingham states that "a mixture of liquids may have an indefinite number of fluidities dependent upon the method of mixing, in other words, upon the structure of the liquid." He also states that colloidal solutions show differences in fluidity due to differences in structure. Thus it is possible that cake or other batters made with the same materials and the same proportion of materials may show differences in the structure of the finished cake on account of different methods of mixing, giving different viscosities to the batter.

Some substances flow readily; others resist flow; and some must have weight applied to start flow. When a substance tends to resist a shearing force it may exhibit a flow that is characterized as viscous, turbulent, or plastic. If the substance entirely regains its original shape, when the shearing stress is removed, it shows perfect elasticity. If the original shape is not entirely regained and the substance is deformed to an extent directly proportional to the shearing force, then the substance is said to show viscosity. This flow that is directly proportional to the shearing force is called linear flow. By this is meant that if a weight of 1 pound produces a definite deformation, a weight of 2 pounds produces twice that deformation. Turbulent flow is the flow obtained when the ratio of the shearing force to the deformation decreases.

A pure liquid at a given temperature and pressure has a definite fluidity. The viscosity of water is approximately six times as great at 0° as at 100°C. The viscosity of sols usually decreases with an increase in tem-

perature, part of this being due to the effect of temperature upon the intermicellar liquid. Gortner states that in "colloid systems changes due to temperature are influenced not only by the viscosity of the dispersion medium but likewise by the effect of temperature on solvation." Thus gelatin and agar-agar form sols with rather low viscosity at high temperatures when compared to the viscous liquid or plastic gels they form at low temperatures. Starch usually forms a suspension at low temperatures, and its decided increase in viscosity or plasticity comes with rapid hydration at the gelatinization point. Gortner states that heating a starch paste beyond the gelatinization temperature causes a decrease in viscosity or plasticity. Electrolytes added to lyophilic systems, often even in traces, cause great changes in the viscosity of the sol.

**The factors affecting the viscosity of lyophilic systems.** Gortner adds an eleventh factor, that of rate of shear, pointed out by Sharp and Gortner, to the ten given by Ostwald that cause variation in the viscosity of lyophilic systems. They are as follows: (1) concentration, (2) temperature, (3) degree of dispersion, (4) solvation, (5) electrical charge, (6) previous thermal treatment, (7) previous mechanical treatment, (8) the presence or absence of other lyophilic colloids, (9) the age of the lyophilic sol, (10) the presence of both electrolytes and non-electrolytes, and (11) the rate of shear.

Viscosity is closely related to the consistency of the finished product in food preparation. So close is this relation in many cases that the ten factors listed by Ostwald may nearly be taken as ten commandments of food preparation. Thus the consistency of a custard is influenced by the concentration of egg or the protein micelles; the temperature to which it is cooked; the degree of dispersion of the micelles, which is influenced by the reaction and other factors; the degree of hydration, which is influenced by reaction, the kind and concentration of salts present, etc.; the beating of the egg; the use of milk or water; how long the custard has aged in addition to the age of the eggs and milk when used; the kinds and concentration of salts in the egg and milk as well as the addition of sodium chloride and the non-electrolyte sugar.

Since the line of demarcation between sols and gels is not a definite one, fruit jellies, gelatin, milk, cream, as well as egg dishes, may be added to the group of foods in which the consistency of the finished product is related to viscosity. But this does not end the application, for the structure or type of product in baked goods is closely related to the viscosity of the batter or dough, which in turn is influenced by all these factors. Of course these factors or nearly the same ones affect other properties as well as viscosity of food materials. Thus the extensibility of gluten, the heat coagulation of proteins, etc., are influenced by many or all of these factors.

**Plasticity.** Bingham defines plasticity as "a property of solids in virtue of which they hold their shape permanently under the action of small shearing stresses but they are readily deformed, worked or molded, under

somewhat larger stresses. Plasticity is thus a complex property, made up of two independent factors, which we must evaluate separately." Modeling clay is plastic. Plasticity is an important property of fats used for cakes, biscuits, and pastry. A plastic fat has a consistency such that it will form a thin sheet or layer in a batter or it will retain air bubbles when "creamed." The enclosing of these air bubbles in the fat is an aid in leavening cakes and may assist in obtaining a velvety texture, for the enclosing of the air renders the fat more plastic, thus more easily distributed in the batter at lower temperatures.

### Energetics

Burns states, "Energy is the underlying cause of all changes in matter. This does not seem a very satisfactory definition, but, so far, it is the only one possible. . . . Energy, then, is that which produces an effect on our senses." It is measured by its power to do work.

Energy in some form is often applied to the materials used for food products. This energy may be electrical, mechanical, or in the form of heat.

An electric current passed through a food may be used to cook it. Very interesting experiments are being carried out along this line of work by the Household Equipment Department at Iowa State College. One of the striking results is the very short time required to cook the food. The passage of an electric current is used by some companies to pasteurize milk and by some to sterilize fruit juices.

Mechanical energy is used to beat, stir, fold, knead, or grind food.

The frequency of application of heat to foods does not need to be mentioned, for this is what the term to cook means. Foods may be cooked by radiant heat; or by transmission of the heat by conduction, i.e., from particle to particle; or by convection, which is the diffusion of heat through a gas or liquid by movement of the gas or liquid particles. A combination of these methods may be used to transmit the heat. Oven cooking employs all three.

Kinetic energy is due to motion. It may be due to motion of the substance itself or of the particles composing it. It is directly available for work. Potential energy is associated with position, i.e., composition, stress, or strain. Kinetic energy is necessary to liberate it to perform work.

Just as matter is indestructible, though its form may be changed, so is energy indestructible. This constitutes the first law of thermodynamics. The law of Hess states that the amount of heat generated by a chemical reaction is the same whether it takes place all at once or in steps.

The second law of thermodynamics concerns the degradation or dissipation of energy. In practise, some of the freed energy is converted into heat, which is diffused among the surrounding objects, and, so far as work is concerned, is lost. Burns states the law simply: "Every change takes place at the cost of a certain amount of available energy." He adds that the second law lends itself to the deduction that the cause of all change is the

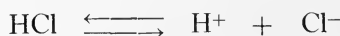
tendency of energy to attain the same uniform degree of intensity as that of its environment. This means that any system tends to change to the most stable state.

Bread during baking tends to attain a physico-chemical equilibrium. But the temperature attained during baking is much higher than the storage temperature. Freshly baked bread does not taste or feel like bread 24 hours old. Bread can be stored so that it loses no moisture, yet readjustments in the loaf take place, so that staling occurs. If bread is stored at temperatures of 60°C. or above, the texture remains more like that of freshly baked bread and staling is not perceptible. But at this temperature bacterial changes occur readily. If the bread has not lost considerable moisture, upon reheating it, it acquires the characteristics of freshly baked bread.

The principle of Le Chatelier gives the factors of equilibrium: "Every system in chemical equilibrium, under the influence of a change of any single one of the factors of equilibrium, undergoes a transformation in such direction that, if this transformation took place alone, it would produce a change in the opposite direction of the factor in question. The factors of equilibrium are temperature, pressure and electromotive force, corresponding to three forms of energy; heat, electricity and mechanical energy."

### Hydrogen-Ion Concentration

The symbol  $pH$  is very commonly used in present-day literature. Some explanation of the term and its relation to hydrogen-ion concentration is desirable. Perhaps it will be best to review briefly what is meant by hydrogen-ion concentration. In a solution of hydrochloric acid in water, the molecule of the acid consists of an atom of hydrogen united to an atom of chlorine. Hydrochloric acid molecules are found in the solution, but not all the acid remains in the molecular form. Part of the acid molecules are ionized into hydrogen ions and chlorine ions, the degree of ionization depending upon the concentration, the more dilute the acid solution the greater the percentage of hydrochloric acid ionized. The hydrogen ions are positively charged, and the chlorine ions are negatively charged. In symbols, the ionization of hydrochloric acid is expressed as follows:



When a substance is ionized in solution the solution conducts an electrical current.

When water is ionized it gives both hydrogen ions and hydroxyl ions. Since the ionization of water is very slight, the amount of hydrogen and hydroxyl ions in a liter of water is not great.



In pure water the concentration of hydrogen ions and hydroxyl ions is



equal at 22°C. The reaction of water varies at various temperatures, so that the following discussion is confined to room temperature or 22°C. The concentration of the hydrogen ions and hydroxyl ions is  $\frac{1}{10,000,000}$  of a gram-molecular weight (mole) each per liter. A normal solution of hydrogen ions contains 1 gram-molecular weight (1 gram) of hydrogen ions per liter of solution; a normal solution of hydroxyl ions contains 1 gram-molecular weight (17 grams) of hydroxyl ions per liter of solution. A liter of pure water contains  $\frac{1}{10,000,000}$  of a mole of hydrogen. This requires many figures to express as a fraction, so for convenience the concentration is expressed as follows:  $\frac{1}{10,000,000} = 10^{-7}$ . Again for convenience Sørensen proposed to disregard the minus sign and use the numerical value of the exponent 7 to express the reaction corresponding to the concentration of hydrogen ions.

$$\text{Thus } \frac{1}{10,000,000} = 10^{-7} = \text{pH } 7$$

When the concentration of the hydroxyl ions is equal to that of the hydrogen ions, the concentration of hydroxyl ions is also  $\frac{1}{10,000,000}$  of a mole or  $10^{-7}$ . This is the neutral point. The term pH is used to denote the concentration of the hydrogen ions only. Sometimes pOH is used to denote the concentration of the hydroxyl ions. Thus when the concentration of the hydrogen ions is pH 7, that of the hydroxyl ions is pOH 7. If the concentration of the hydroxyl ions is multiplied by the concentration of the hydrogen ions a definite product is obtained. In fractions this would be written thus:

$$\frac{1}{10,000,000} \times \frac{1}{10,000,000} = \frac{1}{100,000,000,000,000}$$

But in the exponential notation it is expressed as follows:

$$10^{-7} \times 10^{-7} = 10^{-14}$$

When the hydrogen-ion concentration in a solution is increased, the hydroxyl-ion concentration is decreased, so that the product of the concentration of the hydrogen and hydroxyl ions always gives  $10^{-14}$ , and this is a constant for the product of these two ions. Thus in a solution that has a pH 6 the hydrogen ions exceed the hydroxyl ions but the product of their concentrations is the constant  $10^{-14}$ . In a solution that has a pH 6 the concentration of the hydrogen ions expressed in fractions is  $\frac{1}{1,000,000}$  of a mole of hydrogen. In the same solution the concentration of the hydroxyl ions is  $\frac{1}{100,000,000}$  of a mole. The product of these two concentra-

tions gives the constant. Expressed in exponential notation it is  $10^{-6} \times 10^{-8} = 10^{-14}$ . In a solution that has a  $pH$  8 the hydroxyl ions exceed the hydrogen ions but the product of their concentration is again  $10^{-14}$ . When the concentration of the hydrogen ions is  $pH$  3 or  $10^{-3}$  then the concentration of the hydroxyl ions is  $10^{-11}$  and their product is again  $10^{-14}$ .

Literally, the term  $pH$  means to a power. It is used to express the reaction of a fluid, that is, its degree of acidity or alkalinity, but it does not do this directly, as is shown in the above equations. It is an inverse logarithmic function, deprived of its minus sign. Experimentally it is determined electrometrically and is really a number obtained from determining the electromotive force (E.M.F.) of a substance in a suitable apparatus and by using this value of (E.M.F.) in a formula, computing the  $pH$ .

Hydrogen-ion concentration refers to the concentration of the ionized or active ions per liter of substance. The  $pH$  value does not represent this directly but for all practical purposes may be taken as a value representing it.

The relation of hydrogen-ion concentration and  $pH$  values in solutions of varying normalities is given below.

TABLE 3

Solution	Grams of hydrogen ion per liter	$pH$ value
Normal	1.0	0
$N/10$	0.1	1
$N/100$	0.01	2
$N/1000$	0.001	3
$N/10,000$	0.0001	4
$N/100,000$	0.00001	5
$N/1,000,000$	0.000001	6
$N/10,000,000$	0.0000001	7

The above arrangement shows that the  $pH$  value is not an arithmetical series or ratio but varies according to the logarithmic notation. Thus  $pH$  2 is not one-half of  $pH$  1 but one-tenth of it.

The number of times the hydrogen-ion and hydroxyl-ion concentrations of a solution exceed that of pure water may be shown as follows. The arrangement is by Alexander.

The  $pH$  values are determined by two methods: the principal one is by electrometric determinations, the other is by the use of indicators. The latter is a rapid and a very useful way to determine an approximate  $pH$  value and to check apparatus. For an accurate determination the electrometric method must be used.

TABLE 4

$pH$ value	Number of times that the H- or OH-ion concentration exceeds that of pure water	
1	1,000,000	
2	100,000	
3	10,000	acid side
4	1,000	H-ion concentration
5	100	
6	10	
7	0	pure water, neutral
8	10	
9	100	
10	1,000	
11	10,000	alkaline side
12	100,000	OH-ion concentration
13	1,000,000	

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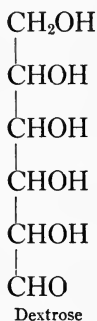
## CHAPTER II

### SUGAR COOKERY

#### Classification of the Carbohydrates

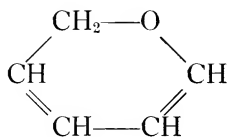
The carbohydrates are divided into three groups: the monosaccharids, disaccharids, and polysaccharids. The monosaccharids are composed of one saccharid or sugar group. They are sometimes called simple sugars. The monosaccharids differ from each other in the number of carbon groups and in the molecular arrangement. The monosaccharids contain alcohol groups (HCOH), the number of which may vary from one to six. In addition to the alcohol group a monosaccharid contains either an aldehyde (HC = O) or a ketone (C = O) group. Thus they are aldehyde or ketone derivatives of complex alcohols and as such are called aldoses or ketoses.

A biose is a sugar with two carbon groups, an alcohol group being attached to one carbon and an aldehyde group to the other. A triose has three carbon groups and has alcohol groups attached to two carbons and either an aldehyde or ketone to the third carbon. The common monosaccharids in foods are the hexoses, which contain six carbon groups. Five of the carbons have alcohol groups, but the sixth has an aldehyde or ketone. The common hexoses are dextrose and levulose, the former being an aldose, and the latter a ketose. The following formulas though not conveying the exact arrangement of the molecule illustrate the above points.

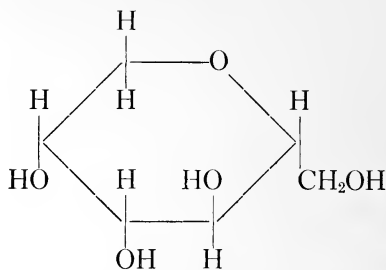


All sugars higher than tetroses may assume two structural forms, the pyran and the furan. The pyran form for a hexose sugar is a ring composed of five carbons and one oxygen with one carbon outside the ring; the furan

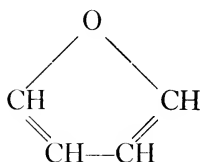
form is a ring of four carbons and one oxygen with two carbons outside the ring.



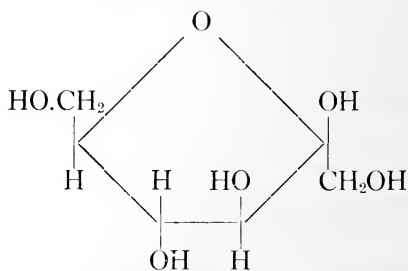
Pyran



Beta-fructopyranose



Furan

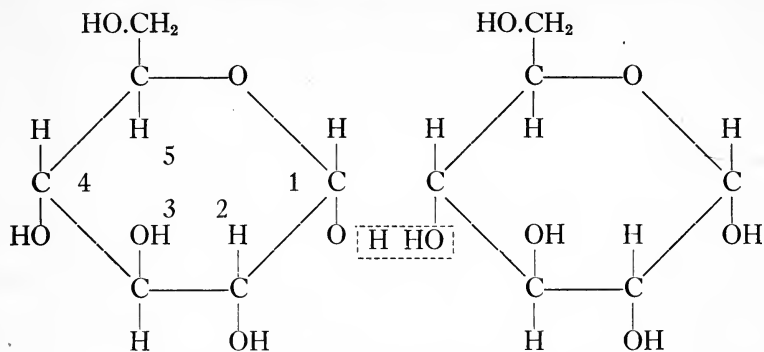


Beta-fructofuranose

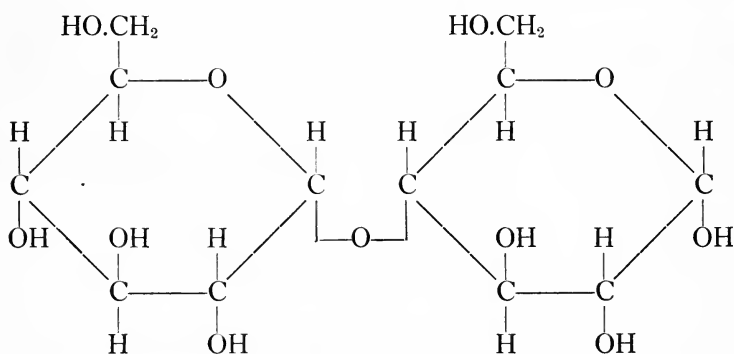
The two structural forms of the sugars are represented by the terms glucopyranose and glucofuranose for glucose, fructopyranose and fructofuranose for fructose, etc. To avoid confusion of nomenclature, prefixes are added to the terms indicating structural form to differentiate the stereochemical forms (the same chemical and basic structural form but with different spacial arrangements of the hydrogen and hydroxyl groups). Thus the prefixes alpha-, beta-, gamma-, etc., added to the name of the sugar with the ending denoting the structural form, such as alpha-glucopyranose, beta-glucofuranose, definitely identify each sugar.

Haworth and his coworkers at Birmingham have worked out in detail the way in which sugar units are united into chains. Haworth states that there are several ways in which two glucose units may be joined through the intermediary of a common oxygen atom. But of the several OH positions available for providing the union of two glucose units, it has been found that the union is formed through the first carbon of one unit and the fourth carbon of the other glucose unit. Maltose is formed, as shown, by the union of two alpha-glucopyranose units. The union of about 30 alpha-glucopyranose units in this manner, according to Haworth forms starch, though all investigators do not agree on the number of glucose units in the starch chain. (See discussion of starch in Chapter XI.)

Cellulose is composed of many beta-cellobiose units. In a manner similar to that in which maltose is formed, two beta-glucopyranose units form



The union of two  $\alpha$ -glucopyranose units gives  $\alpha$ -maltose



$\alpha$ -maltose

beta-cellobiose. Sucrose is composed of one alpha-glucopyranose united through the first carbon to beta-fructopyranose.

The disaccharids contain two monosaccharid sugar groups; the polysaccharids contain many sugar groups. There are also trisaccharids. There is always the possibility that the trisaccharids and some of the other rare sugars may become commercially important, but at the present time they are little used except in scientific work.

The common disaccharids found in foods are sucrose, maltose, and lactose. Sucrose is composed of one dextrose and one levulose group; maltose is made up of two dextrose groups; and lactose is composed of one dextrose and one galactose group.

Following is a list of the common carbohydrates used in foods. For a complete list a physiological or organic chemistry may be consulted.

**MONOSACCHARIDS:**

Dextrose or glucose  
Levulose or fructose

**DISACCHARIDS:**

Sucrose  
Maltose  
Lactose

**POLYSACCHARIDS:**

Dextrins  
Starch  
Cellulose  
Pectins  
Gums

### Sources of the Common Sugars

Dextrose or glucose, for it is known by both names, is widely distributed in fruits, honey, and some vegetables. The sugar known by the trade name "Cerelese" is practically a pure crystalline dextrose and is made from corn. The term dextrose or glucose should be applied to crystalline dextrose or its solution. Commercial corn sirup has been incorrectly called glucose. It is made from corn, the starch being hydrolyzed with acid. Hydrolysis is carried to the point at which 40 to 50 per cent of the starch is changed to sugar, the remainder being split into dextrans. The sirup contains both dextrose and maltose, but for convenience the sugar is usually all determined and expressed as dextrose. Thus corn sirup is a mixture of dextrin, maltose, dextrose, and water.

Levulose or fructose is also widely distributed in natural foods, often accompanying dextrose, or dextrose and sucrose. At present, pure crystalline levulose is expensive. Honey contains nearly equal parts of dextrose and levulose. When honey crystallizes, the greater part of the levulose is in the sirup and the dextrose in the crystals.

Sucrose is widely distributed in plants, often with dextrose and levulose. The common sources of it commercially are the sugar beet, the sugar cane, the sugar maple, and the sugar palm. It is the common granulated sugar on the market and is practically pure whether obtained from the beet or cane. Maple sugar is not purified, for it would then lose the flavor for which we prize it.

Maltose is formed as an intermediate product when starch is hydrolyzed by boiling with mineral acid in the manufacture of commercial corn sirup from corn. Commercially it is prepared from starch by a diastatic enzyme and it is also found in germinating cereals and malt products.

Lactose is obtained from milk. One of its uses is for infant feeding.

### Relative Sweetness of the Sugars

Sweetness is a quality that is detected by taste, but there is no exact test for it. Much depends upon how the test is conducted, whether the tongue is dry or moist, upon what part of the tongue the sample is placed, and with several other conditions, the fatigue of the sense of taste. Some persons detect sweetness in less concentrations than others. It cannot be expected that all people will agree in their estimates of the relative sweetness of the sugars, even with carefully worked out tests.

In rating the sweetness of the various sugars it is a commonly accepted practise to rate sucrose as 100. Sugars sweeter than sucrose are ranked higher than 100, and those less sweet are ranked lower.

Biestler and Wood of the University of Minnesota give the following rating to sugars:



Levulose.....	173.3
Sucrose.....	100.0
Dextrose.....	74.3
Maltose.....	32.5
Lactose.....	16.0

Sale and Skinner of the Bureau of Chemistry (Water and Beverage Laboratory) rate the sugars as follows:

Sucrose.....	100
Dextrose.....	50
Levulose.....	150
Maltose.....	50
Invert sugar.....	85

Paul in comparing the sweetness of several sugars with sucrose gives the following value:

Sucrose.....	100
Dextrose.....	52
Levulose.....	103
Lactose.....	28

A commonly accepted value of dextrose at the present time is about 70 to 75. There is the probability that this is too high and that 50 is a better figure. Levulose is conceded by all to be sweeter than sucrose, but again there is no agreement as to how much sweeter. Some authorities rank it 120 to 125. With the higher figures for the sweetening powers of dextrose and levulose it would seem that invert sugar should be sweeter than the original sucrose. But the manufacturers of carbonated beverages, to whom this would be beneficial, since they use solutions of sirup, do not think that invert sugar is any sweeter than sucrose, even though 342 units of sucrose yield 360 units of invert sugar or a gain of 5 per cent in weight.

### Effect of Acid upon Sugars and Hydrolysis of Sugars

Strong concentrated acids decompose all the sugars producing humus or caramel substances. The weak acids, malic and citric in fruits, lactic in sour milk, acetic acid, and salts with an acid reaction like cream of tartar, affect the sugars in different degrees, depending on the particular acid used, the strength of the acid, whether it is heated, and the length of time of heating.

The monosaccharids, dextrose and levulose, are not affected to any appreciable extent by weak acids. When sucrose is cooked with weak acids it is partially hydrolyzed to dextrose and levulose, but since the invert sugars are not affected by the acid practically no other change takes place.

Lactose is only very slowly hydrolyzed by acid to dextrose and galactose.

Maltose is less readily affected by acid than sucrose, but is slowly hydrolyzed to two molecules of dextrose.

**Sucrose and fondant.** Sucrose is very easily hydrolyzed, even by very

weak acids, though the addition of water to the sugar molecule cannot be brought about by mixing sugar and water, but may be brought about by enzymes as well as acids. The weak acids used in cookery—lemon juice, vinegar, fruit juices, or the acid salt cream of tartar—all cause sucrose to combine with water forming dextrose and levulose. Hydrolysis takes place more rapidly if the solution is heated. In making fondant with cream of tartar, if the sirup is boiled slowly for a long time, more inversion may take place than when the sirup is boiled quickly with a larger amount of cream of tartar. Compare the length of time required to bring about crystallization in Experiments 7C, 1, and 7C, 2. Hydrolysis of fondant containing cream of tartar occurs during storage though the rate is slow at the storage temperature. Fondant made with cream of tartar and stored in a fairly tight container becomes softer than fondant of the same consistency before storage, but without the addition of cream of tartar. The amount of the acid salt to bring about this softening at room temperature imparts a slightly sour taste to the fondant. To many persons this slight acidity improves the flavor. In fondant made with a larger amount of cream of tartar (Experiment 7C, 4), considerable hydrolysis may occur with short storage.

To determine the effect of salts found in hard water upon the decomposition of dextrose in fondant, some fondants were made with 10 per cent of dextrose added to sucrose and distilled water. To the solution different salts similar to those found in water were added, the fondants made and stored in a heavy glass container, with a tight-fitting lid. They were kept for two years. Acid calcium phosphate was added to some of the fondant to compare an acid-reacting salt containing calcium with the other calcium salts used. At the end of one year the fondants made with calcium acid phosphate were plastic and kneadable, whereas those made with magnesium sulfate, calcium sulfate, and other salts, as well as the control with no salt, were too hard and dry to be kneaded. Here slow hydrolysis from the calcium acid phosphate probably occurred over a long period, but drying out of the fondant was also prevented, which was due to the hygroscopic property of the levulose. If fondant is to be stored for some time before it is molded the fondant made with an acid salt remains soft and plastic, or keeps better than fondant made without an acid or acid salt.

Hydrolysis of sucrose is often spoken of as inversion and the resulting sugar as invert sugar. The reason for this name is found in the effect of invert sugar upon a beam of light. If a straight beam of light is allowed to pass through a solution of sucrose in an instrument called a polariscope, the beam of light is rotated to the right and the sucrose is called dextro-rotary. After the sucrose is hydrolyzed, the ray of light is rotated to the left and the invert sugar is levo-rotary. Because of this inversion of a beam of light, hydrolyzed sucrose is called invert sugar. Dextrose is dextro-rotary and sucrose is levo-rotary. It is due to the fact that levulose rotates

the beam of light further to the left than dextrose rotates it to the right that the rotation of invert sugar is opposite to that of sucrose.

**Hydrolysis of sugars by enzymes.** Enzymes also bring about hydrolysis of the disaccharid sugars. Since heat destroys enzymes the reaction must occur at a low temperature. The enzyme invertase causes hydrolysis of sucrose to dextrose and levulose. Maltose is prepared from corn by using an enzyme.

**Hydrolysis in chocolate creams.** Jordan states that the liquefied centers of chocolate creams and other confections are brought about by acids, acid salts, or enzymes. The substance bringing about the hydrolysis is added when the fondant is fairly hard and the softening due to the hydrolysis occurs during storage. Paine states that the amount of the acid or acid salt required to bring about inversion imparts a perceptible acid taste to the fondant. Evaporation of liquid from the fondant must be prevented, or the fondant loses water and becomes dry. Then some moisture is necessary for hydrolysis to occur. The enzyme, invertase, may be added when the fondant is beaten or when it is molded before dipping. The proper amount of invertase is added for the inversion of the fondant, and according to Paine this inversion takes place more readily at pH 4.4 to 4.6. To give this acidity citric acid is added in small quantities. Invertase may be used in fondant for chocolate creams, in confections with fruit like cherries and pineapple, and in bonbons. The fat of chocolate prevents the confections dipped in it from losing moisture by evaporation. The bonbons dry out more rapidly than the chocolate-covered candies. Paine states that the addition of a small amount of egg albumen or egg white lessens evaporation from the fondant.

**Hydrolysis of starch.** Starch, like sucrose, is very readily hydrolyzed by acids, and the reaction takes place more rapidly at a high temperature. When starch is used with acid fruit juices, a larger proportion of starch is required to thicken the mixture to a definite consistency than is needed for an equal quantity of water or milk. Fillings for lemon or cherry pie, because of the hydrolysis by acid during cooking, need a larger proportion of starch for thickening than fillings like chocolate cream.

### Effect of Alkalies Upon Sugars

Strong alkalies, like strong acids, decompose the sugars. Weak alkalies or salts with alkaline reaction, like sodium bicarbonate, common baking soda, also act upon the sugars. Even alkaline salts found in hard water may produce considerable decomposition in some of the sugars. Of the disaccharids those most easily affected by acids are least readily decomposed by alkali, and *vice versa*. Sucrose is scarcely acted upon by a weak alkali, but maltose and lactose are affected more readily.

The monosaccharids are easily decomposed by alkalies, even very weak ones. If the sugar is allowed to stand in a solution with a weak alkali

many substances may be formed. Decomposition is brought about so rapidly with strong alkalis that not so many products are formed with it. Nef states that, of the 116 possible decomposition products with dextrose and a weak alkali, 93 have been isolated. Very weak alkalis may cause rearrangement of the molecule. In the manufacture of dextrose great care must be taken to keep the reaction acid to prevent an off color and taste. The action of an alkali upon dextrose produces first a yellow tinge which becomes deeper and finally brown if carried far enough. This decomposition is called caramelization. With very slight caramelization of dextrose the flavor may not be very noticeable, but it may become strong and bitter, and characterized by a strong, pungent, acrid after-taste. In sections of the country where the water is very hard, enough decomposition to affect the flavor may be brought about in ordinary cooking. This is more noticeable when the sugar is cooked slowly. The addition of a little lemon juice, vinegar, or the acid salt, cream of tartar, will prevent the discoloration and the change in flavor. In some instances this browning or caramelization is an advantage. For example, baked beans brown better when dextrose is added than when sucrose is used.

Levulose, like dextrose, is unstable in an alkaline solution, decomposing as readily or more so than dextrose and giving many decomposition products. But in cookery its decomposition by alkalis can be prevented in the same way as that of dextrose. Candy made from honey often has a strong flavor that may be rather disagreeable, owing to decomposition of the dextrose and levulose during cooking. If just enough acid is added to combine with the alkali present, the characteristic flavor of honey is retained.

### Moisture-Absorbing Power of the Sugars

All sugars should be stored in a dry place for they deteriorate if stored where it is damp. This power of absorbing moisture can be made use of to improve some foods, but it is a detriment in others.

Browne reports that the sugars having the highest absorptive power from a saturated atmosphere are the levulose-containing substances: invert sugar, honey, levulose, and molasses. He finds that the percentage of water absorbed has no relation to the percentage of levulose present. This would suggest that cakes made with levulose-containing products would not dry out so rapidly as cakes made with sucrose. In practise, this is found to be true. Cakes made with part levulose or levulose-containing substances do not dry out so rapidly as those made with sucrose.

Honey and molasses are used in many family recipes for cookies, particularly the kinds made for holidays, for they can be made a long time in advance of their intended use and they remain moist with storage—in many instances the moisture content seems to increase during storage.

Invert sugar either added to food or formed by inversion during cooking is found in many food products. In the bakery trade it is used to prevent

drying and checking. The acid in fruits inverts sucrose. The amount of total sugar that can be held in solution in a given quantity of liquid is greater if it contains a mixture of sucrose, levulose, and dextrose. Rich preserves made of fruit containing little acid do not crystallize so readily during storage if lemon juice is added when they are being made. The lemon juice brings about more inversion than the less acid fruit juice. The invert sugar does not crystallize so readily as the sucrose, the total quantity of sugar held in solution is greater, and there is less evaporation.

The levulose-containing substances should be avoided for hard candies. Duryea states that maltose is better to use in hard candies than dextrose, because the candies remain drier. He also adds that another advantage of using maltose in hard candy is that maltose is not so readily affected by alkali. The decomposition caused by use of dextrose and alkaline water is avoided.

### The Melting Point of the Sugars and the Effect of Heat

When sugars are heated without the addition of water a point is reached at which they change from a crystalline to a liquid state. This is called the melting point.

Mackenzie states that the melting point of sucrose is  $160^{\circ}$  to  $161^{\circ}\text{C}$ . Impure solutions of sucrose will give variable melting points. After sugar is melted and cooled slowly it forms the hard amorphous sugar sometimes called "barley sugar." The amorphous form of sugar like the amorphous sulfur slowly reverts to the crystalline form. If sucrose is heated above the melting point brownish-colored substances called caramel are formed. In the presence of moisture, caramelization may begin at temperatures below  $100^{\circ}\text{C}$ . Caramel is composed of a number of substances, decomposition products of sucrose with loss of water.

Maltose melts at about  $100^{\circ}\text{C}$ . Having a lower melting point than sucrose it decomposes more easily by heat.

Dextrose crystallizes as the hydrate,  $\text{C}_6\text{H}_{12}\text{O}_6 \cdot \text{H}_2\text{O}$ , that is, one molecule of water is combined with the molecule of dextrose. When heated slowly it loses this water of crystallization between  $50^{\circ}$  and  $60^{\circ}\text{C}$ . Perkin and Kipping state that the melting point of the hydrate is  $86^{\circ}$ , and that of the anhydrous form is  $146^{\circ}\text{C}$ .

The melting point of levulose is  $95^{\circ}\text{C}$ .

### Solutions

Sugar and other substances are used constantly in cookery processes. Therefore, it is desirable to know something about the properties of solutions.

A solution is composed of two parts: one, the solute, is the dissolved substance; and the other, the solvent, is the substance in which the solute

is dissolved. A solution is a homogeneous mixture. This means that it is uniformly mixed or alike in all parts.

A solution may be a gas dissolved in a solid, a gas in metal; a gas in a liquid, air in water; a liquid in a liquid, alcohol in water; or a solid in a liquid, sugar in water. It is to the class of solids in liquids that many of our solutions in cookery belong.

### Solubility of Substances in Solution

Solubility means the amount of a specific substance that will dissolve in a given volume of a specified solvent. If the solvent is not mentioned it is understood to be water. Solubility is generally expressed as the number of grams of solute that will dissolve in 100 cc. of solvent, and as the temperature affects solubility it is usually mentioned. If the temperature is not stated it is understood to be room temperature or  $20^{\circ}$  to  $22^{\circ}\text{C}$ .

**Factors determining the solubility.** Temperature, the fineness of division and the nature of the solute, and the nature of the solvent determine the solubility to a great extent. Some substances are highly, others only slightly, soluble in water, and still others are highly insoluble in this solvent. Some substances will dissolve best in alcohol, or chloroform, or ether, or benzine. Some liquids, like alcohol and water, will dissolve in all proportions, but there is a limit to the solubility of all substances of a crystalline form.

**Fineness of division of the solute.** A larger amount of the crystalline solute is soluble if it is very finely divided or powdered than if left in large crystals. This does not refer to the ease or quickness of solution but to the total number of grams dissolved in 100 cc. of the solvent. This increase in solubility is due to the increased surface energy of the smaller particles in the solvent. The diameter of the particles must be less than  $1\mu$  to increase the solubility to any great extent.

**Temperature.** The solubility of most crystalline substances in water is increased by heating, though some are little affected by temperature change, and a few are less soluble in hot water than in cold. Sodium chloride, common salt, is an example of a substance that is little affected by temperature change. At  $0^{\circ}\text{C}$ . about 35.6 grams will dissolve in 100 cc. of water, and about 39 grams at  $100^{\circ}$ . Calcium hydroxide is only half as soluble at  $100^{\circ}$  as at  $20^{\circ}$ . The solubility of the sugars is increased by elevation of temperature. At  $0^{\circ}\text{C}$ ., 179 grams of sucrose will dissolve; at  $100^{\circ}\text{C}$ . 487 grams will dissolve.

**Addition of other substances.** Two forms of the same compound may give different solubilities. Thus anhydrous lactose (without water of crystallization) has one solubility and the hydrated form has another. Sometimes the addition of another substance, organic or inorganic, to the solution will increase or decrease the solubility of the solute. If, after all the sucrose possible is dissolved, some potassium acetate, sodium chloride, or

many other salts, is added to the solution, more sucrose can be dissolved. This may affect the solubility of sugar in candy making, for it is known that different waters, with different proportions and kinds of minerals, do not always give identical results, with the same sugar, for the same kind of candy.

**Saturated solutions.** Once all the solute is dissolved that can possibly be held by a definite amount of solvent at a constant temperature, any excess of the solute remains unchanged. The saturated solution is one that contains all the dissolved solute that it can take up when in contact with undissolved solute. In other words, it is a solution which when placed with excess of the solute at a definite temperature is in equilibrium, i.e., there is neither increase nor decrease in concentration of the solute.

**Supersaturated solutions.** One should not define a saturated solution as one containing all the solute it can hold, for a supersaturated solution holds more than a saturated one. If water is heated to 70°C. and all the sucrose added that can be dissolved by the water at this temperature, one has a saturated solution. There should be no excess of the solid left with the liquid. If this solution is carefully cooled to 40°C. without stirring more sucrose will be in solution than could have been if the water had not been heated above 40°. The cooling of a saturated solution leads to the formation of crystals, and any excess beyond saturation is gradually precipitated as the temperature drops, though crystallization may not begin immediately. But some substances, like the sugars, require longer than others for crystallization to commence, unless the solution is stirred or agitated.

### The Solubility of the Sugars

The solubility of the sugars determines their use to a certain extent. It is obvious to one who does a great deal of cooking that a sugar that requires 6 pounds of water to dissolve 1 pound of sugar, could not be used for concentrated sugar products like jellies, jams, frostings, or even cakes.

**Sucrose.** Sucrose has the greatest solubility of the disaccharid sugars. Browne in his "Handbook of Sugar Analysis" states that, at 20°C., 204 grams are soluble in 100 cc. of water. Thus at room temperature about 2 grams of sucrose are soluble in 1 cc. of water. At 100°C. 487 grams of sucrose are soluble in 100 cc. of water. For solubilities at other temperatures see Table 5.

In Table 5 the solubility of sucrose is expressed in two ways. In column 2 is given the amount of sucrose dissolved in water to make 100 grams of solution. Thus at 0°C., 64.18 grams of sucrose are dissolved in 35.82 grams of water to give a total of 100 grams of solution. The third column states the number of grams of sucrose dissolved in 100 grams of water at a definite temperature.

TABLE 5  
 SOLUBILITY OF SUCROSE IN WATER AT DIFFERENT TEMPERATURES  
 (From Browne's "Handbook of Sugar Analysis")

Temperature, degrees C.	Grams of sucrose in 100 grams of solution, or per cent	Grams of sucrose dissolved by 100 grams of water	Specific gravity of solution
0	64.18	179.2	1.31490
5	64.87	184.7	1.31920
10	65.58	190.5	1.32353
15	66.30	197.0	1.32804
20	67.09	203.9	1.33272
25	67.89	211.4	1.33768
30	68.70	219.5	1.34273
35	69.55	228.4	1.34805
40	70.42	238.1	1.35353
45	71.32	248.7	1.35923
50	72.25	260.4	1.36515
55	73.20	273.1	1.37124
60	74.18	287.3	1.37755
65	75.18	302.9	1.38404
70	76.22	320.5	1.39083
75	77.27	339.9	1.39772
80	78.36	362.1	1.40493
85	79.46	386.8	1.41225
90	80.61	415.7	1.41996
95	81.77	448.6	1.42778
100	82.87	487.2	1.43594

**Percentage of Sucrose in Saturated Solutions.** From Table 5 the percentage of sugar may be obtained. At 0°C., 64.18 grams of sugar and 35.82 grams of water give 100 grams of solution, so that the number of grams of sugar may be read as percentage of sucrose or 64.18 per cent.

**Maltose.** Maltose is not a common sugar on the market. When used to make jelly, it crystallizes from the jelly, like dextrose. Gillis has reported the following solubility.

**Lactose.** The use of lactose in the home is limited because it is not very soluble and lacks sweetness. According to Greenleaf, if lactose is crystallized below 93.5°C. the alpha hydrate form is obtained. Above 93.5°C. the beta lactose is formed. Beta lactose is about one-fourth sweeter than alpha hydrate and dissolves more rapidly, hence does not leave a sandy sensation in the mouth. Hudson states that at the final solubility of lactose there are 1½ parts of the anhydrous to 1 of the hydrate. Hunziker and



TABLE 6  
SOLUBILITY OF MALTOSE IN WATER (*Gillis*)

Temperature, degrees C.	Grams of maltose in 100 grams of solution, or per cent	Grams of maltose dissolved by 100 grams of water
0.6	36.1	56.5
21.0	44.1	78.9
29.6	48.0	93.2
34.4	49.6	98.4
43.5	55.3	123.9
49.4	58.3	139.8
54.2	60.2	151.4
59.8	63.7	175.2
66.3	66.7	200.0
74.2	72.3	261.5
87.0	79.3	383.8
96.5	85.1	569.3

Nissen state that its solution is complete after shaking it 170 hours at constant temperature. Herrington found that the addition of calcium chloride to a lactose solution increased the solubility of lactose from 28.6 to 29.5 grams per 100 grams of water at 32°C. An analysis of the precipitate showed the crystals to be a compound of lactose with calcium chloride. The following table of solubility of lactose is from Hudson.

TABLE 7  
SOLUBILITY OF LACTOSE IN WATER (*Hudson*)

Temperature, degrees C.	Final Solubility	
	Grams of lactose per 100 grams of solution, or per cent	Grams of lactose dissolved by 100 grams of water
0	10.6	11.9
15	14.5	16.9
25	17.8	21.6
39	24.0	31.5
49	29.8	42.4
64	39.7	65.8
74	46.3	86.2
89	58.2	139.2

**Dextrose.** Dextrose and levulose are the only monosaccharid sugars used in cookery to any extent. Dextrose has in recent years been put on the market in crystalline form under the trade name of "Cerelose." Combs and Bele give the solubility of "Cerelose" as shown in Table 8.

TABLE 8  
SOLUBILITY OF "CERELOSE" IN WATER (*Combs and Bele*)

Temperature, degrees C.	Grams of "Cerelose" per 100 grams of solution, or per cent	Grams of "Cerelose" dissolved by 100 grams of water
20	49.7	83.1
63	73.7	281.1

Thus at room temperature about 1 part of "Cerelose" is soluble in 1 part of water. "Cerelose" is less soluble than sucrose and goes into solution at a slower rate.

The solubility of dextrose limits its use in cookery to a certain extent. Jellies average about 60 to 70 parts of sugar by weight and 30 to 40 parts of liquid or juice. Dextrose at room temperature is soluble in water to the extent of 1 part of dextrose to 1 part of water. Since the finished jellies average over 50 per cent of sugar, when dextrose alone is used in jelly it soon begins to crystallize after the jelly is cooled. If the jelly is not covered it crystallizes very rapidly.

**Levulose.** Levulose is very soluble. It has a greater solubility than sucrose. Since it is very soluble it must be present in very large quantities before it crystallizes and is therefore very hard to crystallize. The data in the table for the solubility of levulose are obtained from the results of Jackson, Silsbee and Proffitt. The data in the third column are computed from the grams of levulose soluble in 100 grams of solution.

### Properties of Solutions

A solute dissolved in a solvent affects the properties of the solvent or in other words alters certain of its constant characteristics. No discussion of osmotic pressure is given; the effect on the freezing point is discussed in the chapter on freezing. These characteristics may be listed as follows:

- a. The vapor tension is lowered.
- b. The boiling point is elevated.
- c. The freezing point is lowered.
- d. The osmotic pressure is increased.

**Vapor tension.** Vapor tension may be defined as the vapor or gaseous pressure of a liquid. The vapor tension of a liquid depends upon the amount of vapor formed. Some liquids, like alcohol, evaporate rapidly and have a high vapor tension. Others, like water, evaporate more slowly. This gaseous pressure soon reaches a maximum at any given temperature. The maximum pressure at a definite temperature represents the vapor tension of the liquid.

TABLE 9  
SOLUBILITY OF LEVULOSE (*Jackson, Silsbee and Proffitt*)

Temperature, degrees C.	Grams of levulose in 100 grams of solution, or per cent	Grams of levulose dissolved by 100 grams of water
20	78.94	374.8
25	80.29	407.3
30	81.64	444.6
35	82.98	487.5
40	84.34	538.5
45	85.64	596.3
50	86.90	663.3
55	88.10	740.3

**Effect of the solute on vapor tension.** When a substance is dissolved in a liquid the vapor tension of the solvent is lowered, i.e., there is less tendency to pass into the vapor state, hence the gaseous pressure is decreased.

If water is the solvent, there is a tendency with a high concentration of some substances for vapor from the air to enter the solution, thus increasing the quantity of the solvent. This is particularly true of sugar solutions, when the humidity of the air is high and the solutions are concentrated. On damp, rainy days, fondant and similar candies have to be beaten for a longer time to crystallize, unless they are cooked to a little higher temperature so as to obtain a greater concentration.

The fact that it is harder for the vapor to leave the surface of the liquid when there is a soluble substance in it is made use of in the following or similar ways to keep food moist. A covered vessel containing food loses moisture from the food until the air space is saturated with vapor. If the vessel is tight enough, the food does not dry out to an appreciable extent. If two dishes are placed in an enclosed vessel, one of them containing water and the other a heavy sugar solution, the sugar solution, since it loses vapor with difficulty and absorbs liquid, will gradually absorb water from the other dish. If two foods are placed in the same container, the one with more sugar will gradually absorb moisture from the other. This is why an apple is often put in a box with a fruit cake, the apple drying

up and keeping the cake moist. Cake and bread should not be stored together, as the bread will become dry quickly.

### The Boiling Point of Water and Solutions

Water standing in an open vessel gradually evaporates, so that eventually all the water disappears in the form of vapor. We know that evaporation takes place more rapidly on warm days than on cool ones, and more rapidly from a wide shallow vessel than from a narrow deep one. As the temperature is increased, the rapidity of the motion of the molecules is increased. Therefore a larger number escape from the liquid as the temperature increases, most of them being carried away by air currents.

**Saturated vapor.** If we cover a vessel of water, leaving an air space between the surface of the liquid and the cover, evaporation takes place for a time just as from an uncovered vessel. But when the vapor cannot be carried away, the air above the liquid soon becomes filled with vapor molecules. Of course some of them reenter the liquid. When they are entering the surface of the liquid as rapidly as they are leaving it, the air is said to be saturated and is in equilibrium with the liquid, i.e., the saturation point is reached when the air holds all the vapor possible at that temperature. If the temperature is increased the velocity of the molecules is increased, and they leave the surface of the liquid faster than they enter until equilibrium is again established. If the temperature is reduced, a part of the vapor condenses into the liquid and forms drops of liquid on the sides and cover of the vessel or on the surface of the liquid.

**The boiling point.** When water is heated slowly enough, air bubbles are noticed forming on the sides and bottom of the pan. They come from the air that has been held in solution by the water. A similar thing may be noticed on a warm day when a glass or pitcher of cool water is left in a warm room. The air bubbles collect on the sides of the glass or pitcher, and if the vessel is jarred many of them will rise to the top of the water and break. If heating of the water is continued the vapor begins to form. Many of the first vapor bubbles collapse before they reach the surface.

Since the heat is applied at the bottom of the pan the vapor forms at the bottom of the liquid. With the increased speed of the molecules, due to the increased temperature, greater pressure is obtained, so that the formation of vapor is more rapid until a point is reached at which the rate of loss of heat from the water in the escaping vapor is equal to the heat received by the liquid. If the rate at which the heat is applied is constant, the bubbles are uniform in size. If a thermometer is held in the liquid it is found that when this point is reached the temperature is constant. This is the boiling point. A child might say that when a liquid is bubbling it is boiling, and it would be a fairly good definition. However, the chemist or physicist would word his definition differently. With vapor formation, pressure is exerted. Since the bubble is less dense than the liquid it comes

to the surface. But the bubble cannot reach the surface until the pressure within it is just a little greater than the pressure of the liquid on the bubble. The pressure on the bubble in an open pan comes from the weight of the column of liquid above it and the atmospheric pressure on the surface of the liquid. Another way to define the boiling point is to say that it is the temperature at which the pressure of the saturated vapor within the liquid is just greater than the outside pressure on the surface of the liquid.

If you live at sea level the boiling point of water is  $100^{\circ}\text{C}$ . The Bureau of Standards defines the boiling point of water as the point at which ebullition is violent. Slow-bubbling water does not register quite as high a temperature as rapidly bubbling water, but in cooking food in water there is no great advantage in having the water boiling violently. The food will cook nearly as rapidly in the slower bubbling water. With gas or electricity it is an economy of fuel to lower the heat when the water begins to boil, unless it is desirable to evaporate the liquid quickly.

The conversion of water from a liquid to a gaseous state requires a certain amount of energy. This energy is expressed in terms of heat. To change a gram of water at  $100^{\circ}\text{C}$ . to vapor at  $100^{\circ}$  requires about 540 calories of heat. If the heat applied to boiling water is increased, the quantity of water changed to vapor in a given time is increased. The vapor escapes from the surface of the liquid, but in a pan the free surface is limited. However, in boiling water it escapes from the free surface and from the surface of the bubbles. The temperature of the water cannot be increased because the heat lost by evaporation is equal to the heat received. If the heat is increased, the heat lost by evaporation is increased and the surface of the bubbles is increased enormously beyond the free surface of the liquid to aid evaporation.

**Lowering the boiling point.** The boiling point of a liquid may be lowered by reducing the pressure on the liquid. This may be done by boiling the liquid in a partial vacuum. The boiling point is also lowered with increased elevation above sea level. The atmospheric pressure is not so great at high altitudes because of the lessened column or depth of air. For each 960 feet above sea level the boiling point is decreased  $1^{\circ}\text{C}$ .

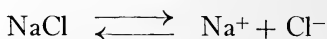
**Elevation of the boiling point.** The boiling point of a liquid can be elevated by increasing the pressure upon it. This may be done by preventing the vapor above the liquid from escaping. If a soluble substance is added to a liquid the resulting solution has a higher boiling point than the pure liquid.

The pressure of a gas increases as the temperature increases. When vapor is confined, as in a pressure cooker, the boiling point of a liquid in the cooker is elevated. As the temperature is increased, the pressure of the confined vapor on the surface of the liquid is increased. Therefore a higher temperature is required to form great enough pressure in the vapor bubbles within the liquid for them to reach the surface of the liquid.

Thus the boiling point is elevated. The higher the temperature of the confined vapor the greater the pressure on the liquid. The greater the pressure on the liquid the higher the boiling point.

**The boiling point of solutions.** Each gram-molecular weight (mole) of a non-ionized substance in a liter of water elevates the boiling point  $0.52^{\circ}\text{C}$ . A gram-molecular weight of a substance is its atomic or combined atomic weights. For example, sucrose is composed of carbon, hydrogen, and oxygen with the formula  $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ . The atomic weight of carbon is 12; that of hydrogen is 1; of oxygen, 16. Thus 12 carbons, 22 hydrogens, and 11 oxygens give a molecular weight of 342 grams. The boiling point of a liter of water containing 342 grams of sucrose is elevated  $0.52^{\circ}\text{C}$ . Two moles of sucrose would elevate the boiling point  $1.04^{\circ}\text{C}$ . The boiling point can be elevated as long as the substance added is soluble. When the solution becomes saturated, or the point is reached at which no more can be dissolved, the boiling point is constant for substances that behave normally in solution. If boiling is continued so that the solvent is vaporized, the excess solute beyond saturation is crystallized. This is illustrated in Experiment 3 in the laboratory outline.

**Effect of ionized substances on the boiling point.** Some substances when dissolved in water are ionized. In a solution of sodium chloride, for example, not only sodium chloride molecules are found but also sodium ions and chlorine ions.



The atomic weight of sodium is 23 and that of chlorine is 35. If 58 grams of sodium chloride (a mole) are added to a liter of water, and the sodium chloride is completely ionized, the boiling point will be elevated  $1.04^{\circ}\text{C}$ . The mole of sodium will elevate it  $0.52^{\circ}$  and the mole of chlorine will elevate it  $0.52^{\circ}$ . Sometimes a substance that ionizes in solution is not completely ionized. When this happens, the boiling point is elevated according to the degree of ionization.

At high altitudes it is possible to cook foods more rapidly by adding salt to the cooking water. To be very effective this requires such a large quantity of salt that the food becomes too salty. It may be used for potatoes that are not peeled.

Sugar solutions behave abnormally in regard to the boiling point. In Experiment 4 it is found that the sugar solutions do not behave like the salt solution. They do not reach a constant boiling point. A mole of sucrose (342 grams) measures about  $1\frac{3}{4}$  cups. It can be readily seen by consulting the solubility table of sucrose that its solubility will account for only a partial elevation of the boiling point. The boiling point of the sugar solution increases with its concentration until the melting point of the sugar is reached. Occasionally, in cooking a sucrose solution (Experiment 4A), some of the sucrose crystallizes on the edge of the pan, thermometer, and top of the sirup, similar to the salt solution, but this is not the usual result.

When the melting point of the sucrose is reached these crystals melt. Temperatures far above the melting point of the sugars can be obtained. However, with the very high temperatures, caramelization or decomposition of the sucrose occurs quite rapidly.

There is no very satisfactory explanation for the abnormal behavior of the sugars. Chemists tell us that one explanation may be that the sugar and water combine chemically giving a new compound with a new boiling point, or the combination of the sugar with the water may give a very concentrated solution, thus elevating the boiling point.

**Boiling point of sucrose solutions.** Browne in his "Handbook on Sugar Analysis" lists the boiling point of sucrose solutions as follows.

TABLE 10  
BOILING POINT OF SUCROSE SOLUTIONS (*Browne*)

Per cent sucrose.....	10	20	30	40	50	60	70	80	90.8
Boiling point.....	100.4	100.6	101.0	101.5	102.0	103.0	106.5	112.0	130.0

A 10 per cent solution of sugar is one that contains 10 grams of sugar and 90 grams of water or one having these proportions.

**Heat of solution.** Some substances that are soluble may liberate heat when they go into solution. The example of mixing water and sulfuric acid ( $H_2SO_4$ ) is a well-known one. Other substances, instead of giving off heat, cause the temperature to drop when they go into solution. They are said to have a negative heat of solution, and heat is absorbed.

If sugar and water of the same temperature are mixed, the temperature of the solution drops as the sugar is dissolving. Salt and many other substances also absorb heat as they go into solution. When the substances that absorb heat as they go into solution are crystallized from solution, heat is liberated and the temperature is elevated slightly. This is often noticeable in making fondant or fudge. Frequently the sirup softens so that it is not so viscous and is easier to stir when crystallization starts. As the first crystals formed are not visible, one may think that the sirup is not going to crystallize because of this softening. It is more noticeable with larger amounts of fondant and fudge than with very small ones.

### Crystallization

In making icings, frostings, or candy like fondant and fudge, it is necessary to crystallize the sugar solution. For crystallization to occur, nuclei must form in the solution. To these nuclei the material of the solution is added to form crystals. Both the rate of formation of nuclei and the rate of crystallization are affected by the nature of the crystallizing substance,

the concentration, the temperature, agitation, and the impurities present in the solution.

**Nature of the crystallizing substance.** Some substances like salt crystallize readily from water solution. It requires only a very slight supersaturation to start nuclear formation, and all excess salt in the solution beyond the saturation point is precipitated as crystals. Some substances do not form nuclei or crystallize so readily as salt. With sucrose it is often necessary to have a considerable degree of supersaturation before crystallization commences. Sucrose crystallizes more readily than levulose.

**Formation of nuclei.** Nuclei cannot form and crystallization cannot occur except from a supersaturated solution. The formation of nuclei, that is the uniting of atoms to form nuclei, is influenced by several factors. If a solution is left to stand, a few nuclei may form spontaneously in various places, and from these nuclei crystallization proceeds. When only a few nuclei develop spontaneously in the solution, the crystals grow to large size. Usually nuclei formation and crystallization do not begin immediately after supersaturation occurs. The rate of nuclear formation may be favored by specks of dust in the solution. Agitation or stirring of a solution increases the rate of nuclear formation. A drop in temperature at first favors, and then retards, the formation of nuclei. Instead of spontaneous formation of nuclei, seeding a solution may be used to start crystallization.

**Seeding.** When crystals of the same material are added to start crystallization the process is called seeding. These crystals serve as nuclei for crystal growth. If the quantity of crystals added is large and the size of the crystals small, it serves as many nuclei in the solution, and the resulting crystals are small. If the quantity of material added is very small, the nuclei formed are few in number and the crystals formed are large. One may think of all crystals as being large enough to be visible, whereas many of them may be very small, so small in fact that they may float in the air. Tutton tells of crystals difficult to obtain, but after being obtained several times in the laboratory they were then easily obtained. If crystals are floating in the air there is the possibility that they may serve to seed solutions, and thus start crystallization.

**Rate of crystallization.** To the nuclei formed in the solution new molecules from the solution are deposited, in a regular order or manner, so that each crystal has a typical shape. One side or face of a crystal may grow more rapidly than another. The rate at which the nuclei grow to larger size is called the rate of crystallization. This rate may be favored by the concentration of the solution and its temperature; it may be hindered by foreign substances.

**Concentration of the solution.** A more concentrated solution favors the formation of nuclei. A fondant sirup cooked to  $114^{\circ}\text{C}$ . contains less water and is more concentrated than one cooked to  $111^{\circ}\text{C}$ . Thus nuclei form more readily in the one cooked to  $114^{\circ}\text{C}$ . Large, well-shaped crystals form more readily if the degree of supersaturation is not too great. The



most favorable supersaturation for crystal growth, of a sucrose solution boiled to 112°C., is that between 70° and 90°C. Although crystallization occurs in a very short time when the sirup is stirred at these temperatures, the crystals formed are larger than when the sirup is cooled to a lower temperature. See Figs. 1 and 3. Supersaturation and a low temperature are desirable for the development of small crystals. The viscosity of a very supersaturated sirup delays crystal growth.

**Temperature at which crystallization occurs.** It is a well-known fact that, in general, chemical precipitates come down more coarsely crystalline if crystallized at high temperatures. Barium sulfate is a good example of a substance that crystallizes in large crystals at high temperatures. The sugars follow this general rule. Other things being equal, i.e., concentration, etc., the higher the temperature at which crystal formation occurs, the coarser the crystals formed.

A drop in temperature at first favors the formation of nuclei, and then hinders it. Crystallization is favored in sugar sirups by cooling to a certain temperature, but is hindered when cooled to a lower temperature. Since the viscosity of a saturated sugar solution becomes increasingly greater as the temperature falls below 70°C., crystal formation is also slower as the temperature falls.

**Agitation.** Stirring a solution favors the formation of nuclei and hinders the depositing of the material of the solution on the nuclei already formed. Hence, crystals in solutions that are stirred do not develop to the size that they do in spontaneous crystallization. Bancroft states that "The mean size of crystals is determined by the total amount of the material crystallizing and number of crystals. The really important thing therefore is the number of nuclei which are formed under any given conditions." If small crystals are desired, then the conditions should be such that many nuclei are formed. Small crystals are obtained in sirups of definite concentration and temperature, if the sirup is stirred until the mass is kneadable. However, if the sirup is stirred for only a short time, some nuclei are formed, but after agitation is stopped, the formation of new nuclei is not favored and crystal growth is favored. Fig. 2 shows crystals from fondant stirred for only a few seconds. The crystals are much larger than those in Fig. 1, which shows crystals from fondant that was stirred until the mass could be kneaded. The same thing is illustrated in Fig. 10, which shows crystals from divinity that would not quite hold its shape but spread when dropped on oil paper. The crystals from the same divinity (Fig. 9) which was stirred until it would hold its shape, but was glossy and not dry in appearance when dropped on oil paper, are small. Divinity with the small crystals is very smooth and velvety on the palate. This emphasizes the importance of stirring candy and icing sirups until practically all the material is crystallized, if small crystals are desired.

**Adsorption and impurities in the solution.** Freundlich states that "in the vast majority of cases the foreign substance lowers the rate of

crystallization." The rate of crystal growth is retarded because of adsorption of the foreign substance by the crystals. If the substance is strongly adsorbed, crystallization may be retarded to such a rate that it is practically abolished, even though the solution is very supersaturated with the crystallizing substance. Since the adsorption prevents crystal growth, if a precipitate is formed in the presence of a substance strongly adsorbed by the precipitate, it will crystallize in a much finer state of subdivision. Sometimes the substance is more strongly adsorbed at one face than at another, so that this face grows more slowly than is customary and thus becomes comparatively larger in relation to other faces. This explains why crystals from pure solutions may have different shapes from those obtained from impure solutions. Speaking of sugar manufacture and crystallization of sucrose, Zitkowski says, "If the content of non-sugars in the solution is high enough crystallization may be prevented even though evaporation is carried to the point of dryness." The addition of other carbohydrates, such as dextrose, levulose, and starch, to sucrose solutions retards the crystallization of the sucrose. The extent to which they delay crystallization depends upon how strongly they are adsorbed and the proportion added.

Other substances strongly adsorbed by sucrose crystals are fat and proteins. Hence, the use of butter, milk, and egg white all retard crystal growth.

**Crystallization of sucrose in sugar manufacture.** In sugar manufacture, when it is time to start crystallization in the mass of boiling sirup, the sugar boiler may lower the pressure, which causes violent boiling or agitation, or he may add a sirup or water to change the concentration or temperature. He may also seed the sirup by adding a sufficient amount of small sugar crystals. The crystals when first formed are too small to be visible in the sirup but grow to visible size. This may be in a few moments. The sugar boiler controls the temperature, pressure, and density to bring the crystals to the desired size. If they are too small when finished, too much sugar is lost in washing the liquid from the crystals. If they are too large, the public does not care for them.

**Grades of sugar.** Rice states that there is a surprising lack of information about the various grades of sucrose sugar produced and their specific uses, probably because the information has not been given general circulation. He lists 36 grades of sucrose, to which may be added many more grades made for a specific use with a particular equipment. The following classifications are those given by Rice.

The refined sugar distributed for household use is somewhat smaller in grain size than that found some years ago, because the general demand has been for a more rapidly dissolving sugar. As the finer grain gives a whiter appearance, the tendency has been to produce a finer sugar. Fine Granulated is produced in the largest quantity of any grade. In the same class, each with increasingly finer grain or crystal size, are Extra-fine Granulated, Berry or Fruit or Fruit Powdered (it is designated by all

these names), and Coating. Rice states the name Fruit Powdered has nothing to do with fruit nor is the sugar powdered. The "Coating" is used where unusually fine crystals are desired.

Four sugars, produced especially for use when high-temperature cooking is necessary in making clear hard candies and very white fondants or pan-coated goods, or when an extremely hard grain must be used, are Coarse, Standard, Medium, and Manufacturers' Grade. Manufacturers are tending to use Manufacturers' Granulated, which varies from the others only in that it is the finest of the four and will dissolve much faster. In this same class are the Sanding sugars. Sanding sugars are used to sprinkle upon the surfaces of many soft candies and fruit products to prevent their sticking together. They are also used to sand gum drops and fruits which are to have further quantities of sugar crystallized upon their surfaces. The crystals of Sanding sugar are generally nearly perfect and exact in size.

There are generally produced three grades of machine powdered sugar differing only in the degree of fineness: Coarse Powdered, having about the fineness of Coating sugar; Standard Powdered, being somewhat finer; and XXXX, commonly known as Confectioners', being as fine as practical to produce with the ordinary type of sugar mill. A still finer powdered sugar, made with an improved powdering mill, is sometimes designated as 6X or Special XXXX. This last sugar is particularly valuable in preparing cold icings, because they remain softer longer than when prepared with coarser powdered sugars. The smaller the particle size the greater the amount of moisture held, because of the proportionally greater surface area. Rice states the number of X's applied to different sugars means nothing in actual fineness. Powdered sugars may be treated to prevent caking. Usually 3 per cent of cornstarch is added. A tri-calcium phosphate has been introduced for this purpose and 1 per cent of it is more effective than 3 per cent of cornstarch. Its use is not as yet permitted in some states.

Rice describes a new and different sugar called transformed sugar. It is produced in the same way as refined sugar up to the point of crystallization. It is then treated to give a very small grain with exceedingly irregular surface, the surface being penetrated by cracks or recesses which cause the grain to crumble easily, and, because of the relatively large surface, to dissolve almost instantly when dropped into water. The particles may be crushed easily and are used in chocolate coatings. "The crevices in these grains are very small and naturally are full of air. When this sugar is used for creaming with shortening in the production of cake or in very dry dough for biscuits, this finely divided air cannot collect and escape in large bubbles but acts as a leavening agent and reduces the necessity for most, if not all, other leavening agents." Because of its fine and fluffy condition it can replace powdered sugars in various prepared drinks and food mixtures. At present there are seven grades of transformed sugar, varying in fluffiness and color.

Soft brown sugars are graded according to color and range from a nearly

white No. 1 to No. 15, which is as dark as roasted coffee. The grain of these sugars is softer than that of refined sugar and the percentage of invert sugar increases with increasing darkness in color.

**Amorphous sugar.** When sucrose is melted, or when solutions of sucrose are heated to high temperatures and then allowed to cool, crystallization does not occur immediately. A very brittle, very hard, solid, transparent mass is formed. This form of sucrose is known as amorphous sugar. It crystallizes very slowly, sometimes taking several months or years to crystallize. Candies of this type are extremely hard. Some candies are cooked to stages between those of the soft crystalline ones and the hard amorphous forms. Caramels are examples of this type of candy—they are fairly soft, yet are not crystallized.

**Crystallization in candy making.** Large crystals are the result of growth, for which several days or weeks may be required. The growth of the crystals is favored if the solution is not stirred, if the supersaturation is not great, and if no crystals are added to the solution. Since small crystals are desired in candy making, the procedure followed is the opposite of that for obtaining large crystals. The period of crystallization is short, usually not over 30 minutes is required, the supersaturation is great, and the solution is stirred after supersaturation is attained.

### Stages of Cookery of Sucrose Solutions in Candy Making

**The "cold-water" test.** In the "cold-water" test, one can tell, from the firmness or hardness of a portion of the sirup which has been dropped into cold water, whether the sirup has reached a concentration required for the type of candy desired. The degree of firmness in the cold-water test is designated by different descriptive terms, such as soft ball, medium ball, hard ball, and brittle. It should be remembered that there is no definite stage between a soft ball and a medium one, but as the concentration of the solution gradually increases, the firmness of the sirup tested in cold water increases. One factor that causes variations in this test is the fact that the colder the water in which the sirup is tested the firmer the tested portion. Another cause for variation is that the portion being tested is not always left long enough to become cooled.

Yet with long practise the cold-water test can be used with great precision to denote the stage of cookery of a sirup. It is the different interpretations of what constitutes a soft or medium ball that makes this test a more difficult one to use. The number of terms used by different persons to suggest the same stage of cookery is illustrated by the following. In looking over a large number of recipes for a candy contest, it was interesting to find that of 600 recipes nearly 200 had exactly the same proportion of sugar, corn sirup, water, and egg white. But the directions for making the cold-water test in these 200 recipes varied. Here are some of the terms used to describe the portion of sirup tested in the cold water: Soft ball, medium

soft ball, medium firm ball, firm ball, hard ball, solid ball, real hard, very hard, hardens, threads, soft crack, cracks, crackles, cracks and hops, hairs, spins hairs, strings, snaps, breaks, and brittle.

**Stages of cookery.** In part the descriptions of stages of cookery of sugar sirups are from "Terminology Used in Food Preparation." A sucrose solution that has reached a concentration indicated by a temperature of 110° to 112°C. does not form a ball when a portion of the sirup is tested in ice water, but spins a two-inch thread when dropped from a fork or spoon.

At a temperature of 113° to 115°C. a soft ball is formed when a portion of the sirup is tested in ice water. This ball is easily molded in the water, but does not retain its shape at room temperature. Sirup cooked to this stage is used for fondant, fudge, and penuchi.

At a temperature of 118°C. a firmer ball is obtained. At 122°C. the ball is still harder and less readily molded in the water. At 122°C. the ball retains its shape at room temperature. Sirups for caramels are cooked to 118° to 122°C. Temperatures of 118° to 123°C. are used for sucrose sirups that are to be poured over beaten egg white.

The sirup at temperatures of 121° to 130°C. forms an increasingly harder ball, which holds its shape, yet is plastic, when a portion is dropped into ice water; it is used for popcorn balls, nougat, divinity, and some taffies. The sirup at temperatures of 132° to 143°, called the soft-crack stage, separates into threads which are hard but not brittle when dropped into ice water. It is used for butterscotch and taffies. Sirups cooked to 149° to 154°C., the hard-crack stage, separate into separate threads which are hard and brittle when dropped into cold water; used for brittles and glacés.

The length of the thread or hair that forms when a fork or spoon containing some of the sirup is lifted into the air may also be used to indicate the stage of cookery.

**Effect upon stage of cookery of addition of corn sirup and other sugars to sucrose solutions.** The addition of corn sirups and other sugars to sucrose solutions modifies the firmness of the portion tested at a definite temperature in cold water.

Commercial corn sirup is composed of dextrin, dextrose, maltose, water, and a small amount of ash. Frandsen, Rovner, and Luthly state that its composition is as follows:

	PER CENT
Dextrin.....	29.8 to 45.3
Maltose.....	4.6 to 19.3
Dextrose.....	34.3 to 36.5
Ash.....	0.32 to 0.52
Water.....	14.2 to 17.2

Since the composition of corn sirups may vary slightly, this may result in different degrees of firmness when different corn sirups are used with

sucrose solutions. The use of corn sirup with sucrose in taffy, brittles, or caramels, candies that do not require crystallization, produces a definite stage of hardness when determined by the cold-water test at a lower temperature than when sucrose is used alone. Dextrin is the ingredient of the corn sirup that brings about this result, for if dextrin is used alone with sucrose the temperature for a definite degree of hardness is still lower than when corn sirup is used. In some of the early references on sugar cookery the term glucose is used for corn sirup.

Table 11 shows the effect of different proportions of sugar upon the stage of hardness in sugar cookery. Miss Daniels has reported similar results in part.

TABLE 11

Amt. of dextrin	Amt. of corn sirup	Amt. of sucrose	Amt. of dextrose	Soft ball	Medium ball	Hard ball	Crack	Cara-melized
				Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.
1 cup	2 cups	1 cup		107	109	114-118		
		1 cup		109	111	114	120	135
	1 cup	1 cup		110-111	113	115-116	120-122	140
		2 cups		112	114-115	118-120	126-128	145-150
	1 cup	2 cups		113-115	118	122	132	155-170
		1 cup	1 cup	118	122	132	140-145	
		2 cups	125-128	132	140			

It can be seen from this table that the greater the proportion of corn sirup used the lower the temperature to which the sirup needs to be cooked for a definite stage of hardness.

### Fondant

Fondant is made when sucrose is cooked with water to a definite temperature, the sirup is cooled and beaten, and the mass crystallizes. According to accepted standards for good fondant, it should be snowy white. The crystals should be so small that they are imperceptible and not gritty on the palate. The fondant should be soft enough to be plastic and velvety but not dry and crumbly.

**Cooking of fondant.** Enough water should be added to dissolve all the sugar during the cooking period. With rapid boiling a larger proportion of water can be used. With a slow fire and slow boiling, it is preferable to use less water, or a long time is required for the cooking process. With larger quantities of sugar the proportion of water is reduced because

evaporation is relatively more rapid from the small quantity of sirup. Covering the pan during the first part of the cooking period allows the steam to dissolve and wash down crystals from the sides of the pan.

Some directions state not to stir the sirup while it is boiling. It is well to stir it to be sure all the sugar is dissolved, so that there are no crystals in the sirup to start crystallization while it is cooling. The danger in stirring candy while it is boiling comes from splashing the sirup on the sides of the pan. These drops of sirup on the side of the pan become dry and nuclei form which serve as a basis for crystallization while the sirup is cooling. A damp cloth is often used to swab the sides of the pan to prevent nuclei and crystals forming there during the cooking of the sirup. Since boiling solutions of sugars are not saturated solutions, any candy can be stirred as much as desired while it is boiling without causing crystallization, provided the sirup is not splashed on the sides of the pan. But after the sirup stops boiling it cools quickly and soon reaches the supersaturation point. If the sirup is poured for cooling from the pan in which it is cooked, it should be done quickly. Directions often state not to scrape the portion clinging to the pan with the spoon. Of course this is because the small amount of sirup left on the sides of the pan soon cools to the supersaturation point, and if it is stirred, as it must be in scraping it from the sides of the pan, crystals may form that will seed the entire mass. The thermometer should not be allowed to roll around in the sirup while the sirup is cooling for this agitates the sirup. The pan should be set level so that all parts of the sirup cool equally. The container in which the fondant is poured to cool should have a smooth surface, as rough surfaces may induce crystallization.

In the preceding pages the factors determining the size of crystals in sugar crystallization are discussed. These factors are applicable in making fondant and fudge.

**Concentration and temperature for cooking the sirup.** A sucrose solution containing 80 per cent of sucrose, i.e., 80 grams of sucrose and 20 grams of water, boils at  $112^{\circ}\text{C}$ ., is saturated at  $90^{\circ}\text{C}$ . and supersaturated below  $90^{\circ}\text{C}$ . Therefore, no crystals are formed in a sucrose solution cooked to  $112^{\circ}\text{C}$ . until the temperature drops below  $90^{\circ}\text{C}$ . Woodruff and van Gilder found that fondant cooked to  $115^{\circ}\text{C}$ . has an average water content of about 13 per cent. The higher the temperature to which the sirup is cooked, the less the percentage of water in the fondant. If fondant contains too small a proportion of water, it is dry and crumbly; if too much, it is sirupy and runny. When the sirup is cooked to  $109^{\circ}$  to  $111^{\circ}\text{C}$ . (Experiment 7B), the fondant contains a high percentage of moisture. Sirups cooked to this temperature give a fondant too fluid to knead or mold, unless it is beaten when hot. Fondant sirup for ordinary home use may be cooked from  $113^{\circ}$  to  $115^{\circ}\text{C}$ . The lower temperature gives a softer fondant for remelting and making candy like peppermints; the higher temperature gives a drier fondant for molding. It should be

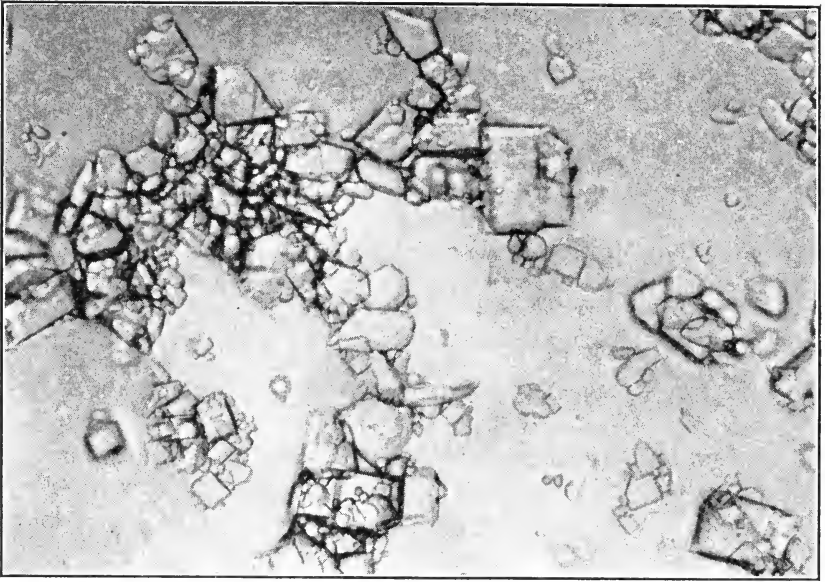


FIG. 1.—Crystals from fondant. The sirup was cooked to 113°C.—then beaten immediately until the mass was stiff enough to knead. Magnification approximately  $\times 200$ .

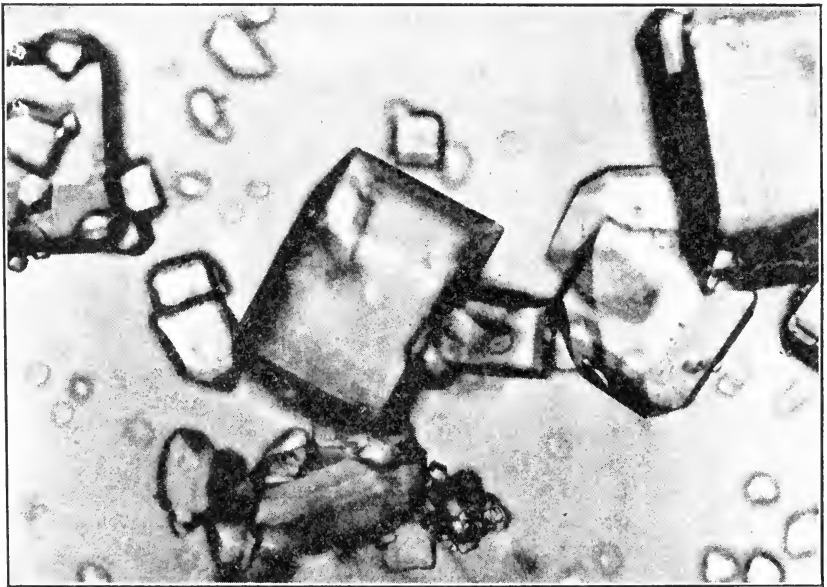


FIG. 2.—Crystals from fondant. A portion of the same sirup as that in Fig. 1. It was beaten slightly while hot to start crystallization; then left to stand several hours until the whole mass was crystallized. Magnification approximately  $\times 200$ .  
(*Photomicrographs of sugar crystals by courtesy of Ethel L. Swanson.*)



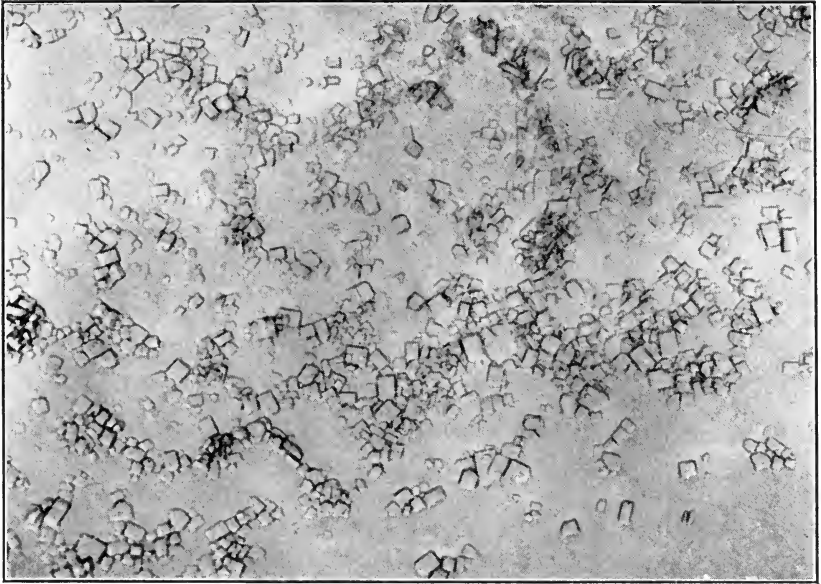


FIG. 3.—Crystals from fondant. A portion of the same sirup as that shown in Fig. 1. Cooled to 40°C. Then beaten until the mass was stiff and kneadable. Magnification approximately  $\times 200$ .

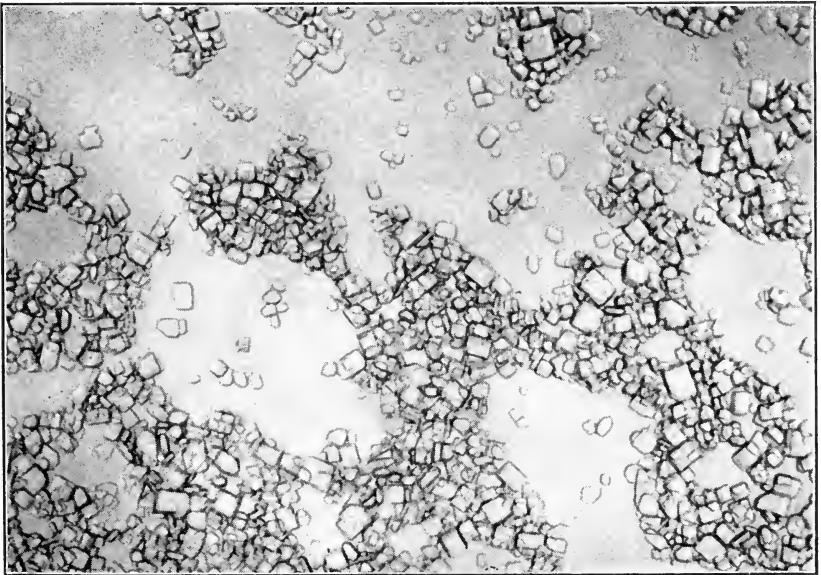


FIG. 4.—Crystals from fondant. A portion of the fondant shown in Fig. 3, immediately after adding 6 per cent of beaten egg white. Magnification approximately  $\times 200$ .

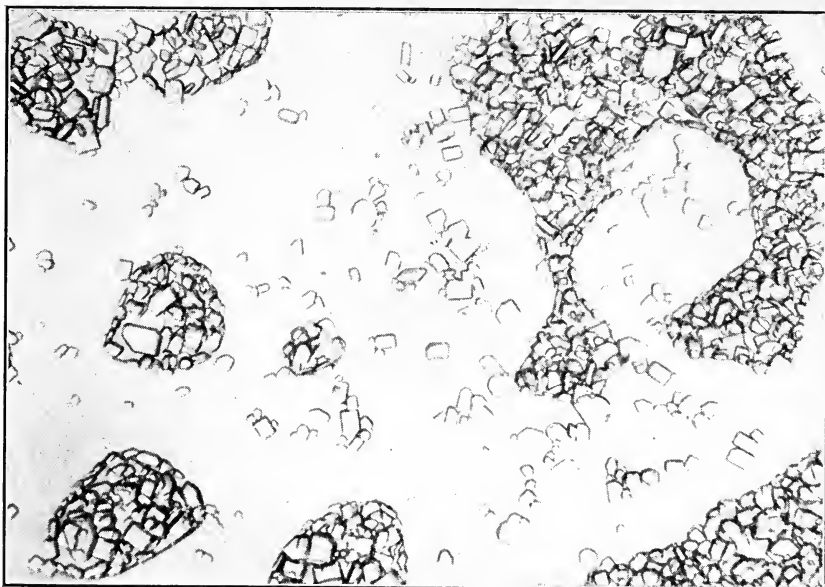


FIG. 5.—Crystals from fondant. A portion of the same fondant shown in Fig. 3 after 20 days' storage. Note aggregation of the crystals. Magnification approximately  $\times 200$ .

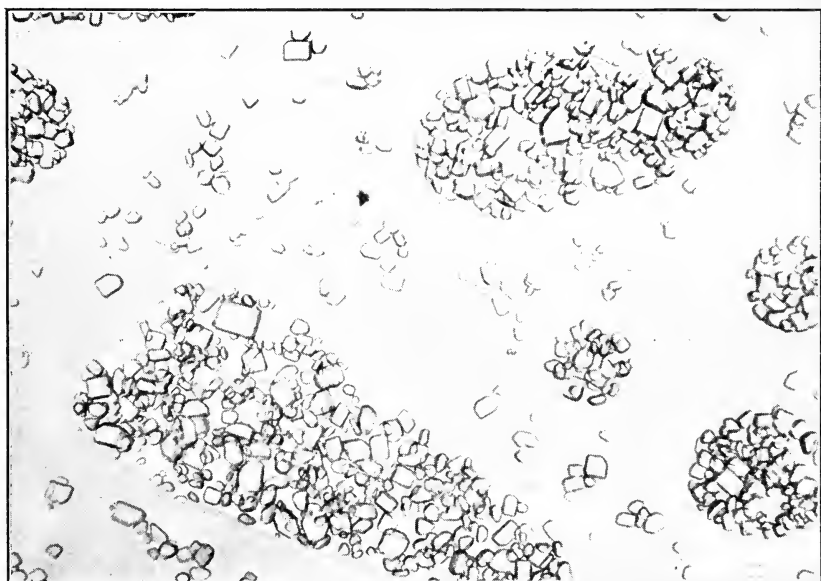


FIG. 6.—Crystals from fondant to which 6 per cent egg white was added after 20 days' storage. Compare with Fig. 4. Magnification approximately  $\times 200$ .



FIG. 7.—Crystals from fondant. A portion of the same fondant shown in Fig. 3 after storage for 40 days. Note the growth of crystals. Magnification approximately  $\times 200$ .

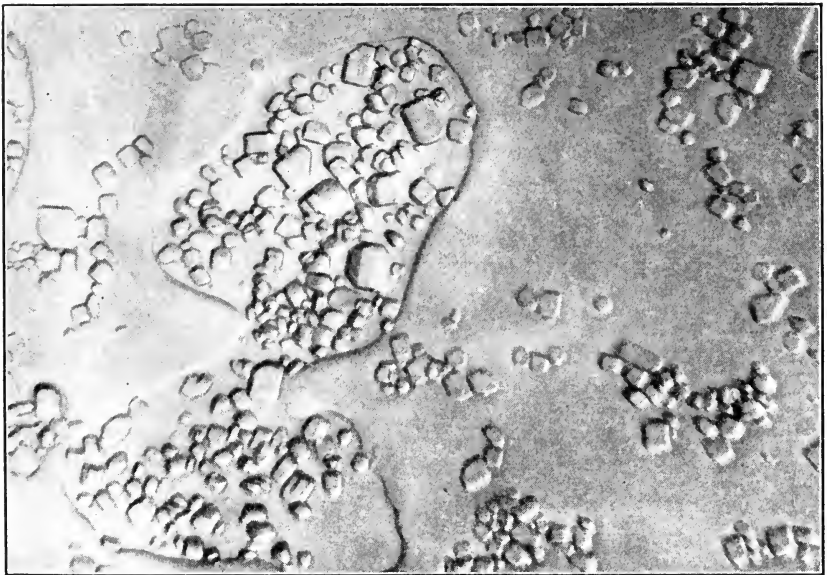


FIG. 8.—Crystals from fondant, with 6 per cent of added egg white after 40 days' storage. A comparison with crystals in Fig. 4 and Fig. 7 shows that egg white tends to retard crystal growth during storage. Magnification approximately  $\times 200$ .

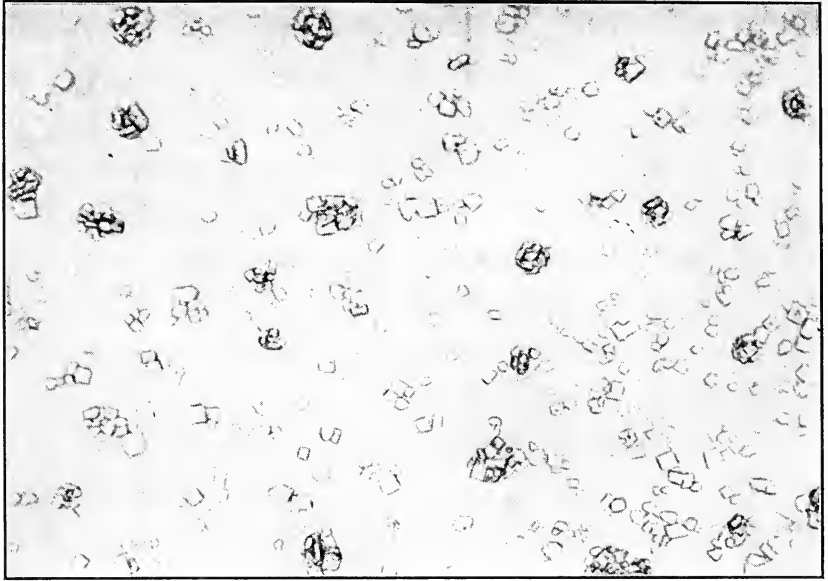


FIG. 9.—Crystals from divinity which was beaten until a piece dropped from a spoon would hold its shape, yet still appear glossy. Magnification approximately  $\times 200$ .

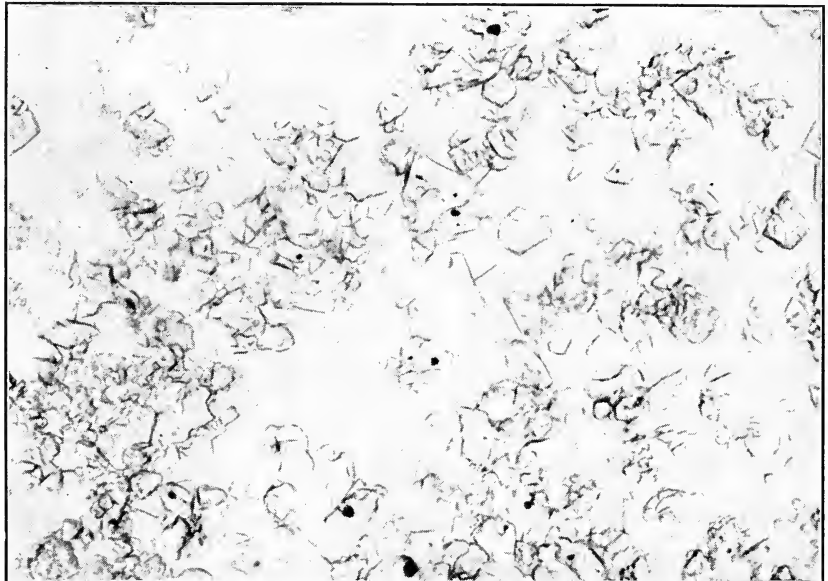


FIG. 10.—Crystals from divinity. Some of the same divinity as that shown in Fig. 9. But these pieces were not beaten as long as those in Fig. 9. They flattened out when dropped from a spoon. These crystals and those shown in Fig. 2 emphasize the importance of beating candy sufficiently. Magnification approximately  $\times 200$ .

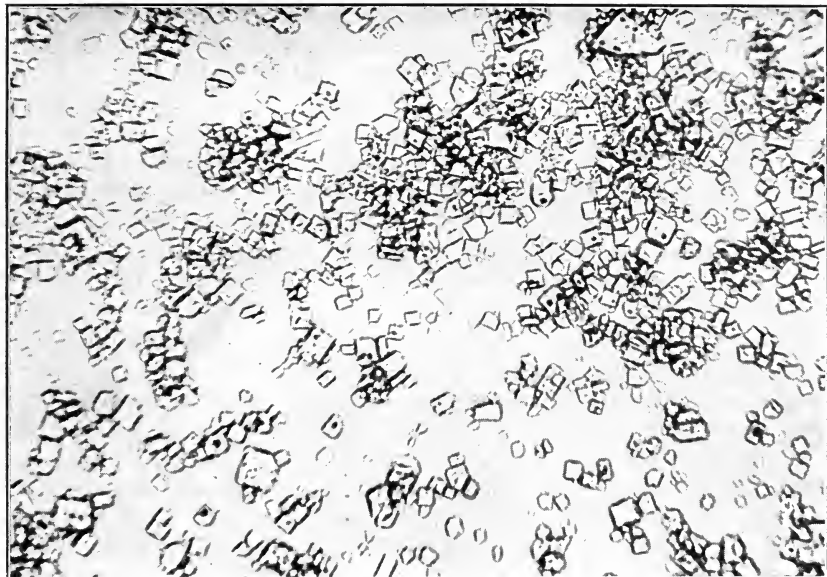


FIG. 11.—Crystals from divinity. Same as those shown in Fig. 9, but after 40 days' storage. Compare with crystals in Fig. 7 and Fig. 8. Magnification approximately  $\times 200$ .

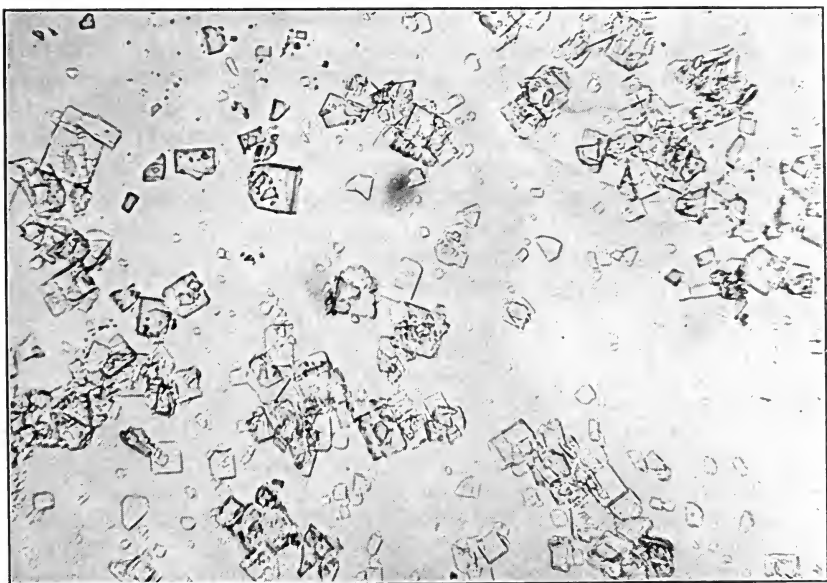


FIG. 12.—Corn sirup, sucrose and water cooked to  $119^{\circ}\text{C}$ . and beaten while hot until the mass was stiff. Corn sirup retards crystal growth, see Fig. 1, but not to the same extent that both corn sirup and egg white do. See Fig. 9. Magnification approximately  $\times 200$ .

remembered that evaporation is greater from a small quantity of fondant, while it is being stirred, than from a large quantity. On rainy or damp days, when the humidity is high, moisture may be absorbed from the air by the sirup, so that it is preferable to cook the sirup to the higher temperature. Cooking the sirup to a temperature above 116°C. gives a fondant that is too dry and crumbly. Jordan states that commercially the amount of moisture in fondant is controlled carefully and according to the use for which it is intended, as a difference of 1 per cent of moisture results in a fondant too soft to handle or too dry to knead.

**The growth of crystals in fondant.** Freundlich states that "surface tension is also the cause of recrystallization, in which small crystals unite to larger ones. Probably this phenomenon is similar to the union of minute droplets to larger ones, when in direct contact, for it is unlikely that the formation of larger crystals could be due to the increased vapor pressure of the smaller ones bringing about a distillation; the process takes place far too rapidly to allow of the latter explanation." Water in fondant is a saturated sucrose solution. The crystals are in contact with this saturated solution. Owing to the higher surface energy of small crystals, as discussed in Chapter I, the smaller crystals dissolve, and the larger crystals increase in size.

Crystals in fondant may grow in size during storage. Halliday and Noble have reported the growth of crystals in fondant stored for 17 days. Figs. 3 to 8 show crystals from fondant. Fig. 7 shows the growth of crystals in fondant after 40 days' storage. Compare these crystals with those shown in Fig. 3.

**The addition of egg white to fondant.** Egg white may be added to fondant. Paine states that the clumping together of air particles into larger particles lessens the intensity of the white and that the addition of a small quantity of egg white to fondant prevents the aggregation of the air particles, thus aiding in keeping the fondant white. The beaten egg also incorporates additional air.

The addition of beaten egg white to fondant also retards the rate of crystal growth during storage. Figs. 4, 6, and 8 show crystals from fondant to which egg white has been added. Since the egg white is adsorbed by the crystals, the effectiveness of the egg white in preventing crystal growth may partially depend upon how the egg white is distributed throughout the fondant. Swanson found that not much more than 6 per cent of beaten egg white could be added to the fondant, without the fondant becoming too fluid. She found 3 per cent of added egg white to be as effective as 6 in preventing growth of crystals during storage.

**The addition of dextrose, levulose, or invert sugar to fondant.** Dextrose, levulose, or invert sirup may be added directly to sucrose solutions to aid in regulating the size of the crystals. Or, invert sugar may be formed during cooking of the sucrose sirup by adding citric, tartaric, or acetic acids. Often cream of tartar is used for inverting sucrose in fondant.

It is difficult to regulate conditions, such as the time of cooking, to obtain a definite percentage of invert sugar for sucrose is inverted more rapidly with higher temperatures and greater acidity. Hence, it is sometimes preferable to add a definite quantity of dextrose, levulose, or invert sugar. Woodruff and van Gilder found that cream of tartar inverted the sucrose more slowly than citric, tartaric, or hydrochloric acids at the same  $pH$ . Cream of tartar can be added in sufficient quantity to produce enough invert sugar to give small crystals and to add to the smoothness of the fondant. If added in too large a quantity, too much invert sugar is formed, so that the fondant is too fluid. The flavor of the fondant is quite acid when a large proportion of cream of tartar is used.

The larger the quantity of dextrose or levulose added in making fondant the longer the time required to beat the sirup to bring about crystallization. With too large a proportion of these sugars the fondant is soft. When fluid centers of confections are desired, it is necessary to add substances that bring about inversion of the sucrose after the fondant is dipped in chocolate or treated in some way to give a firm outer coating.

Woodruff and van Gilder state that sirups with concentrations of 43 per cent or more invert sugar would not crystallize; those containing 16 to 23 per cent formed a semi-fluid mass of crystals; and those containing 6 to 15 per cent gave a plastic, moldable product. With 11.1 per cent or more of invert sugar the crystals of maximum size measured 10 to 13.2 microns and the grain was exceedingly fine to tongue and roof of the mouth. Fondants containing 7 per cent reducing sugars of either kind (glucose or levulose) were of agreeably fine texture, with their largest crystals measuring 15 to 19 microns. Crystals in candies of observed coarse texture measured 45 or more microns. Differences in crystal size of 6 to 10 microns, which was the difference of crystal measurements of fondants rated very fine and slightly coarse, could be detected by the tactile sense.

Halliday and Noble have reported that the addition of corn sirup, which contains dextrose and dextrin, tends to prevent the growth of crystals during storage of fondant. They also found that fondant made with cream of tartar retarded crystal growth during storage.

**Color of fondant.** Fondant crystallizing without stirring is not snowy white but more transparent. The snow-white appearance of the stirred fondant is due to the small air particles. When the water contains alkaline salts the fondant without cream of tartar added has a yellow or gray tinge; that with cream of tartar or acids is white.

Fondant made with hard water,  $pH$  7.2 to 7.8, has a creamy tint. This may be caused by slight traces of flavones in the sugar, but it is probable that it is due to caramelization or some other cause. If, to some of the same sugar and water, a little cream of tartar is added, a snowy white fondant is always obtained. If, however, corn sirup is added to the sugar to make fondant with the above water a gray color develops. The color is so pro-

nounced that the fondant is not attractive looking. If distilled water is used with the corn sirup and sucrose, the gray color does not develop.

**Ripening.** When fondant stands 12 to 24 hours it seems more moist and is more plastic and kneads more easily than when it was first made. In the candy trade this is known as "ripening." Fondants that contain substances that cause slow hydrolysis of the sucrose become softer on account of the formation of invert sugar, but "ripening" is an additional process and occurs in fondant containing only sucrose. Carrick suggests that the reason for this "ripening" is that the small crystals in the mass are dissolved, thus letting the large crystals move more easily, and they are thus more plastic.

**Honey fondant.** Candies made from pure honey, on account of their high levulose content and the moisture-absorbing property of honey, usually become very sticky in a few hours after they are made. Phillips reports the combination of honey, whole milk, and lactose sugar to make fondant. Stratton combined honey and lactose in fondant. Fondant usually contains some crystals of each of the sugars that enters into its composition, but in Stratton's combination the crystal phase was entirely lactose, the crystals being particularly minute. But the lactose crystals have a tendency to grow so that fondants smooth at first became somewhat grainy. It was found that the honey fondant would absorb a relatively high percentage of whole milk by mechanical mixing, and that this milk tended to prevent the growth of the lactose crystals. It was also found that the honey has an unusual preservative action, for the milk in the mixture remained sweet as long as the candy was kept.

### Fudge

The factors that control the size of the crystals in fondant making also determine the size of the crystals formed in fudge. Fudge is often made of brown sugar. Brown sugar contains a higher percentage of invert sugar than granulated sugar. Thus it crystallizes less readily than granulated sugar.

Fudge also ripens with storage and if placed in a container with a tight-fitting lid becomes much softer and more velvety after 24 hours' storage.

In substituting cocoa for the chocolate in fudge, Reese found that the quantity of cocoa was a matter of individual preference, although 3 to 3½ tablespoons to each cup of sugar was preferred by the majority of judges. But, if other conditions were standardized, the final temperature to which the sirup was cooked depended upon the proportion of cocoa used. Cocoa contains considerable dextrin. It is probably the presence of this ingredient that affects the consistency of the sirup so that with increasing amounts of cocoa the temperature to which the sirup is cooked should be lower. For a sirup cooled to 40°C. and requiring about 12 to 15 minutes to beat to



bring about crystallization, the fudge containing 1 tablespoon of cocoa is cooked to 112.5° or 113°C. For each additional tablespoon of cocoa the temperature to which the sirup is cooked can be lowered one-half degree. These conditions hold for the recipe given in the laboratory outline. With larger proportions of butter, the temperature to which the sirup is cooked should be elevated.

### Caramels

Caramels, taffy, and brittles are types of candy that are firm but not crystallized. To prevent crystallization larger quantities of dextrose, levulose, corn sirup, or other substances are added than when making fondant or fudge. If these substances are not added directly, then larger quantities of substances that produce inversion of sucrose are used, thus giving a higher percentage of invert sugar.

Corn sirup and molasses are the materials most commonly used in caramels to prevent crystallization. The temperature to which caramels are cooked depends upon the ingredients used to prevent crystallization and their proportion. With increasing amounts of corn sirup, because of its dextrin content, the temperature to which the caramels are cooked is lowered. But with molasses or honey the temperature to which the caramels are cooked is much higher than when corn sirup is used. In the recipe given in the experimental outline with 1 cup of corn sirup to 2 cups of sucrose, a temperature of 119° to 120°C. produces the degree of firmness liked by most people. If the corn sirup is increased to 2 cups and the sucrose reduced to 1 cup the same firmness is produced by cooking to a lower temperature or 116° to 117°C. If dextrose, honey, or molasses is substituted for the corn sirup, the temperature to which the sirup must be cooked to give the same firmness is above 120°, sometimes as much as 126°C. or higher, the temperature depending on the type of molasses or the proportion used.

**Sugar reactions with proteins.** Ramsay, Tracy, and Ruehe found that when milk, albumin, or casein is heated with lactose or dextrose a brown discoloration occurs. As the temperature is raised dextrose and casein become so firmly attached to each other in a protein-sugar complex that no amount of washing will remove the sugar.

**The amount of milk in caramels.** A large quantity of milk in caramels develops a flavor that can be obtained in no other way. Slow cooking develops more of the brown color and flavor than rapid cooking. The color comes from lactose-protein and dextrose-protein compounds and the caramelization of the lactose with high temperatures and long cooking. If all the milk is added when cooking is first started the milk may curdle. If most of the milk is added slowly after the sirup is thick it very seldom curdles. In using large quantities of milk in caramels the protein of the milk will tend to prevent crystallization.

Large quantities of fat increase the richness of caramels.

Caramels are stirred or handled as little as possible after the sirup stops boiling until they are cool. After the boiling is stopped they soon reach the saturation point, which for caramels is above 100°C., and stirring the sirup or scraping the pan tends to produce crystals.

### Taffy

Taffies or pulled candies have vinegar, lemon juice, or cream of tartar added during cooking. These substances cause inversion of the sucrose, which prevents crystallization. Dextrose, corn sirup, or molasses may be added to the sucrose to prevent crystallization. Pulled taffies become white, or if made with molasses become much lighter in color, on account of the air bubbles incorporated during pulling.

The cooking temperatures of pulled candies vary according to the ingredients and their proportion used, but follow the same general rules as for caramels. Those containing large quantities of corn sirup are cooked to lower temperatures. Taffies are firmer than caramels and are therefore cooked to higher temperatures.

### Brittles

Brittles are much harder than caramels or taffies and are cooked to high temperatures. At the temperatures to which they are cooked caramelization of the sugar may take place, and this as well as added substances tends to prevent crystallization. If caramelization is very extensive, a number of decomposition products of sugar may develop, among which are some acid substances. The greater the amount of caramelization the stronger the flavor developed. Soda is often added to brittles. It not only neutralizes the acidity developed and lessens the bitter flavor but owing to gas formed gives a porous texture to the brittle.

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## SUGAR COOKERY

### Laboratory Outline

Keep a record of the experiments performed in a permanent note book. The experiments should be written up under the following headings. The object of the experiment, what happens, the results, and most important, the conclusion drawn or the application of the results in preparation of food. Suggestive headings for record of what happens are given under most of the experiments.

#### Experiment 1.

To determine the relative solubility of the various sugars.

Measure 20 cc. of water for each sugar to be used. Place in a Pyrex cup or a glass. Take the temperature of the water. Weigh the following amounts of sugar.

Sucrose.....	60 grams
Levulose.....	70 grams
Dextrose.....	20 grams
Maltose.....	20 grams
Lactose.....	5 grams

Add a small portion of the sucrose to one of the containers of water. Stir until all is dissolved. Add another portion of sucrose and continue until you have as much of the sucrose in solution as can be dissolved. Take the temperature of the solution while the sugar is dissolving. The stirring should be continued at intervals for 1 hour. Weigh the sucrose that is left and subtract the amount from 60 grams to obtain the amount dissolved. Your results will be only approximate for solubility should be determined in flasks to prevent evaporation. However, the results that you obtain will show the comparative solubility of the different sugars. If any undissolved sucrose remains after stirring for some time, set the container in warm water and stir until all the sucrose is dissolved. Put the container away in the laboratory and look at it occasionally to watch the growth of crystals. Compare the crystals formed with those of other sugars.

Repeat the above directions for each sugar. For the less soluble dextrose and maltose add smaller portions when dissolving the sugars. Lactose has the least solubility of the above sugars and should be added in very small portions.

Kind of sugar	Grams dissolved	Temperature of water at first	Temperature while sugar is dissolving
Sucrose			
Levulose			

## Experiment 2.

To determine the boiling point of water at the elevation above sea level at which you live.

Place 1 pint of water in a sauce pan. Heat slowly. Notice the temperature at which bubbles begin to form on the sides and bottom of the pan. Of what are these bubbles formed? What becomes of them? At what temperature do the vapor bubbles begin to form? Do the first ones reach the surface of the water? At what temperature does the water boil? Are you at sea level or above it? What is the boiling point of water at sea level? Observe the surface of the liquid and the size of the bubbles. Heat the water so that the bubbles form rapidly. Is the temperature the same as when the bubbles form slowly? How do the surface of the water and the size of the bubbles compare with those of the slow-bubbling liquid? Does the temperature rise? Explain.

Compare the temperatures registered by the thermometer when held in the water so that the thermometer bulb does not touch the bottom of the pan and when it touches it. Compare the temperatures registered when the bulb of

the thermometer is only partially immersed and when it is immersed so that there is  $\frac{1}{2}$  to 1 inch of water above the bulb. How should you apply these results to cooking sirups to a definite temperature in class results? Is the temperature the same when the thermometer bulb touches the bottom at the center and at the sides of the pan? (This may or may not vary according to the type of gas burner or the electric unit used.)

Temperature		Temperature		Type of bubble	Breaks
Slow-bubbling liquid	Rapid-bubbling liquid	When bulb of thermometer is partially immersed	When bulb touches the bottom of pan		

Results and conclusions.

### Experiment 3.

To determine the effect on the boiling point of water when a soluble substance is added.

To 1 cup of water add a scant  $\frac{1}{4}$  cup of salt. Heat to the boiling point. Note the temperature. Continue boiling. Does the temperature change? Continue boiling until the temperature remains constant. What other change occurs? What is the effect on the boiling point when salt is added to water? Results and conclusions.

### Experiment 4.

To determine the boiling temperature of sugar sirups corresponding to the "cold-water tests" used in candy making.

A. Sucrose sirup.

Dissolve 1 cup of sucrose (granulated sugar) in  $\frac{1}{2}$  cup of water. (The proportion of sugar and water used may need to be increased. The quantity of sirup should be sufficient to cover the thermometer stem to a depth of  $\frac{1}{2}$  inch above the bulb. The amount of sugar needed depends upon the size of the pan and the length of the thermometer bulb.) Bring the solution to boiling. Note rise in temperature with constant boiling. Explain. Why can a higher temperature be obtained with the sugar solution than with the salt solution?

Cook the sirup in sauce pans of the same size and shape. At the temperatures given below remove portions of the sirup. Remove the pan from the stove when making each test. Drop a tablespoon of the sirup in cold water. Note the consistency. Is it easily molded? Does it ring when hit against the side of the container? When do threads or hairs begin to form when a portion of the sirup is allowed to flow from a spoon? How do the character and length of the threads vary at different temperatures? Keep the series of tests on your work tray for comparison with the following experiments and with your neighbors' results. Note the texture at room temperature. Is it soft, firm, or brittle? Put a portion in your mouth. Does it dissolve rapidly on the tongue? To what stage in candy cookery does each of the temperatures given correspond?

Compare with results given in candy and in cook books. Tabulate your results.

Temperature		Texture			Threads	Stage of cookery	Used for
°C.	°F.	In water	Room temperature	On the tongue			
111							
113							
118							
122							
132							
145							
170							

B. Sucrose and corn sirup.

Dissolve  $\frac{1}{2}$  cup (100 grams) of sucrose and  $\frac{1}{2}$  cup (162 grams) of commercial corn sirup in  $\frac{1}{3}$  cup of water. Repeat directions under 4A. What is the effect on the stage of cookery or hardness when one-half sucrose and one-half corn sirup are used? Compare your results with those of Miss Daniels in J. Home Econ. 6: 457 and 482 (1914).

Temperature		Texture			Threads	Stage of cookery	Used for
°C.	°F.	In water	Room temperature	On the tongue			
111							
113							
118							
122							
132							
145							
170							

C. Sucrose and crystalline dextrose.

Dissolve  $\frac{1}{2}$  cup (100 grams) of sucrose and  $\frac{1}{2}$  cup of crystalline dextrose (80 grams) in  $\frac{1}{2}$  cup of water. Repeat directions under 4A. How does the hardness of the sirups obtained under 4A, 4B, and 4C compare for any given definite temperature, for example, 118°C.?

Temperature		Texture			Threads	Stage of cookery	Used for
°C.	°F.	In water	Room temperature	On the tongue			
111							
113							
118							
122							
132							
145							
170							

#### D. Sucrose and dextrin.

Dissolve  $\frac{1}{2}$  cup (100 grams) of sucrose and  $\frac{1}{2}$  cup of dextrin in  $\frac{1}{2}$  cup of water. Repeat directions under 4A.

Temperature		Texture			Threads	Stage of cookery	Used for
°C.	°F.	In water	Room temperature	On the tongue			
111							
113							
118							
122							
132							
145							
170							

Results and conclusions.

### Suggestions for Variation of Experiments and Additional Experiments

Repeat Experiment 4C, using one-half sucrose and one-half sorghum. Repeat using molasses for the sorghum.

Repeat 4B, using 2 parts of sucrose and 1 part of corn sirup. Repeat using dextrose for the corn sirup.



Repeat 4B, using 1 part of sucrose and 2 parts of corn sirup. Repeat using dextrose for the corn sirup.

## Taffy

### Experiment 5.

To determine the conditions necessary for making a pulled candy.

Recipe:

Sugar	1 cup	200 grams
Water	$\frac{1}{2}$ cup	

Directions. Combine the ingredients. Cover the pan for the first few minutes of boiling. Why? Cook to the desired temperature and pour quickly into a buttered plate. Do not scrape the cooking pan with the spoon. Cool the sirup until it can be handled without burning the hands. Pull until light in color.

1. Cook to 128°C.
2. To the above recipe add 1 teaspoon of cream of tartar.
3. To the recipe add  $\frac{1}{4}$  cup (81 grams) of corn sirup. Should the temperature to which the sirup is cooked be higher or lower than 128°C.?
4. To the recipe add  $\frac{1}{2}$  cup (162 grams) of corn sirup. Should the temperature to which the sirup is cooked be higher or lower than 128°C.?
5. To the recipe add  $1\frac{1}{2}$  tablespoons of vinegar.
6. To the recipe add  $\frac{1}{2}$  cup (162 grams) of sorghum or molasses. To what temperature should the sirup be cooked?
7. To the recipe add  $\frac{1}{2}$  cup of honey (162 grams). To what temperature should the sirup be cooked?

Is 128°C. always the best temperature for pulled candies? Look up recipes in cook books. What do they contain besides sugar and a liquid? What is the purpose of the added substances? When the candy has hardened examine a portion under the microscope. Is the candy crystallized? Save portions of all candies for several days. Do any crystallize after long standing? Compare the behavior of this candy with that of sulfur in the crystalline and the amorphous condition.

Enumerate all the factors which may cause the relationship between the cold-water test and a given boiling temperature to vary. What would the results be if 1 or 2 tablespoons of lemon juice were added to the pulled candy recipe?

Temperature cooked to	Texture	Flavor	Comments

Results and conclusions.

## Caramels

## Experiment 6.

To determine the conditions necessary for making caramels.

Recipe:

Sugar	2 cups	400 grams
Corn sirup	1 cup	328 grams
Butter	2 tablespoons	28 grams
Milk	3 cups	732 grams

Prepare one-quarter or one-half of the recipe.

1. Combine all the ingredients and stir while cooking to prevent scorching. Cook to 121°C. and turn into a buttered pan very quickly, taking care not to scrape the contents of the cooking pan with the spoon while pouring the caramel mixture. Do not try to drain the last of the contents of the cooking pan into the cooling pan. When cool enough, cut into squares with scissors or a knife.

2. Combine all the ingredients but reserve two-thirds of the milk. Cook until quite thick, about 119°C.; then add half of the remaining milk so slowly that the mixture does not stop boiling. Cook until the sirup becomes thick again; then add the remainder of the milk slowly. When the temperature reaches 121°C., remove from the fire and follow directions under 1.

3. Repeat 2, but cook to 119°C.

4. Repeat 2, but use 1½ cups of sugar and 1½ cups of corn sirup. Cook to 118°C.

5. Follow directions under 2 for combining but use 1 cup of sugar and 2 cups of corn sirup. Cook to 116° to 117°C.

6. Substitute 1 cup of sorghum for the corn sirup. To what temperature does it need to be cooked to have the cold-water test the same firmness as in 3? Follow directions under 2 for combining and cook so that the caramels will be as firm as those under 3.

7. Repeat 6 but substitute strained honey for the sorghum.

8. Substitute 2 cups of cream for the 3 cups of milk. Omit the butter. Follow directions under 2 for combining. Add ¼ teaspoon salt. Cook to 119°C.

9. Reduce the milk to 2 cups and increase the butter to ½ cup. Follow directions under 2. Cook to 119°C.

10. Substitute ¾ cup of evaporated milk for the 3 cups of milk. Follow directions under 1. Cook to 119°C.

11. Substitute 1 cup of water for the 3 cups of milk. Follow directions under 1 for combining. Cook to 119°C.

12. Add 2 squares of chocolate (56 grams) to the recipe. Follow directions under 2 for combining. Cook to 119°C.

*Cold-water test for caramels.* The caramels are cooked sufficiently when a portion of the sirup dropped in cold water is as firm as that wished in the finished caramel. If small quantities of ingredients are used in making caramels, it is difficult to use a thermometer for the stirring of the viscous sirup pulls and piles it up against the thermometer. The viscosity of the solution also seems to have a tendency to hold in for a few seconds some of the steam

formed. Thus it is difficult to secure accurate readings, the temperature fluctuating considerably.

Wrap portions of each of the caramels and store until the following class period. Do any of them crystallize? Do the larger proportions of corn sirup keep better? Do any with the small proportions of corn sirup crystallize? When the proportions of the ingredients of the recipe are changed is the temperature as indicated by the thermometer or the cold-water test a better indication that the sirup is the right concentration for removing from the fire? Can smaller quantities of milk be used?

Temperature cooked to	Firmness	Texture	Flavor	Color

Results and conclusions.

## Fondant

### Experiment 7.

To determine the factors which influence the rate of crystallization of sucrose and the size of the crystals.

Dissolve 1 cup of sucrose (200 grams) in  $\frac{1}{2}$  cup of water. (Increase or decrease these proportions if necessary.) Use pans of the same size and shape. Be sure the pans are smooth. Because the sirup splashed on the sides dries less readily from the heat of the burner, a pan with a straight side or one that curves in at the top is preferable to one that slopes outward at the top. If desired the sirup may be poured into plates for cooling instead of following directions under the outline. If this is done the containers into which it is poured should be smooth and the same size and all should be cooled in the same manner. Great care should also be taken to pour the sirup rapidly and not to scrape the pan.

If the amount of water in the fondant is to be determined, the pan and the stirring spoon should be weighed before the fondant is cooked. The weight of the fondant, before removal from the cooking pan, minus the weight of the sugar used gives the amount of water in the fondant.

#### A. Temperature at which the sirup is beaten.

1. Cook the sirup covered for 4 or 5 minutes. Remove the lid and continue boiling until sufficiently concentrated. (Cook to  $113^{\circ}\text{C}$ . if the day is clear, and to  $114^{\circ}$  or  $115^{\circ}\text{C}$ . if rainy or if the humidity is high.)

Boil the sirup without stirring or if stirred follow the caution given in the text. Cool the sirup in the sauce pan to  $40^{\circ}\text{C}$ . then beat until stiff. If a wooden spoon is used for beating it is less likely to form blisters on the hands than a metal spoon. After crystallization has occurred, knead until soft. Care should be taken that no crystals form on the side of the pan during cooking or cooling, for they will seed the mass and the time for beating will thus be shorter for A2 and A3 than would normally be required and the crystals larger.

2. Repeat 1 but cool only to  $70^{\circ}\text{C}$ . before beating.

3. Repeat 1 but beat the sirup as soon as it is removed from the stove.

Examine portions of each fondant under the microscope. Wrap portions from each experiment in oiled paper and put away in a tightly covered container until the next lesson. What is the effect of 24 hours' storage on the firmness and the texture of the fondant? Why do the directions under A1 state not to stir the sirup while cooking?

Temperature cooked to	Temperature cooled to	Time required to beat to crystallize	Size of crystals

Results and conclusions.

B. Concentration to which the sirup is cooked.

Repeat A1, but cook the sirup to 111°C. Compare the length of time required to beat to crystallize with that for A3.

C. Effect of added substances.

1. Repeat A1, but add 1 tablespoon of butter to the sugar and water. Follow directions under A1.

2. Repeat A1, but add  $\frac{1}{4}$  teaspoon of cream of tartar to the recipe. The proportion of cream of tartar may need to be varied somewhat with the hardness of the water, but the rate of cooking will have more effect than the hardness of the water. Boil over a large gas burner so that the time of cooking does not exceed 10 to 12 minutes. Follow directions under A1.

3. Repeat C2, but cook slowly, taking at least 2 or 3 times as long to cook as for C2.

4. Repeat A1, but add 1 teaspoon of cream of tartar to the recipe.

5. Repeat A1, adding 1 tablespoon of corn sirup to the recipe.

6. Repeat A1, adding 4 tablespoons of corn sirup to the recipe.

7. Melt 4 tablespoons of sugar. Stir while melting. Do not have the heat intense enough to decidedly darken or scorch the sirup. When it is all melted and a golden brown color, add boiling water and stir until dissolved. Then add to the fondant recipe and follow directions under C1.

Sugar grams	Water grams	Added substance	Cook to °C.	Cool to °C.	Time required to cook to reach 113°C.

Time required to beat to crystallize	Amount of water in fondant	Color	Texture	Flavor	Yield

If C4, 6, and 7 do not crystallize let them stand until the next lesson. What would be the effect on the rate of crystallization if these candies were allowed to cook to a higher temperature? If they were beaten hot? What is the effect on the rate of crystallization of sugar when considerable hydrolysis has occurred, as in C3 and C4, or when a large amount of corn sirup or caramelized sugar has been added, as in C6 or C7?

Test portions of A1 and C2 with Fehling's solution.

What is the action of cream of tartar when added to fondant? What would be the result if vinegar or lemon juice were substituted for the cream of tartar in C2 and C3? Is the fondant obtained in C2 and C3 superior to that obtained in A1? Compare the keeping qualities of the different fondants by putting some of each away in a covered container and observing at different periods. Examine portions of each under the microscope.

### Experiment 8.

To determine the comparative ease of crystallization of different sugars in making fondant.

A. Repeat Experiment 7A, but substitute dextrose for the sucrose.

B. Repeat Experiment 7A, substituting levulose for the sucrose. If levulose cannot be obtained use honey, which contains a high percentage of levulose. Or use the liquid portion of crystallized honey, which is nearly pure levulose.

If any under A or B do not crystallize, recook them. See if they will crystallize after being cooked to a higher temperature.

## Fudge

### Experiment 9.

To determine the factors influencing the consistency and flavor of fudge.

Recipe:

Sugar	1 cup	200 grams
Milk	$\frac{1}{2}$ cup	122 grams
Butter	1 tablespoon	14 grams
Chocolate	$\frac{3}{4}$ square	21 grams

Combine sugar, chocolate, butter, and liquid. Stir until the sugar is dissolved and the chocolate is melted. Cook to the temperatures given below. If the mixture is poured into another container for cooling, be sure the container is smooth. If it is poured into a platter or similar utensil, cooling will be more rapid and even more so if the platter is set on a cake rack or is elevated. Use containers of the same size and the same method for all the experiments. Cool to 40°C. and beat until the mass begins to crystallize. Turn quickly into a buttered pan or knead as desired. Select thermometers that have the same boiling point. The recipe may need to be doubled or increased so that the quantity of material in the cooking pan will be great enough to cover the bulb of the thermometer in order to obtain an accurate reading. How should the thermometers be held in the sirup to determine

differences in consistency of the finished fudge, when the difference in temperature to which the sirup is cooked is only 1 degree?

Compare the texture and consistency of each fudge. What temperature is most desirable for fudge that is not kneaded? For fudge which is kneaded? If granular fudge is desired and the sirup is stirred while hot, should the sirup be cooked to the same degree as for fudge that is beaten after cooling? In making 4 times the recipe would you take 4 times the quantity of liquid? Why?

A. Temperature to which the sirup is cooked.

Temperature cooked to	Time required to beat to crystallize	Texture	Consistency
1. 110°C.			
2. 111			
3. 112			
4. 113			
5. 115			

Results.

B. Kind of liquid.

Cook to the temperature found best under 9A.

1. Use water for the liquid.
2. Use milk for the liquid.
3. Use cream for the liquid.
4. Use cream for the liquid and omit the butter.

C. Time of adding the fat.

1. Add fat at first so that it is in the sirup during the cooking process.
2. Add fat after removing from the fire. Put fat on top of hot fudge, but do not stir until cool enough to beat. Compare flavor and texture with the fudge under C1.

D. The proportion of cocoa used.

The thermometers should have the same boiling point and all conditions should be carefully standardized. Follow directions under A.

1. Substitute 1 tablespoon (7 grams) cocoa for the chocolate. Cook to 114°C.
2. Substitute 2 tablespoons (14 grams) cocoa for the chocolate. Cook to 113°C.
3. Substitute 3 tablespoons (21 grams) cocoa for the chocolate. Cook to 112°C.
4. Substitute 4 tablespoons (28 grams) cocoa for the chocolate. Cook to 111°C.
5. Substitute 5 tablespoons (35 grams) cocoa for the chocolate. Cook to 110°C.

If D1 is too hard repeat the series cooking D1 to 113°C. and decreasing the temperature 0.5° for each tablespoon of cocoa added. Place portions of the fudges away to ripen. Compare texture and flavor. Which proportion of cocoa do you prefer?

Write a summary of the factors that influence the flavor and consistency of fudge.

### Suggestions for Variations of Experiments or Additional Experiments with Fudge

Prepare fudge by adding 1 tablespoon of corn sirup to the recipe.

Prepare fudge by adding 2 tablespoons of corn sirup to the recipe. Compare flavor, texture, glossiness, and keeping qualities with fudges made under Experiment 9.

Prepare fudge by adding fondant to the fudge.

#### Experiment 10.

To determine the effect of a weak alkali and heat upon crystalline dextrose when it is used in fondant.

Recipe:

Crystalline dextrose	1 cup
Water	$\frac{1}{3}$ cup

1. Use distilled water and cook until a medium firm ball is formed in cold water. Cool to 50°C. and beat.

2. Repeat 1, but substitute hard water for the distilled water.

3. Use 20 per cent, or  $\frac{1}{5}$  cup, of dextrose, and 80 per cent, or  $\frac{4}{5}$  cup, of sucrose. Use distilled water and cook until a soft ball is formed in cold water. What is the temperature? Cool to 50°C. and beat.

4. Repeat 3, but substitute hard water for the distilled water.

5. Repeat 3, but add 200 parts of magnesium carbonate per million parts of water to the recipe. (This is less than the proportions of carbonates found in much of the water used in different sections of the country.)

6. Repeat 3, but add  $\frac{1}{64}$  teaspoon of soda to the recipe.

7. Repeat 3, but add 1 tablespoon of vinegar or lemon juice to the recipe. Cream of tartar,  $\frac{1}{4}$  teaspoon, may be used for the vinegar or lemon juice.

The main principles of sugar cookery are covered, and some are repeated, in the preceding experiments. Some frostings and some candies have added substances, like egg white, which retard crystallization. The principles for cooking are the same as those used in cooking and preparing the candies of the preceding experiments. However, to have frostings a consistency to spread and cut well, variations in temperature of cooking from that of candy may be necessary.

### Suggestions for Additional Experiments

1. Prepare chocolate fudge icing and use on cake or cookies. Determine the temperature to which the sirup should be cooked.

2. Substitute brown sugar for white sugar in icing.

3. Make caramel or burnt-sugar icing by melting one-half the sugar to be used to a golden brown color. Then dissolve in water. Add the remainder of

the sugar, and the butter, and cook to the same temperatures used for chocolate fudge icing. Which temperature produces the best texture of icing?

4. Prepare boiled icing by pouring the cooked sirup over beaten egg white. Prepare an outline for making this type of icing, giving variations in temperature to which the sirup is cooked before adding to the egg white and the temperature to which the sirup is cooled before adding the sirup to the egg white. Vary the amount of sugar used for different proportions of egg. Consult any reference that you wish for making your outline and use the results of any of the sugar experiments.

For a control use 1 cup sugar, 200 grams,  $\frac{1}{4}$  cup corn sirup, 82 grams, and  $\frac{1}{4}$  cup of water. Cook to  $119^{\circ}$  or  $120^{\circ}\text{C}$ . and pour slowly into 1 stiffly beaten egg white, beating as the sirup is added. For divinity beat until pieces dropped on wax paper will hold their shape.



## CHAPTER III

### FREEZING

A pure liquid has a definite freezing point. In freezing the fluid changes from a liquid to a solid state. Water freezes at  $0^{\circ}\text{C}$ . or  $32^{\circ}\text{F}$ . Just as sugar solutions in cooling may give supersaturated solutions before crystallization starts, so water may be supercooled before it freezes. Furthermore, the conditions for supersaturation and supercooling are similar. For supersaturation the solution must not be agitated and no crystals must be added. If a test tube of water containing a thermometer is immersed in a mixture of ice and salt, the temperature of the water will drop to  $-4^{\circ}\text{C}$ . or lower. If the slightest movement is made or if a small crystal of ice is added the water will crystallize quickly, and the temperature rises to  $0^{\circ}\text{C}$ ., for water in freezing gives off heat. A gram of water changing from  $0^{\circ}$  to ice at  $0^{\circ}\text{C}$ . gives off 79.9 (or about 80) calories of heat. When the water has been supercooled, this heat of solidification elevates the temperature of the ice and liquid to  $0^{\circ}\text{C}$ . The heat of crystallization may be absorbed by the liquid or given off to the surroundings if the freezing liquid is not insulated.

#### The Freezing Point of a Liquid

The freezing point of a liquid cannot be defined as the temperature at which the liquid becomes a solid, for supercooled liquids are cooled below the freezing point. The freezing point and the melting point are identical, so that the freezing point may be defined as the temperature at which the solid melts. The freezing point of a liquid may also be defined as the temperature at which the solid and liquid are in equilibrium. Here equilibrium means the temperature at which any proportion of solid and liquid can exist without change, that is, no solid melts and no liquid freezes. For water, this temperature is  $0^{\circ}\text{C}$ . Of course, equilibrium can exist for a long period of time only if the solid and liquid are completely insulated or if the temperature of the surroundings is at the freezing point of the liquid. If the temperature of the surroundings changes slightly above  $0^{\circ}\text{C}$ . so that heat is absorbed, some of the solid melts. If the temperature of the surroundings is below  $0^{\circ}\text{C}$ ., so that heat is withdrawn from the mixture, the liquid freezes. After all the liquid is frozen, the temperature of the ice may drop below  $0^{\circ}\text{C}$ ., just as the temperature of the ground or a stone may assume the temperature of the surroundings.

If ice and water that are not at the same temperature are mixed, they are not in equilibrium, since ice and water are in equilibrium only at the freezing point or  $0^{\circ}\text{C}$ . If the temperature of the ice is  $0^{\circ}\text{C}$ . and the temperature of the water is  $20^{\circ}\text{C}$ . some of the ice melts. In melting, each gram of ice absorbs 80 calories of heat, and the temperature of the water is lowered. If sufficient ice is added to the water, and the temperature of the surroundings does not influence the mixture, ice melts until the temperature of the water reaches  $0^{\circ}\text{C}$ . and equilibrium is established. If the quantity of ice added to the water is not sufficient to lower the temperature of the water to  $0^{\circ}\text{C}$ ., the temperature of the water is lowered as long as the ice melts and provided the surroundings do not influence the temperature. After the ice is all melted the temperature of the water cannot be lowered except from the surroundings.

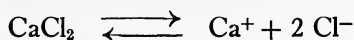
### Lowering of the Freezing Point

When a soluble substance is dissolved in a liquid the freezing point is lower than that of the pure solvent. A gram-molecular weight (mole) of a non-ionized substance in a liter of water lowers the freezing point  $1.86^{\circ}\text{C}$ . The lowering of the freezing point can be continued as long as the substance is soluble. If no more than 3 moles of a non-ionized substance are soluble in a liter of water, the freezing point cannot be depressed below  $-5.58^{\circ}\text{C}$ . Substances that are not very soluble do not affect the freezing point particularly, because such a small portion of a mole of the substance is dissolved. Thus substances in suspension, such as fat in milk or cream, do not affect the freezing point of an ice-cream mix in the same way that sugar does, for the fat is not soluble.

**Ionized substances and the freezing point.** Sugar does not ionize or dissociate in the solution to an extent great enough to influence the freezing point. Salt belongs to the groups of electrolytes which dissociate into ions in the solution. The amount of ionization depends upon the concentration of the solution: the less concentrated the solution the greater the dissociation. In a very dilute solution, complete dissociation into ions may occur. If 58 grams of salt or sodium chloride in 1 liter of water are completely ionized into sodium and chlorine ions, there will be 1 mole of sodium ions and 1 of chlorine ions. Thus the two lower the freezing point ( $2 \times 1.86$ ) or  $-3.72^{\circ}\text{C}$ . The molecular weight of sucrose is 342 grams, that of levulose is 180, and that of dextrose is 180 grams. None of the sugars ionize to an extent that affects the freezing point. Compare the freezing points, if  $\frac{3}{4}$  cup, or 150 grams, each, of sucrose, levulose, or dextrose is added to a quart of cream.

Calcium chloride ionizes into 3 ions. Therefore, a mole of calcium chloride depresses the freezing point more than a mole of sodium chloride.

The calcium chloride is also more soluble than sodium chloride, so that a greater number of moles can be dissolved in a liter of water.



### The Freezing Point of Ice Cream and Ices

Milk, which contains sugar and other dissolved substances, has a lower freezing point than water. When sugar is dissolved in water and some fruit juice added to make a sherbet or ice the freezing point of the sherbet mixture is about  $-4^\circ$  to  $-5^\circ\text{C}$ ., depending upon the proportion of sugar added. Ice cream containing about  $\frac{3}{4}$  cup of sugar to a quart of cream freezes between  $-1^\circ$  and  $-2^\circ\text{C}$ ., or about  $29^\circ\text{F}$ . Ice cream usually contains a smaller percentage of sugar than ices or sherbets.

### Freezing Mixtures

When a crystalline substance is added to a liquid its freezing point is lowered. However, as a solution freezes it separates into crystals of the solvent and crystals of the dissolved substance.

Suppose 10 grams of salt are added to 90 grams of water to give a 10 per cent salt solution. The salt dissolves and the temperature of the solution is lowered. The freezing point of salt solutions may be shown in the diagram by the line *AB*. The temperature is represented vertically and the percentage of salt in the solution is represented horizontally.

The freezing point of water is  $0^\circ\text{C}$ . This is represented on the line *AB* of Fig. 13, at *A*. The freezing point of a 10 per cent salt solution is about  $-5^\circ\text{C}$ . This is shown at point *X*, where the freezing-point line *AB* cuts the line indicating a 10 per cent salt solution. If the salt solution is cooled to  $-5^\circ\text{C}$ . some of the water freezes. This leaves a greater concentration of salt than 10 per cent in the rest of the solution. Thus the freezing point of the rest of the solution is lowered. If cooling of the solution is continued, ice will continue to form, and the remaining salt solution will become more concentrated and its freezing point lower. The lowering of the freezing point can be continued until the line *AB* cuts the line *BC*. The point *B* represents the limit of the solubility of the salt at a temperature of  $-22^\circ\text{C}$ . Below this temperature the salt and water separate, both crystallizing. This is called the cryohydric point. Both the ice and salt may be cooled to lower temperatures than  $-22^\circ\text{C}$ . after they are in solid form.

If salt is mixed with water a saturated solution is obtained when the solution contains 35.6 grams of salt per 100 grams of solution at  $0^\circ\text{C}$ . If this solution is cooled below  $0^\circ\text{C}$ . the solubility of the salt is not so great at the lower temperatures. This is shown on the line *CB*. A little below  $0^\circ\text{C}$ . salt combines with 2 molecules of water. Thus the slope of the

curve for solubility of salt changes below  $0^{\circ}\text{C}$ ., and the salt is found in solution as the dihydrate. If a saturated salt solution is cooled below  $0^{\circ}\text{C}$ ., the excess salt beyond saturation point is precipitated from solution. This will continue until the cryohydric point is reached.

Salt is often added to ice for a freezing mixture. When salt is added to water and ice at  $0^{\circ}\text{C}$ ., they are not in equilibrium, even if the surroundings are at  $0^{\circ}\text{C}$ ., for the addition of salt lowers the freezing point of the solution. Since they are not in equilibrium the ice melts and the salt dissolves in the water. There is always a film of water on the surface of the ice. As the salt dissolves in this small amount of water it absorbs heat. This absorbed heat is taken from the brine or from the surround-

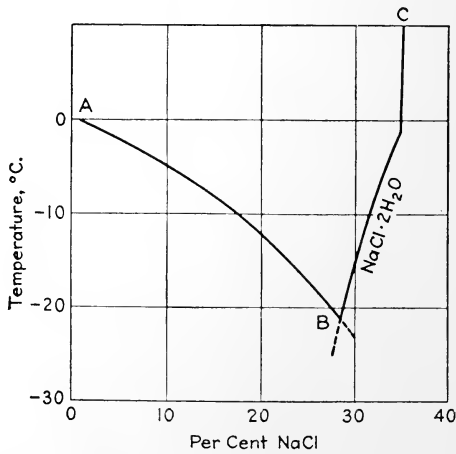


FIG. 13.—The freezing point of solutions containing different percentages of sodium chloride and the solubility of sodium chloride below  $0^{\circ}\text{C}$ ..

ings. If the heat is taken from the brine the temperature of the brine is lowered.

When salt is added to ice, one of three things may happen, depending upon the proportion of ice and salt, and the surrounding temperature or insulation. All the salt may be dissolved. When this happens the melting of the ice lessens the concentration of the salt solution and the temperature is not lowered beyond the point obtained when the solution contains the highest concentration of salt. All the ice may melt. When the ice is melted the temperature cannot be lowered to a greater extent, for there is no more ice to melt to absorb the heat. The cryohydric point may be reached. At this point the solution becomes solid and separates into ice and salt.

**Ice-cream freezers.** An ice-and-salt mixture is used to lower the temperature of other substances. An ice-cream freezer is a utensil made to freeze a substance placed in a center metal container. Outside this metal

container there is a space in which the cooling medium is placed. The outer wall of the ice-cream freezer is often of wood, which is a poor conductor of heat. Since it conducts heat slowly it partially insulates the ice and salt from the surrounding air. The freezing mixture absorbs heat. In doing this it lowers the temperature of the brine and removes heat from the contents of the center can. In order to freeze the contents of the can the temperature of the brine formed must be lower than the freezing point of the mixture to be frozen.

To freeze the contents of the ice-cream can, considerable heat must be removed from it. As a result, a corresponding amount of ice must melt to absorb the heat. Therefore, the contents of the can do not begin to freeze until considerable brine has formed. Conduction of heat is more rapid by water than by air. Before the brine forms and replaces the air spaces around the ice, conduction of heat from the can is slow. After all the salt is dissolved or all the ice is melted, the temperature of the brine cannot be lowered, unless the temperature of the surrounding air is lower than the temperature of the brine. In ice-cream making the temperature of the surroundings is usually much higher than the temperature of the brine. When the quantity of ice left in the freezer is small the temperature of the surrounding air may heat the brine more than the melting of the small amount of ice cools it. Before this stage is reached the freezer needs fresh ice and salt packed around it.

The lowest temperature obtainable for a brine from a salt and ice mixture is about  $-22^{\circ}\text{C}$ . (Walker reports  $-21^{\circ}$  and Bigelow  $-22.4^{\circ}\text{C}$ .) This temperature is called the cryohydric point. If calcium chloride is used with ice the lowest temperature obtainable is  $-55^{\circ}\text{C}$ .

At the cryohydric point 29 parts of salt are soluble in 71 parts of water. No more salt can be dissolved at this temperature. This proportion of salt to ice is about 1 to 3 and is often used in freezing mixtures.

Ice in the refrigerator is probably about  $0^{\circ}\text{C}$ ., but ice from out of doors on a cold winter day may have a temperature far below  $0^{\circ}\text{C}$ . When ice at a very low temperature is used for freezing, a brine will form more quickly and freezing start sooner if water is poured over the ice and salt.

### Proportion of Ice and Salt for Freezing and Packing

**Rate at which the temperature is lowered.** The rate at which the temperature of the brine and thus also that of the mix to be frozen is lowered depends on the proportion of ice and salt, and on the fineness of division of the ice and salt. Small pieces of ice provide greater surface and thus melt faster than large pieces. Fine salt dissolves more quickly than coarse salt, but a fine table salt is likely to lump. Crushed rock salt is good to use.

**Two procedures are used in freezing.** The smooth, velvety texture of ice cream and ices depends on several factors. One important factor is

the size of the crystals formed. The proportion of ingredients, their treatment, and the incorporation of air bubbles into the mixture while it is freezing are also important. Small crystals may be obtained by the quick-freezing method. A very low temperature is used, the mass being frozen so rapidly that many nuclei are formed and there is little crystal growth because of the short time. This process is easier to use commercially than in the home, because of the very low temperature employed for freezing. Judging from reports in the ice-cream trade journals, it is successful in some instances and not in others.

The other procedure is to freeze at a slower rate, depending on agitation to form many nuclei. Air is incorporated in the mix in both processes. A temperature of  $-8^{\circ}$  to  $-10^{\circ}\text{C}$ . is sufficiently low to freeze most ice creams, sherbets, and ices. For home freezing, 1 part of salt to 8 of ice is a good proportion. Commercially, 1 part of salt to 12 of ice is often used. Washburn states that a proportion of 1 part of salt to 40 parts of ice will freeze if given ample time. The air globules are retained in the mixture better after it has nearly reached the freezing point. The air is beaten in by the dasher paddles. In freezing very rapidly there is not time to incorporate as much air as when the mix is frozen at a somewhat slower rate.

**Packing the freezer.** Commercially most ice cream is now held in mechanically operated freezing units or rooms, although the same proportions of ice and salt may be used for packing that are used for freezing. For home-made ice cream the same proportion of ice and salt may be used as for home freezing, or about 1 of salt to 8 of ice. In packing, the ice should be pressed down tight in the can. This will force the surplus water out of the opening in the container. If the water is drained off it only takes a longer time for the brine to form again, and cooling is slower. A little salt should be added to the ice left in the freezer before the new ice is added. For home-made ice cream that is not to stand very long before serving, a larger quantity of salt may be used to advantage. This will cause the temperature to drop quickly and hardening of the cream will take place more rapidly.

The ice and salt may be mixed together before putting in the freezer, but a better way of packing is to fill the freezer half full of ice, then add a layer of salt. The ice and salt are then added in alternate layers until the top is reached. The water from the melting ice washes the salt towards the bottom of the freezer, and once it reaches the bottom it is of small use for cooling purposes. Therefore, it is preferable to pack the freezer with the salt towards the top.

**Mousse.** For packing home-made mousse, the proportion of salt to ice must be large, 1 to 3 or even 1 to 2. Whipped cream which has air beaten into it is added to a mousse. The mousse is molded and often is not stirred while freezing, although it may be stirred very slowly. Heat or cold penetrates more slowly to the center of a mixture that is not stirred.

In addition, the air and the high fat content of the whipped cream are poor conductors of heat and cold. Thus a mousse requires a low temperature and long time to cool. The ice and salt may need to be repacked unless set where the air is cold.

### The Composition of Ice Cream

A simple home-made ice cream may be made with cream, sugar, and flavoring. Flavoring is added to increase the palatability. The flavoring may be extracts, fruit, or nuts. Sometimes egg is added to home-made ice cream. Cream containing 17 to 20 per cent butter fat, or if not homogenized, 22 per cent fat, gives a good home-made ice cream. Washburn states that the weight of sugar added may be one-sixth of the weight of the cream. Three-fourths of a cup of sugar to a quart of cream gives about this proportion, and this produces an average sweetness. The serum solids usually average about 6 per cent in home-made ice cream.

Sommer states that a good commercial ice cream is obtained with the following proportions:

Fat	12.5%
Serum solids	10.0
Sugar	16.0
Gelatin	0.25 to 0.50
Egg yolk solids	0.50
<hr/>	
Total solids	39.25 to 39.50%

Sommer also states that a richer ice cream has not proved generally successful because of the higher cost, but is preferred by many consumers. In the richer cream the fat is increased to 16 per cent and the serum solids reduced to 8 per cent. Although Sommer recommends the egg yolk solids, many manufacturers omit them. Gelatin, called a binder, is used to prevent coarse crystallization. Commercial ice cream must have condensed-milk or dry-milk products added to raise the serum solids to 8 or 10 per cent.

The milk solids include the butter fat, the milk proteins, the milk sugar, and the ash; serum solids exclude the fat; total solids of ice cream include the milk solids and the added sugar. The total solids vary, but Sommer states they should not exceed 41 per cent. Each of the ingredients of the milk and also the added sugar has an effect on the body and the texture of the ice cream. The ingredients likewise affect the flavor.

### The Flavor of the Ice Cream

**Fat.** The flavor of the ice cream is influenced by the ingredients that go into it. They should be free of foreign odors and flavors. Ambrose states that "increase in butter fat gives the richness of flavor that can be obtained in no other way."

Williams and Campbell conducted experiments in ice-cream making in which the fat content was varied: creams were made with 12, 15, and 18 per cent fat, the other constituents remaining the same, and the method of making being kept uniform in each experiment. Purchasers were allowed to sample the three ice creams on the first day and on the following day could purchase their choice. The records showed that 80 per cent of the purchasers favored the ice cream containing 18 per cent fat, 10.4 per cent favored the ice cream containing 15 per cent fat, and 7.6 per cent of the purchasers favored the ice cream containing 12 per cent fat.

**Salt.** Salt may be added to ice cream, and for some persons the flavor is thereby improved. It is so easy to add too much that it is often better to omit it. A good proportion to use is about  $\frac{1}{2}$  teaspoon of salt per gallon of mixture.

**Acidity.** Acidity of the cream affects the flavor. The acidity of milk and cream increases with age. An acidity of 0.30 per cent produces an apparent sour taste; that usually preferred for ice cream is from 0.16 to 0.20 per cent.

**Sugar.** Williams and Campbell in experiments with ice cream, conducted like those just referred to with the fat, but in which the percentage of sugar varied, found that 61.4, 28.4, and 10.2 per cent of the purchasers showed a preference for the 19, 16, and 13 per cent sugar, respectively. This gives a total of 90 per cent favoring the ice cream with 16 or more per cent of sugar.

**Serum solids not fat.** Similar experiments with serum solids not fat showed that 55.6, 25, and 18.6 per cent of the purchasers favored the ice cream containing 12, 9, and 6 per cent of serum solids, respectively.

In regard to gelatin, 63.2, 13.8, and 23 per cent of the purchasers favored the ice cream containing 1, 0.5, and 0 per cent of gelatin, respectively.

Fisher states that the serum solids do not affect the flavor until a content of 12 per cent and beyond is reached. To obtain this amount of serum solids, condensed-milk or dry-milk products must be used. With 12 per cent or greater a condensed-milk flavor is imparted to the ice cream. Fisher also states that butter fat improves the flavor slowly.

**Sandy ice cream.** When too great an amount of condensed milk is added, there is danger of the lactose crystallizing at the low temperatures in the holding room. When the lactose crystallizes, a sandy or gritty texture is imparted to the ice cream. Such ice cream is called sandy. Leighton and Peter have reported that lactose does not usually give sandiness to the ice cream unless the concentration of serum solids is high, i.e., about 12 per cent or more. The lactose may crystallize in the ice cream when the percentage of lactose is 6 per cent or more.

**Flavoring.** Flavoring is added to the ice cream. Too little flavoring to blend with the cream and sugar gives a flat taste; too much makes the flavoring the only ingredient evident to the taste. Dahle states that "Noth-



ing is to be gained by the use of cheap flavors." Crushed fruit, fruit juices, and nuts are also used to flavor ice cream.

### The Body and Texture of Ice Cream

By body, the whole mass of ice cream is referred to—its firmness, its resistance; texture refers to the finer particles of the ice cream.

**Effect of fat on texture.** High butter fat produces a firm body, for the chilled fat particles are very firm. Too much fat produces a very hard ice cream. Fillers are sometimes used to give a better body. In home-made ice cream when little cream is used, egg may be added to produce a firmer body, and to add flavor.

**Effect of proteins on texture.** The milk solids not fat and the protein content particularly affect the body of the ice cream. The casein and albumin of milk are found as calcium and magnesium caseinates and albuminates in the milk. As such they imbibe water and swell. With too little protein the body has little resistance, and with too much protein its hydration produces a very soggy, heavy ice cream. Mortensen states that high serum solids give a smooth mix for they absorb the water, but their use can be carried to an extreme. He adds that those who do not use a high percentage of serum solids must pay more attention to the treatment of the mix. Combs and Martin concluded that a certain amount of acidity produces a finished appearance in the mix. They have found that too high acidity causes the ice cream to melt quickly, since the reaction is brought nearer the isoelectric point of casein and at the isoelectric point very little water is held by casein.

**Effect of treatment of the mix on texture.** Any treatment of the ingredients of the ice cream or of the mix itself that increases the viscosity affects the body and texture of the ice cream. Pasteurization, homogenization, and aging all affect the viscosity and will be discussed later. Though the texture of the ice cream, like the body, is affected by the ingredients used and their proportions, it is also affected to a greater extent than the body by the freezing process. The texture of ice cream depends largely on the size of the crystals and the amount of air incorporated during freezing.

**Incorporating chocolate or fruit.** Some special problem studies have indicated that the temperature at which the chocolate is combined with the other ingredients is the most important factor in obtaining a uniform color and not a speckled product. The temperature at which the chocolate is combined, at least with a portion of the ingredients, should be above the melting point of the chocolate. The chocolate may be added to a portion of the milk which has been warmed or made into a sirup. Martin advises that the chocolate be made into a sirup with the sugar and a portion of the milk.

Fruit, such as strawberries, raspberries, and peaches, may be put through a sieve before adding to the mix. If larger pieces of fruit are desired, they can be prevented from freezing into chunks of ice by letting them stand for some time, or over night, in a heavy sirup. The sugar entering the berries or fruit lowers the freezing point of the fruit, so that it does not freeze or is less hard. To keep the fruit as whole as possible, the sirup should be added to the cream mix. Then the fruit is added after the cream is in a soft frozen state.

**The freezing process.** If the ice-cream mix has not been cooled before it is put in the freezer it is better to turn the freezer slowly until the mix is cooled. If the freezer is turned rapidly while the mix is at a temperature above  $4.5^{\circ}\text{C}$ . or  $40^{\circ}\text{F}$ . the butter fat is clumped together and a buttery product results. If carried far enough, butter may even be churned in the mix. The mix does not hold the air incorporated in it until its temperature is cooled to about  $1^{\circ}\text{C}$ . or  $34^{\circ}\text{F}$ ., so that rapid turning is of no advantage from this standpoint until the mix is cooled. With a freezer turned by hand, if the freezer is turned rapidly all the time, one's energy is often expended before the freezing is finished, and it is during the latter part of the freezing period that the turning should be rapid. The size of the crystals formed during freezing depends upon the rate of turning of the freezer and the length of time of the freezing process. Stirring the solution during crystallization increases the number of nuclei formed, and the resulting crystals are smaller than if the mixture is not stirred. If the ice cream is not stirred during freezing, few nuclei are formed, the water crystals join onto each other, and a product with very coarse, large, spiny crystals is the result. On the other hand, if the ice cream is stirred the size of the crystals depends upon the rate of turning. Very slow turning while freezing is in progress results in larger crystals; rapid turning results in smaller crystals. If the freezer is turned very slowly the crystals build onto the crystals already formed; with rapid turning many new crystals are developed. The time of the freezing process also affects the size of the crystals. If the crystals are formed very rapidly, too little air is mixed with the cream, which produces an ice cream without a velvety texture. Since rapid freezing occurs with low temperatures it is better not to have the temperature of the brine too low, thus 1 part of salt to 8 parts of ice produces good results.

**Overrun.** The addition of air to the ice cream during freezing causes it to swell so that the ice cream increases in bulk. This increase is known as the swell or overrun.

This swell or overrun due to the incorporation of air particles gives a smoother, more velvety texture to the ice cream. Mortensen states that it is preferable to have the air cells in the finished cream small, for the strength of the film of a small air cell is stronger than that of a large one. To obtain small air cells in the ice cream the mix should be viscid. A viscid

substance resists incorporation of air, and it will be worked in in finer divided portions. With increased viscosity the air is held in the mix better after it is incorporated. Mortensen includes homogenization as an important factor in increasing the viscosity of the ice-cream mix.

As the swell in freezing improves the texture, it is desirable to obtain it in home-made ice cream. In the home-made ice cream the freezer is often filled so full that there is no room for overrun and no air is beaten into the ice cream during freezing. Filling the freezer two-thirds to three-fourths full gives good results for home-made ice cream. In home freezing the overrun obtained is seldom as great as with commercial ice creams, for the freezing conditions in the home are not controlled so carefully as in the factory.

Too great an overrun produces an ice cream of poor body and quality, for it becomes very frothy and foamy. An overrun of 50 per cent is considered to give a desirable texture.

**Percentage overrun.** The percentage of overrun depends upon the speed of freezing and rate of turning.

TABLE 12  
EFFECT OF THE SPEED OF THE MACHINE ON OVERRUN (*Baer*)

Revolutions per minute	Overrun		Time of freezing	
	Lot I	Lot II	Lot I	Lot II
50	25	33	10	11
50	28	33	11	10
50	25	35	9	12
150	48	43	7	7
150	48	39	8	5
150	50	40	7.5	6
175	45	58	7	6
175	50	50	7.5	6.5
175	52	55	8	6

The above table, from Baer's results, shows the effects of the speed of the machine on the overrun. He concluded that 50 revolutions per minute were too slow, as the overrun was too low, the texture of the ice cream was coarse, and the body weak and spiny.

From the table it will also be noted that increasing the speed of the freezer shortens the freezing time. The first crystals are formed at the edge of the ice-cream mix and against the side of the metal container. The faster speed of turning keeps these crystals scraped away and brings warmer portions of the mix against the can to be frozen. In this way the

whole mass is chilled and frozen more rapidly than it would be if the mix were not stirred.

For home freezing it is probably better to over-freeze a little but not too much, if the ice cream is to be served soon after it is frozen. After stirring is stopped the rate of cooling is slower. Therefore it requires a period of standing after the freezing process is completed for the ice cream to harden suitably for serving. Increasing the quantity of salt for packing also increases the rate at which the ice cream hardens.

### The Factors Affecting the Viscosity of Cream and Ice Cream

**Aging.** Sherwood and Smallfield have reported that in some cases aging shows an increase in viscosity of the cream whereas in others it does not. When the viscosity is increased the fat globules are larger and clump. They have found that agitation of the cream reduces the size of the fat globules and the viscosity of the cream. Mortensen states that cream just separated from fresh milk should be aged 24 hours before it is used in ice cream, even if it is not pasteurized. Aging also gives a cream that whips better. The viscosity of a cream increases noticeably for about 6 hours after it is separated and then increases at a slower rate.

**Homogenization.** Williams lists the benefits of homogenization, as applied to ice cream, under 6 heads as follows:

1. Increased viscosity.
2. Reduction in time required for aging.
3. Less physical and mechanical loss of fat.
4. Better whipping qualities.
5. Better freezing qualities.
6. Greater uniformity and palatability.

Ice cream made from homogenized cream is smoother and has smaller crystals. In homogenization of the cream the fat globules are broken up. As the size of the globules is decreased the surface area increases. The fat globules are surrounded by a film of protein. After homogenization, owing to the increased surface, a larger amount of protein is held in the film around the fat particles. The increase in the number of the fat globules and the protein held in the film increases the viscosity of the cream. After homogenization the cream should not be agitated. The higher the pressure used during homogenization, the greater the viscosity obtained in the cream.

With homogenized cream, less fat and less milk solids not fat can be used and a texture obtained that is as good as that from an unhomogenized cream with higher fat content and with higher milk solids.

**Pasteurization.** Pasteurization decreases the viscosity of the cream. Cream needs to be aged after pasteurization before it is used in ice cream.

### The Use of Gelatin in Ice Cream

Gelatin is used in ice cream to prevent the formation of coarse crystals, during softening and hardening of ice cream packed in an ice-and-salt mixture, while it is held for selling. Holdway and Reynolds have demonstrated that gelatin in ice cream prevents it from losing its shape while it is melting.

### Sugar in Ice Cream

Sugar is used for sweetening the ice cream. It increases the total solids, thus improving the body. Too high a percentage lowers the overrun and gives an ice cream that is too sweet.

Sucrose is used in ice cream. Other sugars may be used, such as invert sugar from sucrose, corn sugar, and levulose. Since the commercial levulose is too expensive, honey may be used. Corn sugar or dextrose is not so sweet as sucrose and therefore can be substituted successfully for only about 25 to 35 per cent of the sucrose in ice cream.

### Making Ice Cream in Refrigerators at Home

Ice cream may be held as well as frozen in mechanical refrigerators. When frozen in them the ice cream often does not have a good texture because it is not stirred sufficiently during the freezing process. Some units have been made that stir the mixture while it is freezing but they are not common. However, quite acceptable ices, sherbets, and even ice cream may be made by adding substances, such as egg white or whipped cream, that tend to delay crystal growth. Beaten egg white is best for ices and sherbets, because this product is more typical of an ice or sherbet texture than the product formed by adding rich whipped cream. A good time to add the beaten egg white to ices is just as the mixture starts to freeze, for the stirring at this time aids in the formation of more nuclei. Whipped cream may be added before or after the mixture is placed in the refrigerator tray, depending on the type of product to which it is added.

### Ice-Cream Improvers

The published results of Isenberg and Baer, on the use of ice-cream improvers in commercial products, indicates that they would be of practically no benefit in home-made ice cream.

### Home-Made Ices and Sherbets

Ices and sherbets have a lower freezing point than ice cream, for they usually contain a greater quantity of sugar. The use of gelatin and egg

white in home-made ices seems to improve the texture in some instances, but in others to have little effect. When the hot sirup is poured over the beaten egg white the results obtained are as good as when the beaten egg white is added during the freezing process.

The sherbets in which milk and fruit juices are combined give delightful-flavored products for home freezing.

### Classification of Ice Creams

Various classifications of frozen products have been proposed. Sommer gives the following classification of ice cream and related frozen products:

- |                     |                                  |
|---------------------|----------------------------------|
| 1. Plain Ice Cream  | 6. Parfait or New York Ice Cream |
| 2. Nut Ice Cream    | 7. Puddings                      |
| 3. Fruit Ice Cream  | 8. Custards                      |
| 4. Bisque Ice Cream | 9. Ices                          |
| 5. Mousse           | 10. Sherbets                     |

Sommer stresses that classification is based on composition rather than ingredients used.

Plain or Philadelphia ice cream has ingredients and composition as previously given for commercial ice cream. It may be flavored with a variety of flavors, such as vanilla, chocolate, maple.

Nut or fruit ice creams are plain ice cream with nuts or fruit added.

Bisque is made from a plain cream basis with such additions as macaroons, grape nuts, dried and broken sponge cake, or marshmallows.

A mousse has a whipped cream base.

Parfait, or New York ice cream, is made from the same ingredients as plain cream except the amount of egg used is sufficient to produce a distinctly yellow color. In some states the amount of egg yolk is specified.

Puddings differ from fruit ice cream in containing a mixture of fruits and to justify the name pudding should have eggs in amounts similar to New York ice cream.

Ices are made from fruit juices diluted with water and sweetened.

Sherbets are made from the same ingredients as ices with the exception that milk, cream, or ice cream is used in place of part or all of the water to dilute the fruit juices.

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## FREEZING

## Experiment 11.

To determine the temperature of the brine when different proportions of ice and salt are mixed.

The ice for all the freezing experiments should be in pieces of the same size, for the very large pieces melt more slowly because of small surface area. Put the ice through the ice crusher, which gives pieces of more uniform size. If it cannot be crushed in a crusher, but is broken with a hammer or shaved with a pick, put it through a large-screen mesh to obtain pieces of uniform size. The temperature obtained will be only approximate. For very accurate, careful work the temperature must be taken in insulated, closed flasks.

1. Weigh  $\frac{1}{4}$  pound of rock salt and an equal amount of ice. Mix well. Find the minimum temperature that can be obtained with this mixture and the length of time required to reach it.

Repeat using the following proportions.

2. One part of salt ( $\frac{1}{4}$  lb.) to 3 of ice ( $\frac{3}{4}$  lb.).

3. One part of salt ( $\frac{1}{8}$  lb.) to 6 of ice ( $\frac{3}{4}$  lb.).

4. One part of salt ( $\frac{1}{8}$  lb.) to 8 of ice (1 lb.).

5. Use equal parts of sugar to ice ( $\frac{1}{8}$  lb. of each).

What would the result be if the above experiments were repeated using coarse crystalline salt in place of the rock salt? Does the sugar have the same effect as salt? Why?

Lowest temperature obtained	Time required to reach the lowest temperature

Conclusions and applications.

## Ice Cream

## Experiment 12.

To determine the effect of the rate of turning on the texture of ice cream.

Directions for freezing experiments:

The freezers for the following experiments should be in good working order. The dashers should turn and scrape the crystals from the side of the can as they are formed.

To find the approximate swell of the ice cream the depth of the mixture should be measured in the can before and after freezing. If the depth is 2 inches before freezing and 3 inches after freezing the approximate swell is 50 per cent. The frozen mixture is not level across the top, so this method gives only an approximate measure of the swell.

Before the freezer is packed, the dasher, lid, and handle should be put in



place. Otherwise in packing the can is often pushed to one side and it is difficult to get the handle in place. See that the handle turns properly.

Measure the approximate amount of ice and salt required for your particular experiment. For a freezer of 1-quart capacity, and using the proportions 1 part of salt to 8 parts of ice by measure, about 10 cups of ice are required for freezing. This will sometimes pack or partially pack the freezer also. Consult the instructor for the method to use for mixing ice and salt to place in the freezer. More uniform results are obtained with class work by mixing the salt and ice before placing in the freezer unless uniform methods of packing are employed. The better way of packing is to measure the ice required to pack the freezer half way to the top. Then add a layer of salt, using  $\frac{1}{8}$  of the measure of the ice. Add a layer of ice to  $\frac{3}{4}$  the distance from the top. Add a layer of salt, again using  $\frac{1}{8}$  the amount of the ice. Add ice nearly to the top of the can and the same proportions of salt. If the ice and salt are not measured, different amounts will be used for the different groups and the results will not be uniform, for the variables of the same experiments will increase.

Remove the handle and lid after the ice is packed and add the mixture to be frozen. If the freezer is the type that will freeze with the lid off, leave the lid off and adjust the handle. By freezing in this way the ice and brine will not come to the top of the can, but if not more than 1 cup of the mix is used in a quart freezer the frozen mixture will not come more than half way up the can, and the ice and salt will be sufficient for freezing.

Record the total time of turning the freezer and the time when the first crystals are formed; notice when the swell begins. Turn until the frozen mixture is the consistency of good thick gravy. Compare with your neighbors' so that all will be of the same consistency when the freezing period is stopped.

If the freezer will not turn with the lid removed, the end point of the freezing will need to be determined by removing the lid. Compare with your neighbors' so that as nearly as possible all will be of the same consistency when the creams are packed. If the lids of the freezers cannot be removed, neither the swell nor the time when the first crystals form can be observed. Nor can the time required for freezing be estimated very accurately. The results are less uniform with this type of freezer and sometimes are not worth while. Obviously, if some freezers are not in working condition the results from them should not be recorded. If the dashers do not work properly then the results can be used for slow-turning freezers.

Remove the dasher, put on the lid, plug the hole in the top of the lid and pack to harden. If the period of hardening can be only a short one, a larger proportion of salt to ice may be used for packing. Consult the instructor for the proportions.

Freezing mixtures that contain the same proportion of ingredients will have the same freezing point. Take the temperature while freezing in the can that is turned slowly. Since it is to be turned slowly the results for it will not be affected if the turning is stopped while the freezing temperature is taken.

Take the temperature of each of the frozen mixtures before tasting. During hardening some of the frozen mixtures may reach lower temperatures than others. Why? Because of this lower temperature they will be harder and colder. If possible they should be the same temperature before tasting. If they are not

the same temperature in tasting do not confuse coldness and firmness of body with texture. The body should be firm and the texture smooth and velvety, that is, the crystals should be small and the cream should not be buttery.

An electrically operated freezer is preferable for many of the freezing experiments, as the rate of turning can be kept uniform. But unless it has different speeds, it cannot be used for determining the effect of rate of turning the freezer.

It is better for two girls to work together for each of the freezing experiments.

#### Recipe:

Cream	1 cup	240 grams
Sugar	3 tablespoons	37.5 grams
Vanilla	$\frac{1}{4}$ teaspoon	

Use coffee cream containing 18 to 20 per cent fat. Dissolve the sugar in the cream. Add vanilla and freeze.

1. Turn slowly all the time: about 40 turns or less per minute.
2. Turn slowly at first, then rapidly while freezing; 40 turns or less per minute at first, then about 100 turns per minute.
3. Turn rapidly all the time: about 100 turns per minute.

The following headings are suggested for records of the freezing experiments. After all the experiments have been performed, write a summary of your conclusions and applications.

Freezing temperature	Time to freeze	Swell Per cent	Temperature of mix when tasted	Texture	Flavor

#### Results.

#### Experiment 13.

To determine the effect of the richness of the cream used in making ice cream.

Use the same proportions given in Experiment 12. Use 1 part of salt to 8 of ice. Turn slowly at first, then rapidly during the freezing period, or use an electric freezer.

1. Use cream containing 18 per cent fat.
2. Use cream containing 24 per cent fat. If equal quantities of coffee cream (18 to 20 per cent) and whipping cream (30 to 32) are mixed, a cream with approximately 24 per cent of fat will be obtained.
3. Use a cream containing 30 per cent fat.

Does the amount of fat affect the freezing point? What would be the effect of a longer freezing period on the creams with a high fat content? Would it be advantageous to use a smaller proportion of salt for freezing these ice creams?

## Ices and Sherbets

**Experiment 14.**

To determine the best proportions of ice and salt to use in freezing an ice.

Recipe:

Water	1 cup	240 grams
Sugar	$\frac{1}{2}$ cup	100 grams
Lemon juice	$\frac{1}{4}$ cup	60 grams

Dissolve the sugar in the water and bring to the boiling point. Cool to 30°C. and add the lemon juice, then freeze. Turn the freezer slowly at first, then rapidly or use an electric freezer. Try each of the following proportions of salt and ice. See freezing directions, Experiment 12. Compare the consistency of the frozen ices, the fineness of the crystals, and the flavor. Compare the swell obtained with the different proportions of ice and salt.

1. Use 1 part of salt to 3 of ice.
2. Use 1 part of salt to 6 of ice.
3. Use 1 part of salt to 8 of ice.
4. Use 1 part of salt to 12 of ice.

What is the proportion of ice and salt given in cook books as best for freezing ices? Are your results in accordance with these proportions? Are the best proportions for an ice and for an ice cream the same?

What would be the effect of adding a larger proportion of sugar to the recipe? If you wish to add whole strawberries or other fruit to a frozen dessert, how would you treat them to prevent their freezing into chunks of ice?

**Experiment 15.**

To determine the effect of the rate of turning the freezer upon the texture of an ice.

Use the proportions of salt found best in Experiment 14. See Experiment 12 for freezing directions.

Notice when the ice begins to turn white. When does the swell begin? Compare the texture of the finished products.

1. Turn slowly all the time, about 40 turns or less per minute.
2. Turn slowly at first, 40 turns or less per minute; then rapidly while freezing, about 100 turns per minute.
3. Turn rapidly all the time, about 100 turns per minute.
4. If you have a vacuum freezer use it for one lot, or freeze one lot in the mechanical refrigerator.

**Experiment 16.**

To determine the effect on the texture of an ice when a binder is added.

Use 1 part of salt to 8 parts of ice or the best proportions found in Experiment 14. See Experiment 12 for freezing directions.

1. Prepare the lemon ice as given in the recipe for a control.
2. To the recipe given add  $\frac{1}{2}$  teaspoon of gelatin. Hydrate the gelatin

by letting it stand a short time with 1 tablespoon of water. Then dissolve in the hot sirup.

3. To the half-frozen ice, add  $\frac{1}{2}$  egg white beaten stiff. Finish freezing.

4. Prepare lemon ice adding both  $\frac{1}{2}$  teaspoon of gelatin and  $\frac{1}{2}$  egg white beaten stiff. See 2 and 3 for directions for adding to the ice.

5. Pour the hot sirup over  $\frac{1}{2}$  egg white beaten stiff. Beat while adding the sirup. Cool, add lemon juice, and freeze.

6. Repeat 1, but do not make a sirup of the sugar and water. Dissolve the sugar in the cold water, add the lemon juice, and freeze.

7. Repeat 6, but substitute milk for the water.

Which mixtures give the best textures? Which are the easiest to prepare and freeze?

Results.

### Suggestions for Additional Experiments

To determine the effect on the texture of ice cream when a filler is used.

Recipe:

Cream	$\frac{2}{3}$ cup	160 grams
Sugar	3 tablespoons	37.5 grams
Milk	$\frac{1}{4}$ cup	80 grams
Vanilla	$\frac{1}{4}$ teaspoon	

a. Add  $\frac{3}{4}$  tablespoon of flour (5.3 grams) to the recipe. Boil and cool before freezing.

b. Add  $\frac{1}{4}$  beaten egg (12 grams) to the recipe. Scald. Cool, then freeze.

To find the effect of aging the cream. Use cream with the same percentage of fat, but have one lot 24 hours older than the other.

To find the effect of homogenizing the cream. Use cream of the same percentage of fat and the same age but have one lot homogenized, the other unhomogenized.

## CHAPTER IV

### FRUITS AND VEGETABLES

#### Losses in Cooking Vegetables

The losses that occur in cooking fruits and vegetables are of three types: first, the losses due to volatile substances; second, the losses due to the solubility of some of the substances of the fruit or the vegetable in water during preparation and cooking, and the discarding of this water; third, the losses due to the destruction of some substances by heating.

The volatile loss is composed largely of water but includes some acids and substances that give flavor and odor. The greatest part of the volatile loss can be replaced by the addition of water. The other volatile substances affect the flavor more than the food value and will be considered later.

Water in which fruit is soaked and cooked is seldom discarded, so that this type of loss pertains more to the cooking of vegetables. Vegetables contain the following food nutrients: protein, fat, carbohydrates, minerals, and vitamins. Decrease of these nutrients during cooking is due largely to their loss. Vegetables contain little fat, thus fat loss in their cookery is relatively unimportant. The starch from vegetables is insoluble in water. The loss of starch from vegetables occurs when the cell walls are broken by cutting in preparation, disintegration through over-cooking or from abrasion, which may occur in violent boiling and cause the sloughing off of parts of the vegetable near the surface.

**Nitrogen.** The nitrogenous or nitrogen-containing part of fruits and vegetables may be classified for convenience as composed of proteins and non-proteins. The nitrogenous content of vegetables, with the exception of the legumes, is low. The albumins are soluble in water and dilute salt solutions, the globulins in dilute neutral salt solutions. They are both coagulable by heat. Their greatest loss would occur when the vegetable is soaked before cooking, or when cold water is added to the vegetable to start the cooking process. In salted water some of the albumins and globulins would be dissolved.

McKee and Smith in their investigations of the protein of the cauliflower found that 68 per cent of the nitrogen of the edible part belongs to constituents soluble in water or dilute salt solution; 12 per cent to compounds soluble in 0.3 per cent sodium hydroxide, but not soluble in water; and 16 per cent to substances insoluble in either water or dilute alkali. Their results show a large proportion of the nitrogen compounds

soluble in water and dilute salt solution, indicating that it is preferable to start cooking in boiling water to coagulate the albumins and globulins.

Some of the nitrogenous substances are soluble at all temperatures. The foaming of the cooking water is partially due to these substances, and partially to tannins and saponins. All these substances lower the surface tension of the cooking water and favor foaming. Foaming occurs in the cooking of some vegetables, such as peas and asparagus, more than in others.

The important changes in the cookery of vegetables come from the loss of sugars, vitamins, and minerals. The sugars are very soluble in cold and hot water. Their loss is lessened if the vegetable is left in large pieces, which give less surface for contact with the water than small pieces.

**Vitamins.** The loss of vitamins in cooking may come from destruction by heat or by oxidation as well as loss in the discarded cooking water.

**Mineral salts.** The principal minerals in foods that may be lost during cooking are the salts of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), sulfur (S), iron (Fe), chlorine (Cl), and iodine (I). Sodium, potassium, magnesium, and calcium are a valuable part of the mineral content of fruits and vegetables, as an excess of this group over the phosphorus, sulfur, and chlorine group produces an alkaline ash reaction in the body after the food nutrients have been absorbed from the intestinal tract. Potassium particularly is found in high percentage in most vegetables. Most of its salts as well as those of sodium are quite soluble in water so that their loss in discarded cooking liquor may be high. As a rule, the calcium salts are not so soluble as the other salts found in vegetables; in some vegetables they seem to be in an insoluble form, but in others the calcium loss is about one-fourth of the total calcium of the food. Magnesium salts are more soluble than those of calcium. Vegetables, with the exception of the legumes, contain small percentages of phosphorus when compared with some other foods. The phosphorus salts are easily soluble, and the phosphorus loss in discarded water may amount to 50 per cent or more of the total phosphorus of the vegetable.

The solubility of most of the salts found in vegetables increases with increasing temperature of the water, so that at 100°C. they are more soluble than at ordinary temperatures.

Peterson and Hoppert, using medium and large quantities of water for cooking vegetables, report the loss of calcium to be practically nothing in spinach. In other vegetables the loss is about 30 per cent of the total calcium. They report that the magnesium loss varies from 20 to 45 per cent, the phosphorus from 20 to 50 per cent. Berry reports as high as 60 per cent for magnesium and 52 per cent for phosphorus.

The following losses for cooking vegetables in water are reported in U. of Minn., Agri. Expt. Sta. Bull. 54, and in U. S. Dept. Agri. Farmers' Bull. 73.

TABLE 13  
LOSSES IN COOKING VEGETABLES VARIOUS WAYS IN WATER

Vegetable and method	Loss of total nitrogenous matter, per cent	Loss of total mineral, per cent	Loss of total sugar, per cent
Potatoes peeled and soaked several hours before cooking.....	52	38	..
Potatoes started to cook in cold water.....	16	19	..
Potatoes, cooking started in boiling water.....	8	about 19	..
Potatoes cooked in skin.....	trifling	trifling	..
Carrots cut in small pieces...	42	47	26
Carrots cut in medium pieces	less than	less than	26
	42	47	
Carrots cut in large pieces...	20	25 plus	16
Cabbage, started in hot water	about 33	about 33	..
Cabbage, started in cold water	about 50	about 50	..

Iron. The iron of foods is very important nutritionally, because of the fact that many dietaries do not contain the minimum daily amount recommended by Sherman. The loss of iron in cooking should be avoided. Iron salts are quite soluble. Blunt and Otis report the following losses of iron when the vegetables were cooked in water: spinach 43 per cent; string beans 39 per cent; navy beans 32 per cent; peas 36 per cent; and

TABLE 14  
IRON LOSS IN SALTED AND UNSALTED WATER (*Steinbarger*)

Vegetable	Unsalted water, per cent	Salted water, per cent
Potatoes cut in halves.....	63.2	83.7
Carrots.....	16.4	27.8
Cabbage.....	27.4	40.7
Onions.....	46.5	71.4
Cauliflower.....	30.7	47.4
Spinach.....	19.3	46.8
Green beans.....	24.5	38.8

potatoes 15 per cent. Peterson and Hoppert report from 20 to 30 per cent iron loss for various vegetables. Morgan reports +6 to 50 per cent loss for canned peas.

Steinbarger reports the loss of iron as greater in salted than in unsalted water. Table 14 is from her results.

The vegetables given in Table 14 were cooked the following lengths of time: potatoes and onions 20 minutes; green beans 90 minutes; and the others 30 minutes. The results suggest some connection between iron salts and the globulins. The iron salts of potatoes have been reported as more concentrated near the surface, which may account for their high iron loss.

**Losses due to method of cooking and preparation.** The losses through cooking of vegetables depend upon several factors, which include: (1) the method of cooking, (2) the nature of the vegetable, (3) its preparation, (4) the length of time of cooking, (5) the temperature of cooking, (6) the quantity of cooking water, (7) whether started in hot or cold water, and (8) the reaction of the cooking medium. Some of these have been considered under nitrogen and vitamin losses.

Baking results in small nutritive losses.

All investigators report small losses in steaming; this seems to be an ideal way of cooking vegetables whose color and flavor are not altered by this method.

Masters and Garbutt report practically no loss in cooking vegetables in water, if the amount of water added is small and is evaporated just to dryness at the close of the cooking period. They designate this as the conservative method of cooking. If it is not practicable to evaporate the water to dryness, the use of as small a quantity of water as possible seems preferable to using a very large quantity.

Leafy vegetables like spinach offer a larger surface area for loss than the compact ones like carrots. Soaking in water before cooking may increase the losses, and vegetables like carrots and potatoes, when cooked whole, in their skins, or left in large pieces lose less than if cut in small pieces.

Loughlin reports that the amount of the sugars, the vitamins, and mineral salts dissolved in the cooking water is increased if a large amount of liquid is used, if much cut surface is exposed, and if the cooking time is prolonged.

Thompson reports that the total loss of solids, ash, and iron is greater in vegetables that are over-cooked than in those just sufficiently cooked.

### The Plant Acids

The plant acids, the plant pigments, and the cellulose are constituents of the vegetable less often considered than the other food nutrients. Knowledge of the common reactions of these constituents renders one able to serve fruits and vegetables that are attractive in appearance, color, and texture.



**Plant acids.** Plants contain organic acids. According to chemical classification the acids may belong to different groups, but for consideration in cooking they may be divided into two classes, the volatile and non-volatile ones. Volatile acids are the ones that volatilize and pass from the liquid as vapor. The odor of acetic acid or vinegar during cooking is well known. The following acids of the  $C_nH_{2n}O_2$  series are volatile, the first ones being more volatile than the last ones:

Formic acid	$H \cdot COOH$
Acetic acid	$CH_3 \cdot COOH$
Propionic acid	$CH_3 \cdot CH_2 \cdot COOH$
Butyric acid	$CH_3 \cdot CH_2 \cdot CH_2 \cdot COOH$
Valeric acid	$CH_3 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot COOH$
Caproic acid	$CH_3 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot COOH$

Formic and acetic acids have been obtained from plants during distillation. Onslow states that propionic acid has only rarely been found in plants.

The amount of volatile acids found in plants varies; it also varies in the same plant. Koch found that cooking 125 grams of spinach for 1 hour and collecting the distillate required 18 cc. of  $N/10$  NaOH to neutralize the volatile acids. Another experiment in which the same weight of spinach was used and cooked for the same length of time required only 6 cc. of  $N/10$  NaOH.

**Non-volatile acids.** Not all the acids found in fruits and vegetables are volatile. The following are some of the more common non-volatile ones found in foods:

*Dicarboxylic acids*

Oxalic acid	$COOH \cdot COOH$
Malonic acid	$COOH \cdot CH_2 \cdot COOH$
Succinic acid	$COOH \cdot CH_2 \cdot CH_2 \cdot COOH$
Glutaric acid	$COOH \cdot (CH_2)_3 \cdot COOH$
Adipic acid	$COOH \cdot (CH_2)_4 \cdot COOH$

*Hydroxydicarboxylic acids*

Malic acid	$COOH \cdot CHOH \cdot CH_2 \cdot COOH$
Tartaric acid	$COOH \cdot CHOH \cdot CHOH \cdot COOH$

*Hydroxytricarboxylic acids*

Citric acid	$COOH \cdot CH_2 \cdot COH \cdot CH_2 \cdot COOH$ $\quad \quad \quad  $ $\quad \quad \quad COOH$
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**Acids in vegetables.** The acids are found in the fruits, leaves, stem, and root stocks. The acid may occur in the free form, but is often combined as a salt or an ester.

Because of oxaluria the oxalic acid content of vegetables is of interest. Onslow states that oxalic acid "occurs very frequently and widely dis-

tributed in plants, usually as the calcium salt, and apparently less frequently as the sodium and potassium salts. It has rarely been detected as the free acid. The calcium salt is precipitated on adding calcium acetate to a solution of the acid. Calcium oxalate is insoluble in acetic acid, but soluble in dilute mineral acids." It is found in the rumex or dock family, of which different docks and sour grass are used as food. Sorrel and rhubarb contain a rather high percentage. Rider has reported the most extensive determinations of oxalic acid in leafy vegetables. She has found that the amount in spinach ranges from 0.486 to 0.692 per cent. Beet greens give an equivalent or slightly higher amount than spinach, and New Zealand spinach contains a still higher percentage. No oxalic acid was found in dandelion greens, kale, turnip greens, and mustard greens. McLaughlin has reported the oxalic acid content of eight samples of New Zealand spinach as ranging from 0.49 to 0.53 per cent, anhydrous. As these figures indicate, the amount in different samples of the same vegetable may vary. Rider mentions this fact in connection with the samples she analyzed. Nelson has reported 0.31 per cent oxalic acid in spinach.

Succinic acid is found in many plants, and glutaric and adipic have been isolated from the sugar beet.

Malic acid is found as the free acid and as the salts of malic acid in many plants, and particularly in apples and pears.

Citric acid is found in tomatoes and it is found in smaller quantities in other foods. Blunt reports small amounts in cabbage, asparagus, and string beans.

Nelson has reported that spinach contains both citric and malic acids. The ratio of citric to malic acid in broccoli was 3:2. The leaves and buds contained approximately the same proportions. Small amounts of oxalic and succinic are also present. The acid content of lettuce was as follows: oxalic, 1-malic, and citric, 0.011, 0.065, and 0.048 per cent respectively.

Tomatoes, which have the highest amount of acid of our common vegetables, contain citric acid. Blunt reports 0.42 per cent.

**The acids found in fruits.** Conflicting reports appear in the literature regarding the particular acid in different foods. Bigelow and Dunbar suggest that this is due to the inaccurate methods of analysis often used and to the difficulty in separating the different acids from one another. Nelson has reported the approximate percentages of the various acids in fresh fruits, the average total acidity being calculated as citric. His results are given in Table 15.

Nelson states that the most common acids in fruits, citric and malic, may occur in different proportions or one alone may be present. "The total acidity of most fruits varies with the variety and the degree of ripeness. The relative proportions of the various acids may also vary with the degree of ripeness, variety, and climatic and soil conditions."

Rhubarb contains some oxalic acid; cranberries and plums some benzoic. Other acids sometimes found in small quantities are succinic, lactic, iso-

TABLE 15  
THE ACIDS OF FRUITS (Nelson)

Fruit	In-vestigator	Citric %	Malic %	Tar-taric %	Ben-zoic %	Oxal-ic %	Suc-cinic %	Lac-tic %	Iso-citric %	Total acidity (titrat-able) %
Apple (Winesap)	N	trace	0.50	.....	.....	.....	.....	.....	.....	0.51
Apricot (dried)	N	0.35	0.81	.....	.....	trace	.....	.....	.....	1.16
Banana.....	P	.....	0.24	.....	.....	.....	.....	.....	.....	0.26
Blackberry.....	N	trace	0.16	.....	.....	trace	trace	.....	0.92	1.08
Blueberry.....	N	1.56	0.10	.....	.....	.....	.....	.....	.....	1.66
Cherry.....	F	0.01	1.25	.....	.....	trace	0.07	0.13	.....	1.36
Cranberry.....	N	1.82	0.46	.....	0.07	.....	.....	.....	.....	2.35
Currant.....	F	2.30	0.05	.....	.....	trace	trace	.....	.....	2.35
Fig.....	N	0.34	trace	.....	.....	.....	.....	.....	.....	0.35
Grape.....	N	.....	0.65	0.43	.....	.....	.....	.....	.....	1.08
Grapefruit.....	H	1.46	.....	.....	.....	.....	.....	.....	.....	1.46
Lemon.....	N	3.84	trace	.....	.....	.....	.....	.....	.....	3.88
Loganberry.....	N	2.02	0.08	.....	.....	.....	.....	.....	.....	2.10
Orange.....	N	0.98	trace	.....	.....	.....	.....	.....	.....	0.99
Peach.....	N	0.37	0.37	.....	.....	.....	.....	.....	.....	0.74
Pear.....	N	0.24	0.12	.....	.....	.....	.....	.....	.....	0.36
Pineapple.....	N	0.84	0.12	.....	.....	.....	.....	.....	.....	0.96
Pomegranate.....	N	1.25	.....	.....	.....	.....	.....	.....	.....	1.25
Quince.....	N	.....	0.68	.....	.....	.....	.....	.....	.....	0.68
Raspberry, blk.	N	1.06	.....	.....	.....	.....	.....	.....	.....	1.06
Raspberry, red	N	1.30	0.04	.....	.....	.....	.....	.....	.....	1.34
Rhubarb.....	N	0.41	1.77	.....	.....	0.12	.....	.....	.....	2.30
Strawberry.....	N	0.91	0.10	.....	.....	.....	.....	.....	.....	1.01
Tamarind.....	F	trace	0.50	7.76	.....	trace	trace	.....	.....	8.00
Tomato.....	N	0.30	0.20	.....	.....	.....	.....	.....	.....	0.50

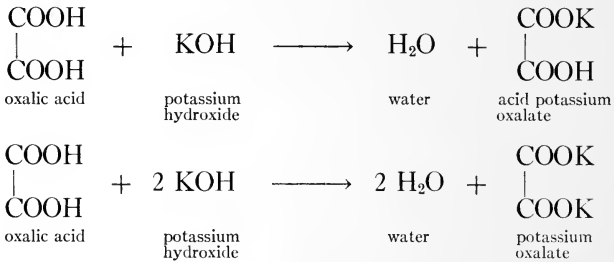
*F* refers to Fransen: *N* to Nelson: *H* to Hartman: and *P* to Pratt.

citric, and acetic. Nelson reports acetic acid in figs, isocitric in blackberries, and tartaric in grapes. Bigelow and Dunbar have reported that both citric and malic acids are found in gooseberry, the total acid for different varieties varying from 1.72 to 2.63 per cent.

Mineral salts of organic acids may be formed during the cooking of fruits in metal containers. Very unpalatable flavors are developed in this way, and the color of the cooked product is darkened. This brings to memory a sample of plum butter sent to the Department. It was nearly charcoal black in color, and as for flavor might have been made from any fruit, for there was little of the original fruit flavor left. The sender stated it had been cooked on the back of the stove in a tin wash boiler for three days and was much perturbed because a neighbor had told her it was poisonous on account of the cooking utensil used. Hence a sample was sent with the request to try it and see if it was poisonous.

Just as inorganic acids may combine with metals to produce acid or neutral salts according to whether part or all of the hydrogen is replaced by the metal, so in a similar way organic acids may combine with metals forming salts.

Thus oxalic acid gives



**Zinc utensils.** Some of the metal salts formed with organic acids are injurious when taken into the body. The zinc salts of organic acids have been regarded as toxic. They are formed when foods containing acids are placed in galvanized containers. Galvanized iron contains some zinc, and when fruits, beverages, or even milk are placed in utensils made of it, the acids of the food combine with the zinc, forming salts.

Sale and Badger have reported that zinc is dissolved from galvanized utensils, and the greater the acidity of the food and the longer the food stays in such containers the more zinc dissolved. Even fresh milk contains enough acid to dissolve appreciable amounts of zinc.

Burke, Woodson, and Heller, after investigating the toxicity of butter-milk held in galvanized containers, question the attributing of the toxicity to zinc in many previous investigations, and think that in some cases the toxicity may have been due to the surface of the galvanized container being contaminated with some other substance, possibly arsenic, lead, or antimony.

The tin salts have not been found poisonous, but large amounts of them in a food, such as would result when an acid fruit is cooked for a long time in a tin wash boiler, produce a very dark color and a disagreeable metallic flavor.

Iron salts with acids may cause discoloration in some food products.

### Plant Pigments

**Chlorophyll.** Chlorophyll, the green pigment of plants, plays an important rôle in their synthesis of carbohydrates. The cells of the mesophyll of the leaf contain chloroplasts or chlorophyll-corpuscles, the nucleus, other substances, and the cell liquid with its dissolved materials. The chloroplasts contain four pigments, two green ones, chlorophyll *a* and chlorophyll *b*, and two yellow ones, carotene and xanthophyll.

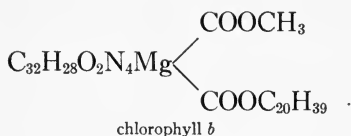
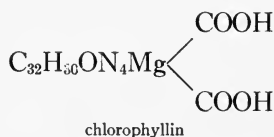
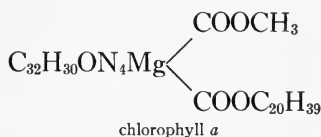
*Solubility of chlorophyll.* Chlorophyll is not soluble in water. Very little

green color is found in the water in which green vegetables have been cooked. Pure isolated chlorophyll is soluble in acetone, ether and benzene. In extracting the pigment from thoroughly dry leaves it is necessary to add about 20 per cent of water to the acetone or other solvent. One explanation for this is that chlorophyll is in the colloidal state in the leaf, and the mineral constituents of the leaf, dissolved in the water, peptize it, rendering it soluble. Onslow states that "the condition of chlorophyll is altered by plunging into boiling water. The pigment is then much more soluble, in ether, etc., even when the leaves are subsequently dried. It is supposed that the chlorophyll has diffused out from the plastids, and is in true solution in the accompanying waxy substances which have become liquid owing to change in temperature."

When green vegetables are dropped into boiling water a change takes place nearly instantly, the green color being intensified. Various explanations have been offered for the phenomenon. One is that the hot water has melted waxy constituents of the leaf so the chlorophyll escapes from the cell more readily or may become more soluble. Or the hot water may have dissolved salts or other substances in contact with the chlorophyll so that it diffuses more readily.

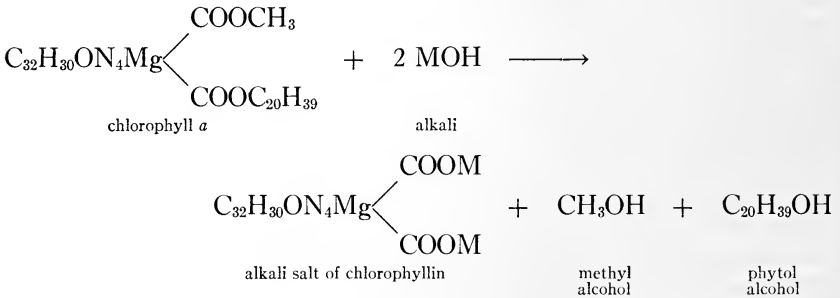
For peas, Kohman states that one factor in the intensification of the green color is the removal of air from the pea when it is dropped in the boiling water. The outer skin of the pea is transparent, the space beneath this being impregnated with air which is removed when the peas are blanched. That this change in color is caused by removal of the air can be shown by subjecting the peas to an adequate vacuum under cold water and releasing the vacuum while the peas are still under the water.

*Composition of chlorophyll.* Willstätter, whose work gave us the formula for and the chemical reactions of chlorophyll, reports that it exists in two forms, depending upon the degree of oxidation in the plant cells: form (a) and form (b). The former exists in the proportion of three to one of the latter.



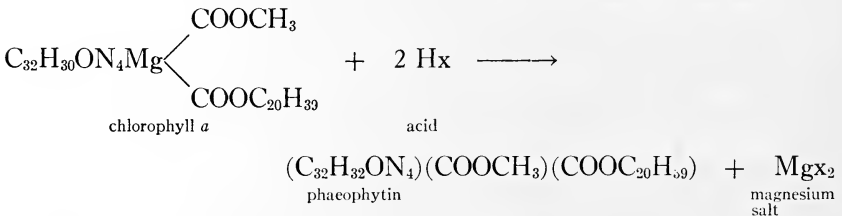
Chlorophyll contains 2.7 per cent of the metal magnesium. It contains two ester groups, one of methyl alcohol (COOCH<sub>3</sub>) and one of phytol alcohol (COOC<sub>20</sub>H<sub>39</sub>).

*Reactions of chlorophyll with alkalis.* Chlorophyll is a neutral substance but gives characteristic reactions when treated with alkalis or acids. Willstätter designates the parent substance of chlorophyll as chlorophyllin. The reaction of chlorophyllin with methyl and phytol alcohols gives the ester chlorophyll. Chlorophyll, when treated in the cold with alkalis, gives alkaline salts of chlorophyllin. The color change is first brown, followed by a return of the green, but it is no longer fluorescent. When chlorophyll is saponified with hot alcoholic alkalis, isochlorophyllins are formed, which are fluorescent.



When the green-colored vegetables are cooked in water with an alkaline reaction, or in water to which a small amount of soda is added, they develop a bright, intense green color.

*Reaction of chlorophyll with acids.* Chlorophyll reacts with acids to give an olive-colored product, without fluorescence, called phaeophytin. The magnesium of the chlorophyll is replaced by hydrogen. From phaeophytin, Willstätter has obtained two decomposition groups: the first, designated as phytochlorins, are olive green and derived from chlorophyll *a*; the second, the phytorhodins, are red and derived from chlorophyll *b*.



*The effect of heat upon chlorophyll.* The chlorophyll is changed to the olive-green color by two means, (1) by hydrogen ions or an acid reaction and (2) by heat. As previously given, the hydroxyl ions, or an alkaline reaction, produces chlorophyll salts with bright green color. In general, the more acid the reaction, the more rapid is this change in color when the vegetable is heated; or, *vice versa*, the more alkaline the reaction, the more slowly the chlorophyll changes to olive-green. Thus in order that the bright green color be retained in cooking green vegetables, they should be cooked

for as short a time as possible and contact with acids should be avoided as far as possible. It is also possible that other ions than the hydrogen and hydroxyl ions may affect the stability of the chlorophyll, for some vegetables with nearly the same  $pH$ , cooked in water from the same source, and with other conditions standardized are more stable to heat than others.

In cooking certain procedures may aid in decreasing the acidity of the cooking water. The vegetables contain both volatile and non-volatile acids, which in the plant are prevented from uniting with the chlorophyll but are liberated when the plant tissues are heated. If the cooking vessel is not covered, the volatile acids may escape with the steam, thus decreasing the acidity.

It has been found that the highest percentage of these volatile acids passes off during the first few minutes of cooking. Hence, if the cooking vessel needs to be covered for a part of the time, it is preferable to have the uncovered period the first few minutes.

Certain water, such as hard water, softened water, or water from many streams, is alkaline in reaction. Rain water, snow, or ice water is usually about neutral. If the cooking water contains alkaline salts, these salts may neutralize the non-volatile acids, and if there is a slight excess of alkaline salts the green color is intensified. To a certain extent the intensification depends upon the quantity of water used, for the larger quantity of water contains a greater quantity of alkaline salts. If the water is only slightly alkaline the plant acids may not all be neutralized and the olive-green color may develop. If the water is very alkaline and considerable water is used, not enough volatile and non-volatile acids will be liberated to neutralize the alkalinity of the water, the cover can be kept on during cooking, and the product will be bright green. With longer cooking the heat may have more effect upon the chlorophyll than the alkaline salts of the water. The addition of sodium bicarbonate (baking soda), Experiment 17A, 5, also intensifies the green color. Canned spinach, asparagus, peas, and string beans have a deep olive-green color due to the retention of the plant acids during processing and to the high temperature at which they are processed. Green vegetables like cabbage, Brussels sprouts, and spinach cooked in milk may remain a bright green color. Owing to the ease with which milk scorches and boils over there is usually less tendency to cook the vegetables too long when milk is used.

Heat decomposes chlorophyll, an olive-green color being produced. The extent of decomposition depends upon the time of heating and the temperature reached. With a very short cooking period little destruction may occur, but with a longer time all the chlorophyll may be decomposed. At lower temperatures the change is less rapid and at higher temperatures more rapid. Thus in a pressure cooker the change is rapid, since the temperature is high and acidity is not decreased because the volatile acids are retained. Increasing the alkalinity by using alkaline water or adding soda

retards the color change by heat. However, the addition of soda is not advisable, because it softens the cellulose rapidly so that the vegetable with slight over-cooking becomes mushy or even slimy and the destruction of some of the vitamins is hastened.

The cooking of green vegetables that contain enough acid to taste sour, like sorrel, sour grass, and dock, always produces this olive-green color no matter how cooked or for how short a time. Their acid content is too high to be neutralized by the alkaline salts of water or the addition of baking soda in small amounts. Green fruits like gooseberries, green grapes, and green plums develop an olive-green color when cooked. If the fruits are mature they may also contain yellow pigments that modify the color to a certain extent.

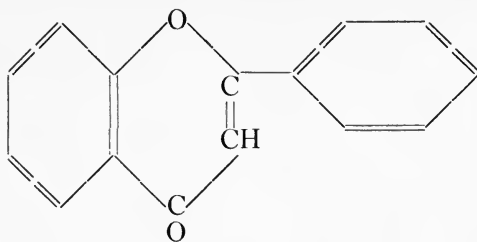
If acid is to be added as a seasoning to green vegetables it is preferable to add it when served, for there will not be so long a time for the acid to react on the chlorophyll and less brown color will develop. When vegetables are cooked with added acid, the softening of the vegetable is prevented to a slight extent.

*Replacing magnesium in chlorophyll products.* It is very difficult to replace the magnesium of the magnesium-free chlorophyll products. It can be done chemically by using a very reactive substance, magnesium methyl iodide, but this is impracticable to use in cooking processes. However, Willstätter states that the acetate salts of some metals such as copper, iron, and zinc will combine with phaeophytin and give very bright green-colored products. This is such a good test for small quantities of these metals that it is necessary in isolating chlorophyll to be extremely careful that it does not come in contact with them. If to the green vegetable to which acid has been added and in which the olive-green color has developed, Experiment 17A, 6, copper acetate is added, a vivid green color will develop on standing.

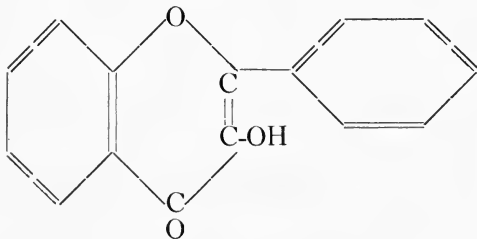
**Carotinoids.** Carotinoids is a term applied to the pigments giving yellow and orange coloring to fruits and flowers, carotene,  $C_{40}H_{56}$ , and xanthophyll,  $C_{40}H_{56}O_2$ . The carotinoids are not soluble in water, and the pigments are not affected, to any great extent, by the concentration of acids or alkalies used in food preparation. The darkening produced by the action of alkalies by caramelization of the sugar in vegetables, like carrots, must not be confused with a change in pigment color. Carotene is easily oxidized when exposed to air. Xanthophyll can also be oxidized in the same way. One of the characteristics of the carotinoids is the intensity of their coloring. The red pigment found in tomatoes is lycopin, an isomer of carotene.

**Flavones and Flavonols.** Flavones and flavonols are amphoteric pigments found in vegetables and petals of flowers. They are also found in the cell sap of the epidermis and underlying tissue of plants. Onslow gives the following formulas:





flavone



flavonol

As they occur in nature they often have other or additional hydrogen atoms replaced by hydroxyl groups. The position of the hydroxyl groups markedly influences the intensity of color, the color usually being deeper if two hydroxyl groups are in the ortho position to each other. The flavone and flavonol pigments are yellow in color. In plants they often occur as glucosides, one or more of the hydroxyl groups being combined with the sugar, and then the color is less intense. They give an intense yellow color with alkalis. Sometimes the quantity of them found in white vegetables is so minute that they are not visible. Adding an alkali or holding them over ammonia vapor intensifies the color and they become visible. The color changes of the flavones cannot be observed so readily in the yellow, red, or green vegetables.

Rice cooked in alkaline water usually has a yellow tinge, and sometimes it is rather deep in hue or has a green tint. Rice from the same source as that cooked in alkaline water, but cooked in distilled water, has a snowy white appearance.

The cooking of cauliflower, white cabbage, and particularly white onions in alkaline water often causes the yellow color to develop. Some white onions cooked in the hard water at Ames have developed nearly a sulfur yellow in color, whereas portions of the same onions cooked in distilled water remained white, or retained their natural yellow tinge.

Potatoes must often contain flavones, as they sometimes develop a yellow or green color in alkaline water. Mashed potatoes that have a strong alkaline taste may be improved in flavor by adding a very small amount of cream of tartar.

Flavones and flavonols with iron salts turn green and then brown. This

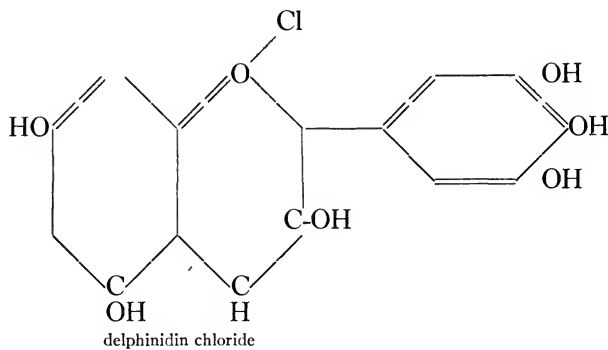
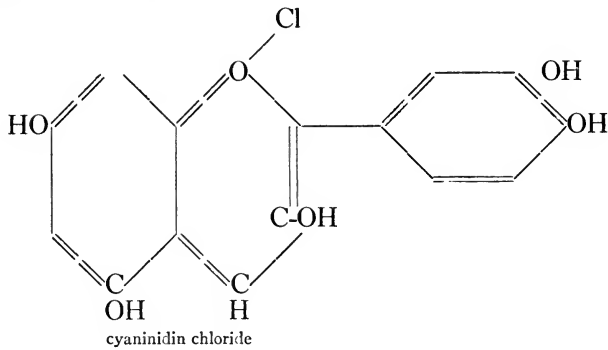
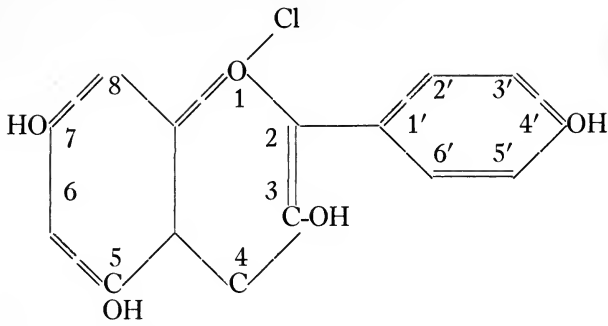
may explain some color changes that occur when foods are cooked in chipped enamel utensils having an iron base.

**Anthocyanins.** The anthocyanins include a group of pigments that, like sugars, have similar composition and properties yet have individual differences. As a rule they occur as glucosides in different parts of the plant and are known as anthocyanins in this combination. When the glucoside is hydrolyzed by boiling with dilute acid the non-glucosidal pigment portion is called anthocyanidin. The anthocyanins are soluble in water. Onslow states that occasionally they crystallize from the cell sap. Most but not all of the anthocyanins are soluble in alcohol. The anthocyan pigments give the blue, purple, violet, and red shades to different parts of the plant. They are very widely distributed. Onslow states that the plant that does not produce them is the exception rather than the rule. They occur in apples, cherries, currants, grapes, blueberries, red and black raspberries, in some varieties of peaches and plums, and in red cabbage, radishes, beets, and other fruits and vegetables.

All the anthocyanins so far isolated have fallen into one of three groups. They are illustrated as the chlorides. The number of hydroxy groups attached to the side benzene ring is made the basis of the classification. The glucosides of these anthocyanidins are called pelargonins, cyanins, and delphinins.

One of the reactions that the anthocyanins have in common is their color changes. Onslow states that the pigment should be pure to test the color reactions, for in the plant the pigment is found with other substances that may modify the reaction. In an acid solution, pure anthocyanins are usually red; in an alkaline one they are violet or blue, but if flavones or flavonols are present, a green color is obtained through the mixture of the blue and yellow. Yet the solutions of many fruit juices show typical color changes. In ordinary solutions of plant pigments they become green, then yellow, and sometimes brown upon the addition of alkali. If the alkali is very weak, or with salts with a weak alkaline reaction, a blue color may form and the green may never develop, or the blue may be intermediate between the red and the green.

*Color changes of fruit juices.* Pratt and Swartout state that the solutions of many fruit pigments act as indicators; that the solutions are easily prepared and stable; that the liquid indicators can be used in titrating acids, but not bases, for in a solution no more than moderately alkaline they soon decompose, all of them producing a brown color which does not change when acid is added. They found that apricots, peaches, pears, persimmons, and tomatoes failed to yield pigments that could be used as indicators. It is interesting that the pigment of cactus holds its red color even in a distinctly alkaline medium. They also state that "the pigment of red beets remained red through the acid range and into the alkaline range at least as far as  $pH$  13.0." In their conclusion they recommend that the greatest usefulness of the indicators is in test papers.



*Fruit colors and punch.* Combinations of fruit juices for punch can yield beautiful, clear colors, or ugly, muddy ones. If a red color is desired, use red- or blue-colored juices and keep the reaction acid by the addition of lemon juice. For a purple shade, choose fruit juices nearly neutral in reaction and do not add lemon juice. A blue color can usually be intensified by the addition of canned pineapple juice. (See the following paragraph.) Alkaline water may or may not give a bluish tinge to red fruit juices, depending on the alkalinity of the water and the acidity of the juice. Orange

TABLE 16

THE pH RANGE WITH COLOR CHANGES OF FRUIT JUICES (*Pratt and Swartout*)

Fruit source	Color change	pH range
Apples	Red to yellowish-green	6.2- 7.2
Blackberries	Red to dark grayish-blue	6.0- 7.4
Blueberries	Reddish-purple to greenish-purple	6.2- 7.2
Cactus	Red to faint purple	9.0-12.0
Cactus	Faint purple to reddish-brown	12.0-13.0
Cherries	Red to bluish-purple	6.0- 7.2
Grapes	Red to purple	5.0- 6.6
Grapes	Purple to green	6.6- 7.6
Plums	Red to yellowish-green	6.2- 7.2
Pomegranates	Red to purple	6.0- 6.8
Pomegranates	Purple to green	6.8- 7.6
Strawberries	Red to yellowish-green	6.2- 7.2

TABLE 17

THE COLOR OF FRUIT JUICES IN NEUTRAL, ACID, AND ALKALINE MEDIUMS  
(*Pratt and Swartout*)

Fruit source	Neutral tint	Acid tint	Alkaline tint
Apples	Grayish-purple	Red	Green
Blackberries	Purple	Red	Bluish-green
Blueberries	Purple	Red	Blue
Cherries	Reddish-purple	Red	Bluish-green
Cranberries	Faint purple	Red	Light green
Grapes	Purple	Red	Bluish-green
Plums	Faint purple	Red	Light green
Pomegranates	Purple	Red	Bluish-green
Strawberries	Reddish-purple	Red	Light green

juice should be added to red or blue fruit juices only when a brownish or magenta shade is desired, for often this combination is not attractive. From the colors produced, or unless very small proportions of one color are used, the red and yellow, blue and yellow, or green and yellow combinations should be avoided.

The color change obtained by the addition of canned pineapple juice to grape, wild grape, blackberry, raspberry, or loganberry juices cannot be explained on the basis of acidity alone. Even if these juices have had a large quantity of lemon juice added they usually turn blue or the original

blue shade is intensified and particularly after the juices have been mixed and left standing a short time. Tin salts from the canned pineapple may be one cause for the color change. In addition, proteins, tannins, and ferric salts may play a rôle in causing color changes. Also many of the salts of the anthocyanins have characteristic colors which are independent of mild changes in acidity. Many organic substances also have characteristic color changes.

*Violet colorations in canned fruits.* Culpepper and Caldwell have reported the cause of violet coloration of some fruits canned in tin containers. The red anthocyan pigments have the property of combining with tin, forming salts that are violet colored. The salts are formed when the material containing the pigment is heated with tin. They find that "the amount of the violet compound formed is determined by the amount of pigment present, and by the degree of acidity of the medium, low acidity favoring its formation, high acidity depressing or suppressing it." The addition of an alkali intensifies the violet color; the addition of acid restores the original red color. The violet color is deepened by standing in the air after opening the can.

*Color changes of red vegetables.* Clark gives in his list of indicators that red cabbage extract is red at  $pH$  2.4 and green at  $pH$  4.5. However, the results in this laboratory have not agreed with those of Clark. In general there is lack of agreement in reports of  $pH$  at which the pigment of red cabbage turns blue. There are probably two reasons for this. The anthocyanins combine with metals to form salts, the particular metal influencing the color reactions. Also the color developed at a given  $pH$  may depend upon the time of exposure at that  $pH$ . The cabbage itself, when cooked in water or juice pressed from the cabbage, shows changes at varying reactions, which have varied slightly at different times. This is probably due to other constituents and their concentration in addition to the red cabbage coloring. Temperature and time of standing before the determinations were made also affect the  $pH$ .

Usually at a  $pH$  of 2.4 to about 4.0 the color is red, showing gradual changes through blue-red, purple or violet, red-blue, and finally blue. These changes occur over a rather wide range of  $pH$ , the blue developing at  $pH$  6 or above. The green color develops with greater alkalinity at about  $pH$  7 to 9. With still higher concentrations of alkali a yellow or brown color develops.

If red cabbage is served raw with a salad dressing containing acid it is bright red or blue-red in color. If cooked in distilled water, it is violet or violet-blue in color, but often becomes blue after standing a few minutes. With a slightly alkaline water the color is blue, for the plant acids lower the  $pH$  of the water. If the water is distinctly alkaline the color becomes green if cooked about 15 minutes or longer. The addition of a little soda to distilled water, Experiment 17B, 5, gives a green color unless the cooking period is exceptionally short. The red vegetables tend to retain

their color better when cooked in milk than when cooked in water. Red onions show the same color changes as red cabbage, but the colors are often muddy. Red cabbage shows color changes in handling it. When the cut edges of the cabbage come in contact with the hands or knife they turn blue. Hands and knives washed in hard water or with soap may have salts with an alkaline reaction on their surface, but the anthocyanins can also form compounds with metallic ions.

Beets do not develop the blue or green color, although the color often contains a considerable amount of blue or purple. Sometimes they turn from red to yellow when cooked. If the cooked beets are placed in acid, the red color is often restored after a short time. Blair states that beets contain two pigments, one being scarlet the other purple. The scarlet pigment is stable to heat, but the purple one fades. The scarlet pigment is stable even in the alkaline range as far as  $pH$  9 or, according to Pratt and Swartout, even at  $pH$  13.0. The color of canned or cooked beets depends upon the proportion of the two pigments present in the beets. This is probably an explanation of why cooked beets vary so much in color, even when cooked under the same conditions of acidity, temperature, and time. Beets have been produced in which the scarlet pigment has been increased and which do not lose color when canned at high temperatures.

*Metals and anthocyan pigments.* The tin salts of the anthocyanins have been mentioned, but the iron salts are even better known. In general, the iron salts of anthocyanins are blue. It is known that juice from blue hydrangeas contains a higher percentage of iron than that from pink hydrangeas even at the same  $pH$ . Some anthocyanins may not combine with iron or other modifications may occur which prevent or are necessary for the development of the blue color, for if some anthocyanins are treated with iron salts the color fades or remains red. Other metals which may combine with the anthocyanins are aluminum, zinc, and lead. Aluminum produces about the same colors as iron, although less intense. It seems reasonable to expect that, if certain salts are present in the vegetable in high concentration or are furnished by the cooking water or the cooking utensil, they will modify colors obtained at a given  $pH$  in cooking. Also, the blue color that develops on the cut surface of red cabbage in a short time after cutting with a metal knife may possibly be due to formation of anthocyanin salts with the metal.

Lathrop states that both iron and tin are "injurious to fruit pigments. The compounds of the pigments with the metals become quickly oxidized on exposure to air, with a marked increase in intensity of discoloration. Tin turns grapes, cherries, raspberries, and blackberries a deep purple and strawberries a pale red. Iron produces dull brownish discolorations. Copper and aluminum are far less injurious and are therefore used wherever fruit must come in contact with metal. Copper being somewhat injurious to the color of grape, aluminum is usually used with grape."

The application of this knowledge comes in cooking fruits, preserves,

and jellies. Since tin cooking utensils are seldom used in household cooking, this metal would be injurious to color of fruits when used in taking seeds from berries with tin colanders, or when such fruits are canned in unlacquered tin. Iron might affect the color of fruits, if such fruits are cooked in utensils from which the enamel has been chipped.

### Tannins

The term tannin is sometimes used to denote a whole group of substances having certain characteristics in common. Sometimes it is used to denote a particular substance, i.e., gallotanic or digallic acid. The former is the meaning used in the following paragraphs.

The tannins are widely distributed in the higher plants. Some plants are very rich in them; others contain very little. The amount in the plant will vary with different years and growing conditions. The tannins are found throughout the plant, but the woody part, the stems, and rootstocks are likely to contain larger amounts. They are found in many fruits, especially during the immature or green stages, and in the seeds of several plants. Lathrop states that stemming of grapes prior to heating for juice extraction is advisable to get rid of astringent tannin of the stems which would be detrimental to flavor.

To some extent the tannin content of fruit is not only dependent upon environmental influences, but upon inherited characteristics. The New York Experiment Station has reported a variety of peach called Sunbeam, which does not turn brown when pared. Kertesz reports its tannin content as very low, 0.0076 per cent.

**Reactions of the tannins.** Thatcher states that chemically the "Tannins are either free phenol-acids, or, more commonly, glucosides of these acids." The structure of the tannins is very similar to that of the anthocyan pigments. They are divided into two general classes, known as the pyrogallol tannins and the catechol tannins. Thatcher has reported the following characteristic reactions.

	PYROGALLOL VARIETY	CATECHOL VARIETY
Ferric salts.....	Dark blue	Greenish black
Bromine water.....	No precipitate	Yellow or brown precipitate
Leather.....	Produces bloom	No bloom
Concentrated sulfuric acid.....	Yellow or brown	Red or Pink
Lime water.....	Gray or blue precipitate	Pink or brown precipitate

Haas and Hill summarize the properties of the tannins under eight headings. Only five will be given here.

1. Tannins are mostly uncrystallizable colloidal substances with astringent properties.

2. They give blackish-blue or blackish-green colors with ferric salts, a fact made use of in the manufacture of ink.
3. In alkaline solution the tannins and many of their derivatives readily absorb oxygen becoming dark in color.
4. They precipitate gelatin from solution and form insoluble compounds with gelatin-yielding tissues, a property which enables them to convert hide into leather.
5. They are precipitated from solution by many metallic salts such as copper or lead acetates, or stannous chloride.

**Astringent qualities due to tannins.** The astringent properties give a slightly bitter taste to some foods, the degree depending on the amount of tannins present. Thatcher states that "Tannins are of frequent occurrence in green fruits imparting to them their characteristic taste. They nearly always disappear as the fruit ripens." Two explanations are suggested for the disappearance of the tannins in ripening fruit. The anthocyan pigments may be derived from the tannins, so that as the fruit colors the tannins disappear; or the tannins may be changed into an insoluble form and therefore are not so apparent to the taste.

Persimmons contain a very large amount of tannin. Green persimmons have a bitter, astringent, puckery taste, that is not easily forgotten, once they have been tasted. Gore's work has shown that most of the tannin of persimmons is enclosed in cells, which he terms giant tannin cells. By artificial processing in carbon dioxide, or by ripening, the membrane containing the tannins becomes hard and insoluble so that the astringent taste is not evident.

**Blue or purple discoloration in English walnuts.** English walnuts are more astringent than other nuts and often develop color changes that are unattractive when combined with other foods. When they are combined with apples in a salad they often develop a blackish blue or purple color. This may come from having prepared the apples with an iron knife, the acid and enzyme of the fruit acting on the iron to produce ferric salts. When this small amount of ferric salt comes in contact with the tannin of the nut and particularly with the skin the purplish color develops. In nut bread, English walnuts often produce a dark color.

**Tannins may produce a gray shade in sugar.** Zerban has found that the color of dark greenish cane juice, which produces a sugar with a gray shade, may be due to tannins, oxidizing enzymes, and iron. When the cane is crushed the acid of the juice forms some ferrous salts with the iron of the roller. Oxidizing enzymes of the juice oxidize the ferrous salts to ferric ones and they combine with the tannins of the juice. A similar change occurs when fruits are pared with iron knives and especially when the juice is left to stand on the knife and it darkens.

**Tannins and discolorations in canned goods.** Kohman has reported that the discoloration, a darkening in color, often found in spots in canned



sweet potatoes is due to tannins. The tannin combines with the iron of the can to produce the dark color. Oxygen is necessary to oxidize the ferrous iron to ferric, so that, unless oxygen is found in the can, either through not exhausting all of the air in processing or to a leak in the can, the discoloration does not occur.

Salsify probably contains large amounts of tannic substances. It turns dark when peeled even if put under water unless a little vinegar is added to the water to acidify it. Salsify or oyster plant and sometimes other vegetables such as carrots stain the fingers when they are pared. This may be due in part to tannins. Lemon juice is effective in removing or lightening such stains because of its acidity.

**Other discolorations with tannins.** Brownish or black discolorations of vegetables in vinegar have been caused by the tannin of the vinegar combining with the iron of the food. The use of a tannin-free vinegar does away with this difficulty. Greenish black spots in chocolate ice cream were traced to the tannin supplied by the chocolate or cocoa and the iron from rusty spots in the can. In green-colored beer the iron came from exposed pipes, the tannin from the hops.

According to Atwater, cherry juice, now commercially marketed, when mixed with gelatin for a molded dessert, sometimes gave a gummy, purplish precipitate. The precipitate was caused from combination of the tannin of the juice with the protein, gelatin; the purplish color came from combination with metals.

Discoloration of pared fruit, considered at greater length in the next section, is caused by tannin compounds in combination with enzyme action.

**Tea.** Black tea is darker than green tea because of oxidation of tannins in the leaf during drying and fermentation. It is also less astringent than green tea because the tannins are in a less soluble form.

Tannins also give precipitates of calcium, magnesium, and iron tannates, when these minerals are present in the water. The film on coffee or tea is from these tannates. When lemon or orange is added to tea, the film usually disappears, for in acid the tannins often lose the darker color acquired in an alkaline medium.

Tannins lower the surface tension of water, and the water in which vegetables containing tannins are cooked is apt to froth or foam.

## Enzymes

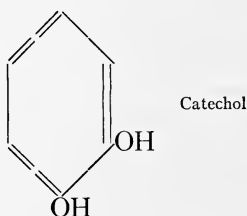
Enzymes control many of the complex chemical processes of plant metabolism. They accelerate reactions which would otherwise take place very slowly, and though they may initiate the reaction, do not form part of its final product. Reactions of several enzymes have been mentioned. A large number of the enzymes are hydrolytic, including the proteinases, lipases, amylases, and others; but there are also oxidizing and reducing and other groups of enzymes. Some of the plant enzymes that digest proteins are

of slight interest in cookery. An enzyme of the pitcher-plant hydrolyzes fibrin. Bromelin of pineapple acts on native proteins, its effect being more often noticed in cookery when uncooked pineapple is added to gelatin, which is liquefied. Papain of the papaw leaf acts on native proteins. Some experiments were tried at the Office of Home Economics to utilize the papaw leaf, the dried powdered leaf, or the extracted enzyme to render tough meat tender. These did not indicate that papain could be successfully used in this way, as the enzyme acted on the surface, powdering or pulverizing it in only a thin layer even after being in contact with the meat for several hours, the interior of the meat not being affected.

**Oxidizing enzymes.** The oxidizing enzymes are concerned with the processes of oxidation and reduction in the plant cells. They are the cause of some of the brown color changes in fruits and vegetables when they are bruised or pared. The principal enzymes that produce the color changes are the peroxidases; the oxidases (classed as laccases or phenolases by some authors), and tyrosinase. The internal browning of fruits when injured involves oxidation as a primary step. But the oxidation requires peroxide oxygen.

Peroxidases will decompose hydrogen peroxide giving "active" (atomic) oxygen. They are practically always present in the cells of the higher plants.

Onslow states that fruits and vegetables containing only peroxidases do not brown when injured. She reports the following of the oxidases. The oxidases are present in about 63 per cent of the higher plants. A plant oxidase is made up of three components: (1) An enzyme, termed oxygenase, (2) an aromatic substance containing an ortho-dihydroxy grouping such as that in catechol, and (3) a peroxidase.



There may be several substances with the catechol grouping, i.e., two hydroxyl groups in the ortho position, found in plants. If the substances with the catechol grouping are present in plant tissue, but enzymes are not present, browning of the tissue in injury takes place slowly, but with oxygenase and peroxidase oxidation occurs rapidly and the material turns brown on injury. Onslow has reported that apples, apricots, cherries, grapes, figs, mulberries, pears, plums, peaches, potatoes, and strawberries all contain oxidases. Bananas sometimes contain substances with the catechol grouping, and sometimes they are absent from the flesh but are found in the skin. Oranges, lemons, limes, and raspberries do not contain all three

components of the oxidase system, and the following contain only a peroxidase: blackberries, pineapple, melon, and tomatoes.

Zerban found that the polyphenols in cane juice may be oxidized by enzymes to a brown color, and to a less extent tyrosin may be oxidized by tyrosinase, giving a dark color.

**Discoloration in pared foods.** Pared potatoes, apples and some other foods will turn dark unless cooked or put under water. The cooking destroys the enzymes, and putting under water prevents the oxygen of the air from coming in contact with the food. This darkening may be due to tannic substances which contain a catechol group or oxidases or both. It may also be due to the flavone and anthocyan pigments, as many of them show the black reaction typical of tannins since they have the same chemical linkage.

Fresh peaches, pears, apricots, apples, bananas, etc., that are to be used for a salad and would lose sugar if kept in water may be pared six to eight hours before serving and kept from turning brown by being dipped in lemon or pineapple juice and put away in a covered fruit jar.

Although the writer has used lemon and pineapple juice for years to prevent discoloration of freshly pared fruits, the reason for this, other than increased acidity, which did not entirely explain the results (pineapple juice was less acid and more efficient than lemon juice), was not known until the work of Balls and Hale was published.

Cruess, Mark, and Quinn state that the oxidase of peaches is not all destroyed by blanching at 120° to 160°F., thus causing internal browning with the formation of crescent shaped areas often seen in sliced peaches. To destroy the action of the oxidase of large peach halves requires heating for 10 minutes at 180° to 200°F. These investigators state that fruit acids such as citric and tartaric are not so effective as hydrochloric acid in retarding browning. Oxidation was completely held in check by 0.25 per cent of hydrochloric acid, so that this concentration on the surface of the peach would prevent browning. Salt and other chlorides will check browning temporarily; but, after standing in a 2-per cent salt brine, the fruit must be rinsed to remove the flavor of salt.

**Prevention of browning by reducing substances.** Joslyn and Marsh state that the primary oxidation step may be prevented by removal of oxygen or the addition of reducing substances. And without oxidation browning does not occur. Sulfites and stannous salts are good reducing substances. Sulfur dioxide has been used for many years to prevent discoloration. They state that orange juice does not brown at high or low temperatures when stored in tin cans. The reason given is absence of oxygen and the reducing action of stannous salts. The addition of ferrous salts in concentrations of 25 parts per million to the orange juice increased browning. Ferrous salts were more effective than ferric salts. Nickel, copper, or stannic salts were without effect, but stannous salts and sulfites protected against browning. However, after these salts were oxidized,

then browning of the juice could occur. The addition of aniline or tryptophane caused immediate browning.

Balls and Hale found that sulfhydryl compounds, some of which occur in common foods, prevent browning of apples. Gluthathione and cystein prevent darkening of the apples even when applied in very dilute concentration. Pineapple juice contains a sulfhydryl compound which is the cause for its inhibition of development of brown color.

**Oxidation and color loss.** A type of oxidation that causes fading of red fruits in canning is explained by Kohman and Sandborn. All fruits and vegetables use oxygen in respiration, and some oxygen is found within the fruit or vegetable. The color of strawberries is deadened if they are heated very rapidly after refrigeration, during which the respiratory processes have been inhibited. However, if they are heated slowly so that the interior oxygen is used in respiration the color remains bright.

### Sulfur Compounds of Plants

Sulfur compounds are present in the plant in three forms: in the amino acids of proteins, i.e., cystine, methionine, and others; volatile compounds; and sulfates.

It is known that a portion of the protein sulfur is readily split off at boiling or higher temperatures. Peterson found volatile sulfur in clover, beet tops, blue grass, and milk. This was unexpected, and he suggests that it may come from two sources, volatile sulfur compounds in the materials used, or from the splitting off of sulfur from the protein and the formation of hydrogen sulfide. He thinks the latter the more probable explanation. He found a larger percentage of volatile sulfur compounds in plants grown in a sulfur-rich soil than in those grown in a sulfur-poor soil.

**Volatile sulfur compounds.** The volatile sulfur compounds are found in the plants as glucosides. When treated with acid or alkali and when acted upon by enzymes, these glucosides yield a sugar or some closely allied carbohydrate and one or more other substances, frequently phenols, allyl sulfide, or allyl isothiocyanate. Most of the investigations of sulfur-splitting enzymes have been made upon myrosin. The strong flavor of old or stored turnips, rutabagas, and cabbage is probably largely due to setting free of sulfur compounds by enzymes. When they are cooked, plant acids are liberated which cause hydrolysis of the volatile sulfur compounds. In addition, hydrogen sulfide is formed by decomposition of the sulfur compounds by heat.

The odor of many of these compounds is familiar, those of onions and garlic, cooking cabbage, etc., being typical examples.

Allyl isothiocyanate is found in mustard seed. It is prepared commercially by macerating the seed, the enzyme then splitting off the sulfur of the glucoside. The oil is then obtained by distillation with steam. Allyl

sulfide is found in the onion family, and is prepared commercially from garlic. The strong flavor of onions, leeks, and garlic depends upon the concentration of allyl sulfide.

These volatile compounds escape from the food more rapidly with rise in temperature and breakdown of the plant cells. Hence, the longer onions, leeks, and garlic are cooked the milder their flavor becomes. Also because finely minced onion has a greater surface area for volatilization to occur than when cut in large pieces, these substances volatilize more rapidly from finely cut pieces. This is why it is preferable to add onion juice, very finely minced onion, or cooked onion to some foods that are not cooked long or that do not reach a high temperature, such as hamburger or stuffing for fowl or meat. Large pieces of raw onion in a stuffing produce a very strong onion flavor, more concentrated in some areas than others, instead of a subtle, well-blended flavor, for the stuffing never reaches boiling temperature.

The amount of onion and/or garlic added, the fineness of division of the pieces, and the length of cooking all affect the flavor of the finished product to which they are added. The flavor of a food like catsup or chili sauce may be ruined by adding a large quantity of onion or garlic in large pieces near the end of the cooking process. The same amount of onion or garlic added in small pieces, or added in large pieces early in the cooking process, could blend with, instead of dominate, the flavor of the other ingredients.

**Sulfur compounds and the cooking of vegetables.** It is commonly known that long cooking of some vegetables such as cabbage, turnips, cauliflower, and Brussels sprouts develops strong, disagreeable flavors, and the eating of these vegetables may cause discomfort and digestive disturbances. The longer cooking and stronger flavor are accompanied by increased acidity of the vegetable. The length of time of cooking for the strong flavor to develop varies with the vegetable, whether the cooking is started in cold or boiling water, and the proportion of vegetable to water.

Simpson and Halliday have determined the total volatile sulfur and hydrogen sulfide evolved when cabbage and cauliflower are cooked for different lengths of time. They found that the most acceptable product is obtained when winter cabbage is boiled 7 to 8 minutes, and spring cabbage 5 minutes. Cauliflower required 8 minutes to become tender. They conclude that with prolonged cooking the decomposition products of sulfur compounds increase, and that these products produce the strong taste and odor associated with cabbage and cauliflower.

Simpson and Halliday report that the amount of hydrogen sulfide increases from the fifth to the twentieth minute of boiling cabbage, and the total volatile sulfur between the seventh and thirtieth minutes. Cauliflower gives off more volatile substances in the same period than cabbage. Masters and Garbutt have found that the amount of sulfide increases up to a cer-

tain point and then decreases, becoming fairly constant. Kohman states that in corn the amount of hydrogen sulfide evolved is greater during the first half hour and decreases with each succeeding half hour.

Shilling in determining the amount of hydrogen sulfide formed in cooking cabbage finds that it varies from 1 to 7 milligrams per 300 grams of fresh cabbage. The wide variation depends upon the amount of green compared with the white, the speed of cooking, the length of time of cooking, and the temperature involved in the method, i.e., boiling in water and the pressure cooker.

Bigelow has reported that the black spotting on the corn around the edges of the can in canned corn is due to the formation of hydrogen sulfide in processing. The amount of sulfide is very small and there is no objection to it except from appearance. Stevenson states that iron sulfide is formed to a greater extent in canned peas than in canned corn. It is not so noticeable in peas on account of their color. In peas it is deposited as scales that break up easily in shipping and handling.

### Flavor

The flavors of fruits and vegetables are due to several constituents, sugar, organic acids, mineral salts, and aromatic compounds.

Sugar is found in fruits and vegetables. Beets, carrots, onions, peas, and other vegetables contain appreciable amounts. In vegetables like peas and corn the sugar is deposited as the insoluble carbohydrate, starch, in the mature seed. Immature peas and corn deteriorate rapidly in sugar content after they are gathered. Kertesz reports that starch increases and sugar decreases in stored fresh peas, but the sugar loss is not due to the transformation of sugar to starch. It is suggested that the apparent increase of starch content is because of loss of other constituents; and, whereas the loss of the sugar is not satisfactorily clarified, it may be consumed in respiration. Losses in sugar content can be prevented by inactivation of the respiratory enzymes by blanching, cooking, or storing near freezing temperatures.

The vegetables with a fairly high sugar content usually have a sweeter flavor if steamed or if just enough water is used to cook them and it is evaporated to dryness at the end of the cooking period. Even mild-flavored onions may be sweeter and better flavored if the water is evaporated than when an excess is left. But there seem to be some exceptions to most rules, and the choice of method of cooking is often a matter of judgment or circumstance. More could be written about flavor, but it has been mentioned so often in connection with different constituents of fruits and vegetables that a great deal would be repetition.

A combination of sugar, acids, and aromatic substances gives flavors that render fruits and vegetables palatable and attractive food products.

**Aromatic compounds.** This classification is not given as a plant chemistry one, but as a group to include all substances that may give characteristic odor and thus flavor to foods.

Many of the aromatic compounds are esters, like amyl acetate, which gives a characteristic odor to pears and is called "pear oil." The odor of pineapple is due to methylbutyrate, which is designated "pineapple-oil." Isoamyl isovalerate produces the characteristic odor of apples.

Thatcher includes all the substances that give characteristic odor to plants under the term "essential oils and resins." Some of these substances are terpenes, alcohols derived from terpenes, the phenols, and sulfuretted oils. Oils of lemon, peppermint, cinnamon, clove, lavender, and others are classified as essential oils.

Allyl isosulfocyanide, oil of mustard, and allyl sulfide, oil of garlic, constitute the best known of the oils containing sulfur.

Tannins impart an astringent, bitter flavor to some foods.

### Cellulose

Cellulose forms the structural, fiber, or woody part of the plant. Other substances such as pectic substances may occur in combination with cellulose. In the young plants or the new growth of older plants the cell walls are at first yielding. As they mature, they grow more resistant and may change physically and chemically, their function becoming more specialized with the occurring changes. In tree trunks some cell walls become woody or lignified. Dorée and Barton-Wright state that the stone cells distributed throughout the flesh and particularly near the core of pears are lignified cellulose.

Cellulose is a carbohydrate. It is found in plants in several forms. There is no unanimity of opinion regarding its definition, although the cotton fiber is always taken as a standard cellulose product.

Hemicellulose, wood cellulose, and gelatinized cellulose are names given to different forms of cellulose. Probably each group includes several products. Schorger defines hemicellulose as "A polysaccharide soluble in dilute alkalies and convertible into simple sugars by heating with dilute acids at atmospheric pressure." He adds that a hemicellulose in the natural state should be insoluble in boiling water.

**Effects of alkalies, acids, and calcium on the structural or woody part of fruits and vegetables.** Ammonia and sodium bicarbonate added to the water in which vegetables are boiled, or ammonia or ammonium carbonate added to water in which vegetables are steamed, causes them to soften in a shorter time than if these substances had not been added. With longer cooking the vegetable becomes mushy and disintegrates. The disintegration begins with the surface layer of the food, and its depth depends on the length of time of cooking and the size of the piece of food.

If vinegar is added to the water in which vegetables are cooked the effect is opposite from that of sodium bicarbonate: a firmer and more solid texture is obtained and the vegetable requires longer to cook. In cooking vegetables like cabbage and spinach the amount of calcium and magnesium salts found in the water seems to have little effect upon the texture or the length of time for cooking.

The pulp and white part of the rind of watermelon as well as the pulp of muskmelon or cantaloupe, and perhaps other foods, can be made very firm and brittle or woody if soaked in saturated calcium hydroxide (lime) water. The longer they are soaked the harder and firmer they become if the water is kept saturated with lime. Five to six hours' soaking is usually sufficient to produce enough firmness to prevent shriveling when cooked in sirups for preserves or pickle. The melon pulp may be cooked in water until transparent and tender, then put in lime water to harden, and finally cooked in a sirup. Or cooking first in only water does not prevent hardening of the pulp by calcium. The few times that cucumbers have been soaked in lime water either slight or no hardening occurred. But other calcium compounds such as calcium chloride do produce hardening in pickles.

**Pickles.** Cucumber pickles are seldom made in class work; but why brined pickles spoil is a perennial question. Rahn has offered a solution of the difficulty. An abstract of his work follows.

The inside of the cucumber is free of bacteria, but the brine into which the cucumbers are placed contains several thousand bacteria per cubic centimeter. There are many different kinds of bacteria present in the beginning but with the strength of brine maintained most of them die. However, a few kinds that thrive in the brine survive. Fresh brine contains no food for bacteria. But with placing of the pickles in brine, or the formation of brine by adding dry salt to cucumbers, small amounts of sugar and other bacterial food are dissolved from the cucumbers as they shrink. Hence bacteria that can tolerate salt grow and decompose the sugar. The resulting decomposition products of the sugar are acid and gas. The gas produces froth. The acid, probably mostly lactic, is very important, for the keeping of the pickles depends upon it. The concentration of the acid is rather high when frothing ceases, varying from 0.6 to 1.2 per cent. The acid is a fairly good disinfectant and practically all bacteria in the brine are killed.

In addition to bacteria, yeasts are present in the brine; but because they need oxygen they grow principally on the surface. The scum yeast feed on the acid of the brine and decompose it, thus decreasing the quantity of acid in the tank or container. If scum grows long enough, all the acid is destroyed and then the pickles become slippery, soft, and mushy. It is better not to stir the pickles too much after they are in the brine, for the acid tends to stay at the bottom of the container and the yeasts grow at the surface.



There are two periods when the acid is low, and these stages are the periods of greatest danger in fermenting pickles. The first stage is before fermentation has started and no or little acid has been formed; the second is after the acid has been used up by scum yeast, for spoilage only occurs when the acidity of the brine is sufficiently low. The slipperiness and softness are caused by so-called potato bacteria, which resist the salt well but do not tolerate acid. Because oxygen is necessary for their growth and the bacteria only grow at the surface, the pickles protruding from the brine become soft. These potato bacteria can cause great loss and damage before a concentration of acid great enough to delay their growth is formed. A single potato bacterium, if all conditions are favorable, produces from 10 to 100 million new bacteria in 24 hours.

Hence, to prevent spoilage all pickles should be kept under the brine. Some acid or vinegar can be added with the brine to prevent spoilage. It has been interesting to see that this has been advocated for commercial practise since Rahn's work was published. Other methods of preventing growth of the yeast are to keep the container in the sunlight or irradiate with ultra-violet light, both of which are not practical in the home. After fermentation is complete, that is, after frothing has ceased, oil or paraffin may be used over the surface of the brine. Since the oil is rather difficult to wash from the pickles, paraffin is preferable.

*Crisping pickles.* Calcium chloride is used to make pickles crisp or firm. It is used either in the last soaking water, when the brine is being removed, or added directly to the sweetened vinegar. The proportion used is one pound per barrel of pickles.

The hardening may come from the calcium combining with the cellulose or it may combine with acid of the pickle or melon or be deposited as calcium salts in the food. Some factors other than the ones mentioned may cause the hardening.

**The effect of sugar on the firmness of fruit.** The effect of sugar of course varies somewhat with the amount used in proportion to the quantity of fruit. Osmosis occurs when a sirup has greater sugar concentration than that of the fruit to which it is added. The vapor pressure of the sirup solution is lower than that of the fruit so that water passes from the fruit to the sirup. This transfer from a region of high concentration to a low one is called osmosis. If a membrane separates the regions of high and low concentrations it is dependent upon the membrane whether all the dissolved constituents of a solution can pass through the membrane. With a semi-permeable membrane only the water can pass through the membrane. Without discussing the possible rôle of the membrane in osmosis or the osmotic pressure that may be produced, it is sufficient for the purpose here to state that as the permeability of the membrane increases larger and larger ions or molecules dissolved in the water may pass through the membrane. The skin and cell walls of the fruit serve as membranes. These

membranes in the different fruits seem to have a greater or a lesser permeability to sugar.

When cooked in a sirup some fruits tend to keep their shape, some become mushy, some shrivel, and others tend to collapse or flatten out. For instance, sweet apples tend to stay whole whether cooked in sirup or in water, whereas sour apples have a greater tendency to break up during cooking. In general, the fruits tend to stay whole better if cooked in a sirup. For purées the fruit is cooked in water and the sugar added later. Cooking seems in most instances to increase the permeability of the fruit membranes to sugar. Some apples, some plums, and most berries can be cooked directly in the sirup without noticeable toughening of the fruit. Peaches, apricots, most apples, and most plums absorb sugar satisfactorily. Lathrop states that the firm texture of the cherry skin and of the peach and blackberry flesh retards penetration of the sugar during cooking. On the other hand, a fruit like Keifer pears is dehydrated if cooked directly in a sirup and becomes shriveled, tough, hard, and rubbery. It is necessary to soften the fruit by cooking and increase its permeability to sugar before the sugar is added. It is of course possible that many changes other than increasing the permeability of the fruit to sugar occur when the fruit is cooked in sirup. Later work has shown that fruit like Keifer pears and quinces can be cooked by adding the sugar directly to them without preliminary cooking. But it is necessary to start with an excess of thin sirup and cook slowly to evaporate the excess liquid, as the sugar penetrates the fruit. So long a time is required that the method is not practical. The fruit becomes more transparent in appearance. It may be that the sugar has some effect on the cellulose.

In fruits like strawberries and seeded sour cherries, and particularly if they are heated rapidly in a sugar sirup, flattening occurs. If a large number of cell walls are broken the fruit becomes mushy. Time is required for sugar to pass through the cell walls of fruits. If osmosis has not progressed far enough, i.e., if the concentration of the sugar within the berry is not as great as in the sirup surrounding it, the berry floats when canned.

In pickling, shriveling can be prevented by heating the pickling material slightly and increasing the concentration of the sugar gradually, allowing about 24 hours or more to elapse before the next addition of sugar. But fermentation is more likely to occur when preserves are treated this way. It is a good practise to add the sugar directly to fruits like strawberries and cherries and let them stand over night. The fruit loses water, shrinks somewhat, and becomes slightly tougher. When heated slowly, and if necessary removed from the heat for a few minutes before boiling commences, there is time for the sugar to penetrate into the interior of the berry, the fruit is plump and will not float when placed in the container. In the commercially vacuum-processed berries, floating in the can is prevented by adding the berries, to which part of the sugar has previously been added, to a hot sirup, but further heating is not continued until the berries have

stood for a few minutes. By producing a vacuum, the greater pressure within the berry tends to puff it up; by breaking the vacuum, flattening occurs. In this way the process of osmosis is helped.

Strawberries and the sour cherries develop a strong flavor when boiled for a long time. Hence time must be allowed for the sugar to penetrate into the fruit before the boiling point is reached. Boiling should be rapid, and the quantity of fruit used in a batch small. The popularity of sun preserves for certain fruits is due to osmosis being slow and complete. If the fruit is heated the heating period is very short, so that strong flavors are not developed, less sugar is inverted and caramelized, and the aromatic substances are not lost to such an extent as in long cooking.

Since strawberries usually contain about 90 per cent water, it seems a better practise to add the sugar directly to the berries, for not as long a time is required to cook the berries to the concentration desired. When water is added to the sugar to make a sirup it is necessary to evaporate the water used in the sirup as well as a part of that contained in the fruit. Increasing the proportion of sugar to fruit also lessens the time required to reach a definite concentration of the sirup, so that the preserves do not develop as strong a flavor. When  $1\frac{1}{2}$  pounds of sugar are used with a pound of strawberries only a short time of cooking is required for the sirup to reach a temperature of  $103^{\circ}\text{C}$ ., which gives a sirup containing 60 per cent of sugar. See Table 10.

### Potatoes

**What constitutes quality in potatoes?** For baking and boiling it is usually accepted that the best potatoes are those that yield a white, comparatively dry, and mealy texture. The homemaker does not like for boiling a potato that sloughs off badly during cooking, though this often occurs with some of the best baking potatoes. For deep-fat frying, dicing for salad, and other purposes a potato that gives a waxy and firm consistency is considered best.

**Some investigations on potato quality.** It is rather commonly believed that to have mealy potatoes the starch content should be high and that the swelling and bursting of cell walls during cooking produces the white, fairly dry, flaky appearance. Sweetman states that the starch grains do not swell sufficiently to burst but the cooking renders the starch granules readily separable. That ease of cell separation is one of the causes of mealiness is unsubstantiated by other investigators. Whittemore and Juschke decided that potatoes were more mealy when fertilized with a high rather than a low quantity of potash (potassium carbonate).

Cobb states that the parts of the tuber having the greatest concentration of starch are mealiness when cooked. The rank in descending order is cortex, external medulla, and internal medulla. Cobb in a series of investigations covering 5 years found that baking gave more mealy potatoes than boiling.

Baked potatoes often lost 25 per cent of their weight by evaporation, whereas boiled ones lost none.

**Environmental factors.** Cobb concluded that if proper cultural conditions were given any type of soil may grow good potatoes. His studies showed that temperature during growing and variety were the most important factors affecting potato quality. A low-average temperature favored better quality. This suggests that one reason why Maine and Idaho are noted for their potatoes is the low-average temperature during growth of the potatoes. Small, immature, or ill-shaped tubers were observed to have poor quality.

Stevenson and Whitman state that a variety producing good-quality potatoes under certain conditions may produce poor ones under other conditions, but a good-cooking variety tends to maintain better quality over a wider range of conditions than a poor-cooking quality.

**Starch granules.** It is possible that two factors determining whether a potato produces a mealy or waxy consistency when cooked are the size of the starch granule and its phosphorus content. See Starch, Chapter XI. Large granules swell and gelatinize at a lower temperature than small granules. Thus, potatoes giving a dry, mealy texture may have a comparatively larger percentage of large granules. Smaller granules are supposed to have a higher phosphorus content than large ones, and the paste-forming qualities of starch are increased when the starch is combined with phosphorus. If paste-forming qualities mean increased adhesiveness, then waxy potatoes may have either smaller granules or a higher phosphorus content or both.

**Storage temperature.** Wright *et al.* found that the storage temperature affected the quality of the cooked potatoes. They stored Irish Cobbler potatoes harvested August 3 for 8 weeks at the following temperatures: 32°, 36°, 40°, 50°, 60°, and 70°F. In general potatoes stored at 40° were considered fair in quality when cooked; those from storage at 32° and 36° were poor; those from 50° good; those from 60° very good, and those from 70° good. The baked and boiled products from potatoes stored at 40° were slightly sweet and watery; those from 36° storage were inclined to be soggy or watery, with a distinctly yellow color and sweet flavor; those from storage at 50°, 60°, and 70° possessed no undesirable sweet flavor and were of mealy texture and cream in color.

**Potato chips.** The most important factor in making potato chips appears to be the sugar content of the potato. With a high sugar content the chips become too brown, with production of a more or less disagreeable astringent flavor, before they are sufficiently cooked. The concentration of sugar increases in potatoes stored at a low temperature. At ordinary temperatures the sugar is used up in respiration; at lower temperatures metabolism is retarded but sugar production by enzymes proceeds, so that sugar accumulates.

Peacock and Brunstetter have reported a very simple test for predetermining the cooking value of potatoes because of accumulated sugars. One cubic centimeter of a saturated aqueous solution of picric acid and 1 cubic centimeter of a 20-per cent sodium carbonate solution are placed in a test tube. To this is added a piece of potato of definite length cut with a cork borer. The solution is heated carefully to prevent boiling over for 1 minute. If the solution does not become much darker it indicates that the potato has little sugar and is suitable for both chips and "French fries." With increasing sugar content the solution becomes darker and darker when time of heating and size of piece of potato are kept standardized. The darkest shade given by Peacock and Brunstetter is a dark garnet-brown; but Swalley tested some potatoes that gave shades two degrees darker in color than dark garnet-brown, the darkest being nearly black. Potato slices fried for a definite time in fat at a definite temperature become browner and browner as the sugar content increases and give perfect correlations with the picric acid test. In general Swalley found that the longer the potatoes were stored at 32°F. (storage was from 11-14 to 12-15), the longer the time required for storage at room temperature (those stored at 32° for 31 days required 45 days at room temperature) before good chips were obtained.

Wright *et al.* found that potatoes stored at 32° and 36° were not suitable for French fries, as they browned too quickly and had a burned flavor. To some extent this was also true of potatoes stored at 40°. As the storage temperature increased the time necessary for cooking increased. Potatoes stored at 60° and 70° gave fries of attractive golden-brown color, mealy texture, and good flavor. Similar results were obtained with chips.

**Preparation of chips.** Because it is difficult or impossible to slice the potatoes evenly by hand, they should be cut with a slicer. If salt is added to the soaking water the slices are partially dehydrated during the soaking; thus a shorter time is required for cooking and no addition of salt is necessary after cooking. For  $\frac{1}{4}$  pound of potato and  $\frac{1}{2}$  cup of water about 8 grams of salt are required.

**Cooking chips.** The cooking time and temperature are dependent to a certain extent on the quantity of potatoes added to a given amount of fat. For  $\frac{1}{4}$  pound of slices about 3 minutes are required when the initial temperature of the fat is 190°C. and the quantity of fat is about 2 to 2½ pounds. Smaller quantities of potatoes cook in a shorter time. The chips are done when bubbling of the fat ceases, which indicates the major portion of the water has evaporated.

### Cooking of Dried Legumes

Different varieties of beans and peas belong to the legume family. The dried legumes commonly used for food are navy, lima, kidney, soy, other

varieties of beans, lentils, and dried peas. The dried legumes contain less moisture than the fresh ones. In cooking, the moisture lost by drying is replaced and water is absorbed. The legume is softened. This requires a longer period than for fresh legumes, so that the methods of cooking that shorten the cooking process are more important than for fresh vegetables.

**Effect of mineral content of the water upon cooking of dried legumes.** Huenink and Bartow in trying to determine why the quality of canned products from some factories was always superior to those of others found that the mineral content of the water affected the softening of dried beans in cooking. Using a sirup and distilled water in canning beans, they found the product very tender and one that would grade strictly fancy on the market. When to the sirup, distilled water, and beans, calcium chloride was added, using lots with 100, 200, 300, 400, 500, 600, and 1000 parts per million parts of water, the hardness of the processed beans increased with increasing calcium chloride, the ones with 1000 being nearly as hard as uncooked beans. The series with 100 to 200 parts of calcium chloride were hard and tough and would grade standard on the market and be called underprocessed. Continuing their work they tried the following salts:

Calcium chloride	$\text{CaCl}_2$
Calcium sulfate	$\text{CaSO}_4$
Calcium bicarbonate	$\text{Ca}(\text{HCO}_3)_2$
Magnesium sulfate	$\text{MgSO}_4$
Magnesium bicarbonate	$\text{Mg}(\text{HCO}_3)_2$
Sodium carbonate	$\text{Na}_2\text{CO}_3$
Sodium bicarbonate	$\text{NaHCO}_3$

They found that the calcium and magnesium salts hardened the beans whether as chlorides, sulfates, or carbonates. The calcium and magnesium bicarbonates had a hardening effect but the results were not as consistent as with the other salts.

Both the sodium carbonate and sodium bicarbonate gave a softening effect, and with larger quantities the beans appeared over-cooked.

The National Canners Association has reported that calcium and magnesium salts harden beans and peas during cooking, having a greater effect upon the beans than on the peas. String beans and corn do not seem to be affected, nor are beets affected up to 350 parts of magnesium or calcium per million parts of water, but the salts of hard water combine with the soluble oxalates of the beet to give a white coat on the surface of the beet.

Van der Marel, investigating the effect of various salts, bases, and acids upon the softening during cooking of dried peas, has reported the following results. Using a "good cooking" variety of peas, and cooking for  $1\frac{1}{2}$  hours he determined the percentage remaining hard at the end of the cooking period.

TABLE 18  
COOKING DRIED PEAS (*Van der Marel*)

Type of water and substance added	Percentage of peas remaining hard after cooking 1½ hours.
Distilled water.....	5
Amsterdam city water.....	14
Formic acid 0.01 <i>M</i> .....	68
Calcium chloride 0.01 <i>M</i> .....	100
Sodium carbonate 0.01 <i>M</i> .....	2

With another variety of pea more difficult to cook he obtained the following results after soaking 24 hours and boiling 2 hours.

TABLE 19  
COOKING DRIED PEAS (*Van der Marel*)

Type of water and substance added	Percentage of peas remaining hard after soaking 24 hours and boiling 2 hours.
Distilled water.....	43
Amsterdam city water.....	67
Sodium carbonate 0.01 <i>M</i> .....	4
Ammonium hydroxide 0.01 <i>M</i> .....	0

Van der Marel decided that the softening effect was due to action on the pectic substances of the peas and that anything that made the pectic substances more soluble had a softening effect in cooking.

The results of Huenink and Bartow and of Van der Marel show why some waters are not desirable for cooking dry legumes. With increasing hardness of the water the hardening effect on the vegetable is more noticeable. Some housewives have found this out from experience. The writer remembers her grandmother's insisting that dried beans should be cooked in cistern water, because they cooked more quickly than in the well water which was permanently hard.

**Hard water.** Hard water contains salts of calcium, magnesium, and sometimes iron. Hardness of water is designated as temporary or permanent. Water containing calcium and magnesium bicarbonates is termed temporary hard water since the heating of the bicarbonates decomposes them and carbonates are formed which are deposited as crusts on the inner part of the tea kettle or cooking utensil. Such waters are rendered less

hard by boiling. Permanent hard water contains the sulfates of magnesium and calcium. Some water is both temporarily and permanently hard.

Softened water, which is used a great deal at the present time, has the calcium and magnesium replaced by sodium. The author has noticed that, since softened water is used in the Home Economics building at Iowa State College, fresh green peas never become hard as they sometimes did with the old permanently hard water and that the difference between the time required for cooking dry beans not soaked and those that are soaked is very much shorter.

**The pectic substances of bean coats.** Snyder noticed that if the seed coat of pea or Great Northern beans was injured or scarified, the beans swelled in soaking and cooked in a shorter time. Next she noticed that entrance of water into the beans is not uniform over the entire surface of the bean but most of the water entered through the micropyle and germinal area. Substances that dissolved the pectic substances shortened the soaking and cooking time. Beans with very hard skins neither soaked nor cooked satisfactorily and contained a higher percentage of pectic substances than skins of beans that soaked and cooked easily. The major portion of the calcium of beans was found in the seed coat.

Snyder's results with calcium and magnesium salts, with acids, and with soda substantiate those of earlier investigators, with the exception that oxalic acid, which cannot be used in preparation of edible products, did not depress absorption of water. Oxalic acid would render the calcium salts insoluble.

Snyder found that  $\frac{1}{8}$  teaspoon of soda per pint of water was sufficient for soaking to shorten the cooking time, except with one very hard water. If the beans were soaked in water at 120°F. the maximum amount of water was absorbed in 6 hours. Molasses and tomato juice had an effect similar to that of acids but could be added without injurious effect after the beans were cooked. Beans that cooked rapidly on top of a burner also baked satisfactorily.

**Masters's results with legumes.** Masters, using London tap water (temporary hardness 12 parts per 100,000 parts of water and permanent hardness 5 parts per 100,000 parts of water) and cooking butter beans, found that soaking made little difference in time required for cooking, but that soaking with sodium bicarbonate in the soaking water did shorten the cooking time. Distilled water gave a shorter cooking time than tap water. Masters also determined the soaking and cooking losses of total solids. It is interesting to note that soaking with soda in the water gave not only a shorter cooking period, but also a slightly decreased loss of total solids. However, there was only a very slight difference. This was with the percentage of soda that she considered to give the best cooking results, 1 per cent (equivalent to about  $\frac{5}{8}$  teaspoon of soda per cup of water). With larger amounts of soda than 1 per cent, greater losses due to disintegration of the beans occurred. With a small amount, 0.25 per



cent, the cooking time was shortened but the total loss of solids was slightly higher than for the other methods of cooking. Losses were also high when large amounts of soda were used in the soaking instead of the cooking water. When other types of beans were substituted for the butter beans, the results were similar, although the cooking time might be longer or shorter according to the nature of the beans, and the cooking losses higher or lower, varying with the thickness of the skins of the beans. The loss of solids during cooking of the butter beans was about 10.5 to 11 per cent if beans were not soaked. If beans were soaked before cooking the total loss was about 12.5 per cent.

One of the methods recommended by Masters for cooking beans is to add soda to the soaking water and salt to the cooking water. She found that discarding the soaking water gave no greater cooking losses than when it was retained and the beans cooked in the water in which they were soaked.

**Class results with navy beans.** The experimental class results for several years at Iowa State College show that, although some navy beans cook in a very short time, the majority require about the same time, which is close to the average given in the following tables. Some require longer cooking. To show this the minimum and maximum time as well as the average are given in the tables. The beans were washed and added to 1 pint of boiling water. If the water evaporated to dryness, boiling water was added. The soaked beans stood over night, usually 15 to 24 hours. All the figures are for 15 or more tests. The water is quite hard, averaging about 340 parts of carbonate per million parts of water. The mineral content as carbonate is as follows:

CaCO <sub>3</sub>	240 parts per million parts of water.
MgCO <sub>3</sub>	100 parts per million parts of water.

For an end point in cooking the beans were cooked so that they would be as whole as possible yet soft all the way through. A common household way of testing when beans are done is to stick them with the point of a sharp knife or fork. This was the test used, but the experiments being done by students through different quarters give differences of opinion as to when the beans were done. For example, the minimum time for beans cooked with soda in tap water is shorter than the minimum time for beans soaked with soda in distilled water, but the averages are reversed.

Soda may be added to the cooking water and not discarded. This was tried in class, but the beans became mushy on the outside and disintegrated while the center was still hard.

In all varieties of beans, cooking with the vessel covered gives a shorter cooking period than cooking uncovered. This may be due to the cooling effect by evaporation of the water at the surface and possibly will not occur with a large quantity of beans and water.

TABLE 20  
CLASS RESULTS FOR COOKING NAVY BEANS BY DIFFERENT METHODS

Method of cooking	Weight of un-cooked beans grams	Weight of soaked beans grams	Weight of cooked beans grams	Time of cooking min.
Tap water				
Minimum.....	50	—	92	80
Maximum.....	50	—	134	105
Average.....	—	—	110	89
Distilled water				
Minimum.....	50	—	91	55
Maximum.....	50	—	122	85
Average.....	—	—	111	70
Soaked in tap water				
Minimum.....	50	98	102	32
Maximum.....	50	106	131	85
Average.....	—	100	116	60
Soaked in distilled water				
Minimum.....	50	98	105	30
Maximum.....	50	105	133	64
Average.....	—	101	118	46
Soaked in tap water, $\frac{1}{8}$ teaspoon of soda added to soaking water, but no soda in cooking water				
Minimum.....	50	95	100	21
Maximum.....	50	106	136	50
Average.....	—	99	116	36
Soaked in distilled water, soda $\frac{1}{8}$ teaspoon added to soaking water, no soda in cooking water. Cooked in distilled water				
Minimum.....	50	96	111	25
Maximum.....	50	104	142	40
Average.....	—	99	121	32
Salt $\frac{1}{4}$ teaspoon added to tap water				
Minimum.....	50	—	91	60
Maximum.....	50	—	116	108
Average.....	—	—	100	87
Soda $\frac{1}{8}$ teaspoon added to tap water Boiled 10 minutes. Discarded				
Minimum.....	50	—	95	30
Maximum.....	50	—	145	116
Average.....	—	—	118	56

Soaked beans are lighter in color and less strong in flavor than the non-soaked ones.

**Lima beans.** Although the work with lima beans has been limited in extent in comparison to that done with navy beans the results have been similar to those obtained with the latter.

Soaking to shorten the cooking period must continue until the beans have absorbed enough water to weigh nearly double their dry weight. When boiling water was poured over the lima beans and left to stand, swelling occurred more rapidly than when cold water was used. The time required for soaking with cold water is 7 to 8 hours or longer, but with the boiling water 4 to 5 hours is usually sufficient.

**Pinto beans.** Greenwood found that the degree of hardness of the water is the most important factor to consider in cooking beans. Satisfactory results were obtained by any method with very soft water, and no method was entirely satisfactory with very hard water. Boiling water 20 to 30 minutes to precipitate the calcium and magnesium salts before using for cooking the beans was beneficial. In using hard water better results were obtained if it was boiled gently and the vessel was well covered to avoid evaporation of water, thus preventing the necessity of adding more water and increasing the total salts added. For the shortest cooking period the beans should be soaked in hot soda water (0.5 per cent solution),  $1\frac{1}{2}$  teaspoons to 5 cups of water.

**Dried soybeans.** The use of soybeans for human consumption is constantly increasing, both the green and dry varieties being used to a greater extent than formerly. Some varieties are nearly impossible to cook but varieties easier to cook are used for edible purposes.

Work with dry soybeans indicates that soaking over night in cold water nearly halves the cooking time. Addition of soda to the soaking water further shortens the cooking time. But pouring boiling water over the beans and letting them soak in this water for 3 or 4 hours results in the shortest cooking time.

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## FRUITS AND VEGETABLES

### Experiment 17.

A. To determine the effect of different methods of cooking on the color of green vegetables.

Use  $\frac{1}{8}$  pound (56 grams) of spinach, lettuce, Brussels sprouts, green beans cut in 1-inch strips, or green asparagus. Use 1 cup of water. Cook 10 to 25 minutes, the time depending upon the vegetable used, but decide upon the length of time the vegetable is to be cooked before experiments are started. Save the water left from each experiment to compare for color and flavor. Notice the texture of the vegetable.

1. Pour boiling water over the vegetable. Cook covered for the length of time agreed upon.

2. Repeat A1, but cook uncovered.

3. Add salt to the cooking water. Use  $\frac{1}{4}$  teaspoon per cup of water. Cook uncovered and start in boiling water.

4. Cook uncovered in boiling distilled water.

5. Cook uncovered in boiling distilled water to which  $\frac{1}{16}$  teaspoon of soda has been added.

6. Cook uncovered in boiling distilled water to which  $\frac{1}{4}$  teaspoon of vinegar has been added.

7. Cook in a steamer.

8. Cook in a pressure cooker, 10 minutes at 15 pounds pressure.

9. Cook in milk.

If desired, some of the cooking water may be tested for iron and phosphates.

In which case is the green color of the vegetable best preserved? Is there any difference in the texture of the vegetables with soda and with vinegar added?

Vegetable used:

Time of cooking	Color of vegetable	Texture	Color and amount of water	Flavor

Results and conclusions.

B. To determine the effect of different methods of cooking on the color of red vegetables.

Use red cabbage if it can be obtained. If it is not obtainable, use red onions or beets. Repeat the directions under A for cooking.

Vegetable used:

C. To compare the effect of different methods of cooking on the color of yellow vegetables.

Use carrots or squash. Repeat the directions under A for cooking. Do not confuse caramelization of sugar by alkali with pigment change of color.

Vegetable used:

Compare the effect of acid and alkali on the green, red and yellow pigments found in vegetables. What is the effect of the soda on the texture? Of the vinegar? Which is the preferable way of cooking each of the different colored vegetables?

### Experiment 18.

To determine the effect of alkaline and neutral water upon the color of white cereals and vegetables.

1a. To  $1\frac{1}{3}$  cups of boiling water add  $\frac{1}{4}$  cup of washed rice. Cook until tender. Add more boiling water if necessary during cooking. Remove about  $\frac{1}{2}$  of the cooked rice from the sauce pan and drain.

1b. To the rice remaining in the sauce pan from 1a, add  $\frac{1}{8}$  to  $\frac{1}{16}$  of a teaspoon of cream of tartar. Cook 2 minutes and drain.

2a. To  $1\frac{1}{3}$  cups of boiling distilled water add  $\frac{1}{4}$  cup of rice washed in distilled water. Add boiling distilled water during cooking if necessary. When the rice is tender remove about  $\frac{1}{2}$  of the cooked rice from the sauce pan and drain.

2b. To the rice remaining in the sauce pan from 2a, add  $\frac{1}{8}$  to  $\frac{1}{16}$  teaspoon of soda. Cook 2 minutes, then drain.

3. Add half a white onion to 1 cup of boiling tap water. Cook until tender. Save the other half of the onion for 4.

4. Repeat 3, but use distilled water. Cook the same length of time as 3.

5. Repeat 3 and 4, using flowerlets of cauliflower or white cabbage.

Results and conclusions.

### Experiment 19.

To determine the effect on the flavor and tenderness of a strong-flavored vegetable cooked by different methods and for different lengths of time.

Use  $\frac{1}{8}$  pound (56 grams) of cabbage, Brussels sprouts, or turnips cut into pieces. Onions can be used but they become milder with longer cooking. Add 1 pint of boiling water. Cook until tender.

A. Methods of cooking.

1. Cook in a covered vessel.

2. Cook in an uncovered vessel.

3. Blanch, i.e., pour off the water after cooking 5 minutes, add 1 cup of freshly boiled water, and finish cooking.

4. Cook in a steamer.

5. Cook in a steamer. Add 1 gram of ammonium carbonate per quart of water to the water in the lower part of the steamer.

6. Cook in a pressure cooker.

7. Cook in a fireless cooker.

8. Cook in a waterless cooker.

9. Cook in a distilling flask, catching the distillate in a flask held in ice water. Catch the distillate in 4 portions, changing the flask every 3 minutes. Do not count the time for the first distillate caught in the flask until the water in the distilling flask is boiling. Cork the flasks containing the distillate until the class is ready to taste and smell the distillate. Which is stronger, the first liquid that distils over or the last portion? Are any of the flavoring and aromatic substances of cabbage, turnips, and onions volatile?

Some of the distillate may be tested for sulfides by adding a few drops of lead acetate. Test the distillate with litmus.

Taste the cooking water and vegetable. In which case is the flavor of the vegetable best? Is blanching desirable? Do these experiments suggest any reason why the juice of most canned vegetables is stronger than that from the fresh vegetables? If you do not want to discard the water in which a strong-flavored vegetable is cooked, how would you cook the vegetable? How use the water? Test some of the cooking waters for sugar.

Vegetable used:

Time of cooking	Tenderness	Flavor of vegetable	Flavor of water	Flavor of distillate	Color of water



## Conclusions.

## B. Time of cooking.

Use  $\frac{1}{4}$  pound (112 grams) of shredded cabbage for each experiment. Should a difference be made in the time for winter and spring cabbage? Have the water boiling when the cabbage is added. The amount of water will need to be increased in each experiment as the time of cooking is increased.

1. Cook 5 to 7 minutes in a small quantity of water. Try to have nearly all the water evaporated at the end of the cooking period.

2. Repeat B1, but cook 8 to 10 minutes.

3. Repeat B1, but cook 25 to 30 minutes. Add boiling water if necessary to finish the cooking. Compare the flavor and color with those of the cabbage cooked a shorter period.

4. To a cup of boiling milk add  $\frac{1}{4}$  pound of finely shredded cabbage. Cook 5 to 7 minutes. Use a pan of at least a quart capacity, for milk boils over readily. Compare flavor and color with B1 and B2.

5. Repeat B4, but cook 15 minutes.

## C. The quantity of water left at the end of the cooking period.

1. Repeat the first two experiments under B, but have about  $\frac{3}{8}$  cup of water left at the end of the cooking period. Drain and save cooking water. How does the quantity of water compare with the measure of the vegetable? Compare the flavor with that of vegetables from above experiments.

2. Repeat C1, but have about  $\frac{3}{4}$  cup of water left at the end of the cooking period. Compare the flavor of the cooking waters.

3. Repeat B and C with Brussels sprouts, cauliflower, and white onions.

4. If the water you use is alkaline in reaction, repeat C1 or C2, using distilled water and cauliflower or white onions.

5. Cook  $\frac{1}{4}$  pound of peas, asparagus, carrots, or other vegetables until tender. (a) Have the water evaporated at end of cooking period. (b) Have about  $\frac{3}{8}$  cup of water left. (c) Have about  $\frac{3}{4}$  cup of water left. (d) Cook in 1 cup of milk.

Time of cooking	Quantity of water left	Texture	Color	Flavor

## Results and conclusions.

What is the effect of long cooking on strong-flavored vegetables? Are some vegetables often over-cooked? Is cabbage sometimes cooked longer than 25 to 30 minutes? Name several strong-flavored vegetables. Do cabbage and cauliflower turn a brownish red unless cooked too long? Do onions become stronger in flavor with longer cooking? What length of time of cooking produces the best-flavored product for onions, cauliflower, and the other vegetables used? With which vegetables would you have considerable water left at the end of the cooking period? Would the age of the vegetable, that is, young or old carrots, turnips, etc., make any difference in the quantity of water that is desirable to be left at the end of the cooking period? With which would you

evaporate the water? Would you increase the water proportionately for a larger quantity of vegetable? Do vegetables like cabbage and onions lose juice during cooking that adds to the cooking liquid? What is the percentage of water found in some common vegetables?

Is the flavor of the vegetables cooked in milk as strong as when cooked in water? Do any of the vegetables curdle the milk? Which ones? (See chapter on milk.)

What is the effect on the color of white vegetables of cooking in alkaline water? In distilled water?

### Experiment 20.

To determine the comparative losses in cooking vegetables by different methods.

A. Use 300 grams of carrots cut into cubes of the same size. Mix well and use 100 grams in each experiment. Use distilled water.

1. Cook until tender in a steamer. Save the water. Partially evaporate the water in the cooking utensil. When it is sufficiently concentrated put into a weighed evaporating dish. Rinse the cooking vessel with a small quantity of distilled water and add to the evaporating dish. Evaporate to dryness. Weigh the residue and determine the percentage of loss in the cooking water.

2. Cook in sufficiently boiling water to barely cover. Measure the quantity of water used. Watch carefully. If the water evaporates before the vegetable is tender add boiling water. Remove the carrots from the cooking vessel when they are tender and rinse the cooking vessel with a small amount of distilled water. Put the water in a weighed evaporating dish. Evaporate to dryness and weigh the residue.

3. Cook in 3 times the amount of boiling water used in A2, so that a rather large amount of water is left when the carrots are done. Evaporate the water according to directions under A1.

B. Use 3 medium-sized potatoes for each experiment. The potatoes should be nearly the same size. Use distilled water.

1. Cook with skins on. Evaporate the cooking water after the potatoes are removed until only a small quantity is left. Put in a weighed evaporating dish, evaporate to dryness, and weigh the residue.

2. Peel the potatoes. Cook until tender. Proceed as in B1. In which case did the greatest loss occur with the carrots? With the potatoes?

Weight of residue	A1	A2	A3	B1	B2

By what methods are the losses in cooking vegetables the greatest? How can the losses be reduced to a minimum? What do you think of the advisability of throwing away the juices from canned vegetables? The water in which vegetables are cooked?

Results and conclusions.

**Experiment 21.**

To determine the best method of cooking dried vegetables.

Use 50 grams of dried beans for each experiment. Keep a record of the time required for cooking, the weight after soaking and after cooking. Start the soaked beans to cook in 1 cup of boiling water and the unsoaked beans in 1 pint. If the beans become dry before they are cooked add boiling water of the same kind used in that particular experiment. Cook all the beans in covered pans. Test the beans with the sharp point of a knife or fork. Compare with your neighbors' results, to try to have all cooked to the same stage of doneness. If you have water softener, to soften hard water, repeat the experiments that call for tap water to compare with the results for hard water and distilled water.

1. Wash the beans and soak over night in tap water. Discard the water in which the beans were soaked. Weigh the beans. Add fresh tap water and cook until tender. Drain and weigh.

2. Soak over night in tap water to which  $\frac{1}{8}$  teaspoon of soda is added. Discard the soaking water and proceed as in 1.

3. Soak the beans over night in distilled water. Discard the soaking water and weigh the beans. Add fresh distilled water and cook until tender. Drain and weigh the beans.

4. Soak over night in distilled water to which  $\frac{1}{8}$  teaspoon of soda is added. Discard the soaking water and weigh the beans. Proceed as in 3.

5. Cook in tap water without soaking. Weigh.

6. Cook in tap water to which  $\frac{1}{8}$  teaspoon of soda is added. Cook for 10 minutes, then discard the water and add fresh water. Cook until tender. Weigh.

7. Cook in distilled water until tender. Weigh.

8. Cook in tap water to which  $\frac{1}{4}$  teaspoon salt per 50 grams of beans has been added. Weigh.

9. Cook in the pressure cooker for 30 minutes at 20 pounds pressure.

10. Cook in distilled water to which 1 tablespoon of vinegar is added.

11. Pour boiling water on the beans. Let stand. Weigh beans every hour to compare the length of time required for soaking in warm and cold water.

Weight of beans after soaking grams	Weight after cooking grams	Time to cook	Texture	Flavor

**Results and conclusions.**

Compare the time required for cooking by the different methods. In which is the best product obtained? Do any of the beans tend to lose their shape? Which beans cook in the shortest time? What is the effect of soaking on the color and flavor of the beans? On the time required for cooking?

**Experiment 22.**

To determine the effect upon the texture of fruit of cooking in a sugar sirup.

A. Cooking in a sirup and adding the sugar after cooking.

1. To 1 cup of water add a cup of sugar. Bring to a boil. Pare and core 6 apples. Do not cut in pieces. Cook in the sirup. The sirup should be in a rather small pan so that the apples are covered by the boiling sirup. Cook until the apples are translucent in appearance. It may be necessary to cook only a portion of the apples at a time.

2. Peel and core 6 apples. Cut into quarters or eighths. For each 1½ pounds of peeled apples add 1 cup of water and cook until soft. When soft add ¾ cup of sugar for each 1½ pounds of pared apples. Compare with the consistency of the apples cooked under 1.

B. To determine the effect of length of time of cooking upon the flavor and the proportion of sugar to fruit upon the texture of the fruit in strawberry preserves.

1. Wash and stem strawberries. For each pound of fruit (approximately 1 quart) add 1 pound of sugar and let stand in the refrigerator over night. When ready to cook place in a rather large sauce pan for the quantity of berries, so that they can boil rapidly without danger of boiling over the top of the pan. Heat slowly and shake the pan occasionally. When the temperature reaches 65° to 70°C. (150°F.) remove the pan from the heat and keep warm for about 5 minutes. Roll the berries occasionally in the sirup. Put over the heat and bring to a boil quickly. Cook until the temperature of the sirup registers 103°C. Let stand until the bubbles cease to form. Pour in sterilized containers. If the berries float to the top of the can repeat the experiment, increasing the time the fruit is held in the sirup at a temperature of 65°C. Let stand a few days before making comparisons with other preserves. Keep a record of the time required for cooking.

2. Repeat 1, but for each pound of fruit add 1½ pounds of sugar.

3. Repeat 1, but for each pound of fruit add 2 pounds of sugar.

4. To 1 pound of berries add 1 pound of sugar. Let stand over night in refrigerator. Bring to boil and boil 5 minutes. Add another pound of sugar and bring to boil. Boil 5 minutes, partially cool, can, and seal.

5. Repeat 4 but pour berries into a large platter and let stand until sirup is the consistency desired. Seal in sterilized jar.

6. Repeat 4, but put berries in a sieve after stemming and pour boiling water over them. Put in kettle, add sugar, and proceed as under 4.

7. Make a sirup of 1 pound of sugar and 1 cup of water. When it is boiling add 1 pound of berries. Cook until the temperature of the sirup registers 103°C. Store according to directions under 1.

C. To determine the effect of time of adding sugar in making preserves upon the texture of a firm fruit like Keifer pears.

1. Pare and core Keifer pears. Cut into quarters or eighths. To each pound of fruit add a pound of sugar and a cup of water. Cook until the sirup is the concentration desired.

2. Repeat 1, but first cook the pears until tender in water. Then add a pound of sugar for each pound of fruit and cook to the same concentration as under 1.

Compare the consistency, texture, and flavor of the apples cooked in sirup with those cooked in water and then sweetened. Which is preferable for an apple that is to be served whole? For a purée? Would putting the cooked

apples through a sieve aid in obtaining a uniform texture for apple sauce? Are the apples used for the experiment a sweet or a sour variety?

What is the concentration of sugar in a sirup that boils at 103°C.? See Table 10 under sugar cookery. It is desirable for some preserves to have a greater concentration of sugar in the finished preserves. If 65 per cent of sugar is desired, to what temperature should the sirup be cooked? If a 70 per cent concentration is desired? What is the effect of longer cooking upon the flavor of strawberry preserves? Is it preferable to add the sugar directly to the berries or to make a sirup first? Why?

Compare with the preserves from B in flavor, color, texture, and yield.

In a fruit like Keifer pears, which contain considerable cellulose, what is the best method of making preserves? What is the effect upon the texture of adding the sugar directly to the fruit? Would you cook dried fruit in a sirup? Why?

## CHAPTER V

### JELLY

The earliest work on jelly from a school laboratory is that of Goldthwaite. Since that time many valuable contributions have been made dealing with jelly making. Probably the most extended recent investigations are those of Spencer, of Olsen, and of Tarr and his associates, Baker and Myers. They believe that the formation of jelly "depends almost entirely upon the application of the laws of chemistry, more especially the laws of physical chemistry."

**Jelly formation.** Spencer offers a new theory for gelation of pectin jells. Stated briefly it is as follows. A pectin sol is stabilized by hydration and a negative charge of the pectin particles. The greatest stability comes in the neutral range as increasing either alkalinity or acidity decreases its stability. In jelly the rôle of the sugar is that of a precipitating agent: the more acid the solution, the less sugar required for the precipitation of the pectin. Salts may aid in precipitation or tend to prevent it, depending on whether they increase or decrease the stability of the pectin.

For theoretical study of pectin jelly Spencer recommends mixing the constituents of the jelly while cold instead of the usual boiling of the sugar and juice, which she calls the hot evaporation method. The reasons for this are four in number. Decomposition of both sugar and pectin occurs during cooking. The proportions of the various constituents change by evaporation, hence it is difficult always to obtain the concentration desired. The precipitating agent sugar has a limited solubility. There is danger of premature precipitation of the pectin if all the cold sugar is added at one time to the hot pectin mixture. For this experimental work dried pectin or a concentrated pectin solution is necessary.

Olsen summarizes the theory of jelly formation as follows: Granted that pectin is a negatively charged hydrophilic colloid, the following may be assumed: (1) sugar is the dehydrating agent; (2) the hydrogen-ion concentration reduces the negative charge on the pectin, thereby permitting the pectin to precipitate and coalesce in the form of a network of insoluble fibers, provided the concentration of sugar is sufficient; (3) the dehydration of the pectin micelles by sugar is not instantaneous but requires time to come to an equilibrium; (4) the rate of hydration and precipitation increases in direct ratio as the hydrogen-ion concentration; (5) the maximum jelly strength is reached when the system reaches equilibrium, and depends upon the position of that equilibrium; (6) any component added to a pectin jelly system, including salts, which causes a change in the ultimate jelly

strength of that system may function either (*a*) by changing the rate of gelation, or (*b*) by affecting the ultimate jelly structure, or (*c*) a combination of these two.

### Fruits Used for Jelly

For a fruit juice to make a good jelly by boiling with the addition of sugar only, the juice must contain a sufficient amount of a substance called pectin and also sufficient acid. Some fruit juices will not make acceptable jelly by this method because they are deficient in pectin, whereas others do not contain enough acid. In the middle states west of the Mississippi River the fruits most commonly used to make jelly without addition of pectin are apples, crab-apples, blackberries, sour plums, grapes, currants, and gooseberries. During the winter months cranberries are used extensively.

Cruess and McNair have reported that the following fruit juices contain sufficient acid and pectin to produce good jelly: blackberries, loganberries, Isabella grapes, Tokay grapes, cranberries, currants, whole lemons, and pomelos. They state that oranges have enough pectin but not always enough acid. Apricots and cherries sometimes make jelly but are usually deficient in pectin. Pomegranates and strawberries have enough acid but lack pectin, and pears, peaches, and huckleberries lack both pectin and acid. Citron melons and mission figs have enough pectin but lack acid. They state that lemon is too high in acid to produce a good jelly, but that two whole oranges and one whole lemon make a good combination, the acidity of the lemon allowing for the deficiency in the orange.

By the addition of pectin and sugar, all fruit juices, so far as the author knows, can be used for jelly.

### The Pectic Substances

**Nomenclature of the pectic substances.** The different names used in the literature for pectin and its related compounds have been numerous. To avoid confusion, the Committee on the Nomenclature of the Pectic Substances (Dore, Chairman) have proposed dividing these into three groups: (1) protopectin, (2) pectin, and (3) pectic acid. The chemical identity of the various pectic substances is not definitely settled, but a great deal of investigational work is being done at the present time.

**Function of pectic substances in plant life.** The pectic substances play an important rôle in plant life. Dore states that the primary function of the pectic substances is the cementing together of the individual cells that compose the plant.

**Sources of pectin in plants.** The pectic substances are found in the leaves, bark, roots, tubers, stalks, and fruits of plants. The pectic compounds occur in two places in the plant cell—in the middle lamella, where

they serve as cementing material, and as thickened places on the cell wall. These two sources may yield slightly different substances. In fruits the pectin is usually found in the pulp and not in the juice, though there are some exceptions. For example, currant juice often contains pectin. The skins and cores of fruit like apples contain large proportions of pectin. Hence, apples and crab-apples are cut into small pieces, but not peeled or cored, for making jelly. Some of the root stocks, such as sugar beets, carrots, rutabagas, and turnips, contain appreciable amounts of pectin.

The amount of pectin not only varies in different fruits, but also in the same fruit at various stages of ripeness and in the same fruit in different years or seasons.

**Protopectin.** Protopectin has been called pectose and pectinogen. It is the water-insoluble pectic substance in plants. It may be rendered soluble by the enzyme protopectinase or by treatment with acid and other reagents. The soluble substances thus formed are designated as pectins.

Sucharipa has presented evidence that the protopectin is combined with cellulose. In the plant, the separation of the pectin from the cellulose is brought about by hydrolysis by the enzyme protopectinase.

The protopectin is the precursor of pectin. As the fruit ripens, pectin increases while the protopectin decreases. Protopectin is also converted to pectin by boiling with dilute acid. Since fruit juices contain acid, some protopectin is changed to pectin when the fruit is boiled. This is the reason why cooked fruit juices are better for jelly than uncooked ones.

Conrad, influenced by Ehrlich's work, found that as the pectin of the fruit increases, a pentose-bearing polysaccharide is liberated at the same time from the protopectin, its proportions paralleling that of the pectin to a great extent. This furfural-yielding polysaccharide is separated from the pectic substances by its solubility in 70 per cent alcohol.

**Pectin.** Among the various names that have been applied to pectin are parapectin, pectinogen, and protopectin. The term is applied to the methylated pectic substances that form a colloidal solution in water. It is the jelly-forming substances of the pectic compounds, although the pectins with fewer methyl groups have less jellying power than those with a greater number.

According to Sucharipa the pectins may be classified into (1) free pectins, which are removable from the plant by water solution, and (2) hydrolysis pectins, which result from treating protopectin with hydrolyzing agents.

**Pectic acid.** In fruit, protopectin is changed to pectin by enzymes of the fruit. With still further ripening, pectic acid is formed from pectin by the enzyme pectase. These changes are gradual, but the larger portion of the pectic acid is formed when the fruit is ripe and when decay begins. In the presence of pectase and calcium, barium, or strontium salts, pectic acid may form a gel.

Dore states that, when the protopectin is in combination with cellulose,



the under-ripe fruit is firm. As the fruit ripens it becomes softer as the protopectin is changed to the pectin. Rotten fruit is entirely disintegrated because the pectin has been changed to pectic acid.

In fruits the rate at which softening takes place depends largely upon the temperature. Haller has shown this for a number of varieties of apples in storage. The rate "at 40°F. was found to be slightly more than double that at 32°, whereas that at 50° was slightly less than double that at 40°, and that at 60° nearly double the rate at 50°."

Pectinase is a term applied to the enzyme which hydrolyzes pectin and pectic acid into their simplest cleavage products.

**Constitution of the pectic substances.** The constitution of the pectic substances is not definitely known. The purest pectins, when treated with a dilute alkali, yield 10 to 12 per cent of methyl alcohol, showing that methoxy groups ( $\text{CH}_3\text{O}$ ) are found in the molecule. As the methoxy groups are split off, different series of pectin compounds are formed, these compounds having different jellying powers. The greater the number of methoxy groups split off, the less the jellying power and the more sirupy the jelly. Pectic acid is the demethoxylated pectin. Since pectic acid is the simplest and the most easily purified of the pectic compounds, it has been prepared in the purest state. Schryver and Haynes have suggested that pectic acid is composed of one molecule of galactose, one of arabinose, and four of galacturonic acid arranged in a ring, the last having the four carboxyls of the acid groups free for methyl ester formation.

Sucharipa states that the chemical difference between free pectins and hydrolysis pectins is that arabinose is in the former, whereas it is split off from the latter by hydrolysis.

Other investigators question the presence of arabinose as a constituent of pectic acid, since it is impossible for it to be formed from galacturonic acid. Acetic acid has been reported among the decomposition products of pectic acid obtained from pectin of flax and sugar beets.

Olsen states that most of the recent work on the chemistry of the pectin molecule fails to consider that pectins may vary depending upon their source. He adds that it has long been known commercially that citrus and apple pectins, irrespective of grade, form jellies of definitely different types, though this has not been recognized in the scientific literature.

**Protopectin and pectic acid do not form jellies.** Protopectin and pectic acid do not form jelly when cooked with sugar and a fruit juice containing acid, although pectin forms a jelly under these conditions. Since over-ripe fruit contains a larger proportion of pectic acid and a smaller percentage of pectin, this furnishes the explanation for the fact that many jelly makers have long known, that juice from partially ripe fruit makes a better jelly than juice from over-ripe fruit.

**Cooked extracted fruit juice is better for jelly.** Fruit juice extracted raw or without cooking will seldom make jelly, or it yields a jelly of poor quality. Since the protopectin is not soluble in the juice of the fruit, if

the juice is extracted raw it remains with the pulp of the fruit. If cooked, some of the protopectin is changed to pectin. Goldthwaite has reported experiments with apple and some other fruit juices extracted raw. Either no jelly was obtained or it had a poor texture.

**Extraction of and preparation of juice for jelly.** Hard fruits like apples and crab-apples are cut into small pieces or ground with a food chopper, barely covered with water, and cooked. Soft berries need little water added,  $\frac{1}{4}$  cup to a pound of fruit often being used. Currants that are not too ripe should have a larger proportion of water. Gooseberries, if green, because of their very high acid and pectin content and the character of the pectin, can be completely covered with water, and sometimes will need additional water. Ripe gooseberries require the same proportion of water used for other berries. After cooking, the juice is drained without squeezing from the pulp by placing the cooked material in a cloth bag. Fruits that are very rich in pectin may have two or three extractions made. These second and third extractions need to be boiled down more than the first extraction to concentrate the pectin. Second and third extractions also do not have as much of the fruit flavor as the first one.

Apple juice sometimes contains starch, particularly that from under-ripe fruit, which renders the juice cloudy. Askew states that starch formation begins near the periphery and progresses toward the core; but as the fruit matures the core area is cleared of starch first, the area near the skin last. Commercially, diastase can be added to convert the starch to sugar and thus clear the juice.

Grape juice contains tartaric acid, which often crystallizes in long needle-like crystals in the jelly. It can be removed partially from the juice by putting the juice in a refrigerator (the colder the better, but it is less soluble at lower temperatures), over night, or for a few days, and then straining the crystals from the juice.

### The Rôle of Pectin in Jelly Formation

According to Spencer's theory, the precipitation of pectin forms the jelly. Sugar, glycerin, or alcohol may be used as precipitating agents. Spencer states "The successful making of alcohol jellies requires rapidity of motion and practice, otherwise one obtains a precipitate and not a homogeneous jelly." The qualitative aspects of the boundary line between fields of the jelly and the sol shown in Fig. 14 are by Spencer. She states that the quantitative aspects of these boundary lines are meaningless, because the pectin used contained some ash. From this figure it is deduced that jellies with sugar as the precipitating agent are not possible in the neutral region owing to the solubility limit of sugar. Although alkaline jellies are interesting theoretically, practically they are of less importance, since they cannot be used as food on account of their flavor.

**Concentration of pectin required for jelly.** The strength of the

jelly is in proportion to the concentration of the pectin, if other factors remain the same. Too small a proportion of pectin yields a jelly that is too soft and sirupy; too great a concentration gives a product that is too firm and hard. However, after a certain amount of pectin has been added any excess remains inactive. The concentration of pectin required for a jelly of good consistency varies with the proportion of sugar used, the acidity of the juice or solution, the salt content of the particular juice being used, the time, and temperature factors. Good home-made jelly may contain 0.75 to 1.0 per cent of pectin. Commercial jelly, on account of shipping, is somewhat stiffer, averaging about 1.25 per cent of pectin.

Pectins from different sources yield characteristic jellies. Olsen states that jellies made from citrus pectins are comparatively friable and

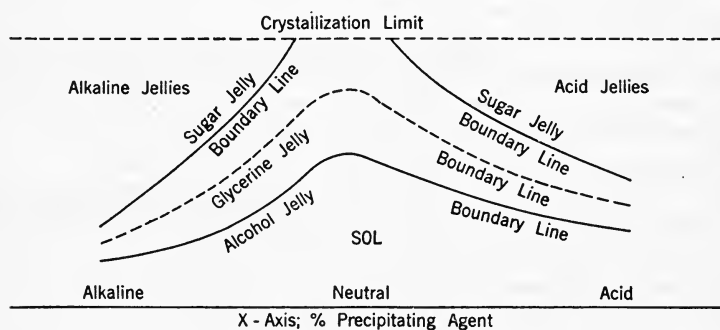


FIG. 14.—From Spencer. "A qualitative view of the relations of the boundary curves of pectin jelly fields for sugar, glycerine, and alcohol jellies. The alcohol jelly field is the largest, and the sugar jelly field the smallest." *J. Physical Chem.* 33: 1993.

have little elasticity; whereas jellies made from apple pectins are highly elastic, but require and tolerate less acid than citrus pectin jellies similarly prepared. Cranberry pectin tends to yield firm jellies which will not spread readily. Cox states that a better-textured cranberry jelly for spreading purposes is obtained if the pectin occurring in the juice is hydrolyzed by adding the enzyme pectinase, available in commercial form under the name Pectinol. A slower-setting pectin is then added to the juice. With a rapid-setting pectin gelation may start before the sirup is poured, and the pouring breaks the structure so that a mass of small lumps is formed.

Three fairly easy methods of determining the amount of pectin present in fruit juice are available for the housekeeper. One is to cook a small portion of the juice with sugar to see if it will form jelly. Another is to test the juice with alcohol. The third is to test the viscosity of the juice with a jelmeter.

**Pectin test by alcohol.** Alcohol precipitates pectin in a jelly-like mass. By the character of the precipitated pectin an approximate estimate can be made of the amount of pectin in the juice. For the test, 1 tablespoon of

juice is poured into 3 to 5 tablespoons of alcohol. Sometimes equal quantities of juice and alcohol are used, but the larger amount of alcohol gives a better test. Turn the container gently from side to side. If a test tube or graduated cylinder is used it can be turned slowly upside down and back to bring all the juice in contact with the alcohol. If the pectin comes down in a solid mass there is a sufficient quantity to make jelly. If the pectin is flocculent or in small flakes the juice needs boiling down to concentrate the pectin.

Johnston and Denton have reported that the amount of alcohol precipitate in citrus pectin extracts does not indicate the jelling power. It may also be possible that the amount precipitated in different juices will show different jelling strengths. Of course, alcohol precipitates such substances as gums and starch in addition to the pectin. The precipitated mass becomes firmer after standing in the alcohol a few minutes, so the estimate should be made just after mixing.

For the pectin test, straight ethyl alcohol, denatured, or wood alcohol can be used. The denatured alcohol is better to use than the wood alcohol and usually gives a satisfactory test. When wood alcohol is used, the precipitated pectin may be redissolved after standing a few minutes. This may also be true of some denatured alcohol.

**Pectin test by viscosity.** Based on the observed correlation of the viscosity of pectin solutions with the jelling power of the pectin, Baker has developed a jelmeter. The viscosity of the fruit juice is determined by the rate of flow of the juice through a given orifice compared with the time of flow of an equal quantity of water at the same temperature. The viscosity or thickness of the fruit juice is dependent principally upon its pectin concentration, although sugars, starches, and proteins influence it slightly. If the approximate viscosity is known, then the amount of sugar to use and the weight to which the jelly should be cooked can be determined. Baker has prepared such tables.

The jelmeter is similar to a graduated pipette. The test is easy to make and practical. It works satisfactorily with the fruit juices that have been tested.

**Effect of high temperatures and a long period of heating upon pectin.** Numerous investigators, among them Johnston and Denton, Sucharipa, and Tarr, have found that high temperatures decrease the jelling power of pectin. Myers and Baker state that "Prolonged heating of pectin solution has a deleterious effect on the jelling power of the solution. The higher the temperature the greater the decrease in jelling power of the pectin." They find that heat has the same effect on the powdered pectin as upon the pectin in solution.

The boiling of a pectin solution with acid decreases the amount of pectin in the solution because of the formation of pectic acid by hydrolysis. Some of Tarr's data seem to indicate that, if the sugar is in the juice during

the boiling period, hydrolysis is delayed. The following table is from Tarr's results and shows that the decrease in jelly strength was considerable when the pectin and acid were boiled before the sugar was added.

**Commercial pectin.** Commercial pectin is on the market in two forms: (1) the liquid form and (2) the powdered dry pectin. The first type of commercial pectin is a concentrated liquid pectin. It usually contains 4 to 4.5 per cent of pectin. The second form is a mixture of dry powdered pectin and sugar. It is similar to dry gelatin and sugar mixtures on the market in that it contains the sugar, and only the juice needs to be added for making jelly. Wilson states that there is no uniformity in jelly strength

TABLE 21

THE EFFECT ON JELLY STRENGTH OF BOILING THE PECTIN WITH ACID PREVIOUS TO ADDING THE SUGAR (*Tarr*)

Time of boiling pectin and acid, minutes	Time of boiling pectin, acid and sugar, minutes	Jelly strength, pressure in centimeters of water	
		Top	Bottom
0.0	19.4	61.5	79.5
1.0	19.2	58.0	77.5
2.0	19.5	58.5	76.5
3.0	17.2	57.5	73.0
4.0	17.5	55.5	70.5
6.0	13.2	49.5	67.5
8.0	11.0	44.0	62.0
10.0	9.0	41.0	58.5
11.3	6.3	39.5	54.5
12.0	6.3	33.5	49.0

of these pectin preparations but that a dry pectin that will jell about 40 times its weight of sugar is a practical one. The dry powdered pectin is sold in large quantities to commercial jelly and jam makers. The dry pectin without the added sugar is now available for the housekeeper.

Rooker states that the powdered pectins will eventually replace the liquid pectins. This is because the "powder is cheaper, is easier to handle, haul, cart, and store. It does not spoil and deteriorate. Powdered apple pectin retains its jellying strength indefinitely while sirup pectins deteriorate if kept any material length of time. A container of powdered pectin may be opened and used as needed, while a container of pectin sirup must be used almost at once or the balance of the opened can will spoil."

Rooker gives many uses of pectin in addition to making jelly and jam. Among these are use in emulsions for pharmaceutical purposes, in emul-

sions for tree spraying, in crushed fruits for soda fountains, as "candy doctors," in confections, etc.

Myers and Baker after extensive experiments with the jelling properties of pectic substances, recommend that pectin should be bought and sold on a basis of jelling strength.

Olsen states that, commercially, pectins are graded on the basis of the amount of sugar they will carry. Thus a 160-grade pectin, as supplied by a definite source, is one which, when used in a jelly containing 65 per cent of sugar by weight with a proper amount of acid in the proportion of one part of pectin to 160 parts of sugar, yields a satisfactory jelly. Olsen has also shown that the strength of a jelly will vary with the temperature to which the pectin is heated. Hence a standardized procedure for testing pectin strength is essential.

With the aid of commercial pectin, which the housekeeper can add to fruit juices that are deficient in pectin, jelly and jam can be made from many varieties of fruit.

### The Rôle of Acid in Jelly Formation

Although acid is not essential for jelly formation its presence in fruit jellies is very important. Singh has reported that "between certain limits the greater the acidity of the juice the lower the amount of sugar required." He adds that it has long been known that juices of high acidity yield firmer jellies than juices deficient in acid but with as high a pectin content.

Spencer has published data showing the increase of rigidity of jellies with increase of acid when the pectin and sugar concentrations are constant. Spencer explains the action of acid in this way. The strength of a jell network depends upon the continuity and the rigidity of the structure. "Continuity of structure, by hypothesis, depends upon the number and proximity of pectin particles at the time of precipitation," which in turn is determined by the degree of dispersion and concentration of the pectin. "Differences in rigidity are due to the amount of water retained by the pectin at the equilibrium established during precipitation." Hydrogen (or hydroxyl) ions lessen the stability of the pectin sol by decreasing the hydration capacity of the pectin. Hence in an acid medium less sugar is required to bring about precipitation. Nearly neutral fruit juices will not form jelly with sugar because the sugar is not soluble enough to allow precipitation of the more stabile pectin. Hence with a definite concentration of pectin the rigidity of the jelly is determined by the sugar and acid concentrations.

**Hydrogen-ion concentration and jelly.** Tarr has determined the minimum amounts of several acids required to produce a jelly and also the amount of the acids to produce an optimum jelly by the hot evaporation method with pectin, sugar, acid, and water. Optimum jelly is defined as

the jelly which in his judgment has the best texture. For jelly formation, when other conditions were standardized, the minimum amounts of the acids were as follows: 8.5 cc. of 0.1 *N* sulfuric acid; 27.5 cc. of 0.1 *N* phosphoric acid; 22.7 cc. of 0.1 *N* tartaric acid; 52.9 cc. of 0.1 *N* citric acid; and 583.3 cc. of 0.1 *N* acetic acid. The total acidity of the minimum amounts required for forming a jelly varied, but the acids were all at the same  $pH$ , 3.40. For optimum jelly the acids were all at  $pH$  3.1.

But although hydrogen-ion concentration controls the formation and character of the jelly to a certain extent, the salt content of pectin or of fruit juices, the temperature to which the pectin is heated, and the rate of pouring may extend this  $pH$  range, as will be seen later. In Tarr's jelly a  $pH$  of 3.46 gave a very tender jelly, but increasing the hydrogen-ion concentration below  $pH$  3.1 gave syneresis or weeping. The best jellies were obtained with  $pH$  3.3 to 3.1. Olsen and others have suggested that with  $pH$  lower than 3.1, jelly failure and increased syneresis may result because of the increased rate of setting. Olsen has shown that an increase of hydrogen-ion concentration increases the rate at which the jelly sets.

The hydrogen-ion concentration of ordinary fruit juices depends upon the particular acid present, upon the quantity of acid present, and upon the "buffer" action exerted by the particular juice.

**Relation of the time factor to optimum acidity.** Olsen assumed that the lowering of jelly strength might be caused by incomplete dehydration of the pectin and lessened precipitation or by a more flexible network of pectin. To test the second postulate he prepared jellies by heating the pectin to 55°C. and to boiling. The jelly at 55° was made as follows: The pectin, 30 grams of sugar, and water to make a total weight of 140 grams were brought to 36°C. The minimum amount of acid, the remaining sugar, and water were boiled together, cooled to 65°C., and adjusted to correct weight with distilled water. The additional acid and the pectin solution were added and stirred, the time was varied from the moment the pectin solution was poured into the warm sirup until the mixture was poured in jelly glasses, as shown in Table 22. The strength was tested with a Tarr and Baker jelly strength tester. Olsen states that a high-grade pectin made by the standardized hot method gives a reading close to 45.

The optimum  $pH$  varies with the time factor. The principal variation is the rate of gelation of the pectin as influenced by the acid concentration. Olsen explains this as follows: "The largest or 'optimum' amount of the acid to be used will be that point at which an additional increase in acid will increase the rate of setting to a point where loss in jelly strength due to a disturbance of the jelly in the stirring or pouring exactly balances the strengthening effect of that same increment of acid." Or in other words, stirring or pouring hinders jelly formation, which is offset by increasing the hydrogen-ion concentration.

**Acids in fruits.** The acids occurring naturally in fruit juices that are used for jelly are tartaric, malic, and citric. Sometimes acetic acid is

TABLE 22

THE RELATION OF THE TIME FACTOR TO OPTIMUM ACIDITY. (*Olsen*)

(The time indicated is the interval between the pouring of the pectin solution into the sugar sirup and the pouring of the mixture into glasses. Jellies contain 60 per cent of sugar, 2.5 grams of apple pectin 119°F., phosphoric acid as indicated. Temperature of pectin solution 36°C.; of sugar solution 65°C.; of final mixture 55°C.) (*Olsen*)

25% phosphoric acid solution cc.	Series B 90 seconds		Series C 50 seconds		Series D 8 seconds	
	Jelly strength	pH	Jelly strength	pH	Jelly strength	pH
0.26	....	....	0.0	3.27	....	....
0.36	33.0	3.10	....	....	36.5	3.13
0.56	69.0	2.80	....	....	67.0	2.88
0.86	....	....	80.0	2.50	....	....
0.96	41.0	2.39	....	....	115.0	2.40
1.06	....	....	75.0	2.37	....	....
1.26	....	....	61.5	2.24	....	....
1.56	19.0	2.13	....	....	120.0	2.13
1.96	14.5	2.03	28.5	2.00	145.0	2.01
3.96	....	....	....	....	135.0	1.76

added to apple juice to make spiced apple jelly. Tarr's results show that acetic acid is of little value to add to a juice to increase its jelling power, because it volatilizes during boiling and is only slightly ionized in solution.

Goldthwaite has reported that, when tartaric and citric acids were used to acidify fruit juices deficient in acid, tartaric acid gave better results, the texture and flavor being better than when citric acid was used. Tarr's results confirm Goldthwaite's observations. Spencer explains this difference in the following manner. Since pectin sols are partially stabilized by a negative charge, the preferential absorption of one anion above that of another would increase the stability of the pectin sol. In other words, the citrate ion is more strongly absorbed than the tartrate ion, hence increases the negative charge on the pectin to a greater extent, making it more stable, less easily precipitated, so that a weaker jelly is obtained with citric acid than tartaric, if the same concentrations of pectin and sugar are used.

**Methods of reporting acidity of fruit juices.** Investigators have reported concentration of acids required for jelly in different ways. The pH gives the concentration of hydrogen ion or ionized part of the acid. Some report acid as number of cubic centimeters per 100 grams of jelly. However, work done some time ago was usually reported in percentage of



some acid, not necessarily the one found in the fruit. It has often been reported as sulfuric acid. The concentration of the acid is determined by titration with an alkali; from the quantity of alkali required the percentage of acid is calculated. Campbell states that 0.3 per cent as sulfuric acid is required to produce a jelly of good quality, the minimum being 0.27 and the maximum 0.5 per cent. Goldthwaite has reported from 0.154 to 1.892 per cent as sulfuric acid. Singh has reported still lower percentages of acids than these, but his jellies with a very low percentage of acid contain an unusually high percentage of pectin.

### The Effect of Temperature to Which Pectin Is Heated on Jelly Strength

Olsen states that the abnormally high jelly strength with pectin heated to only 55°, shown in Table 22, is not the result of the time factor alone. To prove this he recovered the pectin from duplicate batches of jelly, one of which had been heated to 100° and poured; the other poured at 50°C. The recovered pectins were remade into jelly at 50°. Both gave jellies testing as high in strength as the original jelly poured at 50°C. This proved that the lesser strength of the pectin heated to 100° was not due to hydrolysis of the pectin but the effect of temperature upon the gel structure. From these results Olsen concludes that "the structure of jelly is fundamentally different when slowly set from the hot solution than when rapidly set from the cool sirup. If we assume that pectin exists in two states of hydration; that is, if the amount of water bound by the pectin fibrils differs depending upon the temperature at which the pectin is precipitated, then a ready explanation is at hand."

These results are not to be interpreted as showing that hydrolysis of the pectin does not occur with long boiling but that none takes place with a short-boil process.

### The Rôle of Salts in Jelly Formation

The rôle salts play in jelly formation is not emphasized as much as that of pectin, acid, and sugar, but it is an important one. All fruit juices contain salts of the acids found in the fruit. In addition to these, other salts may be found.

Halliday and Bailey have reported that the addition of calcium chloride favors jelly formation, as somewhat lower concentrations of pectin, acid, and sugar are required when it is added. On the acid side, sodium chloride tends to prevent jelly formation, i.e., larger quantities of acid and sugar are required when sodium chloride is added. Spencer has reported that on the alkaline side sodium chloride tends to precipitate the pectin. Spencer has also reported that, with the same anion, chlorine, the precipitating effect of the cation increased with increasing valence, or  $Al > Ca > Na$ . With

the same cation but different anions Spencer gives the order of absorption of the negative ion by pectin as acetate > citrate > tartrate. This means that the tartrate is not so strongly adsorbed as the citrate or acetate ions, hence has less stabilizing effect and is more easily precipitated by sugar. The chloride anion is more strongly adsorbed than the nitrate or sulfate ions.

Salts buffer a fruit juice so that more acid is required to give a definite  $pH$  when salts are present. But the hydrogen ion is not the only positive ion in the fruit juice. Myers and Baker have found that the cation of the salt may supplement the hydrogen ion, but only at definite hydrogen-ion concentrations. No jelly was formed with added salts above  $pH$  3.6. Thus jellies from fruit juices may have a slightly wider range of hydrogen-ion concentration for jelly formation than those from pure water, acid, pectin, and sugar. Myers and Baker used sulfuric, tartaric, and citric acids and the sodium salts of these acids in their investigations.

The negatively charged ion of a salt tends to stabilize pectin sols, but those anions adsorbed most strongly exert the most stabilizing effect. These negatively charged anions may be neutralized by the positively charged ion of a salt, but the adsorption of cations also varies, so that some have a greater destabilizing effect than others. Since all pectins contain salts, the quantitative recipes worked out for one pectin may not give exactly the same results with other pectins because of a different salt content.

### The Rôle of Sugar in Jelly Formation

Sugar, if its concentration and that of acid and pectin is sufficient, precipitates the pectin. Spencer explains this precipitation as follows. When a pectin sol is formed, "an equilibrium is reached between the partial pressure of the adsorbed water" of the pectin "and that in the dispersing medium." When sugar is added to the pectin sol, this equilibrium is disturbed, for when the sugar dissolves in the dispersion medium it lowers the vapor pressure of the dispersing medium. As a result the pectin particles lose water and are less stable. Increases in sugar accelerate the setting of the jelly, probably because of increased dehydration, although rate of setting is also modified by other factors.

**Jelly without added sugar.** Jelly can be made by boiling down some fruit juices until they yield a "jelly test." The concentration of 2 cups of gooseberry juice yields less than  $\frac{1}{8}$  cup of gummy, tough, sticky jelly. If left with the lid off for a few days it becomes dry enough to handle. It is very dark in color, looking and feeling very much like licorice candy. The fruit flavor is present, although scarcely noticeable at first, because of the extremely acid taste.

**When to add sugar in jelly making.** As previously stated, Tarr has found that the jelling strength of the pectin is lessened if boiled before the addition of sugar. Yet, if the sugar is added to the pectin and

acid prior to boiling, the jelly strength is not decreased even when boiled as long as 42.8 minutes. Directions for making jelly often state to boil the juice for a certain number of minutes before the sugar is added. From Tarr's results it would seem a much better practise to add the sugar to the juice and concentrate it after the sugar is added. Long boiling of the sugar and fruit juice produces a darker-colored jelly, the extent of the darkening depending upon the juice and the length of time of boiling. With dark fruit juices this is not desirable, but it may improve the appearance of light-colored ones. To prevent darkening after the sugar is added, the jelly can be made in small lots so that boiling to the desired concentration can be accomplished quickly. In extracting the fruit juice too much water should not be added, as a large quantity of water only dilutes the pectin, and then boiling is required to concentrate it.

**Concentration of sugar in finished jell.** Jelly can be made with a wide range or proportion of sugar to juice, from about 40 to 70 per cent in the finished jell. From the reports in the literature, the average percentage of sugar in commercial jelly, unless acidity or pectin is abnormally high, varies from 60 to 65 per cent. The concentration of sugar desirable in the finished jelly varies somewhat with the juice from which the jelly is made. Thus gooseberry juice, which usually has a  $pH$  2.6 to 2.8 and also has a high pectin content, is usually of better texture if the final concentration of sugar is short of or about 60 per cent. Cox states that for cranberry sauce too stiff a jelly can be prevented by stopping the boiling process when the sugar concentration is somewhat below 60 per cent. Cox states that premature gelation can be brought about by too much pectin, acid, or sugar, or all three. For some fruit juices Tarr and Baker have found that 70 per cent of sugar in the finished product gives a jelly of good texture. With higher concentrations than 75 per cent the sugar may crystallize from the jelly.

**Proportion of sugar and jelly yield in illustrations.** In general, other factors remaining constant, the yield of jelly parallels the amount of sugar added. The gooseberry juice for the jellies in the illustrations is from the same source, so that the pectin content and viscosity of the juice were the same. The percentage of sugar in the finished jell is about 60, since all were boiled to  $103^{\circ}C$ . In Experiment 24 the yield of jelly parallels the sugar added. See Figs. 15 and 16. The firmness of the different jellies varies. The 2 cups of juice boiled down yield less than  $\frac{1}{8}$  cup of jelly. It is very firm, hard, and difficult to pull apart. The percentage of sugar in it is not known, but both the pectin and acid have been enormously concentrated. With  $\frac{1}{4}$  cup of sugar to a cup of juice the yield is a little more than  $\frac{1}{4}$  cup of jelly. This jelly is very firm, solid, and hard. With  $\frac{1}{2}$  cup of sugar to a cup of juice the yield is a little more than  $\frac{1}{2}$  cup of jelly. This jelly is a little more tender than the one with  $\frac{1}{4}$  cup of sugar but produces a jelly that is still too firm. It should be remembered that whereas each cup of juice had the same concentration of acid and pectin before the

sugar was added, the addition of varying amounts of sugar and boiling to  $103^{\circ}\text{C}$ . gives a concentration of practically 60 per cent of sugar in all the jellies. But the boiling to produce a concentration of 60 per cent of sugar thereby concentrates the pectin and acid, the concentration being greater per unit of weight in the jelly to which the smallest proportion of sugar was added. That the acid is concentrated is shown by the flavor, for the



FIG. 15.—The yield of jelly obtained when the proportion of sugar to juice is varied. Experiment 24.

1. Jelly made from two cups of juice without added sugar.
2. A cup of juice and  $\frac{1}{4}$  cup of sugar.
3. A cup of juice and  $\frac{1}{2}$  cup of sugar.
4. A cup of juice and  $\frac{3}{4}$  cup of sugar.
5. A cup of juice and 1 cup of sugar.
6. A cup of juice and  $1\frac{1}{4}$  cups of sugar.
7. A cup of juice and  $1\frac{1}{2}$  cups of sugar.

jelly from  $\frac{1}{4}$  cup of sugar and 1 cup of juice is very tart, the tartness progressively decreasing as larger proportions of sugar are added. This is true of the first extraction of most fruit juices. As the proportion of sugar is increased, the yield of jelly is increased. There is a proportion of sugar that produces the best jelly for the particular juice used. With increasing amounts of sugar beyond the proportion that yields an optimum jelly, the

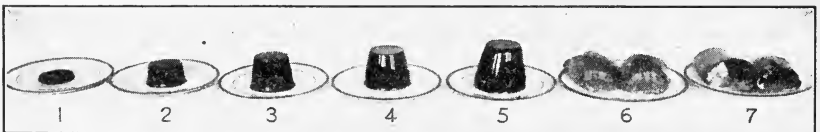


FIG. 16.—Showing consistency and yield of jelly from Fig. 15. Jelly made from first extraction of gooseberry juice.

jelly becomes softer until a proportion of sugar is finally reached that results in a fluid sirup instead of a jell.

**Proportion of sugar for home-made jell.** The proportion of sugar to add to the juice cannot be given definitely for the best texture of jelly, since it varies with the pectin, acid, and salt content of the juice. The amount of pectin varies with the ripeness of the fruit, the quantity of

water added for extracting the juice, and with the kind of fruit. Goldthwaite states that it is better to use too little sugar than too much with fruit juices. She has found with all kinds of fruit juices and average methods of extraction that  $\frac{3}{4}$  cup of sugar to a cup of fruit juice usually gives better results than a cup of sugar to a cup of juice. The author's laboratory and home results agree with those of Goldthwaite that  $\frac{3}{4}$  cup of sugar to a cup of juice gives a better jelly for most fruit juices. Currants if not very ripe need a cup of sugar to a cup of juice, but if a larger quantity of water is added for extraction a smaller proportion of sugar is needed. The pectin content of gooseberry juice is usually quite high, one reason being that they are nearly always picked while green. If the rule of adding water to barely cover is used, the gooseberry juice will often require  $1\frac{1}{4}$  cups of sugar to a cup of juice to give jelly of the best texture.

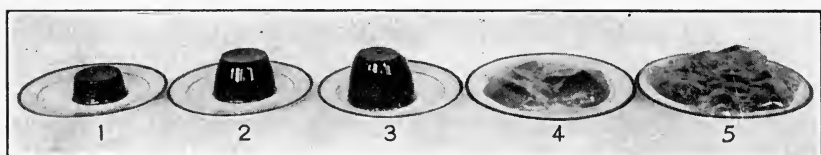


FIG. 17.—The jelly from the second extraction of gooseberry juice is softer than the jelly from the first extraction with corresponding amounts of sugar.

1. A cup of juice and  $\frac{1}{4}$  cup of sugar.
2. A cup of juice and  $\frac{1}{2}$  cup of sugar.
3. A cup of juice and  $\frac{3}{4}$  cup of sugar.
4. A cup of juice and 1 cup of sugar.
5. A cup of juice and  $1\frac{1}{4}$  cups of sugar.

Some idea of the amount of sugar to use can be obtained from the alcohol test. With gooseberry juice and using the larger quantity of alcohol for the test, the approximate proportion of sugar required for a cup of juice can be estimated from the character of the precipitated pectin. After mixing, turn the pectin and alcohol out in a dish. If the pectin precipitate can be picked up in one piece without breaking and feels firm, about  $1\frac{1}{4}$  to  $1\frac{1}{3}$  cups of sugar will be required; if the pectin precipitate can be picked up in one piece without breaking but does not feel firm, about 1 to  $1\frac{1}{8}$  cups of sugar will be necessary; but if the precipitate breaks into two pieces when picked up, about  $\frac{3}{4}$  to  $\frac{7}{8}$  cup of sugar is required. If the precipitate is flocculent the juice needs concentrating or only  $\frac{1}{2}$  cup or less of sugar can be used. A still easier way to determine the best proportion of sugar to add is to determine the viscosity with a jellmeter.

**Sugar, pectin, acid, and salt.** As can be ascertained from the previous discussion there is a relation between proportion of pectin, sugar, acid, and salts, temperature to which the pectin is heated, and time of pouring. Increases and decreases of constituents may be made within certain limits. Salts in the fruit juice or added to it may aid jelly formation or hinder

and delay it, according to whether they tend to precipitate or stabilize the pectin.

**Inversion of sugar in jelly making.** The saturation point of a sucrose solution at room temperature or 20°C. is 67 per cent. Thus jellies containing more than 67 per cent of sucrose at 20°C. are supersaturated, unless something has occurred to the sugar. The pectin tends to keep the sugar from crystallizing from solution, acting as a protective colloid. But even this protective action would not always be great enough to keep the sugar from crystallizing with a concentration of sugar that is increased to 70 per cent or over. When sucrose is heated with acid, some of the sucrose is inverted to dextrose and levulose. The amount of inverted sugar formed during jelly making depends upon the acidity of the fruit juice and the length of time of boiling with the sugar. Since there are three sugars in the finished jelly the percentage or total sugar that can be held in the finished jelly without crystallization occurring is increased. Tarr and Baker report that in a solution containing a mixture of sucrose, dextrose, and levulose, the total maximum solubility is obtained with the proportions of each sugar shown in Table 23 (obtained from Bureau of Standards).

At 20°C. if inversion has occurred to obtain maximum solubility, about 75.7 per cent of sugar is soluble. Thus jelly containing about 70 per cent of sugar is not necessarily supersaturated. The salts and organic constituents of the fruit juice may also increase the solubility of the sugar in a given solution.

**Rate of inversion in different fruit juices.** Tarr and Baker have determined the rate of inversion of sucrose during jelly making with equivalent solutions of sulfuric, tartaric, and citric acids. As would be

TABLE 23

TOTAL MAXIMUM SOLUBILITY WITH CANE SUGAR AND INVERT SUGAR  
(*Tarr and Baker*)

Temperature, °C.	Grams of cane sugar per 100 grams solution	Grams of invert sugar per 100 grams solution	Grams of water per 100 grams solution
20	37.1	38.6	24.3
25	35.7	41.4	22.9
30	33.4	45.6	21.0

expected, they found the inversion was greater with the stronger or more highly ionized acid. Longer heating with a given hydrogen-ion concentration also increased the amount of inversion.

Tolman, Munson, and Bigelow in 1901 obtained results, which we are

now able to interpret on the basis of our present knowledge, on the inversion of sucrose by juices of different fruits. Their work was published before hydrogen-ion concentration was thought of in connection with jelly making. After determining the amount of invert sugar in a series of jellies and jams that they had made, they concluded that the inversion of the sucrose varies with the total amount of free organic acid present and the length of time the product is heated. But they found some exceptions to their conclusions. Crab-apple jelly with 0.17 per cent acid (as sulfuric) gave an inversion of 58.8 per cent of the sucrose, whereas orange jelly of the same acidity gave only 4.9 per cent of sucrose inverted. Since the inversion is in proportion to the hydrogen-ion concentration if time of heating is constant, the greatest inversion occurred with the acid giving the highest hydrogen-ion concentration, the tartaric acid of the grape. In this instance the total acidity was higher too. Plum with a high total acidity of 1.35 per cent yielded a lower percentage inverted than the grape with a total acidity of 0.69 per cent. The plum contains malic acid, which would result in a lower hydrogen-ion concentration than the tartaric.

### Kinds of Sugar Used in Jelly

Most jelly is made with sucrose. There are two sources of sucrose: one, the sugar beet; the other, sugar cane.

**Cane or beet sugar.** For some unexplained reason many persons believe that jelly cannot be made from beet sugar. Shaw in a series of over 2000 tests found no difference in the two sugars. Lowe and Redfield, working in a section of the country where many persons believe that beet sugar will not make jelly, could detect no differences in jellies made from beet and cane sugar. The sugar was sent from different sections of the state. In these experiments the source and kind of sugar were not known until the experiments were finished.

**Dextrose.** Crystalline dextrose when substituted by weight for sucrose in a fruit juice yields a jelly similar in texture to that obtained with sucrose. It is not so sweet as the jelly made with sucrose. In the jelly made with dextrose, crystallization of the sugar occurs. Crystals usually begin to form at the top of the surface of the jelly in 24 hours. They increase until the whole mass is crystallized. The shape of the masses of crystals resembles coral formation or reminds one of the flowerets of cauliflower except that they are colored. See Fig. 18. If the glass is full of jelly the crystals push up the top of the lid and bulge out over the side. Sometimes the first crystals appear in spots throughout the jelly instead of on the surface. Sometimes the first crystals are longer than 24 hours in appearing. If the jelly is turned out of the glass, crystallization occurs rapidly and the whole mass is usually crystallized in 48 hours or less. If dextrose is substituted for 50 per cent of sucrose, crystallization may not occur, and if crystals do appear they are slower in forming. About 50 per

cent of the jellies made in the author's laboratory with one-half sucrose and one-half dextrose crystallized.

**Levulose.** Levulose also forms jelly, but it is more likely to be sirupy, and if a jelly is formed the sirup must be boiled to  $107^{\circ}\text{C.}$ , which brings the levulose nearer to its saturation point.

**Maltose.** Maltose has been used by the author for gooseberry and currant jelly. Maltose is considerably less soluble than sucrose and a little

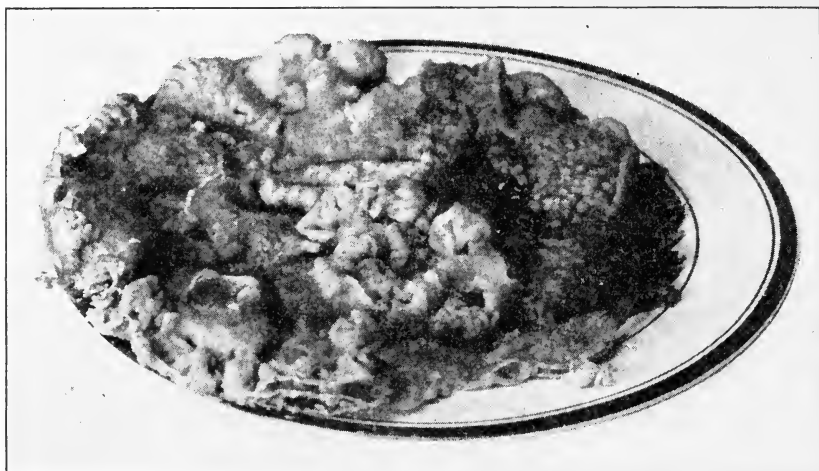


FIG. 18.—Jelly made from crystalline dextrose. Showing crystal formation 48 hours after the jelly had been turned out of the glass and 72 hours after the jelly was made.

less soluble than dextrose at room temperatures. The jelly made with maltose is very tart and crystallizes as readily, or more so, as jelly made with dextrose.

### Syneresis

Syneresis occurs in some fruit jellies. It is probably more common in cranberry jelly than in other fruit jellies. Tarr found that, with a hydrogen-ion concentration greater than  $\text{pH } 3.1$ , fluid exuded from the jelly. Myers and Baker have reported that syneresis in jellies may be brought about by the hydrogen ion alone, or by the hydrogen ion and cation of an added salt together, but not by the cation of the salt alone. They have also reported that the anion of a salt by acting as a buffering agent may prevent syneresis.

Whether syneresis occurs in a jelly also depends on the source of the pectin. The writer has never seen syneresis occur with gooseberry jelly, even when the  $\text{pH}$  of the jelly is  $2.6$  or lower. Some citrus pectins made into jelly show no syneresis at  $\text{pH } 2.0$  or lower.



The rate of dehydration or setting and mechanical disturbance after the jelly starts to set may also influence syneresis.

### Temperature for Boiling Sirup for Jelly

If the boiling point of sugar solutions is referred to, p. 49, it is found that a sugar solution containing 60 per cent of sugar boils at 103.0°C., and a 70 per cent solution boils at 106.5°C. A jelly boiled to 103°C. would contain approximately 60 per cent of sugar, and one boiled to 106.5°C. would contain approximately 70 per cent of sugar. Evidently, a jelly cooked to a temperature between these two temperatures would contain between 60 and 70 per cent of sugar.

Cruess and McNair have reported that jellies containing amounts of sugar indicated by boiling to 65° Brix give a good concentration for jelly. A solution of sugar of 65° Brix boils at sea level at 103.9°C. Cruess and McNair state that if, to the boiling point of water of any locality, 3.9°C. or 7.02°F. is added, a suitable boiling point for jelly will be obtained for that locality.

The directions in the laboratory outline state to boil the sirup to a temperature of 103°C. for jelly. This is for a location where the water boils at 99°C. This is sufficient for fruit juices that contain a high percentage of pectin and have a high acidity. This would give approximately 60 per cent of sugar in the finished jelly. Some juices with a low acidity and pectin content will yield better jelly if boiled to a higher temperature than 103°C. A temperature between 104° and 105°C. yields a jelly with a sugar content of about 65 per cent. If they do not jell with a temperature of 105° to 106°C. the juice does not contain sufficient pectin or acid.

**Jelly test.** The method of housekeepers of determining when jelly is boiled sufficiently is to let a portion of the sirup drop from a spoon. When the sirup "sheets" off the spoon the jelling temperature has been reached.

### Storage of Jelly

Jelly deteriorates in flavor on standing. Freshly made jelly has a better flavor and aroma than jelly that has been made and stored for some time. The cooking causes some decomposition of flavoring products. In standing, some of the aromatic substances and flavoring substances are volatilized and some are probably lost by decomposition.

**Storage, mold, and sugar concentration.** With too high a percentage of sugar, crystallization of the sugar may occur. With too low a concentration, the jelly will mold more readily. It will also ferment more readily than a jelly with a higher concentration of sugar. Singh has reported that jellies made with less than 65 per cent of sugar molded unless the jelly containers were sterilized.

Sterilization of the glasses, and having them dry and hot when the jelly is added, probably aid in preventing mold and also fermentation. Running melted paraffin over the top of the jelly so that it forms a complete seal is an aid in keeping it.

### Definition of Jelly

This chapter would be incomplete without giving Goldthwaite's definition of an ideal jelly. "Ideal fruit-jelly is a beautifully colored, transparent, palatable product obtained by so treating fruit-juice that the resulting mass will quiver, not flow, when removed from its mold; a product with texture so tender that it cuts easily with a spoon, and yet so firm that the angles thus produced retain their shape; a clear product that is neither sirupy, gummy, sticky, nor tough; neither is it brittle and yet it will break, and does this with distinct beautiful cleavage which leaves sparkling characteristic faces. This is that delicious, appetizing substance, a good fruit-jelly."

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## JELLY

**Directions for preparing fruit for jelly.** Apples and crab-apples are washed but not pared. Remove bad spots and wormy places but retain the seeds and core, as they contain pectic substances. Cut in rather small pieces in order to more easily extract the pectin. Gooseberries and currants are washed but do not need to be stemmed. Add sufficient water to cover apples and crab-apples. Green gooseberries can be covered with water; ripe ones should be only partially covered. For most berries about  $\frac{1}{4}$  cup of water to a pint of berries is sufficient, or else the pectin of the juice will not be sufficiently concentrated. Cranberries may be used. Rather ripe cranberries should have a smaller proportion of water than less ripe ones. Drain the juice through a heavy cloth bag. Save the pulp for a second extraction. Water-packed canned gooseberries are excellent to use, as they are easily obtained at any time of the year. The number ten size is more economical. In using the canned gooseberries the juice is not cooked for the first extraction but drained without heating.

### Experiment 23.

A. To determine the pectin content of fruit juice.

To 45 or 60 cc. of alcohol in a graduate add 15 cc. of the juice to be tested. Invert the graduate slowly and turn back. A precipitate in a mass indicates enough pectin for jelly. Pour out in a dish and lift the pectin. (See p. 157.) If a quantitative test is desired, follow some standard directions for pectin determinations.

B. Test the juice with a jelmeter. Add sugar and cook according to directions furnished with the jelmeter. Compare the jellies with those made from the same juice under Experiment 24.

### Experiment 24.

To determine the effect of varying the proportion of sugar to juice in making jelly.

Use a first extraction of juice. Use 240 grams of juice for a cup and 200 grams of sugar per cup. Add the sugar to the juice and boil until the temperature is  $103^{\circ}\text{C}$ . Be sure that the temperature reaches  $103^{\circ}\text{C}$ . before removing from the stove; read to just above the 103 mark on the thermometer rather than below it. Pour into hot, dry, sterilized jelly glasses. Sterilize by boiling in hot water, then set in a place where they will stay hot before adding the jelly. With more than  $\frac{3}{4}$  cup of sugar to a cup of juice, two of the 8-ounce jelly glasses will be needed to hold the jelly. If the percentage of sugar is to be determined in the finished jelly, weigh the pan and spoon before the juice is added. Weigh the pan, spoon, and contents on a balance as soon as the temperature of  $103^{\circ}\text{C}$ . has been reached, then pour into jelly glasses. Determine

the approximate yield of the jelly in cups by filling other jelly glasses with water to the same height as the jelly and then measure the water. This eliminates pouring the jelly into measuring cups and then into the jelly glasses.

1. Boil 2 cups of fruit juice without the addition of sugar until the desired temperature is reached. Does it give the spoon jelly test? Obtain the volume, and label it, and set aside to jell. It is best to put this quantity of juice in a large pan so that it may boil rapidly, without boiling over. When the juice is concentrated to about  $\frac{1}{2}$  cup it may be transferred to a smaller pan, as the quantity of juice at the end of the experiment is so small that it is difficult to get an accurate reading with the thermometer.

2. To 1 cup of juice add  $\frac{1}{4}$  cup of sugar. Cook until a temperature of  $103^{\circ}\text{C}$ . is reached. Pour into jelly glass. Obtain volume, label it, and set aside to jell.

3. To 1 cup of juice add  $\frac{1}{2}$  cup of sugar. Follow directions under 2.

4. To 1 cup of juice add  $\frac{3}{4}$  cup of sugar. Follow directions under 2.

5. To 1 cup of juice add 1 cup of sugar. Proceed as in 2.

6. To 1 cup of juice add  $1\frac{1}{4}$  cups of sugar. Proceed as in 2.

7. To 1 cup of juice add  $1\frac{1}{2}$  cups of sugar. Proceed as in 2. Omit 7 if the alcohol test was not exceptionally rich in pectin.

Temperature Cooked to	Yield, cups	Per cent of sugar in finished jell	Color	Texture	Flavor

Results and conclusions.

### Experiment 25.

To determine the effect on the texture of jelly when the juice is not as rich in pectin as in Experiment 24.

To the fruit pulp left from the first extraction of the juice, add water to barely cover and heat for a few minutes. Drain through a heavy cloth. Whatever the percentage of pectin in the juice in Experiment 24, there will be less pectin in the second extraction. Repeat directions under 24, 2.

1. To 1 cup of juice add  $\frac{1}{4}$  cup of sugar.

2. To 1 cup of juice add  $\frac{1}{2}$  cup of sugar.

3. To 1 cup of juice add  $\frac{3}{4}$  cup of sugar.

4. To 1 cup of juice add 1 cup of sugar.

5. To 1 cup of juice add  $1\frac{1}{4}$  cups of sugar.

Compare the resulting jellies with those of Experiment 24.

Temperature Cooked to	Yield, cups	Per cent of sugar in finished jell	Color	Texture	Flavor

Results and conclusions.

**Experiment 26.**

To determine the effect of boiling the jelly to a greater concentration.

Use juice from the first extraction. Compare the texture, volume, and percentage of sugar in the finished product with jelly from Experiment 24, 2, with the same proportion of sugar.

1. To 1 cup of juice add  $\frac{3}{4}$  cup of sugar. Cook to 104.5°C. Proceed as in Experiment 24, 2.

2. To 1 cup of juice add  $\frac{3}{4}$  cup of sugar. Cook to 106.5°C. Proceed as in Experiment 24, 2.

3. To 1 cup of juice add 1 cup of sugar. Cook to 104.5°C. Proceed as in Experiment 24, 2.

4. To 1 cup of juice add 1 cup of sugar. Cook to 106.5°C. Proceed as in Experiment 24, 2.

Temperature Cooked to	Yield, cups	Per cent of sugar in finished jell	Color	Texture	Flavor

Results and conclusions.

**Experiment 27.**

To determine the effect of cooking slowly on the color of the jelly.

1. To 1 cup of juice add  $\frac{3}{4}$  cup of sugar. Cook to 103°C. Cook quickly. Proceed as in Experiment 24, 2.

2. To 1 cup of juice add  $\frac{3}{4}$  cup of sugar. Cook slowly and cook until a temperature of 103°C. Proceed as in Experiment 24, 2.

Yield	Color	Texture	Flavor

Results.

**Experiment 28.**

To determine the effect of using different kinds of sugar in making jelly.

1. To 1 cup of juice add  $\frac{3}{4}$  cup of sucrose. Cook to 103°C. Proceed as in Experiment 24, 2. Use as a control.

2. To 1 cup of juice add 150 grams of crystalline dextrose. What is the measure of the dextrose? Cook to 103°C. Proceed as in Experiment 24, 2.

3. To 1 cup of juice add 150 grams of levulose sugar. What is the measure of the levulose? Cook to 103°C. Does it jell?

4. Repeat 3, but cook to 107°C.

5. To 1 cup of juice add 150 grams of maltose. Cook to 103°C.

Temperature Cooked to	Yield, cups	Per cent of sugar in finished jell	Color	Texture	Flavor

Results and conclusions.

What happens to the jellies in Experiment 28 after standing a few days? If crystals appear, how long does it take for them to form?

When the juice contains a smaller proportion of pectin, how does the texture of the jell compare for any definite proportion of sugar with that of jell made of a juice richer in pectin? What is the effect on the texture of the jelly of cooking the sirup to a higher temperature or concentration? Which proportion of sugar in Experiment 24 produces the best-textured jelly? Would this proportion hold for all juices? Why? What is the effect on the texture of the jelly when the proportion of sugar used is too small? On the flavor? What is the effect on the texture when the proportion of sugar is too great? On the flavor?

What is the result of substituting dextrose or levulose for sucrose on the texture of the jelly? On the flavor?

## CHAPTER VI

### GELATIN

Gelatin has been used extensively for experimental work in studying the reactions of colloidal substances, particularly in connection with gel formation.

**Uses of gelatin in foods.** In food preparation gelatin is used as a basis to make a flavored gel for salads and desserts. It is used as an emulsifying agent, to form a basis for some types of candy like marshmallows, and it is used in frozen desserts.

**Source of gelatin.** Gelatin is obtained from collagen by hydrolysis. Collagen is a protein and is found in connective tissue, tendons, cartilage, in the organic part of bone tissue, in the inner layer of skin of animals, and in fish skins, scales, and "sounds" or fish bladders. Collagen is not found as a pure substance in these tissues, but in combination with inorganic materials and with other proteins like elastin, mucin, mucoid, etc. White connective tissue is found between the muscle fibers, in tendons, and in the inner layers of skin. It contains a high percentage of collagen. The jellying of meat broth after cooling is due to the gelatin, which has been formed from the collagen of the connective tissue. Sometimes the concentration of the gelatin in the broth is not great enough to bring about the formation of a gel. When pieces of baked fish skins are allowed to cool on the baking pan, they adhere to it quite tenaciously, because of the adhesive quality of the gelatin or glue formed from the collagen of the fish skin.

#### Distinction between Gelatin and Glue

Commercially there is little distinction between gelatins and glues, except that edible gelatin is a high-grade product and complies with the Pure Food Laws. It contains only traces of harmful ingredients, and Bogue states that it should be made from "such stock and by such sanitary methods, as not to be objectionable from the ethical point of view." Glue may be made from the same type of stock as the gelatin, but usually no effort is made to remove impurities.

**Manufacture of gelatin.** In making edible gelatin the stock is or should be selected with greater care than for inedible gelatin or glue. Some edible gelatins are made entirely from bones. Others are made from calf-skin and others from pork skin. The bones of young animals contain more collagen than bones from older animals. For edible gelatin the bones are



washed to free them from dirt, then degreased by extraction of fat by fat solvents. Next the soluble lime salts are removed by leaching the bones with acid. The principal salts in bone are the calcium phosphates, but some calcium carbonate and magnesium phosphate are also found. It is difficult to free the bones from all the traces of inorganic matter, and the electrolytes left influence the  $pH$  of the resulting gelatin. The degreased bone with the inorganic salts removed is known as ossein and contains the collagen from which the gelatin is made. The ossein is soaked in lime water. In the lime water and in acid solution the collagen swells. This swelling makes it possible to hydrolyze the collagen to gelatin at lower temperatures than would otherwise be possible. This is important in the manufacture of gelatin, for with higher temperatures or long heating the jellying strength of the gelatin is lessened. The gelatin is then dried. The gelatin thus obtained has some ash and is not at the isoelectric point, but on either the acid or alkaline side of the isoelectric point. Putrefaction by bacteria must be prevented during the manufacturing process, as the bacterial action lowers the grade of gelatin obtained and odors develop that remain in the finished gelatin even if putrefaction is later stopped.

**Market types of gelatin.** Gelatin is put upon the market in three forms: granulated, pulverized, and sheet. The granulated is the form most commonly obtained.

Sheppard and Hudson have reported a new form of gelatin. It is called pressed foam gelatin. It is said to absorb water rapidly and to dissolve rapidly and it is not excessively bulky.

### Hydrolysis of Collagen

**Temperature.** When collagen is heated with water, gelatin is formed. Bogue states that this occurs at  $80^{\circ}$  to  $90^{\circ}C.$  or at higher temperatures. The reaction occurs more rapidly at higher temperatures, but at these temperatures more of the gelatin is hydrolyzed to proteoses, peptones, or amino acids. When meat is cooked in hot water the collagen of the connective tissue is converted to gelatin. The gelatin is soluble in the hot water, and as it is dissolved the muscle fibers are separated and fall apart. At temperatures below the boiling point of water a longer time is required to hydrolyze the collagen to gelatin.

**Acids.** The addition of a dilute acid hastens the hydrolysis of collagen, but this also increases the hydrolysis of the gelatin to peptones and amino acids. The latter products do not form gels, so that, in the manufacture of gelatin, it is not desirable for the gelatin to contain very much of these products. Softening of connective tissue in cooking meat is brought about in a shorter time by the addition of a small amount of acid. Tomatoes added to a stew will accomplish this purpose. Sometimes vinegar is used.

### Properties of Gelatin

Gelatin is characterized by forming a solution in water at high temperatures and, with high enough concentration, a gel at low temperatures. The dry gelatin has a slightly yellow cast and contains from 10 to 18 per cent of moisture. It swells when put in cold water, the degree of swelling being modified by acids, alkalies, or salts. It dissolves at about 35°C., and it gels at low temperatures, the exact gelation temperature depending upon the concentration and time of standing.

### Swelling and Solution

The extent to which gelatin swells in water is modified by the surface area, its initial  $pH$ , the presence of or addition of acids, alkalies, and inorganic salts, and its previous history. Bogue states that gelatin tends to absorb water equal to the amount of water it held at the last warming, but not very much over this. Thus the degree of swelling is modified by the previous history of the sample. This would include treatment during manufacture.

**Ease of hydration of gelatins.** The pulverized gelatin swells most rapidly, for it is finely divided, hence has a greater surface area. Granulated gelatin absorbs water quickly, not so rapidly as pulverized, but rapidly enough so that it is easily used in the home. Sheet gelatin may be thin or rather thick. The thin form is easily hydrated, but the thick does not hydrate so readily, and therefore requires longer soaking in cold water or a longer period of heating to dissolve. In preparing gelatin dishes the gelatin is usually allowed to soak in a small amount of cold water. During this soaking it swells. Bogue suggests that this swelling, by the formation of capillary spaces in the interior of the gelatin particles, increases the surface of the gelatin.

**Solution.** According to Bogue, soaked gelatin goes into solution more rapidly than unsoaked gelatin owing to solution occurring from the outer and inner surfaces, whereas if gelatin is put in hot water before soaking, swelling is inhibited to a certain degree and solution takes place from the outer surface only. The process of solution may be analogous to hydrolysis of collagen, i.e., just as gelatin is formed more readily from the swollen collagen, so solution may take place more readily from the swollen gelatin. Very little of the gelatin goes into solution while it is soaking in cold water. When the temperature is increased to about 35°C. the gelatin goes into solution rapidly. For food preparation this is often accomplished by adding hot water to the hydrated gelatin. It can also be accomplished by melting the hydrated gelatin over hot water and then adding cold water or fruit juices.

**Initial pH.** Bogue states that ordinary gelatin usually has a pH about 7. The pH of different commercial brands used in the laboratory for food preparation has been found to vary from pH 5 to 7. The isoelectric point of gelatin is given as pH 4.7. At this point it is least soluble, least ionized and swells the least. Bogue has found turbidity and foaming to be at a maximum at the isoelectric point. Loeb states that 1 gram of dry gelatin at the isoelectric point absorbs 7 grams of water. As the pH is decreased below 4.7 or increased above 4.7, greater absorption of water occurs until a maximum is reached. Bogue states that it is desirable from the standpoint of solubility for the gelatin to have a pH of 3.0 to 3.5, or 8 to 9. The variation of the pH of commercial gelatins is due to differences in salt content, which may increase the acidity or alkalinity. This acidity due to electrolytes, or to the treatment in acids and alkalis during manufacture, is often referred to as the residual acidity or alkalinity of the gelatin.

**Acids.** At a pH below 4.7 the amount of water absorbed increases with increasing acidity until a maximum is reached at a pH of about 3.5. As the pH is lowered more than 3.5, the amount of water absorbed decreases. Loeb states that at a pH of 3.2 to 3.5 a gram of dry gelatin absorbs about 35 grams of water. In food preparation the acid fruit juices are added after the gelatin is in solution, so that the extent of swelling during hydration is affected by the initial acidity of the gelatin. In gelatin mixtures that contain acid salts, as acid phosphates and citric acid added for flavoring, the amount of swelling would be affected by the acidity.

**Alkalies.** Alkalies have the same effect as acids upon the swelling of gelatin, except that it is not so pronounced. Bogue states that the maximum swelling on the alkaline side is at pH 9.

**Salts.** Salts also affect the water absorption of gelatin. Some salts inhibit the swelling and others favor it. Ostwald states that when salts and acids are combined the salt usually decreases swelling below the amount which would result in the presence of acid alone, even though the salt alone may increase swelling. Sugar decreases swelling. Loeb states that, if the pH of the solution is kept constant, all ions of the same valency and charge have nearly the same depressing effect upon swelling. The depressing effect increases with increasing valency.

### Gelation and Stiffening Power of Gelatin

Gelation is the formation of a gel or solidification of a gelatin solution. In food preparation it is referred to as the setting of the gelatin. The setting point is no clearly defined point. The gelatin solution becomes sirupy, like a thick sugar solution, then gradually thickens to finally form a firm gel. Thus there is no distinct point at which solidification occurs. If samples of solutions are placed in test tubes, the time at which they cease to flow may be taken as the setting point. In larger containers this is not so easy to ascertain, and it is necessary for members of the class to

compare results and all try to select a definite stiffness as the setting point. Sheppard and Sweet devised an apparatus for determining the setting point. They take the setting point as the point at which a stream of air bubbles ceases to flow through the gelatin solution.

The stiffening power and the viscosity of gelatin are affected by several factors. Usually stiffening power and viscosity run parallel, but this is not always true, for gelatins giving the highest viscosity do not always yield the stiffest jellies. Viscosity of gelatin is measured at a temperature of 35°C. by some workers and at 60°C. by others. At these temperatures gelatin is a liquid and will flow. Viscosity is measured by the rate of flow under standardized conditions; stiffening power or jelly strength is measured when the gelatin is set.

Different brands of gelatin show decided differences in stiffening power when made into gelatin to serve. If two gelatins cost the same per pound, one may be more economical than the other, if equal quantities of the gelatins when combined with the same amounts of sugar, water, and flavoring show different stiffening power.

Time, concentration, and temperature all affect the gelation process and the stiffness of the resulting jelly.

**Time of gelation.** When concentration and temperature are constant a definite length of time is necessary for gelation to occur. This is characteristic of many colloidal changes. With lessened concentration a longer time is required for gelation. At higher temperatures a longer time is required for the solidification to take place.

The firmness of the jelly is also affected by time. Some time may be required after the gelatin solution has cooled to the refrigerator temperature before gelation occurs. The jelly becomes stiffer with longer standing. Gelatins allowed to stand in the refrigerator over night at a temperature of 8° to 10°C. are stiffer than those standing only a short time after gelation has occurred. Clark and Du Bois state that after gelatin has cooled 3 hours at 0°C. little or no further increase in jelly strength occurs. Dahlberg, Carpenter, and Hening found that, for the weak gelatin solutions used in ice cream, gel formation requires a long period of time. They allowed 18 hours for gel formation and aging in most of their experiments. However, they found that the gumminess in ice cream due to too much gelatin increased during 4 to 5 weeks' storage of the ice cream. They attributed this to the "slow rate at which gelatin gels in weak concentrations come to a final equilibrium."

**Concentration.** With a definite temperature and time, solidification occurs only with a definite concentration. With increasing concentration of gelatin the time for setting is shortened. The amount of liquid that a gram of dry gelatin can bind and hold in the form of a gel is high, 1 to 2 grams forming a gel with 99 to 98 grams of water.

Ostwald states, that the solidification of gelatin in  $\frac{1}{2}$  hour depends upon the mode of preparation, but usually requires about 2 per cent at 15°C.

and 1 per cent at 0°C. To serve as food the concentration should not be too high, or the jelly is too stiff to be desirable. Some food gelatins produce a desirable texture for serving with a 1.5 per cent concentration, some require 2 per cent, and some may require as much as 3 or 4 per cent.

Manufacturers often place a quantity of gelatin in a packet or envelope and state the amount of water to be used with it. This amount of water is an average amount required under all conditions for cooling. In some instances it might be desirable to change it, on account of variation in proportion of ingredients or variation in temperatures at which it solidifies, or for other reasons. Recipes containing sauces thickened with egg or starch do not need so high a concentration of gelatin.

It is preferable to use bulk or sheet gelatin by weight, rather than by measure. On account of differences in the size of the gelatin particles, a definite measure does not yield the same weight, hence a different concentration of the gelatin would be used.

**Temperature.** With a definite concentration and time for setting, solidification occurs only with a definite temperature. For a high solidifying temperature a high concentration of gelatin is required. The slower a gelatin solution is cooled, the higher the temperature at which it solidifies. A gelatin solution may be cooled down, by packing ice around its container, to a temperature below that at which setting would occur if a longer time is allowed. On the other hand, gelatin solutions may be mixed and left standing for 2 or 3 hours at room temperature. If they are then put in ice or the refrigerator they set quite rapidly and as if gel nuclei might have started to form while standing at room temperature. At low temperatures all gelatins become firmer. At high temperatures they are liquid, for no gel occurs at temperatures above 35°C. with any concentration of gelatin. With the same concentration one gel may set at 10°C., another at 12°, still another at 14° to 16°C., and others require lower temperatures for setting. The gelatins that set at higher temperatures show jellies of greater firmness than those that set at low temperatures. The ones requiring lower temperatures than 10°C. to set do not serve very well, for they also soften at a low temperature.

**Addition of solidified gelatin to a gel solution.** Lloyd states that gelation is similar to crystallization, in that it takes place from a saturated solution. There are various theories to account for gel formation. It has been suggested that nuclei, strands, rods, or micelles form in the solution and solidification takes place upon cooling, with the formation of a gel structure. If some gelatin that has solidified is added to freshly made gelatin solution solidification takes place more rapidly. Alexander suggests that this is due to the addition of nuclei, and that other particles aggregate around these nuclei. This is similar to "seeding" or adding of crystals to crystalloidal solutions to hasten crystallization. Dahlberg, Carpenter, and Hening find that this property of gelatin has a practical application in ice-cream making. The gelatin is added to ice cream to improve the texture

and body of the ice cream. If the unfrozen ice-cream mix is aged at a temperature just above the freezing point a smoother ice cream is obtained. One reason attributed for this is the low viscosity of the freshly made gelatin solutions compared with the viscosity of the aged solutions, and another is the speed at which the gelatin gel previously aged reforms after whipping during freezing.

**Hydrogen-ion concentration.** The acidity of the gelatin affects its stiffening power. According to the kind and amount of ash and its buffer action the gelatin may have a hydrogen-ion concentration greater or less than its isoelectric point, which is  $pH$  4.7. The initial  $pH$  of different brands and samples tried in the laboratory has been above the isoelectric point. Probably the greater the acidity or alkalinity, unless it is beyond the maximum or minimum  $pH$  for the greatest water absorption, the less firm the resulting jelly. However, the  $pH$  of a gelatin solution does not entirely control the time for setting or the stiffness of the resulting gelatin. Two gelatin solutions may have the same  $pH$  and the same proportions of ingredients added, but one may require much longer than the other to set and never produce as firm a jelly.

**Acids and alkalis.** The addition of fruit juices or acid salts to the gelatin solution increases its acidity, the increase depending on the acidity of the fruit juice added, its buffer capacity, and the quantity added. Lemon juice has a lower  $pH$  than most fruit juices. Its  $pH$  varies slightly but is usually between 2.0 and 2.5. The addition of  $\frac{1}{4}$  cup of lemon juice to  $\frac{1}{2}$  ounce of gelatin with an initial  $pH$  6 to 6.5,  $3\frac{1}{2}$  cups of water and  $\frac{1}{2}$  cup of sugar, lowers the  $pH$  of the mixture around 3. This is lower than the isoelectric point of the gelatin. Many recipes use larger quantities of lemon juice than the proportion given above. This would increase the acidity still more. With a definite concentration of gelatin a less firm jelly is obtained as the amount of lemon juice is increased. A longer time is also required for the gelatin to set with the increased lemon juice or acidity.

Patten and Johnson found that a 3 per cent gelatin solution liquefied on standing when the  $pH$  was sufficiently low. Liquefaction also varied with the temperature. It occurred at a temperature of  $18^{\circ}C$ . when the gelatin solution was at  $pH$  3.6 or lower.

Some of the less acid fruit juices do not increase the acidity of the gelatin mixture as much as the lemon juice. The addition of fruit or vegetable juices such as tomato juice may bring the  $pH$  of the gelatin close to its isoelectric point. The  $pH$  of tomato juice varies somewhat but is usually between 4.2 and 4.8. The juices that bring the gelatin close to the isoelectric point do not increase the time required for gelation to the extent that the lemon juice does. Gelatin made with tomato juice varies in the length of time required for setting. But in recipes lemon juice is usually added in combination with other fruit juices, and either lemon or vinegar is often added with tomato juice for tomato gelatins. Recipes containing a

larger quantity of a very acid fruit juice may need a higher concentration of gelatin to produce a texture desired for serving.

Lemon jellies were made from the same sample of gelatin, using different proportions of lemon juice. When the quantity of lemon juice added was just sufficient to bring the hydrogen-ion concentration of the mixture to about  $pH$  4.7, the isoelectric point of gelatin, the jelly formed was cloudy and more turbid than when the  $pH$  of the mixture was lower than 4.7. Jellies with a  $pH$  lower than the isoelectric point of gelatin were clear and sparkling. They also required a longer time for the gel to form than those with a higher  $pH$ . When the series was repeated but citric acid was substituted for lemon juice, similar results were obtained.

Tartaric acid added to the gelatin solution also increases the time for gelation. A teaspoon of tartaric acid (about 3.5 grams) or a teaspoon of citric acid (about 3.5 grams) added to 3.5 grams of gelatin and 236.5 cc. of water gives the mixture about  $pH$  2.7. The jellies are clear and tart.

Patten and Johnson have reported that a 3 per cent solution of gelatin at  $20^{\circ}$  to  $22^{\circ}C.$  begins to liquefy between a  $pH$  of 8.4 and a  $pH$  of 9.2. It is not completely fluid at  $pH$  9.6.

**Salts.** It has been reported by several investigators that the gelation temperature is affected by electrolytes. The effect is usually given as follows for anions at equal concentrations. The first of the series elevates the gelation temperature, and it is slightly lower for each following anion, until the iodide may lower the gelation temperature below  $0^{\circ}C.$   $SO_4 > citrate > tartrate > acetate > Cl > ClO_3 > NO_3 > Br > I.$  This is the order above the isoelectric point. When enough lemon juice or acid has been added so that the reaction is below the isoelectric point the cations may have more effect than the anions. The order of anions given above indicates that some salts would increase the tenderness of gelatin gels whereas others would increase the gel strength.

Dahlberg, Carpenter, and Hening found that the gel strength was greater in milk than in water, even when the proportion of gelatin added to the milk was based on the water content of the milk and not on its total volume or weight. They found that the change in hydrogen-ion concentration did not account for this increase in jelly strength in all the samples. The other factors that might influence the jelly strength were the salt and protein content of the milk. They state that the "influence of salts on gel strength has been observed by other investigators, so it may be one of the means by which skim milk altered gel strength."

**Sugar.** Small amounts of non-electrolytes do not appreciably affect the viscosity of gelatin solutions, but in large quantities sugar increases the viscosity, as a thick sugar sirup is more viscous than a thin one. Loeb has reported that cane sugar does not diminish the viscosity of gelatin solutions, but at concentrations of  $M/8$  or over may increase it slightly. The sugar has a similar effect upon the stiffening power. Some concentrations of sugar do not seem to affect the stiffening power, but others do. Ostwald

states that 1 gram of sugar added to 9 cc. of a 6 per cent gelatin solution accelerates gelation. This would give about 10 per cent of sugar in the solution. Larger quantities of sugar may retard gelation.

**Opacity in gelatin.** Edwards states that two factors of prime importance in gelatin are its strength and clarity of aqueous solution. In regard to clarity he says that many perplexing problems occur in this connection, for a gelatin may be clear at one concentration but, if further diluted, may appear turbid. He says that a complete explanation of the problem of turbidity has yet to be made, but some causes are as follows: (1) actual dirt, particles of animal tissue and fibers, (2) mold, (3) emulsified grease and calcium salts of fatty acids, (4) protein salts and proteins other than gelatin which precipitate and remain in suspension when the  $pH$  of the solution is varied, (5) a calcium sulfate-phosphate complex which is retained in solution by the presence of sulfurous acid, and (6) colloidal sulfur.

Edwards states that the first two enumerated difficulties should not be present and when detected the gelatin should be condemned. Emulsified grease is more difficult to remove. It results from the employment of greasy material, extraction of gelatin at the wrong  $pH$ , the agitation of liquid in the boiling vat, and improper filtration. The presence of proteins other than gelatin is more likely to occur in a skin gelatin. Mucin and chondrin are readily soluble in weak alkalis and are thrown out of solution by acids. Hence they are less likely to be found in acid gelatins. Cloudiness due to the presence of insoluble calcium sulfate-phosphate complex is more likely to be found in ossein gelatins. Colloidal sulfur is more likely to be found in glue than in gelatin stock.

Gelatin is used in the meat trade for packing tongues, chickens, and glazing hams. Sometimes a cloudy precipitate appears which is caused by too much calcium in the gelatin.

Black mentions that unless the copper content of the gelatin is low a purplish discoloration may appear with meats and particularly with chicken and tongues.

Another cause for turbidity is discussed by Clayton. At the isoelectric point the gelatin solutions always show more turbidity, a 400 per cent increase in turbidity occurring with a  $pH$  variation of 0.03 ( $pH$  4.87 to 4.90). Gelatin stock treated with lime shows greatest turbidity on the acid side of the isoelectric point and, *vice versa*, those stocks treated with acid possess isoelectric points in the region of  $pH$  7 to 8.

**Previous history.** The temperature to which a gelatin has been previously heated will cause a variation in its viscosity. It may also change its stiffening power. This heating may be due to heating during manufacture or to heating for dissolving in the home. The latter is seldom long enough to destroy the jelly strength to any appreciable extent. A gelatin solution that has solidified and then is melted will form a gel in a shorter time for the second or third gelation.



**Agitation and foam formation.** Bogue and Alexander both state that agitation or stirring lessens the viscosity of gelatin solutions. This might also affect the jelly strength. Gelatins are often beaten when they have become thick but not firmly set. The beating incorporates air, forming a foam, and the gelatin mixture increases in volume. Bogue states that the ability for gelatin to form a foam is greatest at the isoelectric point. At this point the gelatin particles have a strong tendency to adhere to each other, and this favors foam formation. If the beating is done at the time when the gelatin has set enough to be quite viscid, but has not become brittle, so that the edges break apart, the volume may be increased two or three times that of the original unbeaten gelatin. The lessening of firmness may be partially due to agitation of the gelatin, but part is due to the incorporation of air. The gelatin at this stage is elastic and stretches to surround the air particles. The gelatin that is to be beaten should have the flavoring in larger quantity than for an unbeaten gelatin as the increase in volume causes the flavor to seem less concentrated. If gelatin becomes too firm before the beating is started the gelatin only breaks and air is not incorporated. Whipped cream and beaten egg white are often folded into unbeaten gelatin or into beaten gelatin.

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## GELATIN

**Directions for cooling gelatin.** The gelatin solutions should be put to cool at the same temperature. Those from the same experiment should be on the same shelf in the refrigerator, as the upper shelves have a higher temperature than the lower ones. A cooling room is a splendid place to put them while cooling. For class work when periods are short the setting may be hastened by putting the containers in crushed ice. The ice should be the same depth around all the containers. It is better to have all the containers for one experiment in the same pan of ice for cooling. The containers should be the same size, shape, and material, for if they are not the same size the surface area for cooling will be greater for some than for others. Enamel or aluminum are good materials for cooling gelatin solutions. Crockery or china cools more slowly than metal.

The proportion of gelatin suggested in the following experiments, 3.5 grams for a cup of liquid, is not the best proportion for all gelatins. With some brands or grades about 2 per cent or about 4.8 grams per cup of liquid will be required for the best results. Find the best proportion of gelatin for the brand that is being used and substitute that amount for the amount given in the experiments. Use the same brand for all the experiments except Experiment 30.

Record the time and temperature when the gelatin is mixed, when it begins to gel around the edges, and when set. If cooled in crushed ice make a record of the temperature every 5 minutes and plot on graph paper. Find the effect on the texture of the gelatin of standing 20 minutes at

room temperature. Most gelatins will need to stand at least 20 minutes or longer for serving.

### Experiment 29.

To determine the effect of dissolving gelatin by different methods on the time required for setting and the temperature at which gelation occurs.

A. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Add 206.5 cc. of boiling water. Stir until dissolved. Record the temperature when mixed and the time when mixed. Set in crushed ice. Record time and temperature every 5 minutes or more often until set. Plot on graph paper.

B. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Let stand 5 minutes, then melt over hot water. The temperature of the hot water should be 85 to 90°C. Stir the gelatin until melted, remove from above the hot water and add gradually while stirring 206.5 cc. of cold water. Follow directions for cooling under A.

C. Hydrate 3.5 grams of gelatin with 30 cc. of cold water for 5 minutes. Stir while adding 60 cc. of boiling water. After gelatin is dissolved add 131.5 cc. of cold water. Follow directions for cooling under A. Compare the length of time required for setting, the temperature at which setting occurs, and the ease of dissolving by each method.

What proportion of an ounce is 3.5 grams? What proportion of an envelope of gelatin? What is the measure in teaspoons? A total of 240 grams of liquid and gelatin is used. What proportion of 240 grams is 15 cc.? What percentage is 3.5 grams?

Gelatin, grams	Gelatin, measure	Gelatin, per cent	Time required to set	Temperature when mixed	Temperature when set

Results and conclusions.

### Experiment 30.

To determine the stiffening power of different brands of gelatin.

Use as many different brands and kinds of gelatin as you can obtain. Use plain gelatin. If acidulated gelatins are used they should be compared with acidulated gelatins and not with plain ones. Notice the color and odor of each gelatin solution. Use a total of 240 grams of gelatin and liquid. Compare the length of time required to set and the firmness of the jellies. Do any of the gelatins require too long a time to set to serve in a reasonable time? Are any of the gelatins too firm?

1. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Dissolve by warming over hot water. Add 176.5 cc. of cold water, 30 cc. of lemon juice, and 50 grams of sugar. Follow directions under 29A for cooling.

2. Repeat 30,1, with as many different brands and grades of gelatin as have been obtained.

Brand of gelatin	Gelatin, per cent	Time to set	Temperature when mixed	Temperature when set	Texture	Color	Odor

Results and conclusions.

### Experiment 31.

To determine the effect of distilled water, fruit juices, tomato, and vinegar upon the stiffening power of gelatin and upon the time required for gelation. Use a plain gelatin.

#### A. Water.

1. Use tap water. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Follow directions for cooling under Experiment 29A.

2. Repeat A1, but use distilled water.

3. Repeat A1, but use softened water if obtainable.

#### B. Lemon juice.

1. Repeat A1, but reduce the cold water to 191.5 cc. and add 15 cc. of lemon juice.

2. Repeat A1, but reduce the cold water to 176.5 cc. and increase lemon juice to 30 cc.

3. Repeat A1, but reduce the cold water to 146.5 cc. and add 60 cc. of lemon juice.

4. Repeat A1, but reduce the cold water to 86.5 cc. and add 120 cc. of lemon juice.

#### C. Grape juice.

1. Repeat B1, but substitute grape juice for the lemon juice.

2. Repeat B2, but substitute grape juice for the lemon juice.

3. Repeat B3, but substitute grape juice for the lemon juice.

4. Repeat B4, but substitute grape juice for the lemon juice.

#### D. Tomato juice.

1. Repeat A1, but substitute tomato juice for the cold water.

#### E. Vinegar.

1. Repeat B2, but substitute vinegar for the lemon juice.

2. Repeat B3, but substitute vinegar for the lemon juice.

Gelatin, per cent	Time required to set	Temperature when set	Proportion of acid added	Color	Texture

Results and conclusions.

**Experiment 32.**

To determine the effect of varying the percentage of gelatin upon the time required for gelation and the stiffness of the gelatin.

1. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Dissolve by warming over hot water. Add 176.5 cc. of cold water, 30 cc. of lemon juice, and 50 grams of sugar.

2. Repeat 32,1, but increase the gelatin to 4.8 grams and reduce the cold water to 174 cc. What is the percentage of gelatin used? Its measure?

3. Repeat 32,1, but increase the gelatin to 5.8 grams and reduce the cold water to 172 cc. What is the percentage of gelatin used? Its measure?

4. Repeat 32,1, but increase the gelatin to 7.2 grams and decrease the cold water to 171 cc.

5. Repeat 32,1, but decrease the gelatin to 2.4 grams and increase the cold water to 192.5 cc.

Gelatin, grams	Gelatin, measure	Gelatin, per cent	Time to set	Temperature when set	Texture

Results and conclusions.

**Experiment 33.**

To determine the effect of high temperatures upon the stiffening power of gelatin.

**A. Plain gelatin.**

1. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Cover the bowl to prevent the steam from condensing in the bowl and increasing the quantity of liquid in the gelatin. If the quantity of liquid is increased, measure it and decrease the cold water added accordingly. Place the covered bowl in a pressure cooker and heat for 15 minutes at 15 pounds pressure. Take from the cooker and add 176.5 cc. of cold water, 30 cc. of lemon juice, and 50 grams of sugar.

2. Repeat A1, but after hydrating add the lemon juice to the gelatin before heating in the pressure cooker.

3. Hydrate 3.5 grams of gelatin in 30 cc. of cold water. Melt over hot water, then add 176.5 cc. of cold water, 30 cc. of lemon juice, and 50 grams of sugar.

Does hydrolysis occur more rapidly when the gelatin contains an acid or when plain? Does the one with the acid ever become stiff enough to serve?

**B. Acidulated gelatin.**

Repeat the directions under 33A, but use acidulated gelatin. Notice the proportions given on the package for a cup of liquid and use the part of a package needed for a cup of the gelatin solution. What is its weight and measure? Make up 1 cup without heating in the cooker for a control. Compare with A for time required to set and the texture of the gelatin.

**Experiment 34.**

To determine the effect of sugar upon the texture of a gelatin jelly.

1. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Dissolve by warming over hot water, then add 176.5 cc. of cold water, and 30 cc. of lemon juice.

2. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Dissolve by warming over hot water, then add 176.5 cc. of cold water, 30 cc. of lemon juice, and 50 grams of sugar.

3. Hydrate 3.5 grams of gelatin with 30 cc. of cold water. Dissolve by warming over hot water, then add 176.5 cc. of cold water, 30 cc. of lemon juice, and 100 grams of sugar. Compare the stiffness of the gelatins and the time required to set. If desired the lemon juice may be omitted in Experiment 34 and the cold water increased to 206.5 cc. This will show the effect of the sugar upon gelation and the stiffness of the jelly without the added lemon juice.

Sugar, grams	Time to set	Temperature when set	Texture	Effect of sugar on texture

Results and conclusions.

**Experiment 35.**

To determine the effect of fresh pineapple on the gelation property of gelatin.

Hydrate 7 grams of gelatin with 60 cc. of cold water. Dissolve by warming over hot water, then add 330 cc. of cold water, 60 cc. of lemon juice, and 100 grams of sugar. Divide into two equal portions.

1. To part one add 2 tablespoons of grated raw pineapple. Cool.

2. To part two add 2 tablespoons of cooked grated pineapple. Cool. Does the gelatin containing the uncooked pineapple gel? Why? What is the effect of cooking upon the pineapple? Results.

**Experiment 36.**

To determine the effect on the texture of gelatin of beating and the addition of whipped cream and beaten egg white.

Make up 4 cups of lemon jelly by hydrating 14 grams of gelatin with 120 cc. of cold water. Dissolve by warming over hot water, then add 720 cc. of cold water, 120 cc. of lemon juice, and 200 grams of sugar. Divide into 4 equal parts. Metal quart cups are good to use for gelatins that are to be beaten as the volume may be measured without removing from the container.

1. Cool.

2. Cool until it becomes thick enough to beat. Beat with an egg beater until the volume increases. Cool until firm. Obtain volume.

3. Repeat 36,2, but after beating fold in a stiffly beaten egg white. Cool until firm. Obtain volume.

4. Repeat 36,2, but after beating fold in  $\frac{1}{2}$  cup of whipped cream. Cool until firm. Obtain volume.

Compare for volume, flavor, texture, and number of servings obtained. Does the volume increase or decrease when the whipped cream is folded into the gelatin? Is the above proportion of lemon juice best for both a plain jelly and a beaten jelly? What proportion of lemon juice and sugar would you suggest for a plain jelly? For a beaten jelly?

Volume	Number of servings	Texture	Flavor

Results and conclusions.

## CHAPTER VII

### MEAT

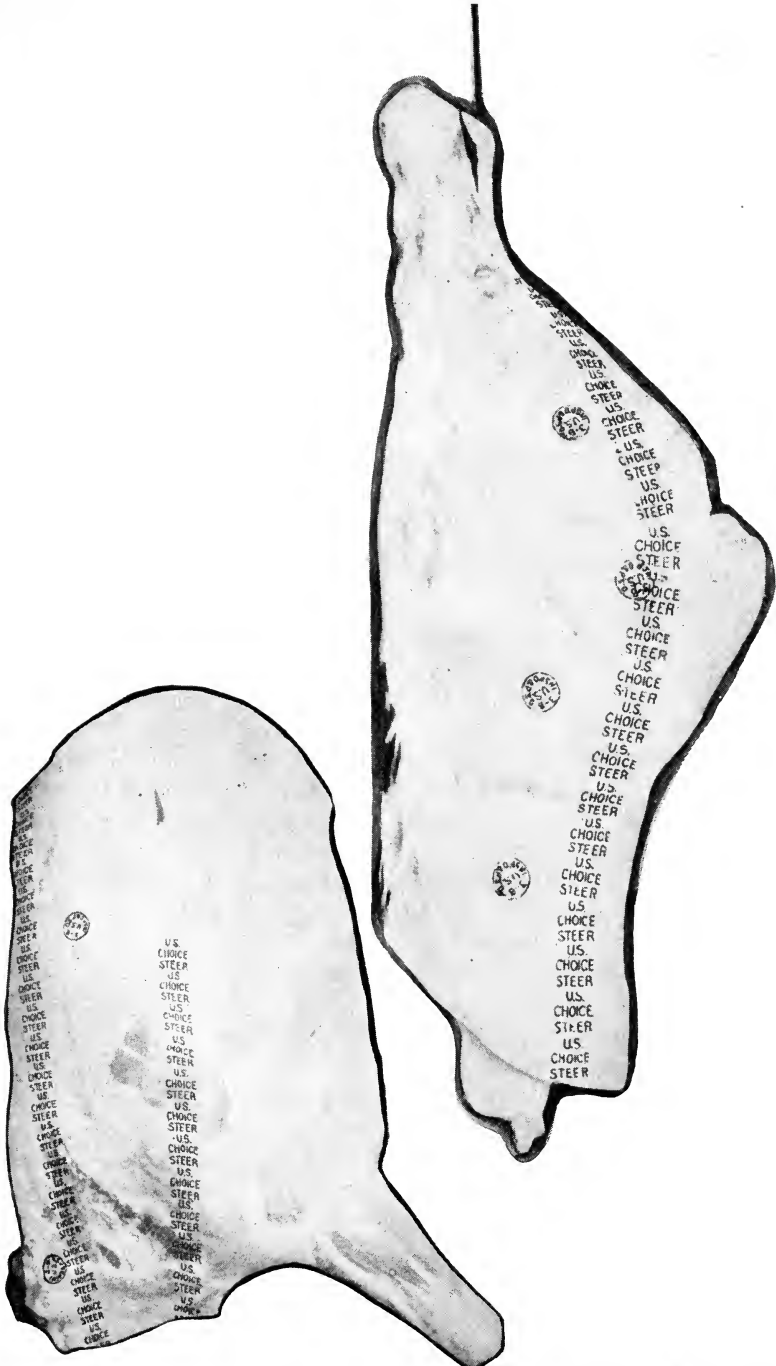
#### Grading and Stamping of Meat

Federal grading and stamping of meat was inaugurated in 1927. Davis states that because the government grading is not influenced by season, geographical location, or any other factor, the purchaser is assured, whether by long distance or over-the-counter sales, of always securing, within certain narrow limits, the same quality of meat when buying a definite United States grade. The service has grown until United States graded meat can be purchased in many, though not all retail markets.

**Classes of meat.** Bovine animals are divided, because of characteristics at different ages, into veal, calves, yearlings, and mature beef. Sometimes baby beeves are given as a separate group between calves and yearlings. The usual trade practise is to group baby beeves with yearlings. Sheep are divided into lambs, yearlings, and mutton. The division into classes is based on sex. Thus the classes of beef are steer-, heifer-, cow-, bull-, and stag-beef. Carcasses from each class are further subdivided into grades. Grading divides, in so far as possible, the carcasses, or subdivisions thereof, of the uncooked meat into groups, the various grades indicating the relative desirability of the meat for ultimate consumption, there being no exact dividing line between one grade and that just higher or lower.

**Basis for grading.** The basis for grading is on what the grader calls quality, conformation, and finish. Quality in so far as appearance can foretell includes relative tenderness, juiciness, and palatability. By conformation is meant the form or shape, animals having broad, large, full muscles, with relatively smaller proportion of bone, being graded highest. Finish refers to the amount, quality, and color of fat within and around the muscle. A few points considered in grading do not always affect the palatability of the meat. For example, the fat of beef usually becomes more yellow with age, so that whiter fat is graded higher than creamy or more yellow fat. Yet in animals of the same age the deeper yellow color of the fat indicates that the animal with more yellow fat had more carotene in its feed. If conformation and finish both rated high, the meat from the animal with yellow fat would undoubtedly be as palatable and also have more nutritive value than meat from an animal with white fat. Grass-fed animals, because the meat is darker in color, may be graded lower, even when all other points rate high.





*Courtesy Bureau of Agricultural Economics, Dept. Agriculture.*

FIG. 19.—Showing the manner of branding for the hind and fore quarters of United States graded beef. The small round marks are inspection brands.

**United States grading is a promiscuous service.** The grading may be done by federal graders or by the packers, but if by the packers only for packer grades. If done by federal graders the meat is stamped with the class of animal and the United States grade. See Fig. 19. The service is paid for by the buyer of the meat. Grading is not a compulsory service but a promiscuous one. Davis states the cost of grading varies in different establishments in proportion to the number of carcasses graded and stamped. But the cost is small, being less than  $1/20$  of a cent a pound. Hence, any extra cost to the consumer should be largely for the quality obtained rather than the cost of stamping. Grading insures the purchaser of uniform quality, and both buyer and purchaser use the same terminology for specifications and qualifications. In Seattle and in some other cities, all retail cuts must be plainly labeled with the United States grade.

**Grades.** In general classes of carcasses are divided into seven or six United States grades, though pork because it is more uniform in quality than beef or mutton has only four grades. Steer- and heifer-beef are divided into seven grades, but cow-, bull-, and stag-beef are divided into six grades, the top grade, Prime, being omitted. Lamb and mutton are divided into six grades.

The seven United States beef grades are designated by both a name and a number and follow: No. A1, Prime; No. 1, Choice; No. 2, Good; No. 3, Medium; No. 4, Common; No. 5, Cutter; and No. 6, Low Cutter. The grades for lamb and mutton are similar to those for beef, except that No. 5 is called Cull and there is no No. 6. The pork grades are No. 1, No. 2, No. 3, and Cull.

The stamp indicating the grade is put on with a roller. The material used for stamping is an edible, vegetable compound which often disappears during cooking. Stamping starts at the shank, continues over the round, the rump, the loin, along the back over the prime-rib beef cuts, and to the neck. See Fig. 19. In beef another line is put over the shoulder. Thus the stamp indicating grade occurs on all major retail cuts. Although, as has been indicated, all the grades may be stamped, in actual practise the bulk of the beef that has been graded and stamped has been the Prime, Choice, and Good grades of steers and heifers. Some Choice cow-beef is stamped. Only a small amount of steer- and heifer-beef below Good is graded and practically no bull- or stag-beef is graded.

The proportion of classes to total beef, in percentage, for a 30-month period, July 1, 1918, to Dec. 31, 1920, are given by Davis and Whalin as follows: Steer, 49.94; bull and stag, 3.57; cow, 36.53; and heifer-beef, 14.96.

The approximate distribution of steer-beef by grades is given by Davis and Whalin as follows: Prime, about 0.5; Choice, 4; Good, 22; Medium, 53; Common, 17; and Cutter and Low Cutter combined about 3.5 per cent.

Very little of the two lowest grades can be purchased on the retail

market, practically all of the meat, except that used for boneless cuts such as tenderloin, being used in products like sausage.

**Packer brands.** Packers designate their better quality of meat by brand names. If the United States grade is stamped on the meat the packer brand is not used.

### Federal Inspection of Meat

All meats shipped from one state to another are under federal surveillance. This includes the meat produced by the larger establishments, about two-thirds of that consumed. Each state and the cities usually have some regulations concerning meats and supervision of local plants.

The purpose of inspection is to insure that the meat sold to the consumer is from healthy animals, in sound condition at the time of slaughter.

The inspection stamp is round and is placed on each wholesale cut and on all grades of meat. In Fig. 19, the four round stamps are inspection stamps placed on what will be the wholesale cuts of round, rump, sirloin, and short loin.

Inspection of carcasses and the supervision of making of meat products safeguard the consumer. However, in one instance, inspection cannot entirely safeguard the consumer. There is no accurate, quick method that can be used in inspection that detects trichinae in trichinae-infected pork, though federal supervision does insure that products to be consumed without further cooking are so treated that no live trichinae are present. It should be stated that only a small percentage of pork is infected with trichinae.

**Trichinosis.** Trichinosis is contracted by eating uncooked, trichinae-infected meat, usually pork. Any animal eating pork may contract the disease, however, and cases have been reported in the medical literature that were traced to the eating of raw, jerked bear meat.

It is assumed that anyone buying fresh pork chops, roasts, etc., will cook the meat. But some people grind raw lean pork, season it, and use it in sandwiches. Others in making homemade sausage taste the uncooked product to see that the seasoning is satisfactory.

Ransom and Schwartz found that live trichinae are quickly destroyed by heating the meat to 55°C. They may be destroyed at 50°C. if the meat is held at this temperature for a sufficient time. Ransom found that trichinae are destroyed by freezing, provided the frozen, infected meat is held at a temperature not higher than 5°F. for 10 days.

All lean pork, in plants under federal supervision, used with other meat, or in pork products that are to be consumed without further cooking, must be treated to make sure that any live trichinae that may be present are destroyed. Such products include soft or fresh and dry summer sausages, frankfurters and Vienna-style sausages, Italian and Westphalian-style hams,

pork butts in casings, cured pork loins in or without casings, capicola, coppa, cotto salami, and other products.

In general the methods used for destruction of trichinae are (1) freezing and storage and (2) heating, or a combination of one or more of these methods.

The freezing treatment is called refrigeration. The lean pork and pork trimmings are frozen. The specifications, based on the work of Ransom and allowing 10 extra days for a margin of safety, are that the frozen meat must be stored for 20 days at a temperature not higher than 5°F.

Heating is called processing. The specifications, based on the work of Ransom and Schwartz and allowing a margin for safety, are that the meat must be heated to 58.3°C. (137°F.). Some products may be heated to only 128°F. but must be held at this temperature, often in a smoke room, for a specified number of hours.

Salt treatment is used for some products, but a large amount, 4.5 per cent, of salt must be used and a dry cure employed. The meat must be held in this salt cure for a period of 20 to 25 days at specified temperatures and further specific procedures must be followed.

### Definition of Meat and Flesh

The Food and Drug Administration in "The Service and Regulatory Announcements of 1933" define meat and flesh as follows: "Meat is the properly dressed flesh derived from cattle, from swine, from sheep or goats sufficiently mature and in good health at the time of slaughter, but is restricted to that part of the striated muscle which is skeletal or that which is found in the tongue, in the diaphragm, in the heart, or in the esophagus, and does not include that found in the lips, in the snout, or in the ears, with or without the accompanying and overlying fat, and the portions of bone, sinew, nerve, and blood vessels which normally accompany the flesh and which may not have been separated from it in the process of dressing it for sale.

"Flesh is any edible part of the striated muscle of an animal. The term 'animal' as herein used, indicates a mammal, a fowl, a fish, a crustacean, a mollusk, or any other animal used as a source of food."

### Muscles

A muscle is an organ made up of fibers held together by connective tissue and surrounded by a sheath of heavier connective tissue. The fibers are grouped parallel to each other in bundles called fasciculi. See Fig. 20. Even the thinner sheets of connective tissue entering the bundle are shown in some portions of the photograph. The connective tissue entering the fasciculi is the endomysium. The size of the bundles or fasciculi varies in different muscles and determines to a certain extent the grain of the meat.

The connective tissue surrounding the fasciculi, the perimysium, varies in thickness, being quite perceptible to the eye in some muscles, as in the outer muscle of prime ribs shown in Fig. 20. In some muscles it is scarcely discernible. The connective tissue enclosing each muscle is known as the epimysium or muscle sheath. The thicker, denser portions of the muscle sheath are often little changed during cooking and constitute tough spots in the meat.

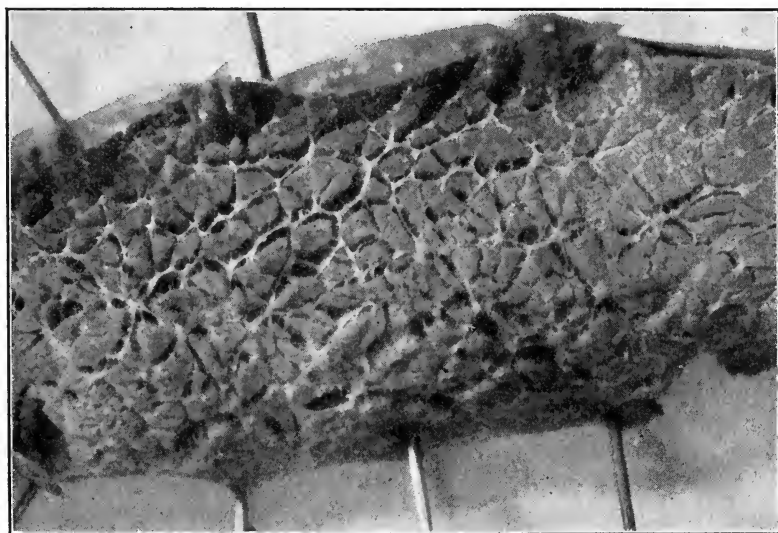


FIG. 20.—This photograph shows the bundles of muscle fibers, the fasciculi, and the surrounding connective tissue, the perimysium. Even the connective tissue entering the bundles of muscle fibers is shown in many places. This muscle is the narrow muscle along the outer edge of a beef roast. The photograph was taken after the meat was cooked. The muscle is pulled apart and pinned back. Enlarged about three times.

The spaces between the muscles, the fasciculi, or the cells are referred to as intermuscular, interfascicular, or intercellular; the area within the muscle, the fasciculus, or cell is called intramuscular, intrafascicular, or intracellular.

**Classes of muscles.** Muscles are divided into two groups, the skeletal, voluntary, or cross-striated and the smooth, plain, or long-striated. The smooth muscles occur in the walls of the hollow viscera, i.e., the intestinal tract, the arteries, veins, etc. Heart muscle is cross-striated but in many of its characteristics it falls between the two groups, voluntary and involuntary. The skeletal and heart muscles compose the muscle designated as flesh by the Food and Drug Administration.

**Some muscles are exercised more than others.** The muscles in the body of an animal are not exercised or used equally. Thus, depending upon

the extent to which the muscles have been used, "tender" and "less-tender" cuts are obtained from the same animal. In general the less-tender cuts are obtained from the neck and legs, the tender cuts along the back.

### Fat

Fat may be deposited around and between each muscle, i.e., intermuscularly; between the fasciculi, interfascicularly; between the fibers, intrafascicularly; or within the fiber, intracellularly. The nodular white spaces between the fibers, Fig. 21, were occupied by fat cells, i.e., intrafascicular fat. The fat was removed in preparation of the section, but the membrane between the fat cells still shows. Although fat deposited around and within the muscle is not important in the contraction of the muscle, that around the muscle, and particularly in roasts, bastes the roast during cooking and thus affects the palatability.

**Fat content.** The fat content of the body, and hence of the muscles and finally the "cuts" of meat, varies with the nutritive condition and age of the animal. Well-nourished animals have more fat distributed over and throughout the muscles. In general older animals tend to deposit more fat within and around the muscle than young ones.

It is generally conceded that the presence of fat around and particularly within the muscle increases the juiciness of the meat. Some water is deposited with the fat and this, combined with melted fat is probably responsible for the apparent increased juiciness.

*Some cuts contain more fat.* Cuts coming from certain locations contain relatively more fat than cuts from other parts of the body. Fat tends to be deposited first subcutaneously and around the internal organs. In general deposition of fat intermuscularly and intramuscularly comes later, and last of all its deposit within the individual fibers. The deposition of fat within the lean tissues is known as marbling, which undoubtedly increases the palatability of the meat. But to secure marbled muscular tissues a rather thick fat covering is essential (i.e., the portion of the cut lying beneath the skin) and, because meat is eaten primarily for its lean content, many housewives think this fat covering of the muscles is unnecessary. The fat covering differs in thickness in various cuts so that no definite statement can be made as to the most desirable thickness. But for a prime rib roast most persons prefer a covering of about  $\frac{3}{4}$  inch, some liking more and others less. The fat covering can become so thick and heavy that it does not materially increase the palatability and is wasteful.

**Adipose tissue.** Adipose tissue is largely made up of fat cells within connective tissue. For human fatty tissue Burns gives the composition: water 15 per cent, fat 82.5 per cent, and protein 2.5 per cent. Gortner states that adipose tissue often contains as much as or more water than it does fat.



*Courtesy of Fred J. Beard, Iowa State College*

FIG. 21.—Longitudinal section of muscle fibers of beef. The white nodular spaces are fat cells. The pulling apart of the fibers in preparation is shown by the long, narrow, white spaces. The burlled looking part of the fibers is due to pulling of the knife edge in cutting. The cross striations show plainly in the fibers to the left of the fat cells. Magnification approximately  $\times 200$ .

**Size of fat cells.** The size of the fat cells varies with the nutritional state of the animal. Hammond states that they may be 10 to  $20\mu$  in a starved animal,  $50\mu$  in one in ordinary condition, and up to  $175\mu$  in a very fat one. The cells are smaller within the connective tissue and in the marbling fat within the muscles and larger around the internal organs and subcutaneously.

### Connective Tissue

Hammond states, that there is evidence that the connective tissues go on growing longer than other tissues in the body, and that maturity in them is not reached so soon as in other tissues. This may be one explanation of why meat from older animals is in general tougher than meat from younger animals. Hammond says that with increased feeding fat is deposited in the connective tissue.

**Kinds of connective tissue.** The connective tissue of meat is composed of two kinds, the yellow and the white. The amount and kind vary in meat from different animals and in different cuts from the same animal. Burns states that the function of the tissue governs the form produced. When binding power alone is required the white tissue is formed, but when elasticity as well as strength is necessary, there the yellow tissue is found. Tendons are composed almost entirely of the white, non-elastic tissue; ligaments are principally the yellow tissue. Many muscles seem to require both elastic and binding tissue, hence both are often found in the connective tissue binding the fibers.

The yellow connective tissue is feebly but perfectly elastic and is found in ligaments, in the connective tissue between the muscle fibers, in the walls of the blood vessels, and in other parts of the body. The best example of the yellow tissue is the ligamentum nuchae of the ox. It is the tough yellow ligament found along the backbone, which is used in elevating the head of the animal; it is much thicker and heavier along the ribs and fore quarter than along the loin.

The white connective tissue is non-elastic and is found in the connective tissue between the muscle fibers and in the tendons, the tendon Achilles being a good example.

**Composition of connective tissue.** The percentage of water in the connective tissue of the young animal is higher than in the older animal. Buerger and Gies have reported that the white connective tissue of the calf contains about 68 per cent of water, whereas that of the ox has about 63 per cent. The solids of the connective tissue are made up of inorganic and organic matter. Buerger and Gies have reported the following composition of the tendon Achilles of the ox; Vandergrift and Gies have reported the composition of ligamentum nuchae of the ox.

The collagen and elastin content of connective tissue are of especial



TABLE 24

COMPOSITION OF THE FRESH TISSUE OF ACHILLES TENDON AND THE FRESH LIGAMENTUM NUCHAE OF THE OX

Constituents	Tendon Achilles, per cent	Ligamentum nuchae, per cent
Water.....	62.870	57.570
Solids.....	37.130	42.430
Inorganic matter.....	0.470	0.470
SO <sub>3</sub> .....	0.031	0.026
P <sub>2</sub> O <sub>5</sub> .....	0.039	0.035
Cl.....	0.147	0.136
Organic matter.....	36.660	41.960
Fat (ether-soluble matter).....	1.040	1.120
Albumin, globulin.....	0.220	0.616
Mucoid.....	1.282	0.525
Elastin.....	1.633	31.670
Collagen (gelatin).....	31.588	7.230
Extractives and undetermined.....	0.896	0.799

interest in meat cookery, for both are found in the connective tissue between the muscle fibers, but heat and moisture affect the two differently.

**Collagen.** Table 24 shows that the white connective tissue contains nearly 32 per cent of collagen and about 7 per cent of elastin. Collagen in the presence of moisture and at high temperatures yields gelatin. Bogue states that collagen is changed to gelatin more rapidly at the boiling temperature of water, or at temperatures above boiling obtained by pressure, and more slowly at temperatures below boiling. The gelatin is dissolved in the water or broth. If the meat is cooked long enough, the larger part of the connective tissue is dissolved, so that the muscle fibers may fall entirely apart. Sometimes in cooked meat only the outer portion of the fibers is separated and the inner portion is still connected. The surface of the meat reaches a high temperature before the interior of the meat, thus the collagen of the connective tissue near the surface may be changed to gelatin first.

**Elastin.** Vandergrift and Gies have reported the yellow connective tissue as containing about 32 per cent of elastin and about 2 per cent of collagen. The elastin is a very resistant, firm protein and is not changed or affected by heat and moisture. In cooking, yellow connective tissue is not softened. Consequently cuts of meat containing large amounts of elastin in the connective tissue will be tough after cooking, whereas cuts containing large amounts of collagen may have part or all of the collagen changed to gelatin.

TABLE 25

CONNECTIVE TISSUE PROTEINS IN MEAT (*Mitchell, Zimmerman, and Hamilton*)

No.	Description of sample	Total nitrogen in sample, per cent	Collagen nitrogen in percentage of total N	Elastin nitrogen in percentage of total N	Collagen and elastin nitrogen in percentage of total N
1.	Beef rib.....	3.19	8.4 7.9	6.4 7.2	14.8 15.1
4.	Beef rib.....	3.35	4.2 4.2	8.1 8.2	12.9 12.4
5.	Beef shank.....	3.42	7.5 6.2	14.4 12.0	21.9 18.2
6.	Pork tenderloin.....	3.68	3.0 2.3	1.7 1.8	4.7 4.2
7.	Chicken, composite boneless meat from 2-lb. cockerels.....	3.63	19.6	5.2	24.8
8.	Chicken, composite boneless meat from 2-lb. pullets.....	3.48	17.8 18.0	3.7 4.1	21.5 22.1
11.	Chicken, breast muscle from 3-lb. cockerel....	3.24	2.1 1.1	0.8 0.6	2.9 1.7
12.	Chicken, thigh muscle from 3-lb. cockerel....	3.21	2.4 2.0	3.7 6.5	6.1 8.5
13.	Chicken, breast muscle from 3-lb. pullet.....	4.06	3.4	0.3	3.7
14.	Chicken, thigh muscle from 3-lb. pullet.....	3.23	12.2 12.4	1.7 1.7	13.9 14.2
15.	Chicken, breast muscle from 4-lb. cockerel....	4.14	6.5 6.8	1.6 1.6	8.1 8.4
16.	Chicken, thigh muscle from 4-lb. cockerel....	3.69	11.9 13.5	1.8 2.4	13.8 13.9

Less tender cuts have more connective tissue. Data given in Table 25 are from the earlier work of Mitchell *et al.*, so that the percentage of elastin given is too high, but the comparative amounts in different cuts are shown.

In later work Mitchell and co-workers found that the percentage of elastin in muscle is small, but in general the less tender contain a larger proportion than the tender cuts.

From the experiments, results given in Table 26, Mitchell *et al.* find no relation between the ordinary market grading of beef carcasses and the connective-tissue content, the eye-muscle of ribs from the carcass of a canner cow having no more collagen than that from a choice steer. The results of their "investigation lend no support to the belief that the appearance, texture, and firmness of beef lean give reliable information concerning its tenderness." This suggests that other factors than the connective-tissue content alone affect the tenderness of meat, for most persons would prefer taking a chance on the eye-muscle of ribs from a choice steer being more tender than that from a canner cow.

Pork contains little connective tissue. Mitchell *et al.* have found that all the different cuts of pork contained more nearly the same percentage of connective tissue than the different cuts of veal or beef.

TABLE 26

THE COLLAGEN AND ELASTIN CONTENT OF THE "RIBEYES" OF THE 9TH, 10TH, AND 11TH RIBS OF BEEVES OF DIFFERENT GRADE (Mitchell, Hamilton, and Haines)

Carcass grade	Estimated age, years	Sex	Dry matter content, per cent	N content, per cent	Fat content, per cent	Collagen-content, per cent	Elastin-content, per cent	Collagen N in per cent of total N	Elastin N in per cent of total N
Choice	1	steer	25.82	3.59	2.50	1.08	0.004	5.4	0.02
Choice	2	steer	27.87	3.55	4.35	1.89	0.006	9.4	0.03
Good+	4	steer	29.07	3.25	7.78	1.19	0.011	6.5	0.06
Good	young	cow	25.16	3.42	2.99	1.16	0.001	6.1	0.005
Good	4	steer	29.48	3.30	7.14	1.33	0.002	7.2	0.01
Good+	2	steer	26.08	3.57	3.54	1.49	0.003	7.4	0.015
Medium+	1	heifer	23.82	3.34	0.97	1.05	.....	5.6	.....
Medium+	..	cow	26.82	3.34	4.63	1.59	0.002	8.5	0.01
Medium+	3-4	steer	26.83	3.36	5.18	1.32	0.008	7.0	0.04
Medium	3-4	steer	26.12	3.40	3.62	1.15	0.032	6.1	0.16
Common+	old	cow	25.22	3.46	2.92	1.74	0.004	9.0	0.02
Canner	14-15	cow	26.62	3.56	3.51	0.92	0.008	4.6	0.04

**Connective tissue in fish.** The connective tissue of fish is small in amount and probably contains mostly collagen with little or no elastin, for it is very easily disintegrated and easily dissolved by cooking, leaving the muscle fibers separated.

### The Muscle Fibers

Each fiber is elongated, cylindrical, and multi-nucleated. Howell states its length does not exceed 36 mm. but the species is not stated. The average length varies in different muscles in the same animal and in the same muscles in different kinds of animals. Hammond says that the average length of goat fibers is said to be greater than those of beef, and those of beef greater than fibers in mutton. The average diameter also varies in different muscles, in different species, and in the same animal with age. Hammond found the average diameter of a particular muscle of Suffolk ram at birth, at 5 months, and at 4 years to be  $12.8\mu$ ,  $40.3\mu$ , and  $54.1\mu$ , respectively. It is commonly accepted that the number of fibers does not increase after birth so that, in spite of increase in diameter with age, the size of the muscle is largely determined by the number and length of the fibers rather than their thickness.

Each fiber is enclosed in the sarcolemma, a thin, elastic membrane. A thin, delicate band occurring regularly along the length of the fiber divides the fiber into its structural units, the sarcomeres, a fiber being composed of a succession of sarcomeres. A dark band shows in the middle of each sarcomere, a lighter band on either side. The material between the fibrils is known as the sarcoplasm and the relative amount of sarcoplasm varies in muscles of different animals.

The contracting tissue, the fibrils, run the length of the fiber. The fibrils consist of alternating light and dark segments which form the cross striations of the fibers. See Figs. 21 and 22. The cross bands are supposed to be of denser structure than the material between these bands. Fig. 22 shows the immense number of these cross striations. The cross striations also show plainly in the fibers of Fig. 21.

All the material within the sarcolemma is known as the muscle plasma and in the living muscle is in a semi-liquid state.

*Effect of exercise and maturity upon fibers.* Beard in his study of "Tough and Tender Meat" states that "muscle fibers attain their maturity by use and age. Development implies increase in size rather than maturity." Beard made a microscopic study of different muscles of five different animals. The animals selected for study were a heifer, a short-fed steer, a prime steer, an old cow, and a veal calf. Some of his observations and conclusions are as follows:

"Connective tissue seems more apparent in thinner fleshed beef.

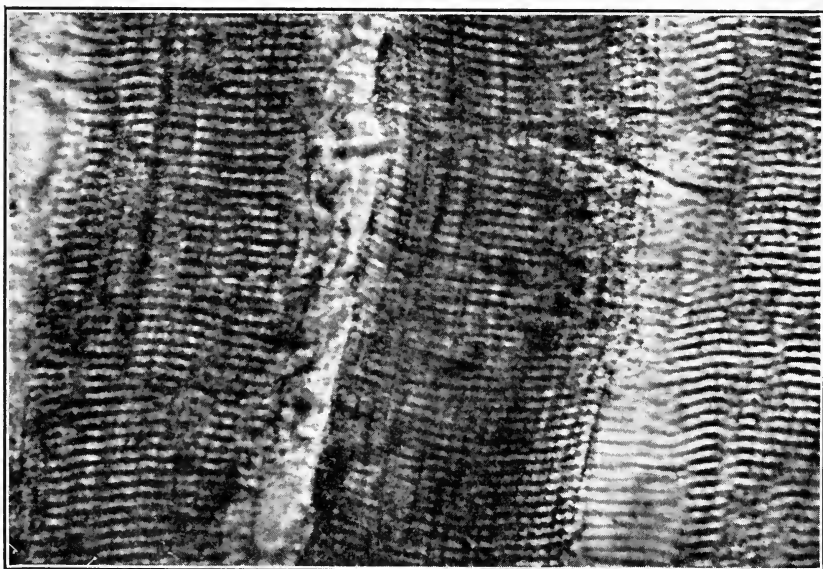
"There was intracellular fat (fatty degeneration) in the fat steer.

“The fat steer had more intrafascicular, intercellular fat than any animals studied.

“The inherent properties of the endomysium contribute to the toughness of meat more than does the size of the fiber.

“The muscle fibers from the region of the toughest meat contain the densest sarcoplasm, while fibers from the tenderest muscles contain the lightest sarcoplasm.

“Intramuscular and particularly intrafascicular fat lessens the toughness of meat.



*Courtesy of Fred J. Beard, Iowa State College*

FIG. 22.—Longitudinal section of muscle fibers of beef, showing cross striations. Magnification approximately  $\times 1400$ .

“Where only a small amount of intramuscular fat is found it is almost always interfascicular. As the interfascicular fat increases in amount intrafascicular fat appears which is first intercellular and in case of excessive adiposity intracellular also.”

Beard states that “while those muscles which are brought most into activity and those performing the greatest amount of work may not possess a larger fiber than those muscles which are less active, the more active muscles do have a thicker perimysium and apparently more substance in the fiber, as manifested in the staining characters of the sections.”

*Toughness of meat.* Since meat is composed of muscle fibers and connective tissue, toughness of meat must be due to either of these, or to both. Toughness of connective tissue depends upon the proportion of elastin and collagen; upon the thickness or density of the tissue, which is brought

about by use and activity; and possibly upon age, for it is common knowledge that meat from old animals and fowls, whether domestic or wild, is tougher than that from young animals. Toughness of the muscle fiber depends upon the development and the density of the fiber due to activity, and possibly to changes brought about by age.

The deposition of fat, either intramuscularly, intrafascicularly, or intracellularly, tends to lessen the toughness. This is shown by the results of mechanical tests with the dynamometer, which are given in Table 27. The muscle used for these tests was the "eye" of beef or the longissimus dorsi. The judges, as shown by scores, agreed with the mechanical tests, the roasts from the fattened animals being judged more tender than the roasts from the lean animals. The possibility of toughness due to power to bind water, which may be influenced by the reaction and salt content of the fibers, thereby affecting the turgidity of the fibers, and the possibility of toughening the fibers by heat coagulation are still to be considered.

TABLE 27  
RESULTS OF TENDERNESS TEST WITH DYNAMOMETER ON FRESH BEEF  
(*Helser, Nelson, Lowe, and Helser*)

	Calves			Yearlings			Two-year-olds		
	Feed-ers	Fat-tened	Per-cent-de-crease in pounds re-quired to shear meat	Feed-ers	Fat-tened	Per-cent-de-crease in pounds re-quired to shear meat	Feed-ers	Fat-tened	Per-cent-de-crease in pounds re-quired to shear meat
Pounds pull required to shear the meat . . . . .	39.50	32.37	18.05	35.41	24.75	30.10	36.78	28.62	22.19

### Constituents of the Muscle Fibers

The muscle fibers contain several constituents, and these are grouped as follows by Howell: "(1) Inorganic salts. (2) Ferments. (3) Pigments. (4) Non-nitrogenous extractives (lactic acid, etc.). (5) Nitrogenous

extractives (creatine, urea, etc.). (6) Carbohydrates and fats. (7) Proteins."

**Inorganic salts.** In meat cookery the inorganic salt most noticeable from the standpoint of flavor is sodium chloride or common salt. The juice from meat that has had no salt added before or during cooking tastes salty. This is due to the sodium chloride of the body fluids, which contain about 0.85 per cent. Care should be taken in adding salt to meat, or the salt added in cooking plus that of the juices will result in an excess of salt in the drippings and in gravy made from them. The muscle fibers do not taste as salty as the juices, particularly if a large portion of the fluid has been lost in cooking. The tissues do not contain as high a percentage of sodium chloride as the fluids of the body.

The inorganic salts are found in a complex salt equilibrium in meat.

**The ferments.** Several different kinds of enzymes are found in muscle tissue. The proteolytic, amylolytic, and lipolytic enzymes act on proteins, carbohydrates, and fats, respectively.

**Pigments and hemoglobin.** When animals are slaughtered for food the blood is drained from the body. However, some blood clings to walls of the capillaries in the tissues. This blood together with the muscle pigments gives to meat its pink or red color.

The hemoglobin of the red corpuscles is the pigment giving blood its purplish-red color. The combination of hemoglobin with oxygen forms oxyhemoglobin, which is a bright scarlet. Meat is a darker bluish-red when first cut, but if the cut surface remains exposed to the air it becomes a brighter red color. When hemoglobin and oxyhemoglobin are acted upon by enzymes, acids, alkalies, or heat, various decomposition products are formed. Hematin is one of the decomposition products formed by heat. The coagulating temperature of oxyhemoglobin is around 64°C. Thus when meat is cooked to temperatures higher than this the production of hematin brings about the brown or gray color of well-done meats. Dilute acids or alkalies may also produce hematin from hemoglobin.

**Muscle pigments.** The red pigments of muscles resemble the hemoglobin of the blood. These pigments are sometimes designated as chromatin substances. Whipple and Robscheit-Robbins call them muscle hemoglobin, and they have reported that the properties of the muscle hemoglobin are practically the same as or identical with those of blood hemoglobin. Whipple has found the content of muscle hemoglobin higher in active hunting dogs than in inactive house dogs. He states that under different conditions the muscles may contain from 10 to 80 grams of muscle hemoglobin for each 100 grams of blood hemoglobin.

Skeletal muscles vary in color in the same animal and in different species. Sometimes the pigmentation varies in the same species but with different types or breeds. Dairy cattle have darker-colored muscles than the beef types. The color of the muscle of the young animal is often lighter than that of the same muscle from an older animal. Veal is lighter in color

than beef, and the leg muscles of broilers are lighter than those of mature fowls. Different muscles of the rabbit vary in color from a very light pink to a deep red. The different muscles of pork also vary in color. In general the muscles of the lower animals are not pigmented, with the exception of the heart muscle. The muscles of fish are white or light in color, but the muscles of nearly all mammals are red. Needham states that "red pigmentation seems to occur in muscles from which the most persistent and prolonged activity is required." Earlier investigators have also suggested that in general pigmentation occurs in muscles used most frequently.

*Effect of ripening upon meat pigments.* Meat that has been ripened 40 to 60 days is usually a deeper gray in color, when cooked, than unripened meat from the same animal, provided the cooking conditions are the same. The darker color may be due to the action of enzymes and acid upon the hemoglobin, so that more hemoglobin is broken down to produce hematin at lower cooking temperatures, or it may be due to other factors.

**Non-nitrogenous extractives.** Lactic acid is always present in muscle tissue. The amount is small while the muscle is at rest and increases during and after exercise. After death the percentage of lactic acid in the muscle increases.

**Nitrogenous extractives.** Muscle tissue contains end products of protein metabolism. These are removed as they accumulate during life from the tissues by the body fluids and are excreted through the kidneys. Creatine and creatinine are found in the muscles and to a lesser extent in the blood. Uric acid and other nitrogenous extractives are also found in the muscles. They are of interest in meat cookery, because they are the source of part of the distinctive flavor of meat, and stimulate the flow of gastric juice.

**Carbohydrates and fats.** The carbohydrate found in the muscle tissue is glycogen.

Burns states "the fat content of the cell is unique. Every cell has a fairly constant content of lipide, although when stained by the usual methods to demonstrate fat, no evidence is given of such a content. This masked fat is only made visible when the cell is diseased or disintegrated."

**The proteins of the muscle fibers.** The proteins of the muscles are composed largely of two types: (1) the structural proteins, which consist largely of collagen and elastin and (2) the protoplasmic proteins, variously called myosinogen, myogen, myosin, and myoglobulin. The two types of proteins behave differently when heated, the effect of heat on the structural or connective tissue proteins having been considered. The proteins of the plasma are soluble in certain concentrations of salt solutions, such as sodium chloride, sodium sulfate, magnesium sulfate, ammonium sulfate, sodium phosphate, and other salts. Hence, they are often referred to as the soluble proteins.

The entity of the meat proteins is in the same status as that of flour



and other food proteins. (See proteins of flour, Chapter XI.) They may or may not be a mixture of proteins having similar properties.

The soluble muscle proteins are most commonly designated as myosin and myogen. They are classified as globulins, the myosin being completely precipitated and the myogen partially precipitated by saturated magnesium sulfate. However, complete information about these proteins is lacking. Moran quotes Muralt as suggesting that the fibrils are composed of a firmer material (myosin) surrounded by the more liquid or gel-like myogen (sarcoplasm). The evidence for this was based on X-ray studies, but is not generally accepted. Since myogen is doubly refractive, this is almost conclusive proof that it occupies the light bands in the muscle fibers.

*Characteristics of proteins.* One of the outstanding characteristics is the extent to which solubility is affected by small changes in salt concentrations. Smith has reported that exhaustive extraction with any given salt yields only a fraction of the total protein. The highest yield, about 90 per cent, was obtained with 1.87 M  $\text{NH}_4\text{Cl}$ , followed by 1.65 M  $\text{LiCl}$ , and a still lower percentage with the other salts tried. Howe found that the total globulins (myosin and myogen) compose about one-third of the total protein of the muscle, and that the insoluble protein composes approximately one-half of the total protein of the muscles of the cow, calf, and rabbit. In addition to variation with concentration, with the number of extractions, and with different salts, the solubility varies with  $\text{pH}$ . In general the proteins are less soluble at the isoelectric point.

The plasma proteins undergo denaturation by heat, acids, and surface orientation. That the lactate ion affects the extent of denaturation and the resulting density of myosin and albumen has been mentioned in Chapter I. Still greater changes are brought about by heat when the meat is cooked. In meat not only myosin and myogen may be found, but also denatured myosin and denatured myogen. In cooked meats these proteins may be entirely denatured.

*Isoelectric point of muscle proteins.* Smith gives the isoelectric point of myosin as  $\text{pH}$  5.0-5.3 and that of myogen as  $\text{pH}$  6.3. Burns has given the isoelectric point of myosin at  $\text{pH}$  3.9 and that for the myoproteins at  $\text{pH}$  4.5 and 5.

### Post-Mortem Changes in Meat

Immediately after slaughter, changes occur in the muscle of an animal. These changes, like the changes in milk and eggs, can be retarded by method of handling and storage. They are brought about by enzymes and microorganisms, and by chemical and physical means which alter the structure and chemical composition of the meat.

Muscle in the living animal is (1) pliant, soft, gel-like, yet somewhat viscous. After slaughter the muscles pass from this state into a stiff or rigid one (2) known as rigor mortis, or muscle rigor. After some time

the muscles again become pliant. This stage (3) is known as the passing of rigor. With longer storage enzymes and chemical means bring about (4) more extensive changes which produce ripened meat. With bacterial action and still more extensive changes (5) incipient putrefaction occurs. The passage from one stage to another is gradual with no definite dividing zone and is accelerated at higher temperatures and retarded at lower ones.

Meat may be cooked during any of these stages and heat denaturation causes characteristic changes which are part of the post-mortem changes. Means of retarding these changes will be considered before these changes are discussed.

Meat cooked before the onset of rigor is said to be tender. But rigor develops quickly so that this period is short. Concerning the question of tenderness of meat before the onset of rigor, Dr. Trowbridge, who has had many years of experience in meat work, wrote the author, "I doubt if freshly killed meat is ever as tender as the same meat ripened."

**Preservation of meat. Freezing.** Meat may be frozen and then stored at temperatures of  $-10^{\circ}$  to  $-15^{\circ}\text{F}$ . In this way the post-mortem changes are nearly inhibited.

**Curing.** Common salt is the basis of all cures or pickles. Although many modifications are used, the methods may be divided into two classes, brine and dry-salt cures. Salt not only preserves but tends to dry the meat. Sugar may be added for flavor. Sugar also tends to keep the muscles softer than when salt is used alone and thus tends to increase the tenderness. When sugar is added to the brine, the process is known as "sugar cure" or "sweet pickle." Saltpeter (potassium nitrate) or Chili saltpeter (sodium nitrate) or the nitrite salts of potassium and sodium may be used in cured meat. The red color of cured meat is due to the action of nitrite on the hemoglobin of the muscle. If only nitrate salts are used in the brine, they are reduced to nitrite by bacterial action.

Cured meat may be smoked and partially dried on the surface. Actual smoke and not chemical treatment to produce a smoke flavor must be used in establishments under federal inspection.

Ham, bacon, and salt pork are probably the best known of cured pork products. The loins when cured are often known as Canadian bacon.

Dried or chipped beef and corned beef are among the more familiar cured-beef products. Beef cured in a brine is known as corned beef. Beef cuts most often cured are the plates, flanks, and rumps, though from the lower grades the chucks and rounds are often used. Dried beef is cured in a sweet pickle, then dried and smoked. Usually the rounds and sometimes the shoulder clods are used for dried beef.

**Cold storage.** The passing of rigor, ripening, and development of putrefaction are delayed by quickly chilling the dressed meat and keeping it at a low temperature just above the freezing point of meat. Moran states that if the dressed meat is chilled slowly more protein is denatured than if it is chilled quickly, and, because bacteria attack denatured protein more

rapidly than native protein, quick chilling is one means of increasing the storage life of meat.

*Chemically conditioned cold.* Moran states that with temperature control alone the storage life of chilled beef is about 35 to 40 days. If, in addition to low temperature control, what is sometimes known as "chemically conditioned cold," i.e., 10 per cent of carbon dioxide, is used in the storage atmosphere, the storage life of the meat may be extended to 60 or 70 days. The carbon dioxide retards or checks bacterial growth but if too much is used with red meats such as beef and mutton, the surface of the meat turns dark. This is because of the decreased amount of oxygen obtained by the meat when carbon dioxide is increased. For fish a higher percentage of carbon dioxide can be used. Stansby and Griffith have reported that haddock packed in ice and plus an atmosphere of 15 to 40 per cent of carbon dioxide have their storage life doubled over that when packed in ice alone.

*Contamination with bacteria and storage life.* Another factor affecting the storage life of meat is the initial contamination with bacteria. But with care the initial contamination should be small. Other things being equal, the smaller the initial load of bacteria the longer the storage life of the meat. Spoilage by bacteria, yeasts, and molds is largely surface, and in general does not extend to a greater depth than  $\frac{1}{4}$  to  $\frac{1}{2}$  inch. Hoagland, McBryde, and Powick in their investigations of changes in beef during cold storage above freezing found that "bacteria and molds grow on the surface of cold storage carcasses but do not penetrate to any great depth (less than 1 inch in 177 days)."

Microorganisms may enter the meat by penetration from the surface, which is a slow process, and by following the cavities in meat, that is, the blood and lymph vessels.

Empey found that bacteria grow and develop very slowly on meat during rigor, as a pH of approximately 5.3 to 5.6 is not a desirable one for their growth. Stansby and Griffith also found that bacteria do not develop rapidly on fish during rigor.

**Humidity.** Mueller and Richardson have reported that dry air as well as the low temperature is a factor in preventing bacterial growth. Hoagland, McBryde, and Powick found that in a cooler with low humidity the growth of mold on the surface of the meat at 177 days was no greater than in a cooler with higher humidity at 53 days.

**Storage of meat in the home.** Proper storage of meat in the home is often a problem. Halves and quarters of dressed animals have a natural protective skin covering. But when wholesale cuts are divided into smaller parts, the surface area for contamination and the contamination both increase from these cut surfaces coming in contact with meat blocks, hands, wrapping paper, and kitchen and refrigerator utensils. In general, unless frozen, meat should not be stored long in the home. Low temperatures and

dry circulating air increase the storage life of meat. Burnett found roasts keep best, steaks and chops next, and ground meat most poorly.

**Rigor.** During rigor meat is less tender than after the passage of rigor, so that rigor is of interest in meat cookery.

*Cause.* The exact cause for the development of rigor is not known. Hardy has suggested that two reversible reactions occurring in living muscle, namely, glycogen  $\rightleftharpoons$  lactic acid and phosphagen  $\rightleftharpoons$  phosphoric acid and creatine, are no longer reversible and after death proceed in one direction with the accumulation of lactic acid and creatine in the tissues.

Lactic acid has some rôle in the development of rigor, as rigor is usually accompanied by or preceded by increase in lactic acid. But, Moran states, under certain conditions, i.e., if an animal has been treated with insulin or iodoacetic, rigor develops without the production of lactic acid. He also adds that there are a number of chemical reactions which take place at death that have not been defined and among them will be found the cause or stimulus leading to the changes in the state of the proteins.

*Time of onset of rigor.* At ordinary temperatures rigor is usually complete in 10 to 12 hours. Rigor is supposed to develop more slowly at lower and more rapidly at higher temperatures. But Smith found the effect of temperature on the rate of onset of rigor to be variable.

*Only skeletal muscles develop rigor.* The proportion of soluble protein is sometimes given as an explanation of why some muscles develop a greater degree of rigor than others. Skeletal muscles contain a higher percentage of soluble proteins than smooth muscles. The carcass of the pig generally does not develop rigor, but occasionally one does. It is therefore interesting to surmise whether this is due to a small proportion of soluble protein or to other causes.

If there is more lactic acid than usual in the muscle of the animal when killed, as happens when an animal is hunted or a chicken is chased before killing, rigor sets in more quickly. Benson has reported that rigor sets in more rapidly in fatigued fish muscle (trawl-caught) than in the muscle of fish taken from a pen.

*Changes occurring during rigor.* In addition to the development of turgidity, other changes occur simultaneously, for enzyme action does not cease at the time of slaughter. There is evolution of heat known as the heat of rigor. The glycogen practically disappears from the tissues and this glycogen loss parallels the lactic acid increase. Moran states that for mammalian muscle the lactic acid reaches a value of approximately 0.8 per cent. The  $pH$  of the muscle falls from  $pH$  7.2 or 7.4 to about  $pH$  5.6 or 5.8, sometimes as low as  $pH$  5.3. Because of various factors, such as amount of glycogen to form lactic acid, the  $pH$  reached during rigor varies somewhat.

It had previously been found without exception that the amount of soluble protein is decreased during rigor; but Smith found no change in solubility of the proteins in his investigation.

*Passing of rigor from muscles.* After a lapse of time rigor passes off. The length of time varies with the speed with which rigor developed, with different conditions and temperatures of storage, and with different animals. It may require 5 to 6 days or longer at refrigeration temperature and a shorter period at higher temperatures. It passes more rapidly from a carcass in which rigor develops early. With the passing of rigor the muscles become more soft and flexible. One observation that the author's family often made was that chickens killed and stored before cooking over night in the cellar were more tender than chickens cooked and eaten the same day they were killed. The temperature of the cellar was higher than that of a refrigerator, and the chickens were often chased before killing; these factors probably affected the time required for the passing of rigor.

The greatest physical change with passing of rigor is the increasing tenderness of the meat.

**Ripened meat.** Noticeable changes that characterize ripened meat, meat from which rigor has passed and which has stood some time, are increased tenderness, change in flavor, and increased ease with which juice may be pressed from the meat. The last is probably related to the increased juiciness of the cooked, ripened meat.

Emmett and Grindley have reviewed the literature on changes in meat during storage. The report of the work of Grassman is from their summary.

In experiments reported by Hoagland *et al.*, for beef stored just above the freezing point of the meat from 17 to 177 days, it is interesting to note that all judges agreed that the flavor and tenderness of the meat are improved with 15 to 30 days of storage. With storage for 45 days and longer, they speak of an "old," "gamey," and "off" flavor. From the comments one is led to believe that they like the meat stored for 56 days better than that stored for 45 days. This was probably due to differences in the character of the quarters of beef from different animals. With longer storage the flavor was not palatable, "old" and "off" being used to describe the flavor developed.

Grassman has reported ripened meat as being more juicy, of better flavor, and more tender than unripened meat. He adds that ripening meat to the extent preferred by the English for roasting is not good for boiling, as it imparts a disagreeable flavor to the broth.

Whether one prefers the flavor of ripened meat or that of fresh meat is largely a matter of personal choice. It is hard to describe the flavor of ripened meat, probably because there are no descriptive terms which convey the same meaning to different people. Ripened meat is more acid, is richer in flavor, and has more of a high or game flavor. Ripening may also improve the flavor of the fat of the beef. The fat from some animals develops a better flavor with ripening than that of other animals. When it is improved, the flavor of the fat is more agreeable and more mellow. However, the kind of feed the animal has received, as well as the age, sex,

breed of animal, and the amount of fat may influence the flavor of the meat and the fat.

*Length of time required for ripening.* The length of time required for ripening varies according to the degree of ripened flavor desired, and the temperature at which the meat is stored. As the temperature is elevated the time for ripening is shortened. At temperatures a little above the freezing point of meat, 20 to 40 days seems to give the optimum flavor. Longer than 40 days gives too high a flavor for most persons. Helser says, "When ripened meat is properly trimmed and prepared there will be no mold flavor at all, but you will have a rich, juicy, tender, and well-flavored piece of meat. One trial will convince anyone."

*Finished carcasses are best for ripening.* Helser states that well-finished carcasses are best suited for ripening purposes. Meat from carcasses of animals that contain little fat "will get sticky, mold, and will have to be trimmed heavily to avoid the moldy flavor." The layer of fat on the outside of the prime beef and the greater quantity of fat in the muscle fibers prevent the putrefactive bacteria from developing. Ripened meat develops a growth of mold on the surface of the meat that must be removed before cooking. Helser states: "The degree of ripeness is judged largely by the length of the 'whiskers,' as the mold is sometimes called."

*Changes in cooked beef due to ripening.* Helser, Nelson, and Lowe have found that roasts from the same animal, refrigerated under the same conditions, show several distinct changes in cooking from that of fresh beef. All the roasts were cooked at the same oven temperature and to the same interior temperature. Roasts cooked after 10, 20, 40, and 60 days of storage show a progressively gray color in the interior of the cooked roasts. Roasts cooked to an inner temperature of 57°C. and cooked on the fifth, seventh, and tenth days of storage were a bright red color; whereas those ripened 60 days have only a little red or rose color. Roasts from calves are less red and more gray in color than roasts from older animals.

Roasts from ripened beef brown more readily—and this is true for both the fat and lean—than unripened roasts from the same animal, cooked under the same conditions. In these experiments the results of scores for palatability indicate that "in order to produce beef for roasts having the most desirable beef flavor, steers should be at least 20 months old, and preferably 30."

After the passing of rigor the roasts are more tender and become increasingly tender with length of storage. Although the tenderness of the meat increases with storage, the increase after 20 days of storage is probably not great enough to pay for the increased cost and trouble of storing.

With longer storage the roasts are more juicy. Also with ripening the quantity of juice collecting in the platter when the roast is carved is decidedly greater than for roasts cooked after 10 days or less than 10 days of storage.

The flavor of the beef improved with ripening, and the maximum

development of flavor, under the refrigeration conditions used, came with 20 to 40 days of storage. For the connoisseur of flavor, this improved flavor is decidedly worth the cost of storage.

**Incipient putrefaction.** Much discussion has occurred concerning the presence of bacteria within muscle. Moran states that in freshly killed muscle there is usually a low bacterial count. Hoagland, McBryde, and Powick found that certain bacteria may normally be present in some carcasses of beef, but they possessed no pathological significance and did not multiply in proper cold-storage conditions. At low-storage temperatures, spoilage by bacteria is most prevalent at the surface of the meat. As has been indicated, growth is slow during rigor, for the acidity of the meat does not favor the development of microorganisms. But with increased storage of meat, the acidity of the meat is lessened or the alkalinity increases and ammonia is liberated.

Of the different tests proposed for the detection of incipient putrefaction, Baker believes that the determination of ammonical nitrogen has been the most useful and the presence of 0.02-0.025 per cent indicates the beginning of putrefaction. Thus Baker suggests that, when the  $pH$  has risen to  $pH$  6.2 the meat has undergone deterioration.

**Changes occurring in meat during storage.** *Changes due to enzymes.* The lipolytic, amylolytic, and proteolytic enzymes act on fats, carbohydrates, and proteins, respectively. During life, these and other enzymes are concerned with the metabolic processes of the body.

Enzyme changes are usually brought about more rapidly with higher temperatures. At very low temperatures the action may be very slow and different from that at higher temperatures owing to differences in activity of different enzymes at different temperatures. Hoagland, McBryde, and Powick have reported that the external fat and kidney fat in beef stored just above the freezing point of the meat showed increased fatty acid content and a corresponding deterioration of these fats. They found less change in the intramuscular fat, as it was protected from bacterial action, and changes in it were due to lipase enzymes. Oxidative changes in fats are of course greater in the surface fat. The surface fat in ripened meat often shows greater changes in flavor than interior fat.

Amylolytic enzymes bring about the change of glycogen to lactic acid. These changes occur rather early in storage.

Proteolytic enzymes bring about changes of the proteins to amino acids, thus increasing the amino nitrogen, or the non-protein nitrogen, or the soluble nitrogen products of the meat. Hoagland, McBryde, and Powick found that, in quarters of beef stored 14 to 177 days, the increase in amino nitrogen amounted to 3 to 7 per cent of the total nitrogen of the beef.

*Autolytic changes in beef at 37°C.* Hoagland, McBryde, and Powick stored pieces of beef free from bacteria in sterile containers at a temperature of 37°C. for periods of 7 to 100 days. Considerable juice exuded from the pieces of meat, which turned brown in color. The beef was also brown

on the surface for about  $\frac{1}{4}$  inch in depth, except where it touched the container, and this was bright pink in color. Hoagland has reported that this deep pink to a purplish-red color is due to hematorporphyrin. Its formation is attributed to enzymes. The meat retained its original form; the sample stored 100 days was somewhat more tender than the one stored 7 days. The changes in the meat that could be detected by the senses of sight, smell, and taste they called organoleptic changes. The odor changed with increasing age. This change they describe as "rather old but not unpleasant." The broiled 103-day sample of meat "is quite tender and has an old, highly acid, and rather disagreeable flavor, which persists in the mouth after eating; the meat is not entirely objectionable but is not appetizing." In ordinary storage conditions meat cannot be kept free from bacteria and is not stored at such a high temperature.

*Chemical changes.* In storage of meat the changes due to different factors such as bacteria, enzymes, etc., are brought about simultaneously. The chemical changes are the changes in the percentage of the different constituents of the meat, however these may be brought about. Stored meat usually loses weight by reason of moisture loss. The acidity increases. Emmett and Grindley found that beef refrigerated 22 days compared with meat from the same animal refrigerated 2 days at 33° to 35°F., "(1) had lost no water, (2) that the percentage of water soluble solids, the soluble, insoluble and total protein, the non-coagulable protein, the nitrogenous and total organic extractives, the forms of ash, the total nitrogen and the total phosphorus all remained practically unchanged. (3) That the only consistent real changes were a distinct increase in the total soluble and the soluble inorganic phosphorus, being 8.0 and 17.9 per cent respectively, and a decrease of 8.3 per cent in the non-nitrogenous organic extractives. (4) The nutritive value of the meat was unaltered." After refrigeration for 43 days the chemical changes in the meat were greater in number than those for the 22-day sample. When allowance was made for the moisture loss they found a definite increase in the soluble dry substance, the nitrogenous, non-nitrogenous, and total organic extractives, the total soluble nitrogen, and the soluble inorganic phosphorus. There was a slight increase in the soluble coagulable and total soluble protein nitrogen and in the insoluble and total nitrogen.

They found the cooked meats from the 43-day refrigerated sample higher in water content, therefore juicier, than the 6-day refrigerated sample. From comparisons of other losses that occurred in the cooked 43-day sample they concluded that it was as nutritious as that from the cooked 6-day refrigerated meat.

### Changes in Cooked Meat and the Cooking of Meat

Meat is cooked to sterilize it and for most persons to make it more palatable. It should be cooked in such a way as to increase its tenderness



if it is a tough cut, and to keep it tender if it is a tender cut. It is desirable in cooking meat to have maximum tenderness of both fibers and connective tissue, so that the meat carves well and cuts easily. Meat cooked so long, or at such a high temperature that the connective tissue is dissolved, is not attractive and the fibers are tough and stringy. As a general rule, it should be cooked in such a way as to retain its nutritive value, i.e., to prevent cooking losses to as great an extent as possible, either dripping losses or destruction of some food constituents by heat. When the drippings are used in gravy or other ways this loss is not a serious one.

The flavor and the tenderness of the cooked meat depend to a great degree upon the quality of the meat before cooking, for cooking cannot make a well-flavored piece of meat from one of poor quality and flavor, nor does it always produce a tender piece of meat. However, the method and length of time of cooking may and often do spoil a good piece of meat, yet the method of cooking may improve a poor piece of meat.

Browning and thoroughly cooking meat develop a different flavor, just as cooking cabbage a long time develops a characteristic flavor. Many persons prefer the development of this flavor.

**Coagulation of proteins.** The heat renders the soluble proteins of meat insoluble, the extent of denaturation depending on the stage of cookery or temperature reached, the time held at this temperature, the  $\rho$ H of the meat, its salt content, its degree of ripeness, and probably other factors. The higher the temperature reached and the longer the meat is held at this temperature, the greater the denaturation. The relation of  $\rho$ H to denaturation has been considered in Chapter I. With increased denaturation the meat becomes firmer and denser, with shrinkage in volume.

**Formation of gelatin.** After the meat is heated in a moist atmosphere to a definite temperature for a sufficient time the connective tissue dissolves. If the concentration of gelatin in the liquid reaches 1.5 or higher percentages, it forms a jelly when cooled. Connective tissue is composed largely of collagen. Collagen is changed to gelatin more rapidly at higher temperatures. Smith states that the phosphate ion accelerates the rate at which collagen is changed to gelatin at a given temperature. The addition of acid to meat may also increase the rate of hydrolysis of collagen.

**Juiciness.** Juiciness is given as a desirable quality of cooked meat. Meat loses moisture during cooking, even when cooked submerged in water. The higher the interior temperature to which the meat is cooked, if the composition and cooking conditions are standardized, the less moist the meat. Meat that contains a large amount of fat within and around the muscle fibers may seem juicy because of melting of the fat by heat in cooking. The fibers with a high fat content may also have a high water content, particularly if part of the fat is in an emulsion that will not break with high temperatures, thus retaining part of the moisture.

Some pieces of meat are apparently far more juicy than others after

cooking. It seems rather certain from the results of Hoagland *et al.*, Grassman, and others, that the increase of amino nitrogen with aging is one factor in bringing this about. The amino acids may not be able to bind as much water as the protein, so that the free water content and apparent juiciness may be increased with increase of amino nitrogen. Sometimes the juiciness seems to be related to the fat content. How great an influence the method of distribution of the fat within the fiber, the salt content of the fiber, the  $pH$ , or the development and maturity of the fiber have upon this point cannot be stated. The tissues of old animals lose their power to bind as much water as tissues from younger animals. Although this may partially explain the better quality of meat from younger animals it does not explain why veal is less juicy than baby beefs. Perhaps, if the water is bound too tightly by the coagulable protein micelles, the dryness is more apparent to the tactile sense.

Child and Fogarty found that approximately 11 per cent more fluid could be pressed from one semitendinosus muscle when heated to an interior temperature of  $58^{\circ}C$ . than for the other semitendinosus muscle from the same animal heated to  $75^{\circ}C$ .

Noble, Halliday, and Klaas found: "When subjected to a pressure of 3,800 pounds per square inch, the ribs cooked to  $61^{\circ}C$ . yielded more juice than those heated to  $75^{\circ}C$ . and the round more than the corresponding ribs. The larger quantity of juice was found to be richer in solids, total nitrogen, and, in one case, also richer in coagulable nitrogen."

Empey states that for uncooked meat there is a direct relationship between the hydrogen-ion concentration of the muscle fiber and its capacity for holding muscle fluid, but the author knows of no work in which juiciness of cooked meat has been related to  $pH$ .

**Change in color.** During the heating of meat, after a temperature of about  $50^{\circ}C$ . is reached, the color gradually changes from red or pink to a lighter shade and finally, if a sufficiently high temperature is reached, becomes brown or gray. Veal and pork are more gray, beef and lamb develop a browner shade. This color change has been discussed in connection with meat pigments, the oxyhemoglobin being broken down by heat to the brown hematin. The degree of ripeness of the meat affects the temperature at which the color change occurs, ripened meat becoming gray at a lower temperature.

The extreme browning on the surface of meat is accompanied by breakdown of surface proteins and fat, probably with liberation of sulfur and other compounds.

**Tenderness.** Methods of estimating. Tenderness is one quality universally desired in cooked meats. Tenderness may be estimated by subjective methods such as the ease of cutting or chewing. At present the most widely used method for comparing the tenderness of meat is the grading chart. The chart developed by the Cooking Committee of the National Project,

"Cooperative Meat Investigations," uses seven numbers and terms to designate the tenderness of the sample. They are: very tender, tender, moderately tender, slightly tough, tough, very tough, and extremely tough. Each judge forms his own standards from the basis of his experience. If the judge has had a complete range of qualities on which to base his standards and is consistent in adhering to them, he may become very proficient in judging comparative tenderness.

Numerous mechanical devices have been devised for estimating the tenderness of meat. The ones most commonly used at present are: (1) the shearing apparatus, which registers the number of pounds required to shear a piece of meat of a given diameter; (2) the penetrometer, with which a specially constructed needle may be used; and (3) a puncturing gage.

*Results of tenderness tests.* There has been considerable discussion as to whether raw meat is tenderer or tougher than the same meat when cooked, which to date has not been settled. Moran and Smith, after studying the effect of ripening on tenderness of beef, say: "It is a matter of general experience amongst those accustomed to raw meat that cooked meat is tougher than raw meat." They also quote Stefansson from "The Friendly Arctic" as follows: "Cooking increases the toughness and brings out the stringiness. I have never eaten any raw meat that was noticeably tough or stringy."

Black, Warner, and Wilson have reported that cooked samples were more tender than raw samples from good and medium-grade three-year-old grass-fed steers and steers fed both grain and grass. The number of steers in each lot was eight, the number of tests for raw and cooked meat was 12 and 4, respectively. Their results are given in Table 28.

TABLE 28

SHEARING STRENGTH OF RIGHT AND LEFT RAW TWELFTH-RIB SAMPLES AND LEFT COOKED ELEVENTH-RIB SAMPLES (*Black, Warner, and Wilson*)

Lot designation	Shearing strength raw muscle lbs.	Shearing strength cooked muscle lbs.
Good grade, grain on grass.....	72.9	32.7
Good grade, grass alone.....	72.6	39.0
Medium grade, grain on grass.....	71.7	34.9
Medium grade, grass alone.....	78.3	38.8

Noble, Halliday, and Klaas found beef more tender, as tested by a penetrometer, when heated to 61°C. than to 75°C.

Lowe compared the penetrometer and shearing apparatus by using both tests to measure the tenderness of the longissimus dorsi of raw and cooked beef rib roasts. The roasts were used in pairs, one roast being cooked, the other left raw. Both methods indicated raw meat to be the tenderest, the rare intermediate, and the well-done the least tender. But penetration tests appear to be influenced by the density of the meat, the meat with the greatest cooking losses, i.e., the well-done, being firmest. Thus penetration tests indicated no difference in meat from different animals when there was little difference in firmness but where both the shearing tests and grading score indicated a range in tenderness. The penetration depth was greater in soft raw meat than in firm cooked meat, the differences being highly significant. Shearing tests showed significant difference in the tenderness of the longissimus dorsi from animals of varying grade and the values obtained were in agreement with the grading score. None of the correlations between penetration and shearing tests were significant, from which it was concluded that shearing was the better method for measuring the tenderness of meat.

*Means of increasing tenderness.* The possible ways of increasing the tenderness of meat may be classed as follows: (1) mechanical, (2) enzyme action, and (3) by peptization and increased solubility of the proteins. The first is a physical, the last two would bring about chemical changes.

Meat is ground to break the fibers and connective tissue, which, because it lessens the need for chewing, increases the tenderness. For very tough cuts this is probably the most satisfactory procedure. In tests that have been made, it was found that meat, ground fine and several times as for Swedish Meat Balls, is more juicy and palatable than meat ground medium or coarse and only once.

Investigators have sought for suitable enzymatic and chemical means of increasing tenderness of meat for years. The proteolytic enzymes found in the meat increase the tenderness but considerable time at low storage temperatures is required. Hence, if a proteolytic enzyme that would speed up the breakdown of the proteins and which would give satisfactory results were found the tenderness of meat could be increased in a shorter storage period. Papain has been tried. The author's results to date with this enzyme have not been satisfactory. When it was applied to the surface of the meat some time was required for the enzyme to act and then only a thin, powdery surface layer was formed. When it was applied just prior to cooking the heat destroyed the enzyme, so that its application was of little or no value. No satisfactory methods of injecting this enzyme have been reported. Investigations that have been reported in connection with flour proteins suggest that it is possible that meat may contain substances that tend to inhibit the action of the proteinases of the meat and if some salt that would counteract this inhibition through oxidation or other means could be injected that the meat would become tender more rapidly.

The changing of collagen of the connective tissues or structural proteins to gelatin during cooking is one means of increasing the tenderness of these proteins, but the solubility of the protoplasmic proteins decreases when they are coagulated by heat.

Another method of increasing the tenderness of meat would be through the use of substances that would peptize both or either the connective or protoplasmic meat proteins, thus increasing their solubility and the tenderness of the meat. Means of bringing about peptization have been discussed in Chapter I. Sugar peptizes some proteins. Many electrolytes also bring about peptization, particularly if mixed intimately with the substance to be peptized. Anions of acids such as tartrate, citrate, and acetate may bring about a greater or lesser degree of peptization. A practical peptizer, if such could be found and used, would be a salt that could be injected and have slight effect at low temperatures but bring about peptization fairly rapidly when heated during cooking of the meat.

Smith states: "It is of interest to note that, in cases where the primary aim of cooking is to make the meat more tender (as, for instance, in stewing), the required degree of tenderness can be reached more quickly by addition of phosphate, or what amounts to the same thing, since the meat itself contains phosphate, of concentrated stock from a previous boiling. The concentration of phosphate which gives the greatest effect is about 0.2M, but a quarter of this will have quite an appreciable effect. A suitable mixture of mono- and di-hydrogen phosphates to give a  $pH$  between 6 and 7 was employed."

Meat is sometimes placed in a pickle of equal parts of vinegar and water and is used for Sauerbraten or similar dishes. Soaking in the acid is supposed to increase the tenderness as well as develop a particular flavor of the meat. If the vinegar contains tannins, the meat should not be cooked in an iron utensil, for a dark color will develop from the tannins combining with the iron. The effect of the acid on the meat, which will probably depend upon the amount of acid added and the resulting  $pH$  of the meat and whether this  $pH$  is at, above, or below the isoelectric point of its proteins, may cause the connective tissue to swell and hydrolyze the collagen to gelatin more rapidly when the meat is heated. Tomatoes or sour cream are also added to Swiss steak and tomatoes to stews. Sometimes the acid appears to increase the tenderness; but often a paired cut without the acid is as tender or more tender than the one to which acid is added.

Baker states that the lactic acid developed in the meat may be responsible for improvement in tenderness. He says that Walsh investigated the development of acidity in lean beef and claims that its formation is important in the preparation of canned meats. Properly matured meat, after canning, "melts in the mouth," the muscle fibers are softened, slicability is enhanced, and the pink color is more vivid. But in maturing or ripening changes are also brought about by enzymes and other means.

### Cooking of Frozen Meat

Frozen meat and poultry are obtainable in retail markets in larger cities. In addition many people freeze meat in mechanical freezer units, and the practise of obtaining compartments and freezing fresh meat in local cold storage plants in rural and small urban communities is increasing tremendously. Hence, the cooking of frozen meat attains importance and knowledge of what happens to the meat during freezing gives understanding of why it should be cooked soon after defrosting, if it is defrosted before cooking.

**Freezing.** When meat is frozen, the unbound water forms ice crystals. These crystals on thawing, with their dissolved substances tend to exude from the cut surfaces of the meat. Empey found the drip from frozen and thawed meat very similar in composition to fluid pressed from unfrozen meat. He found a direct relationship between the hydrogen-ion concentration and the capacity of the muscle to hold fluid. Minimum drip occurred when the  $pH$  of the muscles had not dropped below 6.3. However, he did no work to determine the tenderness of the meat in connection with  $pH$  or at what  $pH$  it would be most desirable to freeze the meat for quality and palatability after cooking. The writer's experience thus far is that meat that is not tender before freezing does not improve in tenderness by freezing. This would indicate that for palatable meat it is preferable for meat to be ripened sufficiently before freezing.

Meat may be frozen rapidly or slowly. In rapid freezing the meat is subjected to a very low temperature so that freezing occurs in a short time. The advantage of this method is supposed to be due to the fact that the ice crystals have little time to grow; hence they are smaller and break the fibers to a smaller extent. There is considerable controversy as to which is the best procedure. Moran says that in their studies rapid freezing possessed no advantages over slow freezing as regarded the quality of the product, but that in each case the most important factor affecting the quality was the storage temperature. Lowe and Keltner found no difference in the quality of poultry frozen by rapid and slow methods. Many reports in the literature indicate that it is preferable to keep the meat or poultry at quite low temperatures,  $-10^{\circ}$  to  $-15^{\circ}F.$ , to prevent desiccation of the meat. Tressler believes it is desirable to have the temperature as uniform as possible, for a fluctuating temperature also increases moisture loss. Each piece of meat or bird should be wrapped to prevent moisture loss. Tressler says, "Severe desiccation causes a considerable loss of flavoring components, and makes the frozen product tougher, less easily cooked, and therefore, less desirable for food."

**Defrosting.** The method of defrosting seems to be particularly important for poultry. Snyder found poultry defrosted in water markedly less desirable in flavor than poultry defrosted in cold air, i.e., in a refrigerator.

The method of defrosting was also more important than drawing and length of storage period in determining flavor, although the giblets of undrawn birds were not so desirable as those of drawn birds.

Many questions are received from Iowa women regarding the flavor of poultry frozen and stored in local plants. It is a common practise for these women to defrost the poultry in water, but their frozen meat is defrosted in cold air.

Beef and meats having extensive cut surfaces of the muscles tend to "drip" more than poultry after defrosting. Since loss of this fluid also



FIG. 23.—Standing rib roast of beef. Showing thermometer inserted for reading interior temperature of the meat.

results in loss of flavor and nutritive value, it is desirable to cook the meat soon after defrosting or even before defrosting. Defrosted meat is also more susceptible to bacterial attack.

**Cooking.** Defrosted meat is cooked in the same way as unfrozen meat. But if cooking is started before the meat is defrosted, then the temperature and time of cooking need to be changed to allow the meat both to thaw and to cook. Otherwise, a steak or roast can be served with a brown appetizing exterior and still be frozen in the interior. The writer prefers to start cooking all frozen steaks and chops before defrosting, as there is then no loss of fluid and flavor. But the meat is not seared. The cooking temperature must be low and the cooking time increased to at least 3 or 4 times longer than for unfrozen meat. Because of the longer time required for thawing and cooking the exterior browns sufficiently without searing.

**The use of salt.** There is no advantage in salting large pieces of meat,

as the salt is placed on the surface of the meat and does not penetrate to any appreciable extent during cooking. Part of the salt is carried from the surface of the meat by the juices and into the drippings. Snyder determined the total and nitrogenous losses in beef roasts and stews. The meat was all from the same carcass, the cooking conditions were standardized, and the roasts or stews cooked in pairs. Similar cuts, cut as nearly alike as possible by an experienced meat cutter, from the right and left side of the animal, were used for each pair, one of the pair being salted, the other left unsalted. The quantity of salt used was about the amount that would be used by housewives in cooking meat, 1.5 grams per pound of meat. The losses were determined on the basis of the uncooked weight of the meat and on surface area, but both methods showed no appreciable differences in the total or nitrogenous losses of the salted and unsalted meats. In the salted roasts the flavor penetrated to less than  $\frac{1}{2}$  inch in depth. The layer in which the salt had penetrated was a deeper gray in color than the corresponding layer on the unsalted roast.

**Records for cooked meats.** In addition to the records of weight, time of cooking, etc., a tracing may be made of the cut surface of roasts, steaks, and chops. A piece of parchment paper is laid over the cut surface and the entire surface rubbed lightly with the fingers to bring it in contact with the meat. The fat leaves the paper semi-transparent, and the moisture from the lean portion slightly puckers the paper. A pencil tracing is made around the edge of the meat and the fat and bone layers. A tracing of this sort is better than a photograph in that the dimensions are actual size. It also shows the exact distribution of fat, lean, and bone. A good grade of thin typewriter paper can be used for making these prints.

### Methods of Cooking Meats

In general meat is cooked (1) by dry heat and (2) by moist heat. Dry heat is generally used for tender cuts, such as roasts and steaks. The meat is surrounded by dry air in the oven, under the broiler, or over coals, or by hot fat. In general, moist heat is used for the less tender cuts and includes methods by which the meat is surrounded by steam or water. This includes cooking meat in water as for stews, in steamers, in casseroles, in Dutch ovens, and even in roasting pans when the lid fits tightly and holds the steam around the meat.

**The tender cuts.** In general these cuts include the prime-rib roasts, steaks or roasts from the loin and sirloin, leg of lamb, fresh pork hams, and pork, lamb, and veal chops.

*Beef ribs.* Prime-beef ribs may be cooked as standing roasts or the bones may be removed for rolled roasts. Since the time of cooking varies with many factors, it is difficult to state a definite time per pound for cooking meat. Table 29 may be used for estimating approximate cooking time of



one-rib and two-rib standing roasts. For three-rib standing roasts cooked to an interior temperature of 57°C. an average time of about 20 to 22 minutes per pound is required when the experimental searing or 150°C. constant temperature methods are used. When the interior of the roast reaches 57°C., the edges of the roast are contracting so that the large center muscle of the ribs bulges. As the roast reaches the well-done stage, all the muscles are contracted to a greater extent so that the large muscle does not bulge as much as when the interior has reached only the rare or medium well-done stage.

A rolled rib roast usually requires longer per pound for cooking than a standing rib roast from the same cut. The rolled roast is usually more compact in shape with a proportionally longer diameter, so that the distance to the center is greater. See Fig. 25.

*Lamb roasts.* A leg of lamb is placed on a rack in an open pan, skin or fell side up; but the fell is placed down for a shoulder roast. The fell can be removed, but Alexander found that its removal increases the cooking losses, increases the cooking time, and does not increase the palatability of the meat.

Alexander and Clark state that approximately 35 minutes per pound may be allowed for cooking by the experimental searing or the 150°C. constant temperature methods, but considerable variation can be expected. They found the cooking time for 750 legs of lamb, roasted by the Cooperative Meat Investigation searing (experimental) method to an interior temperature of 76°C., varied from 25 to 58 minutes per pound, the small poorly finished legs from cull carcasses requiring longer and plump well-finished legs requiring a shorter time. The time is about the same, or somewhat shorter, for the 150°C. constant temperature method, and is considerably shorter if the leg is cooked to an interior temperature of 83°C.

*Veal.* Veal roasts may be cooked in open pans, the time per pound for cooking varying widely with the size of the roast.

*Pork.* The Cooperative Meat Investigation cooking committee used for the searing method 20 minutes at 250° to 255°C., the remainder of the cooking period being at 150°C. For the present constant temperature method, 175°C. is used. A higher temperature is used with pork because of the long time required on account of the slow rate of heat penetration and the higher interior temperature to which pork is cooked, an interior temperature of 78°C. to 87°C. being used. The official testing temperature is 84°C.

*Steaks.* Steaks from 1 to 2 inches in thickness may have a thermometer inserted, the right-angle type being easier to turn for reading as the steak is turned. An interior temperature of 60° to 63°C., when removed from the oven, gives a medium well-done steak. Steaks may be broiled below a gas flame, under an electric heating unit, or over coals, or they may be pan broiled. In broiling, the steak is placed far enough from the heat and

turned often enough to prevent charring or over-browning. If desired, the steak may be turned only once. For a rare or medium well-done steak the cooking temperature does not need to be lowered, but for a well-done steak, or for one thicker than  $1\frac{1}{2}$  inches, the temperature may be lowered after the browning is accomplished. Many people prefer steak cooked at a constant, fairly low temperature. The interior of the medium well-done steak is then more uniform in appearance, being pinkish throughout. Many steaks cooked at high temperatures are likely to have a gray surface layer, a thin pink layer, and an uncooked center portion. The outer surface of the steak does not brown so well at the lower temperature, but these connoisseurs think this is more than compensated for by the uniformity of the interior of the steak. Increased browning of the surface at the lower temperature may be acquired by sprinkling with a small amount of sugar.

The searing time and the total cooking time vary with the temperature used, the stage of cookery, and the thickness of the steak. The total time for a medium-done steak 1 inch thick is 7 to 10 minutes when seared. With a low, constant temperature the cooking time for the same steak may be increased to 20 minutes.

*Chops.* Chops of veal, lamb, and pork may be broiled or pan broiled. Thicker chops, at least  $\frac{3}{4}$  inch thick, but mutton, particularly, as thick as 2 inches, are easier to cook without drying out than thin chops. The time of cooking varies with the temperature and the thickness of the chop from about 8 to 30 minutes. Pork and veal are usually cooked well done. Pork chops require about 10 to 20 minutes, and chops of veal and lamb  $\frac{3}{4}$  to 1 inch in thickness about 8 to 15 minutes.

**Less tender cuts.** The less tender cuts are used for pot-roasts, Swiss steak, braised meat dishes, stews, and soups. If ground, the meat is cooked as a tender cut.

The less tender cuts are usually cooked by moist heat and at fairly low temperatures. The aim is to cook the meat so that the structural proteins, the connective tissues, are softened yet not completely dissolved and the plasma proteins of the fibers are not made tough, rubbery, or stringy. If this is successful, a tender yet easily sliced meat is the result. If the connective tissues are entirely dissolved, the meat is not slicable.

The less tender cuts are often pounded, or seasoned flour is pounded into the meat, or the surface is floured and seared. Pounding appears to be a good means of increasing the tenderness of some of the tougher cuts, particularly those containing a great deal of connective tissue and little fat or when they are not ripened. The flour absorbs and holds moisture; thus to this extent the meat appears less dry. Better grades of less tender cuts containing more fat and cuts from carcasses of younger animals from which rigor has passed do not need to be pounded.

**Cured meats.** Some of the common cuts of cured pork are regular hams, skinned hams, shoulders, shoulder butts, and bacon. The loin, cured, is

sometimes called Canadian bacon. Cured lean meats, because of the action of the salt during curing, are already fairly dry so they should always be cooked to prevent as little moisture loss as possible. This is usually accomplished most easily by slow cooking at low temperatures.

*Hams.* Hams may be cured with a light or a heavy salt cure. The mild-cured ones do not need soaking over night or parboiling before baking. Hams with a heavy salt cure are improved in flavor by soaking over night or for 24 hours.

Hams are roasted in open pans on a rack, fat side up, at 125°C. (about 250°F.) to an interior temperature of 70° to 75°C. If the oven will not maintain as low a temperature as this, 300°F. may be used.

For cooking hams in water, a simmering temperature, 83°C., produces a tender, juicy ham. Water temperatures as low as 75°C. may be used. Hams cooked in water have the cooking losses decreased by cooling over night in the liquor in which they were cooked, but the cooking losses are influenced by the temperature of the liquor. Child found that the cooking losses gradually decreased as the temperature of the liquor decreased. The smallest losses, hence the greatest hydration of the ham, occurred at 1.6°C. (35°F.). In fact the hams averaged a slight gain in weight when put in the refrigerator and the liquor cooled to this temperature. With lowering the temperature below 1.6°C. the losses increased.

The time necessary for baking or cooking ham in water will vary with the size of the ham and the cooking temperature used. For the temperatures given, hams weighing about 12 to 13 pounds require about 23 to 25 minutes; those weighing 18 to 20 pounds require about 18 to 20 minutes per pound.

*Bacon.* Bacon should be cooked at a temperature below the smoking temperature of the bacon fat. Slow cooking at low temperatures is best. For large quantities of bacon an excellent method is to spread the slices on a wire rack, place in a pan, and bake in the oven at 160°C. for about 18 minutes. The bacon needs no turning.

**Covered and uncovered pans for roasting meat.** Grindley and Mojoinner state regarding the losses occurring in roasting beef in covered and uncovered pans: "The total losses were greater when the meats were roasted in a covered pan than when they were cooked in open pans, owing chiefly to the increased amount of water removed. In the same time and at the same temperature the meat was more thoroughly cooked in the covered than in the open pans, possibly because the temperature of the meat was higher in the closed pan." However, they based their conclusions on results of experiments with 1 covered and 15 open pans.

The Cooking Committee of the Cooperative Meat Investigations uses uncovered pans for cooking all experimental roasts and advises the use of uncovered pans in the home. In general the cooking losses are less and the meat more palatable in the uncovered pan, although with such very small

roasts as half of a chicken opposite results may occur. The cooking time is shorter when covered pans are used.

**Pressure cooker.** Gortner, in speaking of the moisture content of dried biological materials, says it depends upon three variables: temperature, pressure, and time. He adds that the moisture content of a sample should not be given without a statement of the condition under which it was dried. One question often asked is why meat cooked in a pressure cooker at a high temperature is tender and not dry. The answer is determined by the meat and these three variables. There would be a far greater tendency to dry the fibers at a high temperature and in a partial vacuum.

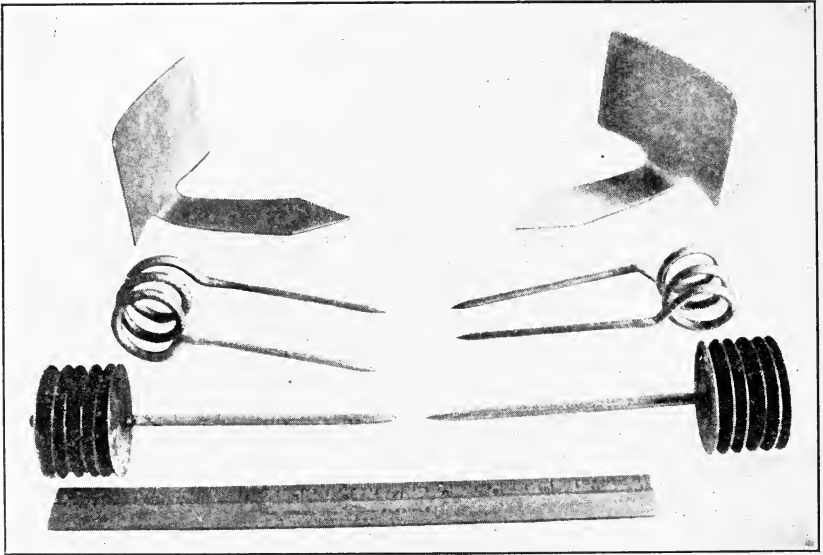


FIG. 24.—Some types of skewers used for roasting meat.

**The use of skewers.** Muscle tissue conducts heat slowly. Most metals conduct heat rapidly. Morgan and Nelson used skewers in cooking standing rib roasts. The skewers were made with a long, narrow portion, about the size of a lead pencil, that was inserted in the meat. The other end of the skewer was in a spiral to give greater surface for receiving the heat from the oven, and thus conducting it into the meat. Pictures of the different types of skewers used in meats are shown in Fig. 24. They found that "the roasting speed was increased 30 to 45 per cent when nickel-plated copper skewers were used. Similarly, smaller and less regular decreases in total shrinkage of weight of meat were found in the skewered as compared with unskewered roasts." They found the efficiency of the skewers in shortening the cooking period greater when a high oven temperature was maintained throughout the cooking period.

### Cooking Temperatures

The best cooking temperatures for meat may not be the same for all conditions. As a general rule, it is agreed that low or medium temperatures are better than high ones for cooking meat. Yet some samples of meat do not seem to be toughened by any method of cooking; that is, if one deliberately sets out to show that higher temperatures toughen a piece of meat, while the same cut from the other side of the same animal cooked at a lower temperature is tender, the results are often not consistent.

**Advantages of low temperatures.** In general, lower cooking temperatures result (1) in less cooking loss, (2) in more juicy meat, (3) in more uniformly cooked meat, and (4) in longer cooking time. The meat is more uniform in color and more juicy throughout; whereas at a higher temperature, the meat is more gray and dry at the surface, there being a sharper contrast between the meat near the surface and that at the center of the cut. A longer cooking time may be an advantage, for the homemaker may safely leave the meat cooking while she attends church, etc.

**Disadvantages of low temperatures.** Often the meat (1) does not brown as attractively at the lower temperature, although occasionally the opposite is true, and (2) a longer cooking time is required. A long cooking time may also be a disadvantage.

**Searing method.** The Cooking Committee of Cooperative Meat Investigations formerly used a searing method for cooking experimental roasts of fresh meat. The roast was seared for 20 minutes at 250° to 275°C. (about 480° to 525°F.) and was then transferred to a second oven at 125°C. for the remainder of the cooking period. It was necessary to transfer experimental roasts to a second oven so that results from different laboratories could be compared, for different ovens cool at different rates. Obviously the homemaker cannot use two ovens. Hence a lower temperature, 200° to 240°C. (about 400° to 450°F.), is recommended for the housewife in searing because the oven will remain at a fairly high temperature for some time after the temperature control has been set at the lower temperature.

**Searing.** Searing browns the meat, develops a characteristic surface flavor, and starts the cooking. Often the statement is made that searing by coagulating the muscle tissue on the surface prevents loss of interior fluids and extractives. Searing increases the cooking losses, though the losses may be largely surface ones. Searing also does not prevent the loss of interior juices in all instances.

**Constant temperature method.** At present the Cooking Committee uses a constant oven temperature 150°C. (about 300°F.) for cooking experimental roasts, with the exception of pork, which is cooked at 175°C. (about 350°F.). At this temperature the cooking time and losses are prac-

tically the same as for the searing method formerly used. The exterior is also browned to about the same extent, although it is sometimes less brown.

The homemaker will find that in using a constant temperature excellent roasts will be obtained if she uses 150°, 125°, or 175°C. Some ovens will not hold as low a temperature as 125°C. (250°F.), even though the regulator carries this temperature. The meat will not brown as readily at the lower temperature, but this can be overcome by using a mixture of salt and sugar or sugar alone to sprinkle over the meat. The meat cooked at 175°C. will not be as uniformly cooked as at the lower temperature.

### Stages to Which Meat Is Cooked: Rare, Medium, and Well Done

The longer a piece of meat is cooked, the more the interior color changes from pink or red to gray, and the greater the cooking losses. Some meats like veal and pork are cooked well done, whereas beef may be cooked rare. There is no definite stage between a rare and a medium-done piece of meat or between a medium well-done one and a well-done one. The meat passes from one stage to another gradually, so that there is no definite end point. Heat penetrates slowly into the interior of a large piece of meat, and the center of the meat, unless very much over-cooked, never attains as high a temperature as the meat near the surface.

**Rare meat.** Grindley and Sprague have suggested, for convenience, that meat with an interior temperature at its center of 60°C. or below be called rare. Such meats are juicier than meats cooked well done. Nearly all the interior may be a bright red color or only a small portion around the center of the meat may be red. The extent or uniformity of the red color depends upon the cooking temperature. As the heat penetrates the meat the color near the surface becomes gray. If the cooking temperature is high, this gray layer may extend nearly to the center of the meat. If the meat is cooked at a low temperature the gray color extends only a short depth and the color of the interior of the meat is nearly uniform. Thus it can be seen that if different cooking temperatures are used the interior of different pieces of meat cooked to the same inner temperature may vary decidedly in appearance. The intensity of the red color may vary with other factors as well as with the cooking temperature. The interior of cooked meat ripened 40 to 60 days is grayer in color than meat that has not been ripened. Veal cooked to the same inner temperature, and with the same cooking temperature, is grayer, and has less red color, than beef. Rare meat also has more of the original meat flavor than well-done meat, for not so much of the fluids and extractives giving flavor to the meat has been lost.

**Medium well-done meat.** Grindley and Sprague have suggested that meat that has reached an inner temperature of 60° to 70°C. be called medium well done. Here the color also varies with the temperature of cooking, the degree to which the meat has been ripened, and in some in-

stances with the age of the animal and the kind of meat. Rare and medium well-done meats are probably more often associated with the color of the cooked meat. Since the color of the cooked meat varies with different conditions, the division into rare, medium well done and well done on the basis of inner temperature of the meat is only an arbitrary one and not always satisfactory. Most people would be agreed that medium well-done meat should not be a deep red or pink, but should show some pink color.

**Well-done meat.** Meat that has a uniform gray color throughout the entire interior of the meat is usually called well done. With veal, this stage of cookery is sometimes reached before or by the time the inner temperature of the meat has reached  $71^{\circ}\text{C}$ . This may also be true of beef that has ripened sufficiently. Unripened beef requires a higher temperature than  $71^{\circ}\text{C}$ . before a uniform gray color is attained, when a low cooking temperature is used. But to some persons the term well done is associated with the degree of cookery, that is, the separation of the muscle fibers due to formation of gelatin from the connective tissue. It may also refer to the dryness of the meat and the loss of juices. The meat may be cooked until it reaches a temperature far above  $71^{\circ}\text{C}$ ., often from  $80^{\circ}$  to  $85^{\circ}\text{C}$ . for roasts and from  $95^{\circ}$  to  $99^{\circ}\text{C}$ . for braised meat.

### Factors Affecting the Time Required for Cooking Meat

Directions for cooking meat usually state the time of cooking in terms of minutes per pound. At best this can only serve as a guide, for several factors may cause variation in the length of time required to cook a piece of meat. The only way of knowing when the interior of a piece of meat has reached a definite temperature and thus a definite stage of cookery is to insert something in the center of the meat by which the interior temperature may be read. For this purpose a thermometer or a thermocouple may be used. The easiest method for household use is the insertion of a thermometer into the meat. Two types of thermometers may be used: a right-angled thermometer with the temperature scale on the horizontal arm (see Fig. 23); or a very short tube-type thermometer about 6 or 8 inches long with the temperature scale on the upper half. The latter must be short to keep the top from touching the upper part of the oven, particularly the small gas ovens and many electric ovens. Thus the graduated scale is condensed, which makes it more difficult to read. The short thermometer is preferable for small roasts of meat and for meat with soft fibers. The right-angled thermometer is suitable for beef roasts, ham, leg of veal, and lamb. It is convenient for taking temperatures of custards, cakes, and other foods, for it can be supported by the horizontal arm from a shelf in the oven.

The following factors affect the time required to cook meat. (1) The cooking temperature. (2) Weight. Surface area. The shortest distance to the center of the thickest portion of the meat. (3) The stage to which the

meat is cooked—rare, or well done. (4) The composition of the meat. (5) The degree of ripeness.

**The cooking temperature.** The higher the cooking temperature the more rapidly will a piece of meat reach a definite temperature, for with a higher temperature at the surface, the more rapidly heat will penetrate to the interior of the meat. As oven temperatures during the cooking of meat may vary many degrees, this factor causes a wide variation in the time required for cooking meat.

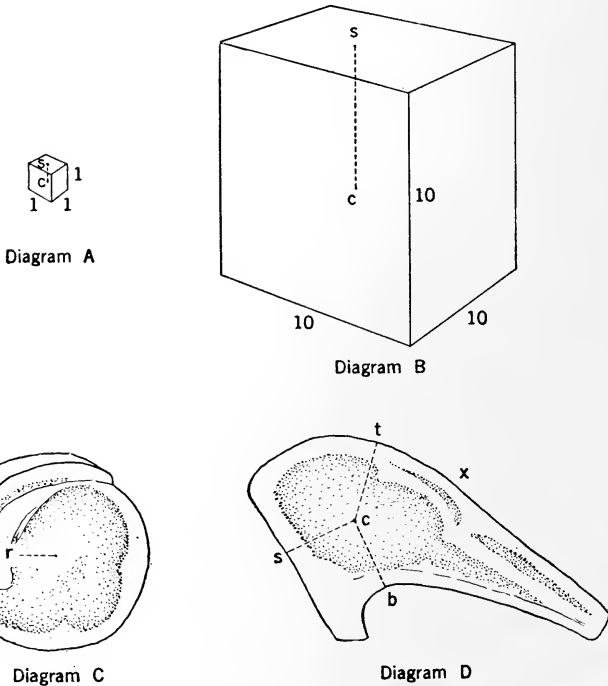


FIG. 25.—To illustrate heat penetration in roasts and to show that the diameter does not increase in the same ratio as the weight.

**Weight. Surface area. Shortest distance to thickest portion of the meat.** The time for cooking meat is often expressed in minutes per pound, but it is also a well-known fact that a heavy piece of meat of the same shape as one of light weight will require a shorter time per pound for cooking if the oven temperatures are the same. The reason for this can best be explained with the aid of a diagram. Suppose a cube 1 inch square weighs 1 ounce. It contains 6 square inches of surface area (see Fig. 25, diagram *A*), and the distance from the sides to the center ( $s-c$  in the figure) is  $\frac{1}{2}$  inch. If the cube is enlarged to 10 times its original size, diagram *B*, its weight is increased to 1000 ounces, its surface to 600 square



inches or 100 times its original surface area, and the distance ( $s-c$ ) to the center is 5 inches, or 10 times the distance of cube  $A$ . In other words, the distance to the center does not increase in the same ratio as the surface area and the weight. In heating these cubes, if the heat travels through the material at a uniform rate it will not take 1000 times as long to bring the center of cube  $B$  to a definite temperature as cube  $A$ , but 10 times as long. The diameter of a sphere or a cylinder does not increase in the same proportion as the surface area and weight. A piece of meat is not shaped like a cube, but some are cylindrical, and in roasts of similar shape the weight increases more rapidly than the distance that the heat must penetrate.

Rolled roasts are cylindrical in shape. Here the length of the radius ( $r$ ) determines the time for the heat to penetrate to the center of the roast, unless the length of the cylinder is shorter than its diameter. See Fig. 25, diagram  $C$ .

In a standing rib roast, Fig. 25, diagram  $D$ , it is not the distance to the center of the meat, which may be somewhere near the portion marked  $x$ , but the distance through the thick portion of the meat, which affects the time required for cooking. The heat travels in from the top along the line  $tc$ , from the side along the line  $sc$ , and from the bottom along the line  $bc$ . Ham, leg of lamb, and leg of veal have the thickest portion of the meat nearer one end than the center of the meat.

It is obvious from the diagrams that the shorter the distance to the center of the piece of meat the more rapidly the heat will penetrate; the longer the distance, the more time will be required. Weight and surface area are not satisfactory to determine cooking time, for the size of the piece and its shape determine the distance to the thickest part of the meat. A thin, wide roast will cook in less time and a thick compact one will take a longer time. The following examples illustrate this. A standing rib roast weighing 11.6 pounds required 1 hour and 52 minutes to reach an inner temperature of  $57^{\circ}\text{C}$ ., when cooked for 20 minutes at  $275^{\circ}\text{C}$ . and for the remainder of the cooking period at  $125^{\circ}\text{C}$ . This gives an average of 9.3 minutes per pound. Another roast weighing 11.5 pounds and with the same cooking conditions required 3 hours and 43 minutes, averaging 19.3 minutes per pound. The first roast consisted of five ribs and was thin and wide; the latter consisted of three ribs and was thick and compact. If roasts are always of the same shape and the same cooking temperature is always used the time for cooking can be estimated more accurately than when the shape of the roast varies.

A large piece of meat cooks in a shorter time per pound than a small one if all other conditions are standardized. Smaller hams and legs of lamb require more minutes per pound than larger ones. The same is true of poultry, smaller chickens and turkeys requiring more minutes per pound than larger ones.

**Time per pound.** Minutes per pound for some roasts are given in Tables 29 and 30, but if not taken in connection with cooking tempera-

tures, size, and the stage of cookery, they are worth very little for a guide in cooking meat. Most of the roasts given in these tables were transferred to a second oven after searing instead of lowering the temperature of the oven in which the roast was seared. This gives a slightly longer time per pound. There may be considerable variation in the time per pound as can be seen in Table 29. In general, the time per pound is longer with the smaller roasts. With a very thin roast the thickness of the slice influences the rate of heat penetration more than the other dimensions or its weight.

TABLE 29

THE TIME OF COOKING PER POUND AND COOKING LOSSES IN ONE-RIB AND TWO-RIB BEEF ROASTS COOKED TO DIFFERENT STAGES.  
SOME CLASS RESULTS

No. of ribs in roast	Weight		Searing temperature °C.	Cooking temperature °C.	Interior temperature when removed from oven	Cooking time		Total cooking losses, per cent
	grams	pounds				Total, minutes	Time per pound	
One	836	1.8	275	125	55	59	33.0	8.4
Two	1560	3.4	275	125	55	93	38.2	11.8
Two	2331	5.1	275	125	55	100	19.5	10.9
Two	2813	6.2	275	125	56	124	20.0	15.1
One	835	1.8	275	125	65	81	45.0	11.0
Two	1575	3.3	275	125	65	116	33.3	14.9
Two	1626	3.6	275	125	65	140	36.0	14.8
Two	1890	4.2	275	125	65	110	26.3	14.0
One	757	1.7	275	125	75	85	50.0	20.0
Two	1603	3.5	275	125	75	190	53.3	21.4
Two	1758	3.9	275	125	75	127	32.5	25.0
Two	2268	5.0	275	125	75	260	52.0	20.2

**Surface area.** Since time per pound does not give a dependable basis for cooking meat an effort is often made to express cooking time in relation to the surface area. Often this is expressed in the following way. The greater the surface area the shorter the time required for cooking a piece of meat if all other conditions are standardized. From the diagrams, Fig. 25, it can be seen that this method would give a less variable cooking time, at least for some pieces of meat of certain shape, than time per pound. This method of expressing time for cooking is also more difficult to determine in the home.

**Stage to which the meat is cooked.** Cooking meat rare does not require so long a time as cooking medium well done or well done, because the last two stages require a higher inner temperature. See Table 29.

**The composition of the meat.** The proportion of fat and lean in the meat affects the time required for cooking. There has been much confusion regarding the rate of heat conduction by fat. In physiology, one is told that a layer of fat over the muscles prevents loss of body heat, because the fat is a poor conductor of heat. In articles on cooking various foods, one often sees the statement that fat conducts heat more readily than muscle tissue. These two seemingly contradictory statements are explainable. Redfield has offered a solution. In studying the rate of heat penetration in canning pork and beef, she found, with all other conditions standardized, that the temperature at the center of the can of pork rose more slowly than the temperature at the center of the can of beef. In order to determine whether this slower heat conduction in the pork was due to its greater fat content, she packed some cans with suet and others with beef round free of all visible fat. She found that the temperature of the suet rose more slowly than that of the beef round until the melting point of the suet was reached. As soon as the fat melted, it conducted the heat faster than the beef round. Fat in a liquid form in cooking is a good conductor of heat, but if it is in a solid form it is a poor conductor of heat. In Redfield's experiments, the fat escaped from the fat cells, the connective tissue forming a piece about the size of a marble around the point of the thermocouple.

The writer's experimental classes, in processing suet, fat pork, lean beef, and lean pork in pint cans in a hot water bath, have found the rate of heat penetration to be much slower in the fat meat than in the lean, even at temperatures of 90°C. and above. When the suet was packed tightly into the jar so that the tissues surrounding the fat cells were broken, Redfield's results were checked.

**Degree of ripeness.** Alexander and Clark found that increasing the length of the ripening period after slaughter shortened the time required to roast leg of lamb. As the ripening period increased beyond two days after slaughter, the cooking shrinkage became smaller and the rate of heat penetration more rapid.

Thus it seems that, if the connective tissue remains unbroken, as it does in the more solid fat and the interior fat of meat cuts, it prevents the fat globules from touching each other and delays heat penetration.

### **Rise of Interior Temperature of Meat after the Cooking Process Has Been Stopped**

When a roast is removed from the oven or a piece of cooked meat is removed from the cooking utensil the temperature in the interior may continue to rise. Heat is carried to the interior of the meat by conduction, that is, from fiber to fiber. When the cooking process is stopped the temperature of the meat half way to the center is higher than the temperature at the

center. This heat is conducted both toward the center and the outer edge of the meat, and as a consequence the temperature at the center of the meat rises.

The factors that may determine the extent of this rise in temperature after removal from the oven are: (1) the cooking temperature; (2) the inner temperature of the meat when the cooking process is stopped; (3) the size of the piece of meat; (4) the composition. It must be remembered that each of these factors may have an influence on the temperature rise of the same piece of meat, and that under some conditions one factor may influence it more than another. Thus they cannot be considered separately, for the high cooking temperature of a steak or roast may affect the temperature rise more than the size. Yet under some conditions size is a greater factor in determining temperature rise.

**Cooking temperature and temperature rise after the cooking process is stopped.** The higher the cooking temperature the greater the tendency for a rise in the inner temperature of the meat. A higher cooking temperature produces a higher surface temperature, and consequently results in a higher rise at the interior after the cooking process is stopped.

**Inner temperature.** The lower the inner temperature at which the cooking is stopped, the greater the tendency for the rise of inner temperature. This is because with a low inner temperature there is a wider variation between the inner and surface heat, which results in greater rise of inner temperature. The inner temperature of foods that contain a high percentage of water, such as cake, meat, and potatoes, never rises above the boiling point of their juices. Heat supplied in amounts greater than the amount needed to reach the boiling point of the juices is used in evaporating the liquid. It is impossible to raise the inner temperature of meat above 100°C. without having a very dry, charred product.

**Size.** In larger pieces of meat, the size of the piece is not so important a factor as those mentioned above in affecting the temperature rise of the interior after cooking has been stopped. But a piece of meat may be so small or thin that the inner temperature does not rise after the cooking process is stopped, because of the rapid cooling from the surface.

**Composition and duration of temperature rise.** No definite relation has been established between composition of the meat and the extent of the inner temperature rise after cooking. It does seem to affect the duration of the temperature rise more than the extent. Meat containing a great deal of fat and meat that has a very thick layer of fat on the surface,  $\frac{3}{4}$  to 1 inch or more, requires a long time for the inner temperature to reach its maximum point. A roast with such a layer of fat may take as long as 1 to 1½ hours to reach its maximum inner temperature, whereas a lean roast of the same shape, and cooked under the same conditions, may take only 12 to 30 minutes to reach its maximum interior temperature, after the cooking process is stopped.

## Factors Affecting the Losses That Occur During the Cooking of Meat

The total loss that occurs during the cooking of meat includes the losses known as drippings and the volatile losses. The greater part of the volatile loss is from evaporation of water. It may include volatile substances from the decomposition of fat and volatile aromatic substances. The drippings include fat, water, salts, and both nitrogenous and non-nitrogenous extractives.

**Time, stage of cookery and losses.** The stage of cookery is one factor that affects the cooking loss. Meat cooked rare gives less total cooking loss than meat cooked well done. A longer time is required to reach the well-done stage, if all other conditions are the same. Thus length of time of cooking and the stage to which the meat is cooked are related factors.

**Composition and cooking losses.** Meat containing a high percentage of fat cooked under standardized conditions gives greater cooking losses than lean meat. The amount of drippings is always greater for the fat meat than for similar lean cuts from the same kind of animal. This is also true for poultry. Cooking temperatures that melt the fat cause a heavy fat loss from the meat.

**Surface area and cooking losses.** The shape and surface area of the meat also influence the loss that occurs during cooking. The greater the surface area of the meat, the greater the area at which losses may occur. Compact pieces of meat with correspondingly small surface areas give smaller losses than irregular-shaped pieces with greater surface areas.

**Cooking temperature and cooking losses.** The cooking temperature is in many instances the principal factor in determining the percentage of weight that is lost during cooking. Occasionally time may be a more important factor than cooking temperature in its effect on the resulting losses. For example, cooking losses were greater for halves of chicken roasted at 125°C. (about 250°F.) than for the corresponding halves roasted at 175°C. (about 350°F.). In the former instance, twice as long was required for the interior of the thigh to reach 85°C. (185°F.). Alexander and Clark found similar results for very small, poorly finished legs of lamb. However, in general the higher the cooking temperature the greater the cooking losses; the lower the cooking temperature the smaller the cooking losses. Intermediate cooking temperatures give corresponding intermediate cooking losses.

**Method of cooking and cooking losses.** The method of cooking the meat may also influence the cooking loss. A broiled steak may have a far greater total loss than a pan-broiled one, yet the interior of the meat may be just as juicy. The radiant heat as well as the temperature reached usually causes a high fat loss from the edge of the boiled steaks, whereas a pan-broiled one may have a small fat loss.

**Degree of ripeness.** Alexander and Clark found cooking losses decreased with longer ripening.

### The Losses Occurring in Cooked Meats

The cooking losses vary with the factors mentioned, time, stage of cookery, cooking temperature, surface area, and composition. Usually, the longer a piece of meat is cooked, the greater the cooking losses; but this is not always true in practise, for owing to differences in surface area and composition of different meats, it is not possible always to standardize all conditions.

**Meats show wide variations in cooking losses.** The cooking losses in meat may vary from 5 per cent to 50 per cent. This is a wide variation. Obviously, meat that has lost 50 per cent of the uncooked weight is either very dry or has lost an immense amount of surface fat. Swiss steak was cooked to determine the effect of different percentages of loss on texture and palatability of the meat. The ones with 50 per cent loss were very dry and unappetizing, even for a person who prefers meat very well done. Here there was little surface fat, because of the cut and type of meat used. A roast with a great deal of surface fat may suffer a rather high loss and be far more palatable than a lean piece of meat. But, in general, a 40 to 50 per cent loss leaves the meat much too dry.

Well-done meat usually shows greater cooking losses. In general, meats cooked rare sustain less loss; the losses may vary from 5 to 20 per cent. Under some conditions they may be higher. Well-done meats usually have a higher cooking loss, from 20 to 45 per cent. However, meats cooked until well done at very low cooking temperatures may have less than 15 per cent cooking losses, so that it is impossible to give definite figures for any definite stage of cookery.

In Table 30 some cooking losses are given, and since cooking losses without cooking temperatures and stage of cookery mean little, these are included. The composition of the meat and relative surface area are not indicated.

**Cooking losses in steaks and chops.** The losses in steaks may vary to a great extent, but usually seem to come within 10 to 40 per cent, when ordinary cooking methods and cooking times are used. High cooking temperatures cause a greater fat loss from around the edge of the steak and also brown it better, giving a more attractive appearance, unless the temperature is so high that the fat is charred. A steak may be cooked at a high temperature, and have a greater loss, due to high temperature, yet be rare in the center, because of a shorter cooking time, than a steak cooked at a low temperature. Steaks and chops that are cooked rare or medium well done may lose from 10 to 25 per cent of the uncooked weight. Steaks and chops cooked well done usually have higher losses, from 20 to 40 per cent. The above figures are taken from losses obtained in cooking steaks and

TABLE 30  
COOKING LOSSES OF ROASTS

Investigator Kind of meat and cut	No. roasts	Average weight of roasts, pounds	Sear- ing temper- ature °C.	Cook- ing temper- ature °C.	Average time per pound, min- utes	Interior tempera- ture when removed from oven °C.	Total cooking losses		
							Average, per cent	Mini- mum, per cent	Maxi- mum, per cent
Dowler Pork, rolled loin	6	3.97	250	150	34.5	77	27.4	20.0	31.0
Hunt Beef, standing, 3-ribs	6	6.26	275	125	18.3	57	16.6	10.6	21.3
Kite Beef, standing, 3-ribs	5	6.98	250	250	16.7	70	41.2	35.4	47.3
Lowe Beef, standing, 3-ribs. Feeders	43	4.65	275	125	22.4	57	10.8	7.2	17.4
Beef, standing, 3-ribs. Fattened	65	8.95	275	125	19.8	57	13.0	6.6	18.4
Beef, ribs rolled	5	14.09	260	125	17.8	57	10.3	7.9	14.4
Pork, loin	5	1.44	275	150	69.0	80	27.4	20.0	31.0
Ham, baked	3	12.2	150	125	22.9	70	15.4	14.4	17.7
Ham, baked	5	19.5	150	125	17.8	70	22.6	15.8	26.6
Ham, boiled	3	18.6	85	85	18.6	70	16.3	12.4	31.5
Lamb, leg	3	5.00	275	125	36.9	75	13.3	7.1	16.8
Snyder Beef, rump	2	7.38	275	125	21.4	57	12.7	12.1	13.4
Shoulder round boned and rolled.	2	5.29	275	125	22.9	57	7.9	6.9	8.9
Chuck ribs	2	4.88	275	125	24.7	57	9.9	9.9	9.9

chops in class work. They are approximate and do not apply to all conditions. Steaks and chops put in a cold pan and cooked at a low temperature for the entire cooking period show low cooking losses. They are juicy but do not brown as well as ones seared at a high temperature, and the fat does not brown well.

**Losses in meats cooked in water.** The losses of meat cooked in water kept at a boiling temperature are usually higher than those cooked in water held at a temperature of 85°C. or lower. Often the loss is twice as great in the boiling water. The extent of surface area, composition, and time of cooking affect the loss. Commercially boiled hams are often cooked at a temperature of about 75°C., for this results in a lower cooking loss, about 15 per cent, which gives a texture that cuts and slices well. One very lean

ham cooked in the laboratory in water at 82° with a total cooking loss of 12.4 per cent sliced well and had an excellent flavor. A cooking loss of 20 to 25 per cent seems to give a flavor to the ham that is preferred by most persons.

### The Percentage of Cooked Meat That Is Edible

Van Arsdale and Monroe have reported their results on "The cost of meat as purchased and eaten." The following table is compiled from their results.

TABLE 31  
COST OF MEAT AS PURCHASED AND EATEN (*Van Arsdale and Monroe*)

Kind of meat	Number of chops, etc.	Per cent edible	Purchase price per pound	Cost per pound cooked edible portion eaten
Rib lamb chop (Frenched)	6	21.00	\$0.28	\$1.360
Rib lamb chop	6	26.39	0.28	1.110
Loin lamb chop	6	44.20	0.28	0.646
Loin pork chops	6	48.00	0.23	0.483
Ham	1	43.80	0.19	0.433
Round beef steak	6	59.61	0.25	0.421
Porterhouse steak	2	56.27	0.30	0.522
Pot roast	1	54.85	0.26	0.485
Fowl	1	23.00	0.25	1.080

From the figures of Van Arsdale and Monroe it will be seen that the loin lamb chops have higher percentage edible portion than the rib lamb chops. Determinations of the weight of the cooked edible portion of rib and loin pork chops made in the author's laboratory give similar results, i.e., the loin pork chops have less waste than the rib pork chops. The percentage of edible round beef steak given by Van Arsdale and Monroe's results is much lower than the total edible portion for this cut of beef, on account of the large percentage of the portion served which was not eaten. Monroe and Van Arsdale have published results of experiments with roasts of beef, veal, lamb, and pork.

The most extensive work on determining the weight and amount of edible and servable meat with which the author is familiar is that of McElhinney. This work was done in the Institutional Laboratory at Iowa State College. The figures in the following tables are compiled from McElhinney's results.



The searing temperature for all the meats with the exception of the ham was 250° to 275°C. for 20 minutes, and they were then cooked at 125°C. for the remainder of the cooking period. The baked hams were cooked at 150°C. for 30 minutes and then at 125°C. for the remainder of the time. For the boiled hams a pint of water was allowed for each pound, and they were cooked at a temperature of 82° to 83°C. The degree of doneness was determined by the use of a chemical thermometer inserted into the roast as previously described.

TABLE 32

THE AVERAGE COOKING LOSSES AND TIME REQUIRED TO COOK DIFFERENT KINDS OF MEAT (*McElhinney*)

Kind of meat	Number of roasts	Total weight of all roasts		Weight after cooking		Total cooking loss, per cent	Minutes per pound for cooking	Inner temperature when removed from oven, °C.	Maximum interior temperature reached, °C.
		lbs.	oz.	lbs.	oz.				
Prime ribs, well done	3	31	4	24	10	22.5	14.6	76	80
Prime ribs, medium	5	60	9	47	10	21.7	9.8	65	70
Ham, boiled	5	104	5	82	12	20.6	17.4	71	74
Ham, roasted	7	126	15	94	7	25.6	14.1	72	77
Veal, leg, roast	6	107	2	76	1	29.0	17.2	71	75
Lamb, leg, roast	4	26	11	18	13	28.0	17.0	79	80
Pork loin, roast	9	74	5	56	3	26.3	16.2	83	85

### Poultry

Vernon determined the shrinkage in dressing and cooking poultry, using fryers, roasters, and hens. Lowe and Vernon determined the dressing and cooking losses for broilers, fryers, roasters, capons, and hens. All the poultry was roasted except the fryers and broilers. The broilers were broiled under a gas flame in the oven, the fryers were dredged in flour and fried in fat. In frying, the lean fryers absorbed fat, and the fat ones lost fat.

The inedible portion includes the weight of all parts of the fowls served but not eaten.

TABLE 33

AVERAGE AMOUNT OF WASTE AND PERCENTAGE EDIBLE OF DIFFERENT KINDS OF MEAT (*McElhinney*)

Kind of meat	Waste						Meat edible but not slicable		Meat slicable		Per cent edible on as purchased basis	Per cent slicable on as purchased basis
	Drippings		Bone		Skin		lbs.	oz.	lbs.	oz.		
	lbs.	oz.	lbs.	oz.	lbs.	oz.						
Prime ribs, well done	3	4	4	2			5	15	13	9	62.4	44.5
Prime ribs, medium	6	1	9	12			15	3	22	3	61.2	39.4
Ham, boiled	10	3	8	14	7	8	18	8	37	12	53.8	36.2
Ham, roasted	29	6	11	8	2	0	21	0	47	13	55.7	37.8
Veal, leg, roast	11	2	9	6			12	12	46	7	55.3	43.3
Lamb, leg, roast	6	13	4	3			3	7	9	8	48.5	37.1
Pork loin	9	11	10	8			8	0	31	1	51.0	40.4

TABLE 34

COST OF COOKED EDIBLE AND SLICABLE MEAT (*McElhinney*)

Kind of meat	Cost per pound as purchased	Cost cooked edible meat		Cost of slicable meat	
		per pound	per 4-ounce serving	per pound	per 4-ounce serving
	cents	cents	cents	cents	cents
Beef, well done	25.0	40.4	10.1	58.6	14.7
Beef, medium	25.0	42.1	12.4	65.2	16.3
Ham, boiled	30.0	57.8	14.4	90.2	22.5
Ham, roasted	33.0	60.5	15.1	88.3	21.8
Veal, leg, roast	28.0	49.5	12.4	63.2	15.8
Lamb, leg, roast	37.5	81.7	20.4	107.4	26.8
Pork loin, roast	27.0	55.3	13.8	71.4	17.8

TABLE 35

DATA FOR DRESSING AND COOKING LOSSES OF DIFFERENT CLASSES OF POULTRY  
BASED ON PER CENT OF LIVE WEIGHT (*Lowe and Vernon*)

	Broilers	Fryers	Young roasters	Capons	Hens	Average all classes
Number of birds....	13	14	9	10	16	62
Dressed weight.....	89.1	89.9	88.9	90.0	92.0	89.9
Drawn weight.....	62.9	67.8	70.6	75.6	71.4	69.6
Cooked weight.....	45.2	51.5	55.8	53.8	49.2	51.1
Fat loss.....	....	....	2.9	9.2	9.0	....
Moisture loss.....	....	....	10.1	12.2	12.3	....
Total cooking loss..	15.7	14.6	13.0	21.4	21.3	17.2
Weight of inedible cooked portion... .	12.8	11.1	14.2	10.8	10.6	11.9
Weight of cooked meat.....	32.4	39.4	41.7	42.9	38.7	39.0
Weight of drippings..	0.6	....	6.3	13.2	11.6	....
Weight of cooked meat and drip- pings.....	33.0	....	48.0	56.1	50.3	....

The term dressed weight is used as in poultry classification and marketing. A dressed bird is bled and has the feathers removed. Market prices from butcher shops are usually for the dressed and not the drawn weight. The drawn weight is the weight after removal of the head, feet, and digestive organs.

As given in Table 35, the average losses for all classes of poultry are 12, 20, 19, and 12 per cent for dressing, drawing, cooking, and inedible loss, respectively. Thus the cooked meat is less than 40 per cent of the live weight.

For the convenience of those buying poultry from the markets, the data in the preceding table are given in the following table, but based on the drawn weight, which makes the percentages higher.

Lowe and Keltner found that the edible meat without skin, based on the uncooked weight of 116 halves of roasters as prepared for the oven, averaged slightly more than 50 per cent. When the skin was included the edible portion was considerably higher.

The cost of the edible meat and of the total edible portion for the different classes of poultry given in Tables 35 and 36 is given in Table 37.

**Roasting of poultry.** The percentages lost in cooking poultry reported by Lowe and Vernon, and tabulated in Tables 35 and 36, were obtained by roasting the chickens in tight-fitting covered roasters at 250°C. for 30 minutes and then the temperature was lowered to 175°C. The pans were

TABLE 36

DATA FOR DRESSING AND COOKING LOSSES OF DIFFERENT CLASSES OF POULTRY  
BASED ON THE DRAWN WEIGHT, PER CENT

	Broilers	Fryers	Young roasters	Capons	Hens	Average all classes
Number of birds....	13	14	9	10	16	62
Drawn weight.....	97.0	97.4	97.5	99.1	98.5	97.9
Cooked weight.....	71.8	75.9	79.1	71.1	68.8	73.3
Fat loss.....	....	....	4.1	12.1	12.6	....
Moisture loss.....	....	....	14.2	16.2	17.1	....
Total cooking loss..	25.0	21.6	18.3	28.3	29.7	22.6
Weight of inedible cooked portion...	20.3	17.6	20.0	14.3	14.9	17.4
Weight of cooked meat.....	51.4	58.1	59.0	56.7	54.0	55.8
Weight of drippings.	1.0	....	8.9	17.5	16.3	....
Weight of cooked meat and drip- pings.....	52.4	....	67.9	74.2	70.3	....

TABLE 37

COST OF EDIBLE MEAT FOR DIFFERENT CLASSES OF POULTRY (*Lowe and Vernon*)

	Live weight average, pounds	Dressed weight average, pounds	Cost per pound dressed weight	Cost per pound cooked meat	Cost per pound edible meat plus drippings
Broilers.....	1.87	1.67	\$0.40	\$1.090	\$1.070
Fryers.....	2.95	2.66	0.34	.778	.778
Roasters.....	4.51	4.01	0.30	.639	.550
Hens.....	5.03	4.63	0.31	.738	.567
Capons.....	7.38	6.65	0.43	.900	.688

uncovered for the last 15 minutes of cooking and the heat increased to brown the roasts. In the covered pans used in these experiments, very little browning occurred while the roasts were covered.

*Methods and cooking temperatures.* In roasting poultry, one is confronted with the problem of cooking tender and less tender muscles at the same time. As a result, when the breast is at its prime, the thigh and leg

muscles may be slightly tough and, *vice versa*, when the thigh and leg are cooked sufficiently to soften the connective tissue, the breast is past its prime and is becoming dry.

Another problem in cooking poultry is the skin. If it is moist and tender, the appearance is less attractive because it is not so brown. When the skin is not consumed this point is not important.

The degree of fatness and its distribution, the degree of post-mortem changes or ripening, the age, and the size may affect the cooking time and losses of roasters. In addition, breed, sex, and the feed the bird has received may have some effect on these factors. Hence, for fair experimental tests the cuts should be paired. To do this Lowe and Keltner divided roasting chickens into halves, the halves being tested one against the other to determine the effect of the cooking temperature, covering the pan, and basting on cooking losses, cooking time, and palatability of the meat. They found the cooking losses were practically the same for halves cooked at 125°C. (about 250°F.) and at 175°C. (about 350°F.), but the cooking time at the lower temperature was more than twice as long as at the higher temperature. The differences in palatability scores for the breast and thigh meat cooked at the two temperatures were practically negligible, with the exception that the breast scored higher in juiciness at the higher temperature, which was probably related to the shorter cooking time. One drawback in cooking halves of birds was the tendency for the muscles of the breast to separate and draw back, which is of course not encountered in roasting the whole bird. In all these tests the half of chicken was removed from the oven when the interior temperature of the thigh was 85°C. (185°F.).

If a searing instead of a constant temperature method is desired, cooking the roast uncovered for 20 minutes at 200°-230°C. (about 395°-450°F.) and then lowering the temperature to 125°C. for the remainder of the cooking period produces a juicy roast. Covering for the last 20 or 30 minutes of cooking increases the tenderness of the skin, as the confined steam moistens the skin.

In tests of the searing and constant temperature methods for cooking turkeys, in an uncovered pan and basting the turkey every half hour, the constant temperature of 150°C. (about 300°F.) has in general proved very satisfactory, the meat being tender and very juicy.

*Covered and uncovered pans.* Lowe and Keltner cooked halves of 22 birds covered, the other halves uncovered. All were cooked at a constant oven temperature of 150°C. and until the interior temperature of the thigh reached 85°C. The cooking time was approximately twice as long for uncovered as for covered halves. The total and volatile cooking losses were greater for the uncovered halves, but the drippings were greater for covered halves. The scores showed that in aroma, flavor, and juiciness the breast of the uncovered halves was more desirable than the breast of the covered

halves. No preference for the thigh was shown for either covered or uncovered halves.

Covering the birds for the last 20 minutes of the cooking period shortened the cooking time, decreased the cooking losses, and increased the tenderness and palatability of the skin but not of the meat. The majority of the scorers preferred the uncovered halves.

*Interior temperatures for cooking poultry.* The insertion of thermometers into muscles of chicken in early tests was not satisfactory, as the thermometer and bulbs were too large. However, it was found that the larger thermometers could be used successfully by inserting them into the stuffing, either through the front or rear cavities of the fowl. For turkeys and geese the thicker part of the stuffing is towards the rear of the carcass; hence it was preferable to insert the thermometer at the rear.

Love and Keltner used in their study a small light thermometer with a very short, small bulb. Placing the bulb of the thermometer into the thickest portion of the thigh muscles and cooking the chicken until a temperature of 85°C. was reached proved satisfactory. The most desirable temperature to which the breast muscles should be cooked has not been determined. Since the breast muscles tended to separate when half of a bird was cooked, thermometers were not used successfully in the breast. However, in the preliminary studies the temperature of the breast was usually 2° to 4° higher than that of the thigh.

Evidently the meat of large fowls is juicier if the interior temperature of the stuffing is lower than for small fowls. This is probably due to their size, the large quantity of stuffing that they hold increasing the distance to the middle of the stuffing.

When chickens were roasted until the interior temperature of the stuffing reached 80° to 83°C., the meat was desirable; but, when cooked to 85°C., the breast of some birds was dry, the drippings and particularly their moisture content increasing rapidly in the last few minutes of cooking. This might indicate that for some birds, depending somewhat upon degree of ripening and other factors, this is a critical temperature. As this point is reached or exceeded, the tendency for the meat of the chicken is to become dry and the drippings loss to increase.

For turkeys weighing 16 to 20 pounds after stuffing, an interior temperature of 75° to 82°C. of the stuffing resulted in juicy meat. But for turkeys weighing 25 to 30 pounds after stuffing a lower temperature gives better results. The type of stuffing used may make some difference in the juiciness of the meat and the cooking losses. Lowe and Keltner found that stuffing made from 1-day-old bread, 100 grams, butter 50 grams, and salt 2 grams, but without the addition of liquid, absorbed an average moisture content of 41.5 per cent. The amount of moisture absorbed varied from 14.6 to 78.1 per cent.

The above results and observations in cooking of poultry suggest that poultry may lose moisture rapidly after a certain temperature is reached,

with the result that the meat becomes quite dry. This loss of moisture seems to occur most rapidly at a temperature around 83° to 85°C. Some meats may become dry more readily within a short range of temperature than others. Ostwald states that "Pork can be distinguished from other meats by the fact that its water holding capacity suffers the least change when cooked or dried." The kind of food the bird has received may influence the juiciness to a certain degree.

*Basting.* Lowe and Keltner found that basting shortened the cooking period, but did not appreciably affect the cooking losses. Butter was used for basting. The salt was removed by washing, the butter was then melted, and the curd allowed to settle. The half of chicken was basted before putting in the oven, at the end of 30, and at the end of 60 minutes, a total of 20 grams of butter being used. Basting increased the desirability of the lean meat of both the thigh and breast.

*Time of cooking.* Roasters weighing 4 to 5 pounds, dressed weight, require about 35 minutes per pound to cook by the searing method. If estimate is based on the stuffed weight, about 30 minutes per pound is necessary. But considerable variation may be expected, larger roasters requiring a shorter and smaller ones a longer time. For the constant oven temperature, 150°C. (about 300°F.), approximately the same time will be required as for the searing method though again considerable variation may be expected.

Table 38, based on laboratory results, gives approximate time for roasting turkey at 150°C. Variation from this time will of course be found. The time given is for uncovered birds. A shorter time will be required when the roast is covered.

TABLE 38  
APPROXIMATE TIME FOR COOKING TURKEY

Turkey	Weight of stuffed bird in pounds	Average total cooking time in hours	Average time per pound in minutes
Small.....	6 to 10	3 to 3½	20 to 25
Medium.....	10 to 16	3½ to 4½	18 to 20
Large.....	18 to 23	4½ to 6	16 to 18

*Effect of feed on fat distribution.* Maw has investigated the effect of cereals, yellow corn, wheat, oats, and barley on the amount and nature of the fat deposited in different parts of the body (flesh, abdominal fat, external fat, and skin). Flesh as used was composed of the breast and leg muscles with external fat stripped clean. The wheat gave an excellent external appearance as it produced an external layer of fat over the carcass

but relatively little fat distributed through the flesh. Table 39 gives his results:

TABLE 39  
DISTRIBUTION OF FAT IN THE BODY (*Maw*)

Cereal	Percentage total fat	Fat in flesh	Fat in skin	Abdominal fat
Corn.....	13.4	30	55	15
Barley.....	12.1	26	59	15
Oats.....	12.1	22	57	21
Wheat.....	12.9	20	60	20

Maw states that the fat laid down in the carcass is replacing the moisture. This fat in the cooked bird influences the apparent moistness of the flesh. The palatability tests indicated the corn-fed birds appeared the most moist, with the best flavor. The barley-fed meat was nearly like the corn-fed; whereas the oat-fed and wheat-fed meats were the poorest in quality, the wheat-fed apparently being the driest and poorest in flavor. These birds were roasted at a constant temperature of 375°F.

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## MEAT

### Experiment 37.

To determine the effect on muscle fiber and connective tissue of cooking by dry heat.

Scrape a piece of lean meat with the dull edge of a knife until the connective tissue and fiber are separated. Save a portion of the fiber and connective tissue to use in Experiment 38. Form in small balls and cook in a hot frying pan. What is the effect of dry heat on the connective tissue? On the fiber? Which is affected the most?

### Experiment 38.

To determine the effect on muscle fiber and connective tissue of cooking by moist heat.

1. Cook a portion of the fiber and the connective tissue in boiling water. If the water evaporates, add boiling water.

2. Cook a portion of the muscle fiber and the connective tissue in water. Do not let the temperature of the water go above 85°C. Compare the texture of the fiber and the connective tissue from Experiment 37 with Experiment 38, 1 and 2. What temperature would be best to cook a piece of meat containing a great deal of connective tissue to soften the connective tissue, yet keep the muscle fibers tender?

Texture		Time to cook	
Fibers	Connective tissue	Fibers	Connective tissue

Results and conclusions.

## Beef Roasts

### Experiment 39.

To determine the effect on beef roasts of cooking to different stages of doneness.

1. *Preparation.* Weigh the roast. Wipe with a damp cloth. A tracing may be made of the cut surfaces of the meat. Determine the place and depth for insertion of the thermometer. Measure the width of the roast. The thermometer is inserted half way. See Fig. 23, p. 225. To determine the depth to insert the thermometer, measure the distance on the two cut surfaces as indicated in Fig. 25, diagram *D*, p. 234. The distance should be the diameter of a circle, so that the bulb of the thermometer can be inserted equally distant from the top, the chine bone, and the bottom of the roast. If the depth on one cut surface is 4 inches and on the other 4½ inches, use an average of these two, or 4¼ inches, for the distance represented by the diameter of the circle. Measure up from the center of the thermometer bulb 2⅛ inches on the stem and insert to this depth in the roast. The incision for the thermometer should be made with a very narrow knife blade, about ¼ inch in width, or a skewer so that the meat will fit tightly around the thermometer. For a rolled roast find the radius (one-half of the diameter) and insert the center of thermometer bulb to this depth in the middle between the two ends of the roast.

Weigh the thermometer and the cooking pan. Use an open pan. A common, sheet-iron pan is suitable for roasting. A standing-rib roast rests on the chine bone and rib ends, which keeps the roast above the drippings. See Fig. 23. A rolled roast is laid on a rack with the fat side up. No water or seasoning are added. Record the inner temperature of the roast and oven at definite intervals, 10, 15, or 20 minutes, during the cooking period. Cook by one of the following methods. If paired roasts are used, one may be cooked by a searing, the other by a constant temperature method.



Volatiles loss, per cent	Interior temperature when removed from oven, °C.	Maximum temperature reached, °C.	Time after removal from oven to obtain maximum temperature	Total time of cooking, minutes	Time of cooking per pound, minutes

Weight of edible cooked portion, grams	Edible portion, per cent	Color		Tenderness	Juiciness
		exterior	interior		

Results and conclusions.

#### Experiment 40.

To determine the rate of temperature rise near the surface of the roast as compared with the center of the roast.

1. Repeat Experiment 39,1, but place a second thermometer  $\frac{1}{2}$  inch from the surface of the roast. Take the readings on both thermometers every 10 minutes. Remove from the oven when the temperature at the center is 55°C. Continue to record the changes in temperature. What differences do you note in the changes of temperature in the two portions of the roast? Plot on graph paper the rise in temperature in the two portions of the roast. Compute losses and make records as suggested under Experiment 39.

#### Experiment 41.

To determine the effect of cooking at different temperatures on standing beef rib roasts.

Three pairs of two-rib roasts can be obtained from one carcass, the pairs consisting of ribs 11 and 12, 9 and 10, and 7 and 8. These pairs can be used to compare the cooking losses, the exterior and interior color, the juiciness, tenderness, and flavor of roasts cooked at various temperatures. See the following suggestions. Cook the roasts to the same interior temperature, 63°C. (If desired either 55°C. or 75°C. may be used.)

1. a. Use a constant oven temperature of 125°C. for cooking one roast of the pair.
- b. Cook the other roast at a constant temperature of 225°C.
2. Compare the effect of constant oven temperatures of 125°C. and 175°C.
3. Repeat (2) but compare 125°C. and 150°C.
4. Repeat (2) but compare 150°C. and 175°C.

5. Repeat (2) but compare 150°C. and 225°C.

6. Use the experimental searing method (20 minutes at 250°-275°C., then transfer the roast to a second oven at 125°C.) with a constant temperature of 125°C.

7. Repeat (6) but compare the searing method and a constant temperature of 150°C.

The lower searing temperature may be substituted for the experimental searing method in any of the above suggestions. In addition the experimental searing method may be used with temperatures of 150°C. and 175°C. to complete the cooking.

If rolled instead of standing rib roasts are used, they should be placed on racks to keep them above the drippings. Compute losses and make records as suggested under Experiment 39.

What is the interior temperature of a roast which is rare? Of a medium well-done roast? Of a well-done roast? In each case what was the number of minutes per pound required for roasting? What is the effect of increasing the size of the roast on the time required per pound? How much did the inner temperature of roasts rise after removal from the oven? What factors cause variations in this rise in temperature? If a rare roast is to be served immediately, at what temperature would you remove it from the oven? Is the rate of increase of inner temperature of the different roasts constant?

## Lamb, Pork, and Veal Roasts

### Experiment 42.

To determine the effect on roasts of cooking at different temperatures.

Use roasts of lamb, pork, and veal, but if possible the roasts should be paired; that is, use the same cuts from the right and left sides of the same carcass. Make tracings of cut surfaces of the roasts. Make a record of width. Determine the total, the dripping, and the volatile losses. Calculate the time of cooking per pound. Find the rise of inner temperature after removal from the oven. Compare the roasts for juiciness, flavor, and tenderness. Record the inner temperature of roasts and ovens at the same intervals used in Experiment 29 and plot on graph paper. Make records as suggested under Experiment 39.

For all the following roasts the bulb of the thermometer should be placed in the center of the thickest portion of the roast, which is not necessarily the center of the piece of meat. If a loin roast of pork is used the thermometer bulb should be in the center of the large muscle along the backbone.

#### A. Lamb.

*Preparation.* Weigh the roast. Wipe with a damp cloth. Insert the thermometer bulb into the thickest portion of the leg. Use two rulers held at right angles to each other to determine the depth of inserting the thermometer bulb. Place the roast on a rack in a weighed, open pan so the skin side or fell side is down if a leg of lamb is used, and up if a shoulder roast is used. Record the temperature of roast and place in oven without addition of water or seasonings. Cook to an interior temperature of 75°C.

1. Use the constant 150°C. oven temperature. Cook one leg of lamb with the fell removed but leave the fell on the other leg of this pair.

2. For paired roasts use any of the cooking temperatures suggested under Experiment 41.

#### B. Pork loin.

*Preparation.* Weigh the roasts. Insert the thermometer in the same manner as for beef-rib roasts. Place the roast with fat side up on a rack in a weighed pan. Cook to an interior temperature of 84°C.

*Searing method.* Because of the long time required to cook pork roasts, a temperature of 150°C. was used for the temperature of cooking in the second oven after searing at 250°-255°C. for 20 minutes with the experimental searing method.

1. For paired roasts use any of the cooking temperatures suggested under Experiment 41, but use the higher cooking temperature with the experimental searing method.

#### C. Veal.

*Preparation.* Prepare in the same manner as other roasts. Place on a rack in an open pan. The cut used for roasting in the Cooperative Meat Investigations is a section of the thigh about 4 inches wide cut through the femur just inside the end of the enlarged joint. Cook to an interior temperature of 71°C.

1. For paired roasts use any of the cooking temperatures suggested under Experiment 41.

### Experiment 43.

To determine the effect on roasts of lamb, pork, and veal of cooking to different stages of doneness.

Follow the directions under Experiment 42 and cook roasts of veal, lamb, and pork. Cook by the constant temperature (150°C.) method and vary the interior temperatures to which the roasts are cooked as follows:

Lamb: 71°, 75°-76°, and 83°C.

Pork: 78°, 83°-84°, and 88°C.

Veal: 71°, 75°, and 80°C.

## Steaks and Chops

### Experiment 44.

#### *Steaks.*

To determine the effect upon steaks of cooking by different methods and to different interior temperatures.

Rib, porterhouse, sirloin, or round steak may be used. Steaks for comparative tests by the Cooperative Meat Investigators are cut 2 inches thick. Steaks 1 to 1¼ inches in thickness are satisfactory for class work.

*Preparation.* Weigh the steak. Make a tracing of the cut surfaces. Measure the thickness. Insert a weighed thermometer, so that the bulb is midway, i.e., ½ inch from the top and from the bottom of a steak 1 inch thick. A right-angle thermometer should be used for steaks to be pan-broiled, but either a tube or right angle may be used for broiled steaks. Steaks may be turned at regular intervals or only once. If turned only once, Cline suggests turning



the steak when about three-fifths of the expected temperature rise has occurred. If the temperature of the steak is  $10^{\circ}$  and it is to be cooked to an interior temperature of  $60^{\circ}$ , the temperature rise will be  $50^{\circ}$ , and three-fifths of 50 equals 30. Thus the steak will be turned when the inner temperature is about  $40^{\circ}\text{C}$ . To turn, stick a fork into the flank muscle, connective tissue, or firm fat and not into one of the principal muscles.

Keep a record of the interior temperature of the steaks at regular intervals. Note and record the temperature rise after cooking is stopped. Plot on graph paper. Record the time for cooking and minutes seared on each side (if searing is used). Compute the total, the volatile, and drippings losses.

Compare the steaks for exterior appearance, interior color, juiciness, flavor, and tenderness. In preparing samples for testing, be sure the scorer gets the same slice from each steak.

Cook all steaks to an interior temperature of  $61^{\circ}\text{C}$ .

#### A. Method of cooking.

1. Broiled. Weigh the broiling pan and rack. Place pan so that the top of the steak will be about 4 inches below the flame. A fireless cooker thermometer may be placed at the left front on the first two rods. Heat the broiler pan and rack until the fireless cooker thermometer registers about  $175^{\circ}\text{C}$ . Place steak on rods in the center of the pan with thermometer at the right-hand side and broil until the desired temperature for turning is reached. Turn so that the thermometer is still at the right-hand side. Turn the thermometer so the reading scale is up. Remove when the desired interior temperature is reached. Note temperature rise. When the maximum temperature is reached, weigh the steak and the broiler pan and drippings.

For variation in temperature of broiled steaks, lower or raise the top of the steak farther from or nearer to the flame.

2. Pan broil. Sear on each side in a hot skillet. Turn. Lower heat and cook slowly until the temperature for turning is reached. Turn and cook until the desired interior temperature is reached. Remove and follow directions under (1).

3. Pan broil. Repeat (2) but use a constant temperature for cooking.

#### B. Varying the interior temperature to which steak is cooked.

1. Use the same method for cooking all steaks. Follow directions under A and cook until the interior temperature reaches rare,  $55^{\circ}$  to  $57^{\circ}\text{C}$ .

2. Repeat (1) but cook medium well done,  $61^{\circ}\text{C}$ .

3. Repeat (1) but cook well done,  $71^{\circ}\text{C}$ .

#### C. Thickness of the steak.

Cook by the same method and to the interior temperature decided upon by the class. Compare the cooking losses and time of cooking.

1. Use a steak  $\frac{1}{2}$  inch thick. (Cannot use thermometer.)

2. Repeat (1) but use a 1-inch thick steak.

3. Repeat (1) but use a steak cut  $1\frac{1}{2}$  inches thick.

#### Chops.

Repeat any of the above experiments using chops of pork, lamb, or veal. Cook pork chops to an interior temperature of  $80^{\circ}\text{C}$ ., lamb to  $75^{\circ}\text{C}$ ., and veal to  $71^{\circ}\text{C}$ .

### Less Tender Cuts

#### Experiment 45.

To determine the effect of various factors in cooking less tender cuts of meat.

*Braising.* Cuts. Use paired cuts. Cuts from the neck, flank, rump, round, or particular muscles from the round such as the semitendinosus may be used. One piece is cut from the right, and a second piece of the same size and from the same position from the left side of the carcass. Pieces weighing about 1 to 1½ pounds are satisfactory for class work.

Preparation. Weigh the pieces. Each member of the class cooks a pair of cuts. Everything, as nearly as possible, should be standardized, except the variable being tested. For example, if the effect of pounding is to be determined, both pieces may be seared but only one should be pounded.

Add 2 grams of salt per pound of meat. Add ¼ cup of liquid per pound and more if necessary, but keep a record of the amount added. With larger pieces of meat a relatively smaller proportion of liquid may be added. If necessary to add water, have it boiling.

Use covered containers, of a size suitable for the pieces of meat being cooked, such as casseroles, Dutch ovens, skillets, etc. For some experiments both pieces of the pair may be cooked in the same container, one or both pieces being marked with a metal tag or with tooth picks. For other tests separate utensils will need to be used for each piece of meat.

Determine only the total cooking losses. Compare the juiciness, flavor, tenderness, and slicability of the meat.

The following suggestions are offered for tests:

1. Pounded vs. not pounded.
2. Floured vs. not floured (neither piece pounded).
3. Floured vs. not floured (both pieces pounded).
4. Seared vs. not seared (neither pounded nor floured).
5. Seared vs. not seared (both pounded and floured).
6. Covered vs. uncovered.
7. Lower (simmer) vs. higher temperature (boiling over flame).
8. Lower vs. higher temperature (in oven).
9. Add tomato juice as liquid to one piece, an equal quantity of water to the other.
10. Repeat (9) but substitute sour cream for the tomato juice.
11. Remove one piece when the interior temperature reaches 75°C., the other when the inner temperature reaches 85°C.
12. Remove one piece when the interior temperature reaches 85°C., the other at 95°C.

Many combinations of the above suggestions and other combinations not mentioned may be tried.

### Cooking Meat in Water

#### Experiment 46.

To determine the effect of temperature of the water upon the palatability of the meat.

*Stews.* Use neck, heel of round, or any of the less tender cuts. The meat is cut into cubes of the size desired, using equal quantities from each side of the carcass. Cook in covered utensils. The amount of water added is usually just sufficient to cover the meat. This will have to be determined in connection with the utensils used for the stew. At the start try using  $\frac{1}{2}$  cup of liquid to each pound of meat. For boiling temperatures this should be doubled. Use 2 grams of salt per pound of meat. For stews the meat is usually prepared in one of three ways. (a) Brown stew. The meat is seasoned and seared in fat before it is added to the boiling liquid. The meat may be floured before it is seared. The flour browns more readily and adds color to the liquid. (b) The meat is added directly without searing to the boiling liquid. (c) The meat, without being seared, is added to the cold liquid and heated slowly to the desired temperature. If vegetables are used with the stew, they are added so that they will just become tender before the stew is served. The broth of the stew may be thickened slightly.

1. Brown stew. Dredge the meat with flour. Add salt. Sear in hot fat. Add the seared meat to the boiling water. Cook one stew at simmering ( $85^{\circ}$ - $90^{\circ}$ C.,  $185^{\circ}$ - $194^{\circ}$ F.) temperature, the other at boiling. Add boiling water to either as needed, but the amount of water when served should not cover the meat or meat and vegetables when served.

2. Repeat (1) but add the unseared meat to the boiling water.

3. Repeat (1) but add the unseared meat to cold water. Heat slowly to simmering and boiling temperatures.

Compare the meat from the various stews for flavor, juiciness, slicability (if pieces are large enough to slice), stringiness, tenderness, and time of cooking.

## Broth

### Experiment 47.

To determine the best method of making broth.

Use  $\frac{1}{2}$  pound of meat for each experiment and 1 pint of water. Add water as necessary to keep the volume constant.

1. Cook the meat in one piece. Start in cold water and heat to  $85^{\circ}$ C. Cook until tender, keeping the temperature  $85^{\circ}$ C.

2. Repeat 1, but cut the meat in 1-inch cubes.

3. Repeat 1, but grind the meat.

4. Repeat 2, but start in boiling water and cook at boiling temperature.

5. Repeat 2, but sear the meat before adding to the water. What are the differences in the broth in each case? How is a clear broth prepared? Strain some of the above broths. To another add a beaten egg white, heat, then strain.

## Ground Meat

### Experiment 48.

To determine the effect of various factors upon the palatability of ground meat.

*Meat loaf.*

Recipe:

Ground lean beef	$\frac{1}{4}$ pound	113 grams	Ground suet	14 grams
Butter	$\frac{1}{2}$ tablespoon	7 grams	Bread crumbs	25 grams
Egg, beaten	$\frac{1}{4}$	12 grams	Pepper	$\frac{1}{16}$ teaspoon
Milk	$\frac{1}{4}$ cup	61 grams		
Salt	$\frac{1}{4}$ teaspoon	1 gram		

Mix the ingredients lightly with a fork. The meat loaf may be baked in individual casseroles or even in pyrex custard cups the same weight being put in each dish. Bake in the oven, putting a right-angle thermometer into each sample, the thermometer being suspended by the horizontal arm on a rack above the meat loaf. Ground meat from the retail market may be used for A and B and the suet omitted.

A. The temperature to which the meat loaf is cooked.

1. Bake in an oven at 160°C. (about 325°F.) until the interior temperature reaches 75°C.
2. Repeat (1) but remove from the oven at 80°C.
3. Repeat (1) but remove from the oven at 85°C.
4. Repeat (1) but remove from the oven at 90°C.

B. The temperature of the oven.

Bake to the interior temperature found best under A.

1. Bake at 150°C. (about 300°F.).
2. Bake at 160°C. (about 325°F.).
3. Bake at 175°C. (about 350°F.).
4. Bake at 185°C. (about 365°F.).

C. Effect of fineness of grinding of the meat.

Bake to interior and at oven temperatures found best under A and B.

1. Grind meat once, using a coarse knife in the grinder.
2. Grind meat once with a medium knife.
3. Grind meat once with a fine knife.
4. Repeat (2), putting meat through the grinder 4 times.
5. Repeat (3), putting meat through the grinder 4 times.

D. The effect of increasing the fat.

Bake to interior and at oven temperatures found best under A and B. Grind to the degree of fineness found best under C.

1. Add 7 grams of ground suet. (If desired butter may be used instead of the suet.)
2. Add 14 grams of ground suet.
3. Add 21 grams of ground suet.
4. Add 28 grams of ground suet.

Compare the flavor, moistness, and texture of the various meat loaves.

*Hamburger.*

## Recipe:

Ground beef	$\frac{1}{4}$ pound	113 grams
Egg	$\frac{1}{4}$	12 grams
Salt	$\frac{1}{4}$ teaspoon	1 gram
Pepper	$\frac{1}{8}$ teaspoon	

Mix the ingredients together with a fork. For uniformity of temperature the hamburger may be baked in custard cups according to directions given under meat loaf. It may also be made into patties and seared, then cooked slowly as is the usual practice.

1. Repeat section A under meat loaf.
2. Repeat section C under meat loaf.

**Cured Meats****Ham****Experiment 49.**

To determine the effect of various factors affecting the palatability of ham.

Hams may be secured with a light or a heavy salt cure. The former do not need to be soaked before cooking; the latter may be improved by soaking.

Preparation. For hams with a light salt cure, scrub with a brush. Dry, then weigh. Insert thermometer so that the center of the bulb is at the center of the thickest portion of the ham, with rind or fat side up. To determine the depth for inserting the thermometer use two rulers at right angles to each other. Or with a steel skewer pierce the rind or fat side, running the skewer point just through the ham. Withdraw and measure the depth the skewer was in the ham. The thermometer is to be inserted half this distance. If the rind has not been removed, it will need to be cut away with scissors or a knife so that the thermometer can be inserted. Use hams of about the same weight for all the tests.

For hams with a heavy salt cure, soak, keeping the time of soaking and the amount of water used standardized. Soak over night using a quart of water to each pound of ham. Remove from the soaking water and drain 10 minutes. Weigh and proceed as for non-soaked hams.

Record the temperature of ham and oven every 10 minutes for the first 30 minutes, then every 20 or 30 minutes. For hams from which the rind has not been removed, remove the rind after the ham comes from the oven. If to be scored hot, cut as soon as the maximum temperature is reached. If to be scored cold, store after removing rind.

**A. Baked ham.**

Place the ham skin side up on a rack in an open weighed pan. Add no water or seasoning.

1. Bake in an oven at 125°C. (about 255°F.) until an interior temperature of 70°C. is reached.
2. Repeat (1) but cook to an interior temperature of 75°C.
3. Repeat (2) but cook to an interior temperature of 80°C.

4. Repeat (1) but have the oven temperature 150°C. (about 300°F.).

#### B. Boiled ham.

Use kettles with covers, ham boilers, or boilers of such size that the water will cover the ham. The ham is placed on a rack, rind or fat side up. Use an ordinary laboratory thermometer to take the temperature of the water. Add 1 quart of water per pound of ham. Occasionally add water at the same temperature as water in which ham is cooked to replace that lost by evaporation.

1. Let simmer in water at 83°C. until an inner temperature of 75°C. is reached. Or, if preferred, use the interior temperature preferred with baked ham. Remove from the water. Drain. Weigh. Keep over night in the refrigerator.

2. Repeat (1) but let the ham cool over night in the liquor in which it was cooked. Let the kettle remain in the room so that the liquid will cool to room temperature. Remove from the liquid. Drain 10 minutes and weigh. Place in the refrigerator to be scored with hams from (1) and (3).

3. Repeat (1) but put the kettle or boiler in the refrigerator over night, letting the ham cool in the liquor in which it was cooked. Remove from liquid. Drain 10 minutes, and then weigh.

4. Repeat (1) but keep the temperature of the water at 87°C.

5. Repeat (1) but keep the water at 78°C.

### Bacon

#### Experiment 50.

To determine the effect on the flavor and the losses of bacon by cooking at different temperatures and to different stages of doneness.

Weigh the bacon before and after cooking to determine the percentage lost during cooking. The difference in weight of the uncooked and cooked bacon is the total cooking loss. The weight of the fat in the cooking utensil is the approximate fat loss.

Have the bacon sliced or cut on a slicing machine 3/32 inch thick. Make a tracing of slices if desired.

1. Place the slices of bacon on a rack 1/2 inch above the bottom of an open pan. Cook in an oven at 160°C. (about 320°F.) for 18 minutes. Do not turn.

2. Place the weighed slices of bacon so that they lie flat and full length in a cold, heavy iron or aluminum skillet. (With a 9-inch skillet 3 slices of bacon will usually lie flat and full length.) Place over a slow fire and cook slowly until a uniform brown in color. It should be medium well done or crisp but not brittle. Turn the bacon frequently and in such a manner that it is cooked uniformly. Often the center, if the skillet is hot, of the slice of bacon is done while the ends are not.

3. Place the weighed slices of bacon so that they will lie flat and full length in a hot, heavy iron or aluminum skillet. Cook rapidly at a high temperature until a uniform brown in color. Turn the bacon frequently and in such a manner that it is cooked uniformly.

4. Repeat 2, but cook the bacon until it is very crisp and well done or brittle. Compare the cooking losses and flavor with 1 and 2.

Which method of cooking gives the best-flavored bacon? Which method

causes the fat to smoke or burn? Does the bacon taste of burned fat? Which method causes the bacon to curl the most? Which method gives the most evenly cooked product? Compare the flavor, the cooking losses, and the cost of the cooked bacon, cooked only until crisp and that cooked until brittle.

Weight of uncooked bacon, grams	Weight of cooked bacon, grams	Total cooking loss, per cent	Fat loss, per cent	Straight or curled	Color	Flavor

Results and conclusions.

### Experiment 51.

To compare the flavor and cooking losses of different brands of bacon.

Cook different grades and brands of bacon in the oven at 160°C., see Experiment 50,1. The different bacons may be scored before and after cooking for the color and uniformity of color of lean and fat, for the percentage of fat and lean, the distribution of the lean and the fat, and for texture. The cooked bacon may be scored for color, the clearness of the fat, the percentage and distribution of fat and lean, the crispness, and the flavor.

Brand of or grade of bacon	Uncooked weight, grams	Cooked weight, grams	Total cooking loss, per cent	Fat loss, per cent	Straight or curled	Flavor

Results and conclusions.

### Suggestions for Additional Experiments with Meats

1. Determine the effect on total cooking loss of cooking roasts in a covered and uncovered pan.
2. Determine the effect of salting on cooking losses of chops, steaks, and roasts.

## CHAPTER VIII

### EMULSIONS

Some substances like alcohol and water are miscible in all proportions, i.e., they mix intimately however small or large the proportions used, whereas other substances like oil and water are not miscible.

When a liquid is dispersed in a second liquid with which it is non-miscible the product is called an emulsion. The boundary surface between these two non-miscible liquids is referred to as the liquid/liquid interface, or the dineric interface. Most emulsions are colloidal systems in which the dimension of the dispersed phase is greater than  $0.5\mu$ , the upper limit of the colloidal realm. However, the stabilizing film in the concentrated emulsions may have colloidal dimensions.

In cookery, the liquid of the emulsion may be water, milk, a weak acetic acid solution, or some similar liquid. The fat or oil may be any fat or oil used as a food. Mineral oils may also be used for emulsions. If emulsions are mentioned in connection with food preparation, mayonnaise is usually the one suggested first. However, all thickened gravies, sauces, and cream soups are emulsions. Fillings for pies like chocolate cream, and French and cooked salad dressings, may be added to the list. In many of the batter products the fat or oil may be partially or wholly emulsified.

**Forming emulsions.** To form emulsions, work must be done. The function of the work is not only to separate the dispersed phase into smaller particles, but to increase the surface area, which gives a better opportunity for the two phases to come in contact with each other and increases the area for adsorption of the emulsifying agent. Stirring, beating, shaking, grinding, or some other method may be used to disperse one of the substances.

**Dispersed and continuous phases.** The substance broken into small portions is called the inside, the discontinuous, or the dispersed phase; the one surrounding the dispersed phase is designated as the outside, the continuous phase, or the dispersing medium. If oil and vinegar are shaken together, French dressing is made, but after standing a few minutes the oil and vinegar separate. This type of emulsion that lasts for a few minutes only is sometimes called a temporary emulsion.

**Emulsifiers.** A permanent emulsion of pure water and pure oil can be formed only when the proportion of oil is very small, less than 2 per cent, and usually not more than 1 part of oil in 10,000 parts of water. For a permanent emulsion with a high percentage of fat or oil, a third substance must be present to prevent the drops of oil or of water from



coalescing or running together. This third substance is known as an emulsifying agent, an emulsifier, or a stabilizer. Its function is to form a film around the oil or water drops and thus keep them dispersed, giving permanence to the system.

### Classes of Emulsions

Clayton states that two very distinct classes of emulsions exist. (1) The very dilute emulsions. These emulsions are simple emulsions, containing only oil and water. In this class only the oil in water emulsions are known. (2) The concentrated emulsions. The more concentrated emulsions may be either of two types according to whether the oil or the water is the dispersed phase. In the (1) oil-in-water type of emulsion the drops of oil are the dispersed or divided phase. In the (2) water-in-oil type of emulsion the water is the dispersed phase. The factors determining the type of emulsion formed will be considered later.

### The Theory of Emulsification

Bancroft states that the necessary conditions for forming a stable emulsion are that the drops of the dispersed phase shall be so small that they will stay suspended and that there shall be a sufficiently viscous film around each drop to keep the drops of the dispersed phase from coalescing.

Many theories have been advanced to account for the way or means by which the emulsion is stabilized by the emulsifier. At the present time no theory has been postulated that seems to apply universally to all emulsions. As Fischer suggests, probably a number of factors play a rôle, and the relative importance of each varies not only in different emulsions but in one and the same emulsion under different circumstances. Clayton in his latest book on emulsions gives a summary of the various theories for emulsions. Only a few will be mentioned here.

**The electrical double layer.** The oil globules in a pure oil and pure water emulsion carry a negative charge. The water ionizes so that both hydrogen and hydroxyl ions are present. The negative charge on the oil may come from adsorption of the OH ions. These adsorbed hydroxyl ions form a layer around the oil globules. A second layer of oppositely charged ions forms a layer in the liquid outside the layer of negative ions. These two layers of oppositely charged ions are known as the Helmholtz double layer. They are not confined to emulsions but accompany all boundary phenomena. The electric charge is a factor in all emulsions, even those stabilized with emulsifying agents.

**The phase-volume theory.** If spheres of the same diameter are packed as closely as possible, one sphere will touch 12 others and the volume the spheres occupy is about 74 per cent of the total volume. Thus if the spheres or drops of the dispersed phase remain rigid it is possible to disperse 74

parts of the dispersed phase in the continuous phase; but if the dispersed phase is increased to more than 74 parts of the total volume, a reversal of the emulsion will occur. However, the dispersed phase does not remain rigid in shape but the drops flatten out where they come in contact with each other, nor are all the dispersed particles the same size (see Figs. 27 to 30), so that it is possible for the dispersed phase to consist of from 1 to 99 per cent of the emulsion.

**Hydration theory of emulsions.** Fischer and Hooker state that hydrated colloids make the best emulsifiers. Fischer states the emulsifying agent, by which a permanent emulsion is obtained, invariably "proves to be a hydrophilic colloid when water and oil emulsions are concerned (a lyophilic colloid of some sort when other than aqueous mixtures are under consideration). Put another way, oil cannot permanently be beaten into water, but only into a colloid hydrate."

Fischer and Hooker have found albumin, casein, and gelatin to be good emulsifying agents. Casein when not hydrated, i.e., at its isoelectric point, is a poor emulsifying agent, but hydrated casein, i.e., acid or alkali casein is a good emulsifying agent.

Fischer states that all permanent emulsions can be explained on the basis of hydrated or lyated colloids. He says that when water changes to a colloid hydrate, its physical constants change; and these include, among others, surface tension, viscosity, and adsorption. The treatment of the colloid, such as freezing or heating, or the addition of substances which alter the water-holding capacity of the colloid may crack the emulsion or lessen its emulsifying ability.

**Interfacial films.** Clayton in discussing "Foods as Colloid Systems" describes interfacial films as follows: "As early as 1840, Ascherson observed 'that coagulation in form of a membrane occurs inevitably and instantaneously when albumin comes into contact with a liquid fat.'—Any solute which lowers the interfacial tension between oil and water will necessarily accumulate at that interface, and in the case of certain proteins, notably albumen, the act of adsorption leads to a change in the physical character of the emulsifying agent, this being 'precipitated' as a fibrous or membrane-fibrous solid, no longer soluble in its original solvent. The existence of such interfacial membranes was verified by Ramsden and other investigators."

In reading the various theories of emulsion one is impressed with the similarity of many factors.

**Oriented wedge theory.** This theory for the manner in which emulsions are stabilized has been developed from the work of Langmuir and of Harkins. It is based upon the concept that the molecules of the emulsifier orient themselves in the interface between the dispersed and continuous phases, forming a wedge, the curvature of which determines the size of the dispersed phase. Fuller accounts may be found in Clayton's book and in the articles of the authorities mentioned above.

**Adsorbed film and interfacial tension theory.** This theory has been developed or rather extended from earlier theories. At the present time it is probably the most universally accepted theory for the formation of emulsions. Bancroft stated the underlying principles, basing them upon Donnan's early work of interfacial tension; but many others have extended the interpretations. Clayton states that with this theory "emphasis is laid upon the fact that emulsification is influenced by (1) the mass of the emulsifying agent present, (2) the ease with which this agent is adsorbed at the interfacial separating surface, and (3) the nature of the ions adsorbed by the resultant film."

The emulsifier may be adsorbed by the water or by the oil, but it is usually adsorbed more in one liquid than in the other and thus lowers the interfacial tension of one liquid to a greater extent than that of the other. If the tension of the water is lowered more than that of the oil, the water has less tendency to form drops, flows to form a film more readily, and becomes the continuous phase. Thus the type of emulsion formed depends upon the nature of the emulsifying agent. The above is often worded somewhat as follows: if the emulsifying agent is more soluble in water than in the oil the water becomes the continuous phase, or if the emulsifying agent is wetted more by the water than by the oil, the water becomes the continuous phase. When the tension on each side of the film or the emulsifying agent is the same no emulsion is formed. This may occur when opposing emulsifying agents are in the mixture and the effect of each counterbalances that of the other.

To form an emulsion the emulsifier must be adsorbed at the interfacial surface and form a sufficiently coherent film to stabilize the emulsion. The reversal of the emulsion depends upon the nature of the ions adsorbed by this film. Bhatnagar stresses more than previous workers the necessity for wetting of the adsorbed film.

The making of permanent emulsions is important for foods, cosmetics, pharmaceutical preparations, sprays, and other products. But breaking of emulsions is important in crude oil operations for recovery of the oil. Hence emulsions have been investigated from many angles and it is not surprising that no one theory applies to all types of emulsions.

### The Type of Emulsion Formed

The type of emulsion formed, i.e.: (1) oil-in-water or (2) water-in-oil, depends upon the nature of the emulsifying agent, the nature of the oil, and the effect of electrolytes. With one emulsifier an oil-in-water emulsion may be formed with a specific oil. Sometimes by the addition of the right substance, usually an electrolyte, the emulsion can be reversed and changed to a water-in-oil emulsion. Other emulsifiers with the same oil will form water-in-oil emulsions.

Bancroft states that a hydrophilic colloid tends to make water the dis-

persing phase, and a hydrophobic colloid tends to make water the dispersed phase.

The potassium and sodium soaps are more soluble in water than in the oil and form oil-in-water emulsions. Magnesium and calcium soaps are more soluble in oil than in water and tend to form water-in-oil emulsions. Aluminum and iron soaps are more soluble in oil than the magnesium and calcium ones and form water-in-oil emulsions.

Bhatnagar emphasizes the influence of the electric charge of the emulsifying agent upon the type of emulsion formed. He makes the following generalization. "All emulsifying agents having an excess of negative ions on them and wetted by water will yield oil-in-water emulsions, while those having an excess of adsorbed positive ions and wetted by oil will give water-in-oil emulsions."

Seifriz, in his work with petroleum oil emulsions stabilized with casein solution, found that the oils with a specific gravity of 0.828 or below form oil-in-water emulsions. When the specific gravity of the oil is greater than 0.857 a water-in-oil emulsion is formed, and oils with specific gravity between 0.828 and 0.857 give coarse, unstable emulsions or cannot be emulsified at all.

**Reversal of type of emulsion.** No definite rule can be given concerning the reversal of emulsions. The addition of an electrolyte in definite concentrations may stabilize some emulsions and bring about reversal of others. Reversal of some emulsions may occur upon the addition of a definite quantity of a hydroxide. Sometimes the addition of more of the hydroxide will again bring about a reversal of the emulsion into the original type. Shaking after standing may cause reversal of some emulsions.

Some ions are antagonistic to each other. Thus Clowes has shown that, if a rancid oil is dropped from a pipette which has the end immersed under water, drops of a certain size are formed. But if the oil is dropped into a sodium chloride solution, the drops are very much smaller. This is probably due to the formation of sodium soaps with the rancid oil and the lowering of the interfacial tension. If the oil is dropped into a calcium chloride solution the interfacial tension is increased and very large oil drops are formed, owing in this case to the formation of calcium soaps. If both sodium and calcium are in the solution they antagonize each other and the result obtained will depend on the concentration of each present. Sodium and potassium are antagonistic to calcium and magnesium.

**Means of determining the type of emulsion.** Several ways have been proposed to determine which of the two liquids is the continuous phase.

The drop-dilution method may be used to determine the type of emulsion by the microscope. To a small portion of the emulsion placed on a slide add a drop of water with a pin point and stir slightly. If the water blends with the emulsion, it is an oil-in-water emulsion, but if oil blends with the outside phase it is a water-in-oil emulsion.

Another method of determining the type of emulsion is to use Sudan III or Scharlach R, red dyes soluble in the oil but not in the water. A small portion of the finely powdered dye is dusted over the surface of the emulsion. If oil is the external phase the color gradually spreads throughout the emulsion. But if water is the external phase the color does not spread but is confined to the oil with which it comes in contact on the surface.

The microscope may be used to determine the type of emulsion formed. If the oil is dyed red, a red field with clear globules indicates a water-in-oil emulsion; red globules in a clear field show an oil-in-water emulsion. Sometimes a multiple emulsion is obtained, i.e., a dispersed phase within a dispersed phase. The only means of identifying a multiple emulsion is by the microscope.

**Some food emulsifiers.** Seifriz has reported that "olive oil stabilized with sodium oleate, sodium stearate, gelatose, gum arabic, albumin, lecithin, saponin, senegin, smilacin, or plant juices (cell sap and protoplasm) forms oil-in-water emulsions, while the same oil stabilized with casein, gliadin, cholesterol, or cephalin forms water-in-oil emulsions." Seifriz has also reported that with casein as the emulsifier the following oils all gave water-in-oil emulsions: olive, castor bean, poppy seed, sperm, and cod-liver oil. Linseed oil forms with casein a dual emulsion with the water-in-oil type predominating. Lecithin favors the formation of oil-in-water emulsions, whereas cholesterol favors water-in-oil emulsions. Saturated casein solutions with common food fats tend to form water-in-oil emulsions.

In food preparation, various fats and oils are used in the formation of emulsions. Oils commonly employed are cottonseed, corn, olive, and peanut. The fats include butter, lard, Crisco, Snowdrift, and others. In a cake batter there are several emulsifiers: the casein of milk, egg yolk, egg white, and the glutenin, gliadin, and starch of the flour. When equal quantities of fat or oil and emulsifying agents were used, the types of emulsions formed varied, depending on the emulsifier used and whether the oil was added to the emulsifier, or *vice versa*.

With egg yolk all the oils and fats gave a very stable emulsion of the oil-in-water type. With egg white as the emulsifier, oil forms an oil-in-water emulsion. Fig. 26 shows an emulsion of corn oil and egg white. When the oil is added gradually to the egg white, a foam as well as an emulsion is formed. The large white spheres are air bubbles. The oil is colored red and in the photomicrograph shows black. The illustration also shows that the oil is adsorbed in the film or layer at the interface between a liquid and a gas.

When a given weight of butter is added gradually to an equal weight of egg white, an oil-in-water emulsion is formed. With the last additions of the butter the emulsion may break. If beating is continued, a water-in-oil emulsion may form. In melting butter the curdy part containing the casein settles to the bottom of the container and consequently is usually

the last portion to be added to the egg white. It may have some effect upon the reversal of the emulsion. Sometimes only an oil-in-water emulsion forms. Whether this is due to the salt or casein content of the butter or to the temperature maintained is not known. The emulsion obtained when egg white is added to the melted butter may be a water-in-oil or an oil-in-water.



FIG. 26.—A coarse emulsion of oil in egg white. Egg white will not foam if a fat like butter or lard is added to it, but with oil both an emulsion and a foam are formed when beaten with an egg beater. The large light spheres are air bubbles. The oil is stained red and appears dark in the photomicrograph. This photomicrograph is interesting for it shows the adsorption or concentration of the oil at the interface between a gas and a liquid (egg white). This adsorption of fat can be seen in later illustrations of cake batter.

Magnification approximately  $\times 135$ .

Lard and Crisco form rather unstable emulsions with egg white, but both types may be formed.

With a saturated casein solution as the emulsifier, the water-in-oil type of emulsion predominates when butter, lard, Crisco, and oil are used. The emulsions are rather coarse and unstable.

**Efficiency of different substances as emulsifiers.** Some emulsifying agents are more efficient than others. No study has been made to compare the efficiency of the various emulsifiers under different conditions and for different emulsions. As a class, the hydrophilic colloids seem to be the most efficient emulsifiers. Clark and Mann have reported the efficiency of sucrose, dextrin, starch, gum arabic, and egg albumin in emulsions of benzene and kerosene in water. The oils composed 75 per cent of the total

volume in each case. The emulsions were made by shaking in a bottle, the oil being added in 3 parts and a total of 4800 shakes used in making the emulsion. They examined the emulsions after standing 1, 4, and 7 weeks and ranked the emulsifiers for stability on a scale of 10.

With benzene and a 1 per cent solution of each emulsifier the order was as follows: egg albumin, 10; starch, 6; gum arabic, 5; dextrin, 3; sucrose, 0. With kerosene the order was as follows: egg albumin, 10; starch, 9; gum arabic, 3; dextrin, 2; sucrose, 2.

Clark and Mann also determined the efficiency of the above emulsifying agents in the presence of electrolytes. In some cases the electrolytes increased the viscosity; in others they lowered it. They concluded that "no one general rule can be made as to the effect which produces the best emulsions for any one substance nor can any one generalization be made for the effect which produces the best emulsion for all substances under all conditions. Those which seem to be of primary importance are viscosity and film formation."

Brooks reports that egg yolk is four times more efficient in mayonnaise than egg white.

### Types of Emulsifying Agents

Emulsions may be stabilized by different substances. They may be classified as follows, the basis being upon the type of emulsifier: (1) those stabilized by an electric charge, (2) those stabilized by colloids, and (3) those stabilized by powders.

**Stabilization of emulsion by an electric charge.** Mineral oil emulsions in which the oil is present in very small amounts belong in the group stabilized by an electric charge. The oil particles are negatively charged. Hydrophilic sols are stabilized by hydration and an electric charge. Ghosh and Dhar suggest that emulsions are similar to sols and that the stability, the separation or coagulation, and the reversal of the emulsion are markedly influenced by its electric charge.

**Emulsions stabilized by colloids.** So many of the emulsifiers are colloidal in nature that this group is the most important in food preparation. The following are commonly used: eggs, gelatin, flour, starch, and milk. Gum arabic, gum tragacanth, Irish moss, and other substances are used less frequently. Pectin is being used to some extent. Gum arabic and gum tragacanth are used principally in cookery of diabetic foods, the Irish moss in puddings.

**Stabilization by powders.** Finely ground particles or powders such as lampblack, mustard, and paprika are a third class of substances used for emulsifying agents. The best examples of this type of emulsifier in prepared foods are the French dressings. At the present time several brands are on the market that are fairly stable. All are deep red in color, so that the

emulsion must be partially and probably wholly stabilized with particles of paprika and mustard. This kind of emulsion is formed by the powder film around the drops of oil which keeps them from coalescing. Clayton reports the results of using finely divided solids as emulsifiers by Bechhold, Dede, and Reiner. "They found that the formation of emulsion depends upon: (1) the grain size of the powder. The smaller the grain the better the emulsion, until an optimum is reached, after which smaller grains have inferior emulsifying properties. (2) The quantity of powder. The more powder there is available the more globules there can be covered, providing the powder is sufficiently fine." They report that zinc dust, iron powder, clay, Kieselguhr, and yeast made very efficient emulsifiers.

### The Making of Emulsions

To make an emulsion it is necessary to break or separate the dispersed phase into small globules. The work for this separation can be done in different ways. Machines of different types are used for making commercial emulsions. They are all designed to break the liquid into globules, either by a rotary motion, pressure, or by some other means. Agitation is used in all of these. Homogenization is used by most commercial firms for making mayonnaise. In making emulsions in the home, different methods are followed. For mayonnaise, an egg beater is often used, French dressing is often shaken, and gravy and sauces are made by stirring, usually with a spoon.

**Optimum degree of agitation for each emulsion.** Clayton says it is well known that agitation can both break and make an emulsion. The amount of agitation required for a given emulsion depends upon the particular emulsion being made and the kind of mixing utensil used. Clayton states: "It is quite reasonable to believe that for any given emulsifying apparatus there exists an optimum speed or degree of agitation or mixing, and an optimum time of mixing or running, whereby the most perfect emulsion can be obtained in a given system. Experiments prove this."

Stamm has reported that the method of preparation affects the size of the particles of the dispersed phase. Harkins (1928) states that the "method used in preparing an emulsion is one of the factors determining the distribution, but the most striking feature of the present work is that the shift of the number maximum is so slight with the different methods of stirring employed." By number maximum Harkins refers to the number of particles of the dispersed phase in a definite volume. Thus the apparatus, its speed, and the time used in mixing emulsions like mayonnaise, may or may not determine to a great extent the size of the particles formed and the stability of the emulsion.

**Intermittent mixing for emulsions.** Clayton states that what may be termed the mechanics of emulsification are far from being understood even now. In some experiments in making different emulsions, investiga-



tors have reported that intermittent shaking is more effective than continuous shaking or agitation. Clayton believes that shaking is an inferior method of making emulsions, but that continuous shaking should give equally as good results as the intermittent shaking, provided the emulsified portions are continuously removed from the mass. Intermittent agitation is explained as being more effective than continuous agitation, because of the rest periods, which allow time for adsorption of the emulsifying agent.

In making mayonnaise, the beating is often intermittent, for in stopping to add oil to the mixture, short rest periods occur.

**Foams and formation of emulsions.** Harkins in commenting on the method of preparation of emulsions, states that in a number of cases the emulsion failed to form after stirring rapidly with a motor-driven egg beater for 5 minutes, which was not in accord with the usual emulsification in a few seconds. He found that in all these cases no foam was produced, and that as soon as a foam formed, emulsification occurred in a few seconds. This may be a factor in the formation of some emulsions in food preparation.

## MAYONNAISE

**Definition by Food and Drug Administration.** "Mayonnaise, mayonnaise dressing, mayonnaise salad dressing, is the semi-solid emulsion of edible vegetable oil, egg yolk, or whole egg, a vinegar, and/or lemon juice, with one or more of the following: salt, other seasoning commonly used in its preparation, sugar and/or dextrose. The finished product contains not less than 50 per cent of edible vegetable oil."

**Does peptization play a rôle in emulsification?** In no theory of emulsification that the writer has read is peptization mentioned. Yet the following comments by Bancroft on peptization so vividly describe what happens in making mayonnaise that they are given. Bancroft, in his chapter, "Preparation of Colloidal Solutions," states that the methods of making colloidal solutions may be grouped under two heads, the dispersion and the condensation methods.

The making of mayonnaise, Hollandaise sauce, gravies, and other sauces in which an emulsion is formed comes under dispersion methods, for although the dispersed phase is not sufficiently small to class the product as a sol, the dispersed phase must be broken into many particles. Bancroft states that one means of dispersion is by the addition of a peptizing agent. He says that peptization is always due to adsorption. "If an adsorbed film has a low surface tension on the water side, it will tend to scrunch up and to peptize the solid as internal phase. If the reverse is the case, the solid will tend to form the external phase." If the word oil is substituted for solid in the foregoing quotation, an excellent picture of the formation of mayonnaise emulsion is obtained. For example, if one-fourth cup of oil is

added to a cup or more of well-emulsified mayonnaise, the oil may be stirred slowly a few times with a spoon, 15 to 20, and presto, it is all emulsified. The stirring could not possibly break the oil into thousands of small particles. Hence, the function of the stirring is to increase the area for adsorption to occur and the squeezing effect of the adsorbed egg yolk breaks the oil into many spheres. For the first addition of oil in making mayonnaise great care must be taken, but large quantities of oil may be added rapidly in the last part of the process.

### Investigations on Mayonnaise and Emulsions

**Air film on the oil phase.** Hall and Halstrom have reported that the presence of an air film on the oil phase, as it is introduced into the emulsifier and forming emulsion in making mayonnaise, results in a less stable, inferior emulsion with lower specific gravity than in mayonnaise prepared with oil having no such air films. For the emulsions having air films on the oil, the oil was added from a buret at a definite rate, the point of the buret being six inches above the surface of the forming emulsion. For oil having no air film the buret point was lowered so that the oil was injected beneath the surface of the forming emulsion. They add, "Clayton predicted that when the dispersed phase is injected into the continuous medium below the surface, intermittent injection would confer no advantage." From their results Hall and Halstrom felt that Clayton's prediction was a sound one.

**Water-holding capacity of emulsifier.** Kilgore states that preserved yolks are available in five main conditions: frozen salted, frozen sugared, fresh refrigerated, especially treated, and dried. This is also the order of their volume consumption by the mayonnaise trade. Kilgore emphasizes that the starting mixture to which the oil is added should not contain too much "free" water. It should have enough "free" moisture to start emulsification yet have a heavy body, like a thick paste, smooth in texture. Frozen and treated yolks, because they have more bound and less "free" water than fresh yolks, are excellent for starting mayonnaise to secure a fine "grain." Yet more of the frozen than of fresh yolks are necessary for an emulsion of good consistency. Kilgore adds that de-fatted mustard flour is an excellent water-holding ingredient; hence it gives a heavy paste and also has decided emulsifying powers.

**Emulsifying properties of mustard.** Kilgore determined the emulsifying properties of mustard in three ways: (1) Foaming ability, (2) the stability of oil drops on a mustard solution, and (3) the stability of emulsions made with mustard solution as the sole emulsifying agent. In a 75-pound batch of mayonnaise about 8 to 9 pounds of vinegar and 5 to 6 ounces of mustard are used, which gives about 3.5 per cent concentration of mustard. The concentrations of mustards used were: 0.1, 0.5, 1.0, 2.0, and 4.0 per cent.

*Foaming.* The mustard was weighed and added to water in glass-stoppered bottles and shaken. Little foam was formed except with the 2 and 4 per cent concentrations. Good emulsifiers for oil-in-water emulsions usually foam readily in water.

*Oil drops on mustard solution.* The mustard solutions were obtained by adding the mustard to water and filtering off the residues of undissolved mustard. About 70 per cent of the mustard was found to be soluble. If drops of oil such as corn oil are poured on water, they spread in a film over the surface of the water. But when drops of oil are placed on water containing an emulsifying agent which favors the formation of an oil-in-water emulsion, spreading does not occur. The drops remain separate and distinct. Kilgore found that a 1 per cent mustard solution afforded protection for the oil drops but a 4 per cent solution gave much greater protection.

*Stability of mustard emulsions.* The corn oil was added slowly to the mustard solution as in making mayonnaise, a high-speed drink mixer being used as a whip. After being stored for one year the emulsions made with 0.1, 0.5, and 1.0 per cent of mustard were broken. Those with 2.0 per cent had some oil on top; and the emulsion with 4.0 per cent mustard did not break and showed no leakage of oil, although it contained 80 per cent of oil.

Corran formed a water-in-oil emulsion of olive oil and lime water. To this emulsion mustard was added. When the concentration of mustard reached 2 per cent, the emulsion broke and reformed as an oil-in-water emulsion. Fine mustard flour was more efficient than coarse mustard flour.

Kilgore in continuing his work with mustard and emulsification found that mayonnaise without mustard had a stiffer consistency than that with a de-fatted mustard flour. But he found this depended on how the mustard was added. If added dry it decreased initial stiffness, but if added wet it increased the stiffness. De-fatted yellow mustard flour lost its emulsifying properties if mixed with vinegar and allowed to stand longer than a day; whereas this was not the case with mustard having a high oil content.

*Emulsifying properties of oils.* Meszaros states the size of the fat drops in an emulsion depends more on the method of preparation than on the properties of the fat. Meszaros has expressed the emulsification capacity in a number (*E* number) which represents the milligrams of fat which can be emulsified under certain conditions in 100 grams of water without the aid of emulsifying agents. Fats tested fall in four groups: (1) Fats which show a very good emulsification capacity (*E* number over 50); as goose fat, horse fat, lard, crude rapeseed oil (crude sunflower oil). (2) Good emulsifying fats (*E* number 20-50), as butter, butter fat, peanut oil, sesame oil. (3) Poor emulsifying fats (*E* number about 10)—coconut oil, palm-kernel oil, soybean oil, beef tallow. (4) Very poor emulsifying fats (*E* number 10)—illipe fat, hardened train oil.

*The method of mixing.* Kilgore, Corran, and Hall and Halstrom

emphasize the method of adding the oil to secure a stable emulsion of desirable consistency. Hall and Halstrom found that the method they called the Compromise Method was the best. For this method a portion of the oil was added by means of a buret above or beneath the surface of the forming emulsion until optimum dispersion was obtained. They state that optimum dispersion might properly be considered the critical dispersion point. At this point maximum thickness is attained and any further addition of oil results in an irrecoverable breaking of the emulsion. This occurred after the addition of 30 to 35 cc. of oil to 20 grams of beaten egg yolk. At this point the vinegar and spices are added. This thins the emulsion but thickening occurs again with the addition of the remainder of the oil. The amount of oil added was such that the mayonnaise contained 89 to 93 per cent of oil.

For the method which Hall and Halstrom called American, the vinegar and spices were added to the egg yolk. After blending of these ingredients the oil was added in the same manner as for the compromise method. Their results follow:

TABLE 40  
STABILITY OF MAYONNAISE (*Hall and Halstrom*)

Method	Manner in which oil was added	Stability of emulsion after storing at 8°C. for 2 years
Compromise.....	Above surface	Fragile, partially separated
Compromise.....	Beneath surface	No separation
American.....	Above surface	Complete separation
American.....	Beneath surface	No visible separation, but fragile

**The emulsifying constituent of egg yolk.** In starting their investigation, Snell, Olsen, and Kremers added lecithin to egg yolk in making mayonnaise. They acted under the general assumption that lecithin is the constituent of egg yolk which is effective in producing emulsions. Hence it was thought that the addition of more lecithin should increase the stability of the mayonnaise. But all the mayonnaises so produced had poor consistency. Next they studied the effect of each of the known major constituents of egg yolk on mayonnaise. It was found that none of these substances was capable of producing the consistency derived from the whole egg yolk.

This led to the investigation which demonstrated that egg yolk owes its emulsifying action to an unstable complex containing both lecithin and protein, which they called "lecitho-protein." This lecitho-protein constituted about 32.5 per cent of the salted yolks.

### Factors Affecting the Ease of Formation and Stability of Mayonnaise

In making mayonnaise, several factors affect the formation of the emulsion, its stability, and ease of making. The major factors may be listed as follows: (1) degree and kind of agitation, (2) the method of mixing, (3) the ingredients used, and (4) temperature. Some of these may be further subdivided.

**Degree and kind of agitation.** This factor has already been partially discussed. Under it can be included the kind of apparatus used as well as rate of agitation. Good stable mayonnaises may be formed by both continuous and intermittent agitation. Hall and Halstrom have demonstrated that very stable concentrated mayonnaise may be formed by continuous agitation if the oil is added beneath the surface of the forming emulsion. Clayton states that it is a well-known fact that agitation can both make and break an emulsion. It has often been observed in the laboratory, when the vinegar and seasoning have been added to the egg yolk before any oil is added, that rapid agitation for the first additions of oil is advantageous; otherwise the resulting mayonnaise is less viscous.

*The kind of bowl used.* Some failures in making mayonnaise are due to putting small quantities of the egg yolk in a large mixing bowl. As a result the egg yolk spreads out in such a thin layer that the egg beater picks up very little of the egg and an emulsion is not formed with the first portions of the oil added. Sometimes the rod at the bottom of the rotary egg beater is thick and holds the beater above the contents of the bowl, provided the quantity of material in the bowl is small and the egg beater is held upright.

**The method of mixing.** Under the method of mixing may be grouped the following: (1) the method of adding the oil, (2) the quantity of oil that is added at first, (3) the time of adding the vinegar, and (4) the time the seasonings are added.

*The method of adding the oil.* Hall and Halstrom have shown that a more stable emulsion is formed when the oil is added beneath the surface of the forming emulsion.

*The quantity of oil that is added at first.* Often the statement is seen that mayonnaise can be made by putting all the ingredients in the mixing bowl and then beating. The author (see Experiment 52C,3) has never been able to do this and has never witnessed the making of it in this way. Many water-and-oil emulsions can be made by putting all the ingredients together and shaking or stirring, but mayonnaise does not seem to belong to this group. It is possible that some factors may occasionally influence the formation of an emulsion so that it is formed when all the ingredients are added at once to make mayonnaise.

Mark expresses the amount of oil that can be added and an emulsion

obtained as follows: "(1) If the proportion of oil to that of egg or of the emulsion already produced was kept below a certain maximum a stable emulsion always resulted, no matter what the temperature or manner of beating, (2) that if the proportion of oil added exceeded a certain maximum, the egg or the emulsion already formed became dispersed in oil and no permanent emulsion was formed, (3) that if the proportion between these limits were used a permanent emulsion might or might not be formed, dependent on such variables as manner of beating and temperature, (4) that if egg was previously diluted by adding vinegar the proportion of oil which could be permanently emulsified was greatly increased during the addition of the first and second portions of oil, but that as viscosity of the mixture increased the maximum ratio of oil to emulsion rapidly approached the value found when egg alone was used at first."

Mayonnaise is formed more readily if the quantity of oil added at first is small. But the quantity of oil that can be added to egg yolk for the first addition of oil and still obtain a stable emulsion depends somewhat upon the rate of agitation, the combined volume of egg yolk and vinegar, the temperature of the ingredients, and other factors. If the above factors are standardized and if the combined volume of the vinegar and the egg yolk is  $\frac{1}{4}$  cup, the quantity of oil that can be added and emulsified is a definite quantity. If the combined egg yolk and vinegar is  $\frac{1}{2}$  cup, the quantity of oil that can be added will be 2 times as much as for  $\frac{1}{4}$  cup under the same conditions. Using 1 egg yolk and 15 cc. of vinegar and beating with a rotary egg beater in a round-bottomed jar, Experiment 52C, 2, 12 teaspoons of oil have been the limit for the first addition of oil. Often only 10 or 11 teaspoons can be added. This large quantity of oil must be carefully emulsified before the second portion of oil is added. The volume of the egg yolk and vinegar is a little over 2 tablespoons. Thus the volume of oil that can be added, 7 to 10 teaspoons, is about the same as the volume of the egg yolk plus the vinegar. The emulsion is formed more easily if smaller quantities, 2 to 3 teaspoons, of oil are added at first. The second addition of oil, and any subsequent addition, must not exceed a definite relation to the volume of emulsion already formed. In making salad dressing with 1 egg, 1 cup of cornstarch paste, a cup of oil, and vinegar, all the oil can be added at first, but here again the volume of the oil is about the same as that of the emulsifier, i.e., the egg yolk plus the cornstarch paste.

**The time of adding the vinegar.** Part or all of the vinegar may be added at various intervals during the mixing or it may be added to the egg yolk alternately with the oil. It may be added after considerable oil is added to the egg yolk (Experiment 52A,1,2,3) or before any oil is added. By the last method the oil may be added in larger quantities for the first and second additions, and the mayonnaise made more rapidly. However, the size of the oil particles that are first emulsified is quite large when the vinegar is added to the egg yolk before the oil is added. But with each

subsequent addition of oil the dispersed particles become smaller, and the mayonnaise stiffer. This is shown in Figs. 27 to 30, which are photomicrographs of mayonnaise. If the oil is added to the egg yolk before the vinegar, the first oil particles emulsified are very small and remain small with subsequent additions of oil. When the vinegar is added, the dispersed globules become larger, and the mayonnaise less stiff.

Kilgore suggests the following method. The salt, mustard, and other dry seasonings are added at first to fresh egg yolks, for they aid in holding the excess moisture. To this is added just enough vinegar to make a heavy paste. Then run in the oil until half is added, add another portion of vinegar, equal to that at the start, and the remainder at the end of the batch.

Corran suggests that the emulsification be carried out in three stages. (1) The dry ingredients, egg yolk, and part of the aqueous ingredients are mixed thoroughly. (2) All the oil is added, forming a creamy nucleus. (3) The creamy nucleus is diluted with the remainder of the aqueous ingredients.

**The ingredients used.** These include the oil, the salt and seasonings, the vinegar, the egg yolks, and even previously emulsified mayonnaise. Any of the edible oils may be used in mayonnaise.

*Salt and seasonings.* Salt, mustard, paprika, and pepper are usually added to mayonnaise. Small amounts of other seasonings may be used. Pasteurized spice mixtures are also now available to the mayonnaise manufacturer. The addition of an electrolyte to an emulsion may produce different results, depending upon the electrolyte, the emulsifier, and the type of emulsion. Some electrolytes cause reversal of certain emulsions; others may tend to stabilize the emulsion. Seifriz in his work with emulsions stabilized with casein found that sodium chloride had no influence on the water-in-oil emulsions, but tended to stabilize oil-in-water emulsions. The effect of sodium chloride would probably vary with the emulsifier and the concentration of the salt. Krantz and Gordon found that the concentration of the sodium chloride affected the stability of some emulsions. In mayonnaise, when egg yolk is used as the emulsifier and with the proportion of salt given in Experiment 52, it has been found that the addition of the salt to the egg yolk before the addition of any oil tends to stabilize the emulsion. In these experiments the vinegar was also added to the egg yolk before the oil was added. When the salt is added to the mayonnaise after the oil has been added, the size of the dispersed oil globules is larger and the emulsion breaks more readily while it is being made, indicating a lessened stability. The amount of salt used in the recipe may tend to lessen the solubility of the egg proteins sufficiently so that a more tenacious film is formed. If the concentration of the salt is great enough to "salt out" the egg proteins, then different results would be obtained. Thus it seems preferable to add the salt to the egg yolk and vinegar before adding the oil in making mayonnaise. Calcium salts, since

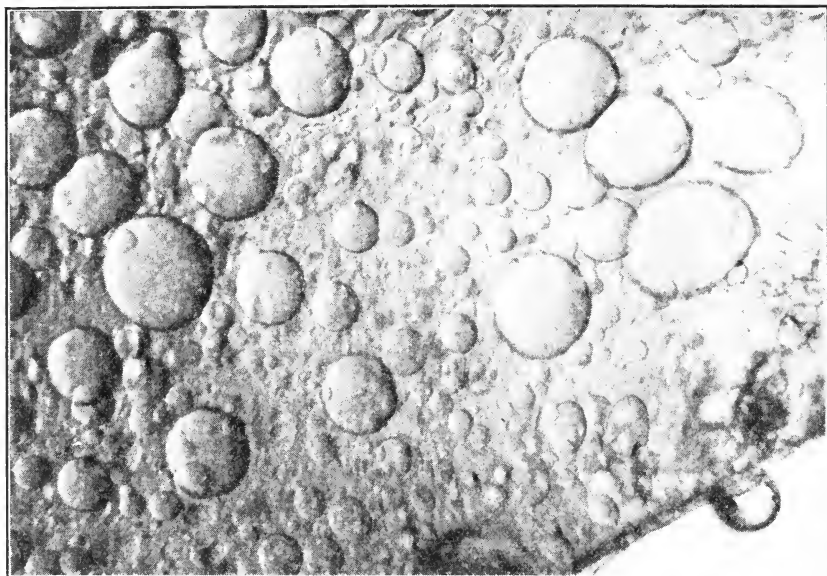


FIG. 27.—Mayonnaise. Showing the coarse emulsion formed after the addition of one tablespoon of oil. The vinegar and seasonings were added to the egg yolk, before the oil was added. Magnification approximately  $\times 200$ .

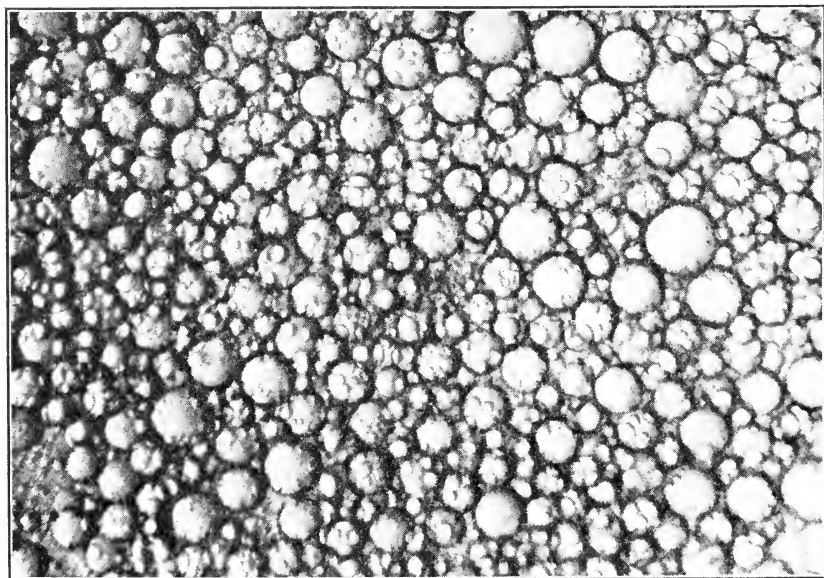


FIG. 28.—Mayonnaise. Same as Fig. 27, but after adding one-fourth cup of oil. Magnification approximately  $\times 200$ .



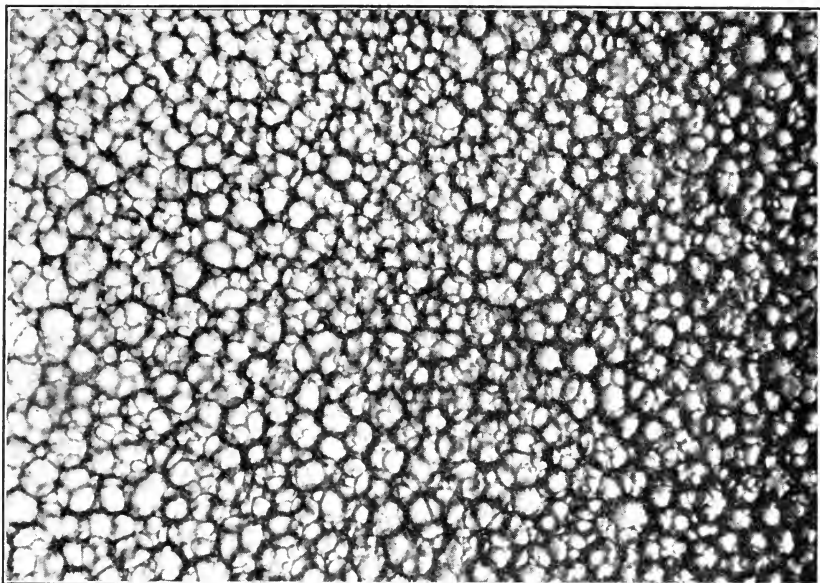


FIG. 29.—Mayonnaise. Same as Fig. 28, but after adding three-eighths cup of oil. As the oil spheres become smaller with the addition of more oil the mayonnaise becomes stiffer. Magnification approximately  $\times 200$ .

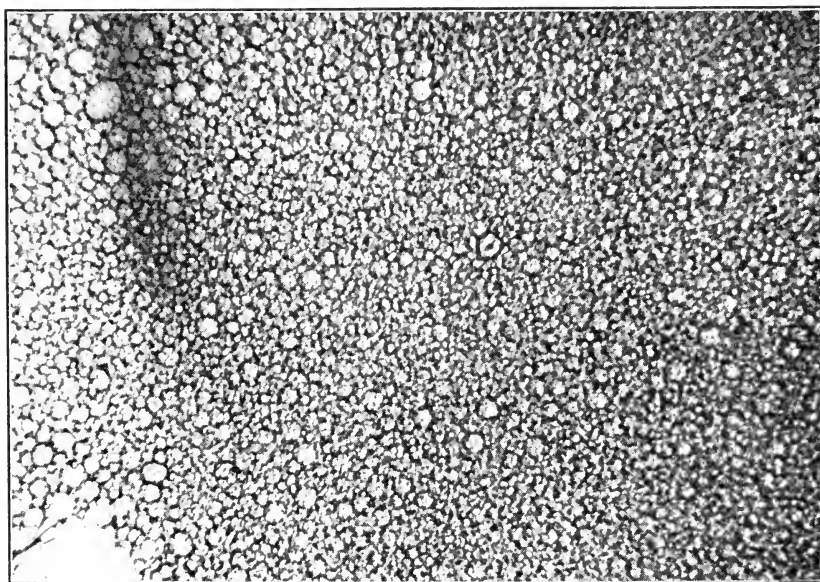


FIG. 30.—Mayonnaise. Same as Fig. 29, but after the addition of one-half cup of oil. Magnification approximately  $\times 200$ .

they tend to form water-in-oil emulsions, are detrimental to mayonnaise. Hence it is recommended that the salt used should contain less than 0.1 per cent of foreign calcium salts. Kilgore's results indicate it is preferable to add the mustard to at least part of the vinegar to make a paste. This is then added to the egg yolk.

*Egg yolks.* Johnson and Mark have reported that cold-storage eggs are inferior to fresh eggs for making mayonnaise.

However, frozen yolks, either salted or sugared, are more extensively used at the present time than fresh yolks. Kilgore states the fresh yolk is usually too light in body to produce a good emulsion at the start. This is true in spite of the fact that fresh yolk is the best possible emulsifier and that less can be used than is required for frozen yolk. The freezing changes the physical consistency of the yolk. Upon defrosting the frozen yolks are very thick and paste like, owing to the binding of the water during freezing.

*The addition of a small amount of emulsified mayonnaise.* Mayonnaise is very easily made if from  $\frac{1}{4}$  to  $\frac{1}{3}$  cup of previously made mayonnaise is added to the egg yolk and vinegar. This gives a larger quantity of material to work with, but if an emulsion is already started the emulsification of additional oil is accomplished more readily. After an emulsion is once formed, subsequent additions of oil are very easily emulsified. This is analogous to seeding in crystal formation and the addition of an old gel to gelatin to hasten jelly formation. Egg yolk is itself an emulsion containing about 30 per cent of fat.

Kilgore states, "another solution to the problem of producing high consistency mayonnaise having medium or low yolk content, is to start the emulsion by means of some finished mayonnaise added to the yolk and spices. This trick of starting an emulsion, or 'seeding' it, by means of one previously made is common in pharmaceuticals. It is the fundamental principle of a process for continuous emulsification."

**Temperature.** Clayton states that, in general, the effect of rise in temperature is to make emulsification easier. The reason for this is that viscosity is reduced with a rise in temperature, but more important, a rise in temperature is accompanied by a decrease in the interfacial tension of non-miscible liquids. Branch states that in commercial production of mayonnaise the temperature of the mixing room is kept at 65° to 75°F.

### Breaking Mayonnaise

Water may separate at the bottom of a mayonnaise after long standing. Robinson states that this seldom occurs if the amount of water in the mayonnaise does not exceed 15 per cent. With the percentage of water higher than 15 the separation occurs more frequently.

Oil may separate at the top of the mayonnaise. Anything that destroys the film-forming properties of the emulsifying agent and lets the dispersed

phase run together destroys the emulsion. Over-heating, when the oil and liquid expand at different rates, the additions of salts, drying of the surface, freezing, and jarring may all cause separation in mayonnaise. The addition of enough salt (sodium chloride) to "salt out" the emulsifier will break emulsions stabilized with proteins, but this requires far more salt than is ordinarily used in mayonnaise. The amount commonly used aids in stabilizing the mayonnaise.

Freezing dehydrates the egg, because the water separates from the egg protein in ice crystals, thus breaking the film. Agitation or shaking in shipping tends to break the emulsion. Evaporation from the surface of the mayonnaise may cause drying of the emulsifying agent and consequently coalescing of the oil on the surface. Mayonnaise keeps better in covered containers which prevent evaporation. Fischer and Hooker state that, if the protein emulsifier is diluted beyond the point at which it will take up all the water, the emulsion tends to break. Heating, resulting in too much evaporation of the liquid, causes separation of the fat in gravies, sauces, and cream puffs.

**Re-forming broken mayonnaise.** The usual procedure to re-form broken mayonnaise is to take a new egg yolk and add the curdled, broken mayonnaise to this gradually. It is added and beaten in the same manner as when the oil is originally added to the egg yolk. But it is not necessary to use egg yolk to re-form the emulsion. It can be re-formed by adding the broken emulsion gradually to a tablespoon of water or vinegar. The broken emulsion must be added gradually to the water or vinegar and beaten during the addition. It will not re-form if the water or vinegar is added to the mass of broken emulsion. See Experiment 52,D.

### The Concentration of Oil in Mayonnaise

The amount of oil that can be permanently emulsified varies with the emulsifier, the oil used, and the manner in which it is added. Pickering has emulsified "99 per cent of paraffin oil in 1 cc. of 1 per cent potash solution by successive addition of small portions." The concentration of oil in food emulsions varies from a very low percentage up to about 85 per cent.

Mayonnaise containing slightly more than 95 per cent of oil has been made in the laboratory, but it usually breaks shortly after a little more than 90 per cent of oil has been added. The stiffening of mayonnaise containing over 90 per cent of oil makes it difficult to mix the last addition of oil. Mayonnaise with more than 90 per cent of oil resembles jelly in consistency; cut with a knife or spoon it retains its shape. It will keep varying lengths of time in a covered jar in the refrigerator. Some break in a short time, but most of them keep for several days or weeks. Probably this variation in breaking is partially due to variations in beating in forming emulsions. After standing a short time, if the dressing is cut or if some is lifted out of the jar, there is a tendency for oil drops to form gradually

on the cut surface. It separates more readily than mayonnaise with a lower percentage of oil. Ordinary mayonnaise containing from  $\frac{1}{2}$  to  $\frac{3}{4}$  cup of oil to 1 egg yolk and 15 cc. of vinegar averages from 65 to 75 per cent of oil. Hall and Halstrom, by introducing the oil beneath the surface of the forming emulsion, obtained mayonnaise with a concentration of 89 to 93 per cent of oil that remained stable for two years when stored at 8°C.

### Some Food Emulsions

**Salad dressing.** The Food and Drug Administration has defined mayonnaise as being made with either egg yolk or whole egg. Hence, a product which may be similar to mayonnaise but stabilized with egg white, or part egg yolk and part starch paste, is called a salad dressing. Homemakers have used many emulsifying agents such as egg yolk, whole egg, egg white, cooked egg yolk, gelatin, starch paste, meat extract, and mashed potato. However, they are not equally efficient. The order for efficiency is as follows: egg yolk, whole egg, egg white, gelatin, and starch paste.

Fats such as butter and lard may be melted and substituted in a mayonnaise formula, but the product is a salad dressing. Mineral oil may also be used in a mayonnaise formula. Boiled salad dressings are also emulsions.

**French dressings.** French dressings are usually temporary emulsions, but some are quite stable. There seems to be less separation of oil at the top and of water at the bottom, if the phase-volume rule is observed, and the oil composes about 74 per cent of the emulsion. The seasonings, powdered paprika and mustard, are the emulsifiers. It is possible that traces of some substances in the vinegar may occasionally aid emulsification.

**Emulsions stabilized with flour.** In gravies and sauces the amount of oil that can be permanently emulsified is much smaller than in mayonnaise. Gravies and sauces in which the oil separates may be made smooth again by adding water and stirring while heating. The addition of water lessens the percentage of oil in the product. Emulsions stabilized with flour or starch need a higher percentage of water than mayonnaise. The starch absorbs a large portion of the liquid, which accounts for a large part of the water, but even if the maximum absorptive power of the starch is accounted for a large amount of water is still needed. This type of emulsion belongs in the class of hydrated colloids referred to by Fischer and Hooker, in which they state that the water must not be reduced below a lower limit and must not exceed an upper limit.

**Cream puffs.** Cream puffs are good examples of a batter in which the fat is emulsified. See Chapter XII, Experiment 80. In the recipe as given in the experiment, the fat constitutes about 17 per cent of the uncooked ingredients, if the fat content of the butter is used as 85, the eggs as 10.5, and the flour as 1.5 per cent. The cooking of the water, flour, and fat will increase this percentage, as will the baking, on account of evaporation of

water. The fat does not run or ooze out of the dough while the puffs are baking.

If the eggs in the recipe are reduced to 2 but no other change is made, Experiment 80C,2, the percentage of fat in uncooked materials is about 18.6. The fat in these puffs runs out of the dough and over the baking pan in large quantities while baking. With the smaller quantity of egg the emulsion does not hold, but if the amount of water added is increased to  $1\frac{1}{4}$  cups when the eggs are reduced to 2, the amount of fat in the uncooked ingredients is about 17 per cent. The fat in these puffs does not ooze out while they are baking. Although the quantity of egg is important, this also shows that it is essential to have a definite proportion of liquid to prevent breaking of the emulsion.

**Cakes.** The fat in a cake batter may or may not be emulsified. A microscopic study of cake batters shows that there is a tendency for oils to be emulsified as oil-in-water emulsions, no matter what the method of mixing. Often the oil is not wholly emulsified, the degree of emulsification varying with the extent of mixing, the temperature, and other factors. When butter or hard fats are used in cakes or batter products, they may be partially or wholly emulsified, if they are melted before adding to the batter and provided the temperature of the batter is not so low as to chill the fat quickly; or they may be emulsified if the temperature of the ingredients is above the melting point of the fat, so that the fat is melted. In ordinary methods and temperatures of mixing cakes, the butter and hard fats do not give oil-in-water emulsions.

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## EMULSIONS

## Experiment 52.

To determine some of the factors that affect the formation and stability of emulsions.

*Mayonnaise:*

Egg yolk	1	18 grams	Mustard	$\frac{1}{4}$ teaspoon
Vinegar	1 tablespoon	15 grams	Paprika	$\frac{1}{4}$ teaspoon
Oil	$\frac{1}{2}$ cup	108 grams	Sugar	$\frac{1}{2}$ teaspoon
Salt	$\frac{1}{2}$ teaspoon			

In studying emulsions, a microscope is a great aid. For very fine emulsions a small portion is placed on a slide and covered with a cover glass. With coarse and unstable emulsions it is better not to use a cover glass for the weight of the cover glass often breaks the emulsion. If the oil or fat is colored a dark red with Scarlet R, the type of emulsion formed can be determined with the microscope. An oil-in-water emulsion has a red oil dispersed in small spheres; a water-in-oil emulsion has a red field and light-colored spheres. To color the oil or fat, add the powdered Scarlet R and then stir. It should stand over night to dissolve the dye thoroughly.

Store the emulsions in jelly glasses. Label, then cover the glasses to prevent evaporation. Put away in the refrigerator to determine the permanency of the emulsion.

A. To determine the effect of varying the method of combining the ingredients in making mayonnaise.

1. Put the egg yolk into a small bowl, add the seasonings and the vinegar, and beat with a rotary egg beater. It may be necessary to tilt the bowl or egg beater at first, in order that the egg beater blades may come in contact with the small amount of material. Add the oil in small quantities at first, about  $\frac{1}{2}$  teaspoon, then in larger quantities as the emulsion is formed.

2. Mix the egg yolk and seasoning. Follow directions under A1, for beating. Add about  $\frac{1}{2}$  teaspoon of oil. Beat, then add  $\frac{1}{2}$  teaspoon of vinegar. Beat. Continue adding oil and vinegar alternately. After all the vinegar is added, add the oil in larger quantities.

3. Beat the egg yolk. Follow directions under A1, for beating. Add the oil a few drops at a time. After the emulsion is forming add the oil in larger quantities. Add the vinegar slowly after the oil is added. Add the seasoning last.

Texture	Stiffness	Ease of making	Flavor	Comments

Results and conclusions.

B. To determine the effect of the temperature of the ingredients in making mayonnaise.

1. Add the vinegar and seasoning to the egg yolk. Beat. Chill in the refrigerator, then set mixing bowl in ice, and add chilled oil slowly. Follow directions under A1, for adding the oil.

2. Heat the oil and vinegar to 100°C. Combine as in A1.

C. To see how much oil can be added for the first addition to 1 egg yolk and 15 cc. of vinegar and obtain an emulsion.

1. Repeat A1, but add 6 or 7 teaspoons of oil at first, then beat and emulsify before more oil is added. Add the same amount of oil for the second portion; then increase the amount for the following additions of oil.

2. If 7 teaspoons of oil can be added under C1, repeat with 8 teaspoons. Repeat C1, adding 9 or 10 teaspoons of oil. Increase the quantity of oil for the first addition as long as an emulsion is obtained.

3. Put all the ingredients in the mixing bowl together. Then beat with a rotary egg beater. After beating a few seconds, let the mixture stand; then beat again. Is an emulsion obtained?

D. To determine the amount of oil that can be added to mayonnaise without breaking the emulsion.

1. Follow directions under A1, but add all the oil possible to the mayonnaise. Keep a record of the amount of oil added. Compare the consistency of the mayonnaise with that obtained in other experiments. Determine its keeping qualities.

2. Repeat D1, but add oil until the emulsion breaks. If oil has been added until the emulsion breaks under D1, use it for this experiment and repeat D2, but do not add quite so much oil. Put a small portion of the broken emulsion, about a tablespoon, in a jelly glass. Label and cover. Divide the remaining broken mass into three parts.

a. Add part one to an egg yolk gradually, beating with the egg beater during the process. What happens?

b. Repeat D2,a, but add the second portion of curdled emulsion gradually to a tablespoon of water or vinegar.

c. Add a tablespoon of water or vinegar to the third portion of broken emulsion. Beat. What happens?

E. To determine the kinds of fat that may be used in mayonnaise.

1. Repeat A1, but substitute butter for the oil. Melt the butter over hot water and keep warm while adding to the egg yolk and seasonings.

2. Repeat E1, but use lard, Crisco, or Snowdrift.

F. To determine the effect of substituting other emulsifying agents for the egg yolk in making salad dressing.

1. Substitute  $1\frac{1}{2}$  tablespoons of cornstarch paste for the egg yolk in the mayonnaise recipe. (Make the paste by cooking  $1\frac{1}{2}$  tablespoons of cornstarch with 1 cup of water.) When the paste is cool but not firm, add the seasonings and vinegar to  $1\frac{1}{2}$  tablespoons of the paste and beat with rotary egg beater. Add the oil slowly at first, then more rapidly after the emulsion begins to form.

2. Substitute  $1\frac{1}{2}$  tablespoons of gelatin for the egg yolk in the mayonnaise recipe. (Make gelatin solution by using 3 teaspoons of gelatin to 1 cup of water.) When the gelatin is thick but not firm put  $1\frac{1}{2}$  tablespoons in a mixing



bowl. Add the seasonings, and the vinegar. Beat. Add the oil slowly at first, then more rapidly.

3. Substitute 18 grams of egg white for the egg yolk.

4. Substitute 18 grams of whole egg for the egg yolk.

Is there much difference in the method of combining ingredients for mayonnaise when egg yolk is used as the emulsifying agent? What effect does the temperature of the ingredients have on the formation of an emulsion? Did you succeed in obtaining an emulsion when the oil and all the other ingredients were combined in a bowl before beating? What is the largest quantity of oil used for the first addition of oil and a permanent emulsion obtained? How much oil did you succeed in adding to the mayonnaise? By examining the emulsions obtained under the microscope, compare cornstarch paste, gelatin, egg white, and egg yolk as emulsifying agents for emulsions.

### Experiment 53.

To determine the type of emulsion formed with different emulsifying agents and oils or fats.

Use oil or fat stained with Scarlet R. Continue beating the mixture for a few seconds after all the fat or oil is added, even if at first it appears that an emulsion will not form. Examine portions of different steps under the microscope.

1. Use a deep, narrow bowl and a rotary egg beater. Add 25 grams of melted butter gradually to 25 grams of egg white.

2. Add 25 grams of melted butter gradually to 25 grams of casein solution. Make the casein solution by adding some powdered casein to water and stir to dissolve as much as possible. After it settles use the clear liquid. The experiment may be repeated using milk.

3. Repeat 52,1, but use oil instead of butter.

4. Repeat 52,1, but use lard, Crisco, or Snowdrift instead of butter.

5. Repeat 52,2, but use oil instead of butter.

6. Repeat 52,2, but use lard or Crisco instead of butter.

### Experiment 54.

A. To determine the proportion of oil and liquid that separates most slowly in French dressing.

Mustard	$\frac{1}{2}$ teaspoon	about	0.8 gram
Paprika	$\frac{1}{2}$ teaspoon		1 gram
Salt	$\frac{1}{2}$ teaspoon		2 grams
Powdered sugar	1 teaspoon		

Add the seasoning to the vinegar and mix. Use a rotary egg beater or a mayonnaise mixer. A 100-cc. graduate is excellent to weigh the oil in. The duplicate portions with lemon juice can be measured by filling to the same height in the graduate. The oil is easily poured from the graduate. Add the oil gradually to the vinegar and seasonings. A duplicate series may be made and the ingredients shaken in a flask.

1. Use 15 grams of vinegar and 82 grams of oil.

2. Use 20 grams of vinegar and 77 grams of oil.

3. Use 25 grams of vinegar and 72 grams of oil.

4. Use 30 grams of vinegar and 67 grams of oil.

B. To determine the effect of substituting lemon juice for the vinegar.

Repeat 54A, substituting lemon juice for the vinegar.

C. To determine the effect of increasing the quantity of paprika.

Use the proportion of oil and vinegar found best under A. Different brands of paprika may be used as they may vary in fineness. The seasonings may all be put in a mortar and ground before using.

1. Use 1 teaspoon (2 grams) of paprika.

2. Use  $1\frac{1}{2}$  teaspoons (3 grams) of paprika.

3. Use 1 teaspoon (2 grams) of paprika and 1 teaspoon (about 1 gram) of mustard.

## CHAPTER IX

### MILK AND CHEESE

In food preparation, milk is used in many ways and combined with many kinds of foods. All the different types of cheese are made from it. Meat, vegetables, and cereals may be cooked in it. It is used as a basis for many sauces. Such sauces may be combined with eggs, with meats, or with vegetables; it is used in puddings and in frozen desserts; it is used for soups and for drinks like cocoa and coffee; it is combined with cereals; it is used in combination with many foods, as in custards, in cakes, and in quick breads.

Milk from different animals is used for food, but in this country unless the source of the milk is mentioned it is understood to be cow's milk.

#### Composition of Milk

Milk from different animals varies somewhat in the proportion of the different constituents. All milk contains a high proportion of water, cow's milk averaging about 87 per cent. The milk from different breeds of cattle varies considerably in composition. The milk of individual cows of the same breed also varies in the proportion of the different constituents. This may be partly due to environment, partly to inheritance, and partly to individuality. Milk may vary particularly in fat content from one milking to the next. The percentage of fat increases during the milking period; that is, the first milk obtained is not so rich in fat as the last portions of milk.

The fat varies for different breeds from about 3.5 per cent for Holstein to about 5 per cent for Guernsey and Jersey.

The protein varies from about 3.3 per cent for Holstein to 4.0 per cent for Guernsey and Jersey. It parallels the fat content somewhat, being highest in the breeds having a high fat content and lowest in those having a low fat content.

The lactose does not vary so much with the different breeds as the fat and protein. The lactose content is from about 4.65 to 5 per cent.

The ash varies from about 0.68 to 0.75 for the different breeds.

#### Constituents of Milk

##### Chemical and Physical Properties

The constituents of milk that are most important in food preparation are enzymes, vitamins, pigments, salts, sugar, fat, and proteins.

**Enzymes.** The enzymes of cow's milk are reported as follows by Rogers; proteinases, lactase, diastase, lipase, salolase, catalase, peroxidase, and aldehydrase. Rogers states that the proteolytic enzyme, galactase, brings about slow decomposition of milk proteins into peptones, amino acids, and ammonia.

**Vitamins.** All the vitamins recognized at the present time are contained in milk. Some are present in comparatively large and others in smaller amounts.

**Pigments.** The appearance of milk is white. This is due to light rays reflected by the colloiddally dispersed constituents of the milk, the calcium caseinate, and calcium phosphate.

Milk contains two classes of yellow or orange pigments. The water-soluble pigment, which imparts a yellow color with a green fluorescence to the whey of milk, was formerly called lactochrome. A name recently suggested for this pigment is lactoflavin. It is regarded as one flavin of a specific group, collectively to be called lyochromes. It is possible that lactoflavin is composed of more than one pigment. Rogers says "lactoflavin forms compounds with saccharides, proteins, and purines (uric acid). These compounds possibly either occur naturally in milk or readily form during isolations, thus accounting for the several lactoflavins isolated from milk." It is probable that the pigment lactoflavin is one of the five fractions of vitamin G ( $B_2$ ). Milk is relatively rich in this vitamin.

A fat-soluble pigment, carotene, found in the fat gives the milk a more or less yellow tinge, which is more pronounced as the fat particles become more concentrated and form cream. The group of pigments called carotinoids, which include carotene, xanthophyll, and related pigments, has been described in the chapter on fruits and vegetables. The chief pigment of butter fat is the carotene, but little xanthophyll being found. The depth of color depends upon the amount of pigment present. The color of carotene in solution varies from yellow to orange and to a deep red-orange as the concentration increases. The amount of carotene found in the butter fat depends upon the extent of carotene in the food of the cow. Green grasses, hay cured to retain its green color, green corn, and carrots are rich in carotene. The carotene content of milk fat is less rich during the winter months, if the food of the cow is poor in carotene during this period. Only in cow's milk is the fat extensively pigmented. With the exception of the fat of human milk, which is often pigmented, the fat of the milk of other animals is either devoid of or contains little pigment.

**Salts.** Milk contains salts of potassium, sodium, magnesium, calcium, phosphates, chlorides, and citrates. Traces of sulfates and carbonates are found. Iron is present in small amount. Iodides are also found in small amounts, the amount being greater in some localities than in others. Iodides may be easily transmitted from the feed to the milk. Supplee and Bellis have found copper to average about 0.52 part per million in freshly drawn milk. Brickner has reported that milk contains 3.6 to 5.6 parts of zinc per

million parts of milk. Manganese in normal milk averages 0.02 to 0.06 parts per million. The greater part of the sulfur is found in the milk proteins. Barger and Coyne state that part of the sulfur in milk is found in the amino acids methionine and cystine of the proteins, but that all of the sulfur is not accounted for.

The salts of milk are found in milk in solution, in the colloidal state, and in combination with the proteins. The exact chemical combinations of the different salts in the milk are not fully determined. For this reason different authorities report different salt combinations. Thus formulas imply definite combination, whereas there is a complex salt equilibrium in milk, which has not been satisfactorily worked out. The citrates, the combinations of which may be trisodium and tripotassium citrate, tricalcium and trimagnesium citrate, are probably entirely in solution. The possible chlorides of potassium, sodium, and calcium are also in solution. Some authorities believe that the phosphates are present chiefly as dicalcium phosphate,  $\text{CaHPO}_4$ ; others believe that tricalcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$ , is the principal phosphate combination. The phosphates are partly in solution, with the greater portion in colloidal dispersion. When the particles of dicalcium phosphate are heated they become aggregated and partially precipitated.

Calcium and magnesium are in combination with the casein to form calcium and magnesium caseinates. Zoller states that there may be traces of sodium and potassium caseinates.

**Lactose.** The solubility of lactose and its properties may be found in the chapter on sugar. It is caramelized by heat at rather low temperatures.

**Fat.** Butter fat is composed of glycerol and fatty acids. Fatty acids of both the saturated and unsaturated series are present. The relative percentage of the unsaturated fatty acids varies with the feed, averaging higher in summer than in winter. Dean and Hilditch state that the oleic and linoleic acids increase by 4 per cent (mols), with a parallel diminution in butyric and stearic acids when cows return to pasture. They also report that with increased age of the cow the unsaturated acids increase at the expense of palmitic acid, which was lowered from 29 to 22-23 per cent by weight of the total fat in the four years of observations made on milk from the same group of cows. The saturated fatty acids are butyric, caproic, caprylic, capric, lauric, myristic, palmitic, and stearic. Arachadonic acid has been reported absent by some investigators. Butter fat contains a higher proportion of the first-named saturated acids than other food fats. The first ones in the series are quite volatile with steam, the volatility decreasing with increase in molecular weight of the acid. Hence, when butter is heated for several minutes, the percentage of the lower saturated fatty acids may be decreased. The unsaturated fatty acids include oleic, linoleic, and arachidic.

Formerly it was thought that the particular flavor of butter was due to the greater proportion of the lower saturated fatty acids, but now it is

known that butters with satisfactory flavor and aroma (Michaelian, Farmer, and Hammer) contain considerable quantities of acetylmethylcarbinol plus diacetyl. The acetylmethylcarbinol in a pure condition is odorless, but by bacterial action it is changed to diacetyl, which in concentrations of 0.0002 to 0.0004 per cent in or added to neutral butter gives a characteristic aroma.

*Size of fat globules.* The fat in milk is found in small globules. These fat globules which are microscopic in size are suspended in the milk. They vary in size from  $0.10\mu$  to  $22.0\mu$ . Most of the globules are less than  $10\mu$  and average about  $3\mu$  in diameter. The size of the fat globules varies (1) with different breeds, being larger in milk from Jersey and Guernsey than in milk from other breeds, (2) with the lactation period, decreasing in size with length of the lactation period, and (3) with feed. Dry feed tends to decrease the size of the globules, succulent feed to increase their size.

*Creaming.* The specific gravity of the fat globules is less than that of the fluid of the milk. Hence there is a tendency for them to rise to the surface to form a cream layer. The extent of creaming depends upon several factors, such as the size of the fat globules, temperature of the milk, acidity, physical state of the fat, etc. Creaming occurs more rapidly in milk when the fat globules are quite large than when they are smaller. In rising to the top of the milk the globules of fat clump together, and this clumping increases the tendency for them to rise to the surface of the milk. As the larger clumps rise they may carry many of the smaller globules to the surface. Therefore, clumping not only aids the completeness of creaming but also the rate, for the rate is more rapid when the fat particles clump quickly. Rogers states that the factors affecting clumping are "temperature, the acidity, the fat content and its degree of dispersion, the degree of agitation, and the fluidity of the system. The fat content, the degree of agitation and the fluidity of the system determine the probability of collisions of the globules." The tendency of the fat globules to clump is greatest when the milk is cooled rapidly to  $7^{\circ}$  to  $8^{\circ}\text{C}$ ., but if the fat globules become solid at the low temperature before creaming is allowed to take place the rate of creaming is retarded. The temperature that favors clumping is also best for whipping the cream. Most cream is separated from the milk by mechanical means. The fat particles left in the milk after separating the cream are those less than  $1\mu$  and those between  $1$  and  $2\mu$  in diameter.

*Butter.* The fat globules in cow's milk are suspended in the milk and thus do not form a permanent emulsion, though they may be so reduced in size by homogenization that they form a permanent emulsion. Of the different theories formulated for explaining the manner in which emulsions are stabilized the adsorption film theory is usually connected with milk. Substances that lower surface tension tend to collect at the interface between two non-miscible systems. Proteins tend to lower the surface tension,

hence tend to collect at the interface. The layer or film around the fat globules probably consists of adsorbed calcium caseinate, with some lactalbumin, globulin, and calcium phosphate. This membrane may be weakened or broken in various ways. When milk is heated slowly, the membrane surrounding some of the fat globules may be broken and a number of globules may coalesce. Sometimes milk that has been heated and then cooled has a more oily appearance due to this coalescing of the fat globules. The membrane surrounding the fat particles may be broken by mechanical agitation. Formation of butter in churning is brought about in this manner.

There are two theories regarding butter formation. One is that the emulsion is reversed from the type found in the milk and that the butter is a water-in-fat emulsion. The other view is that butter is formed by packing the fat globules into a compact mass, and that water and air are enmeshed during this process. Temperature and the formation of a foam are both important in churning. At a temperature above 65°C. there is no aggregation of fat particles. Below 65° the tendency to clump increases and is at a maximum at 7° to 8°C. A favorable temperature for butter formation is below 24° and above 10°C. At temperatures below 4°C. the fat globules do not adhere to each other and aggregation does not take place. At temperatures above the melting point of butter, no butter is formed.

The fat particles tend to clump at the liquid/air interface, so that air beaten in during the churning process accelerates clumping of the fat.

Butter may be churned from sweet or sour cream. The flavor of butter from the sweet cream is milder and different from that of the sour-cream butter. Many housekeepers prefer the sweet-cream butter for table use and the sour-cream butter for cooking.

The adsorbed films surrounding the fat globules may also be destroyed by the addition of acid or alkali. It is by these methods that the fat is set free for a quantitative determination. In the Babcock test, acid is used for liberating the fat globules; in the Höyberg test alkali is used. The Babcock, or some modification of it, is the one usually employed in estimating the fat content of milk and cream.

**Protein.** The chief proteins found in milk in order of their decreasing amounts are casein, lactalbumin, and lactoglobulin.

*Casein.* Casein belongs to the group of phosphoproteins. The form in which the phosphorus exists in the casein is not definitely known, but it is believed to be present in the form of combined phosphoric acid. Casein forms about 3 per cent of cow's milk.

At its isoelectric point, which is  $pH$  4.6, casein is nearly insoluble in water. Casein is amphoteric and forms salts with acids and alkalies. Fresh milk has a reaction of about  $pH$  6.6, so that the casein is present in the milk as salts of bases and is found as calcium and magnesium caseinates. All the alkali caseinates are soluble in water, though the salts of the alkaline earths are less soluble than the alkali ones. Loeb states that below

pH 4.6 the casein chloride, casein acetate, and casein lactate are very soluble in water, but casein sulfate and casein oxalate are difficultly soluble.

According to Zoller, pure casein when heated in water begins to imbibe water at 80° to 90°C. and becomes plastic. In this form it can be molded and shaped. Upon cooling it becomes very hard.

Casein can be precipitated from milk by bringing the milk to the isoelectric point of casein. Coagulation of casein will be considered later.

*Lactalbumin.* The proportion of lactalbumin in milk is much lower than that of casein. It forms about 0.50 per cent of cow's milk. Its isoelectric point is pH 4.55. Since the reaction of fresh milk is about pH 6.6, it is on the alkaline side of the isoelectric point of lactalbumin. Thus it is possible that the lactalbumin is found combined as salts of bases, such as calcium and magnesium albuminates. Osborne and Wakeman think it is uncombined. Lactalbumin is soluble in water, and is coagulated by heating in solution to a temperature of about 70°C. Coagulation may not be complete at this temperature. Palmer states that the lactalbumin is more highly dispersed than the other colloidal constituents of the milk.

*Lactoglobulin.* Lactoglobulin occurs in milk in very small quantities, about 0.05 per cent of cow's milk. Lactoglobulin is insoluble in distilled water, but it is soluble in dilute solutions of strong bases or acids, and in dilute salt solutions. It is coagulable by heat.

### Homogenization of Milk

Globules of butter fat are suspended in the milk. They are surrounded by films of adsorbed caseinates, albuminates, and globulinates. The fat globules of milk are too large to form a permanent emulsion, so they gradually rise to the top of the milk in the form of cream. If the milk or cream is put through a machine called a homogenizer, the fat globules are reduced in size. This is accomplished by using pressure and forcing the milk or cream through small openings. Homogenized milk or cream may form a stable emulsion if the fat globules are reduced enough in size. Hence, when the fat is broken into fine enough globules the cream will not rise to the top of the homogenized milk.

The size of the fat globules after homogenization depends upon the temperature of the milk during homogenization and the pressure used. With increase in temperature the degree of dispersion increases rapidly from 40° to 65°C., so that the smallest fat particles are obtained at 65°. Ordinarily temperatures above 65° are not used for homogenization. The size of the fat particles also decreases with increased pressure.

**Whipped cream is stabilized by proteins.** The fat globules in cream are surrounded by films of protein substances. Homogenized cream also has the film of adsorbed proteins around the fat particles. Clayton states the fat particles in homogenized cream may be 1000 times greater in number than before homogenization. Since the number of fat particles is



increased, the amount of globulins, caseinates, and albuminates used in forming films is very much greater, for the surface area of the fat globules has increased enormously.

Whipped cream is both an emulsion and a foam. The fat particles must be surrounded by a film of protein in order to be stabilized, and the air globules must be surrounded by a film of protein to stabilize them. In homogenized cream most of the protein is used in surrounding the fat globules, on account of the increased surface area of the smaller and increased number of fat globules, and thus there is not enough left to surround the air bubbles. Hence, homogenized cream seldom whips unless protein is added for film forming.

**Factors that affect the whipping quality of cream.** In addition to the protein or film forming in whipping cream, the fat content, the size of the fat particles, the temperature of whipping, and the viscosity are important factors. Dahlberg and Hening have studied the relation of viscosity, surface tension, and whipping properties of milk and cream. They have found that increased viscosity increases the whipping properties of cream, but the lowering of the surface tension does not improve the whipping qualities. They have reported two changes taking place during whipping. The incorporation of air depends upon the milk proteins forming the film around the air globules, and the rigidity or stiffness of the whipped cream depends upon the clumping together of the fat particles. The best whipping cream did not give as large a volume as some other creams, but it had less liquid drain out of it after whipping.

Cream whips better with an increasing fat content up to 35 per cent. The cream with the higher fat content gives more particles for clumping and also increases the viscosity of the cream.

As the fat particles clump at the liquid/air interface, or within the liquid, the increased rigidity they give the foam permits inclusion of more air bubbles and extension of the films with the result that the dryness of the foam is increased. See Fig. 31. Larger fat particles clump more readily and thus form the structural support offered by the fat more easily. This offers an explanation of why cream from milk containing larger fat particles, milk from Jersey and Guernsey breeds, whips more quickly than cream containing smaller fat particles, milk from other breeds.

Aging improves the whipping qualities of cream. The viscosity increases with aging. As a general rule, treatment that increases the viscosity increases the whipping properties. Pasteurization tends to reduce the whipping quality of cream.

Babcock has found that the best whipping is obtained at a temperature of 45°F. or lower. At this temperature agitation favors the clumping together of the fat particles. At high temperatures, both the higher temperature and the agitation increase the dispersion of the fat. Above 50°F. the decrease in stiffness of whipped cream is in direct ratio to increase in temperature, so that 30-per cent cream will not whip at 72°F.

Babcock found acidity up to 0.3 per cent, at which sour taste is evident, had no effect on whipping quality. If acid was added in excess of 0.3 per cent, whipping quality improved, whether added to fresh or aged cream, when the amount added began to curdle the cream.

The addition of sugar to cream either before or after whipping was found by Babcock to decrease the stiffness of the cream. For each 2 teaspoons added to 100 cc. (about  $\frac{1}{4}$  cup) the stiffness decreased four points on the stiffness scale. Adding the sugar before whipping the cream decreased the volume obtained and increased the whipping time.

The denaturation or coagulation of the protein film at the air/cream interface, increases the stiffness of the whipped cream. Since colloidal

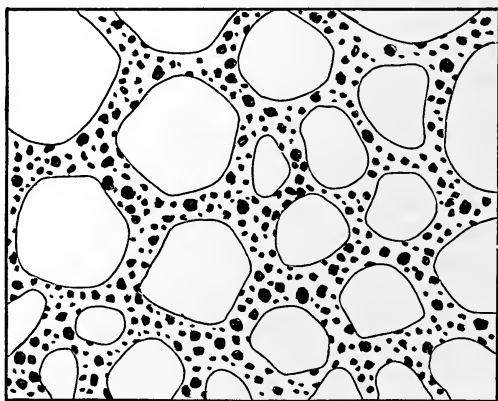


FIG. 31.—Diagram of a cross section through whipped cream. Fat globules of the cream are shown as small black spots. Magnification about 180 (Rahn).

reactions require time, it is a better practise to add sugar to whipped cream after, rather than before or during the whipping process. By this procedure denaturation is more complete, which offers an explanation of why the volume of the cream is less affected by the addition of the sugar last. The addition of sugar lessens the stiffness and decreases the volume of the whipped cream because it either prevents denaturation and/or peptizes the protein film.

### Reaction of Milk

Freshly secreted milk is nearly neutral to litmus. The reaction varies slightly but has an approximate  $pH$  of 6.6. The freshly secreted milk contains carbon dioxide. The amount of this gas in the milk decreases during milking and the subsequent handling of the milk, while the percentage of oxygen and nitrogen increase. For this reason the titratable acidity decreases for a time in milk exposed to the air. Confined milk does not show as great

a decrease in titratable acidity as the exposed milk, for the percentage of carbon dioxide lost is smaller.

**Effect of heating milk on acidity.** When milk is heated at the boiling point or at temperatures above or near the boiling point the titratable acidity at first decreases owing to the loss of carbon dioxide, and then increases. Whittier and Benton report that the hydrogen-ion concentration increases continuously. They find the hydrogen-ion increase and the later increase in titratable acidity is due to the formation of acids from constituents of the milk. The amount of acid produced depends upon the time and temperature of heating, a greater amount of acid being produced with a longer heating period and with higher temperatures. From their experiments they conclude that the acid is produced from the lactose of the milk. They have shown that, the greater the concentration of lactose present, the greater the amount of acid formed at a definite temperature and for a definite time.

### Coagulation of Milk

Under certain conditions, the addition of alcohol as well as the application of heat may cause coagulation of milk. Milk may be coagulated by the addition of rennin or by bringing the acidity of the milk to the isoelectric point of the casein. When milk is combined with other foods, the salt content of the food or the tannin content of the food may be factors that aid coagulation.

**Alcohol coagulation.** The addition of 70 per cent alcohol to milk may cause coagulation. As the  $pH$  of the milk decreases, it becomes susceptible to alcohol precipitation, though this varies with different milks. Usually the milk is precipitated by alcohol while it is still stable to heat and sterilizing temperatures. Some freshly secreted milk is coagulated by alcohol, but this milk is usually abnormal in some way. About 2 cc. of alcohol are added to an equal quantity of milk for the test. Casein is precipitated by alcohol as calcium caseinate, calcium is not released as by acid coagulation.

**Rennet coagulation.** Milk may be coagulated by the addition of rennet. Rennet is an extract that is usually obtained from the inner lining of the stomachs of calves and lambs. The rennet contains an enzyme called rennase or rennin.

The clotting of the milk is generally believed to be the direct action of the rennin on the casein. But the manner in which these changes is produced is not fully understood. A very small amount of rennin is capable of coagulating a large amount of milk. At favorable or optimum hydrogen-ion concentrations for clotting, 1 part of the fairly pure enzyme preparation is able to coagulate 3,000,000 or more parts of milk.

*Mechanism of clotting.* It is usually stated that the casein is changed to paracasein by the action of the rennin. It is also often stated that the

clotting is brought about in two steps, the first being the action of rennin on the casein and the second the precipitation of the changed casein. Rogers reviews the many theories of rennin coagulation. Some investigators claim the changes are purely chemical; others maintain the rennin affects only the physical state of the calcium caseinate. However, if the change can be explained on the basis of colloid chemistry, it is probable that absorption and the electric charge play an important rôle in the process. Rogers states that Hammarsten regards casein in milk as a calcium caseinate-calcium phosphate complex. "As a matter of fact the compound called calcium caseinate is most probably a true calcium phosphocaseinate, if, as seems likely, the second and third hydrogens of the orthophosphoric acid esterified with certain of the amino acids in the casein molecule react with calcium. The correct conception of the term 'calcium phosphocaseinate,' as it is now commonly employed, is that of a colloidal calcium phosphate (or phosphates) sol protected by a calcium caseinate (or caseinates) sol in a manner as yet imperfectly understood." The stabilization of sols is best explained by the theory of Helmholtz, i.e., each colloidal particle is surrounded by an electrical double layer. "In the case of negatively charged sols, in which class calcium caseinate and calcium paracaseinate evidently fall, the outer layer consists of hydrogen ions. If these are replaced by a sufficient number of positively charged ions of higher charge, e.g., calcium ions carrying two positive charges"; or, in other words, if these ions are more strongly adsorbed than the hydrogen ions, the colloid particle will readily precipitate, the rate of clotting being determined by the rate of replacement.

Richardson and Palmer state that rennin itself may reduce the charge of the calcium caseinate micelle and thus reduce the stability of the casein sol. They found indications that the isoelectric point of rennin is about  $pH$  6.9 to 7.0. Above this  $pH$  the rennin is negatively charged and below  $pH$  6.9 it is positively charged. They found that rennin lowered the electrophoretic velocity of calcium caseinate and calcium phosphocaseinate micelles when the casein sol was negatively charged and the rennin was positively charged, but not when the rennin was negatively charged (above its isoelectric point,  $pH$  6.9 to 7.0). From this evidence and from the fact that paracaseinate micelles are not affected by rennin, which agrees with the fact that casein once coagulated by rennin has lost its sensitiveness to this enzyme, they suggest that rennin acts by sensitizing the casein by a preliminary reduction of the electric charge on the casein micelles.

During the clotting of the milk, aside from the consistency of the milk, there is little change in its physical properties. The hydrogen-ion concentration does not change during the clotting process.

**Factors affecting action of rennin.** Several factors influence the activity of the rennin in bringing about coagulation. These may be listed as follows: (1) temperature for rennin action; (2) heating the milk before the addition of rennin; (3) hydrogen-ion concentration; (4) concentration

of casein, calcium, and phosphate ion; (5) character of cations used for coagulation.

*Temperature for rennin action.* The optimum coagulation by calf rennin is about 40° to 42°C. Below this temperature coagulation is less rapid and no clotting occurs below 10° to 15°C. Also no clotting occurs above 60° to 65°C. The clot is softer at low temperatures and tougher and stringy at high temperatures. By optimum is meant the temperature at which coagulation takes place most rapidly for a definite concentration of rennin and milk.

*Effect of previously boiling the milk upon rennin coagulation.* If milk is boiled and then cooled before the rennin is added, the rate of coagulation is retarded and a much softer, more flocculent clot is obtained. Pasteurization also affects the rate of coagulation of the milk and the type of clot formed by rennin but not to the extent that boiling does.

Richardson and Palmer found by electrokinetic evidence that heat increased the electric charge on the casein micelles or the cataphoretic velocity of the casein solution. The fact that rennin does not form as firm a clot with milk that has been previously heated indicates that rennin reduces the charge on the casein particles but not sufficiently to form a firm clot. This offers a colloidal explanation of why the addition of active cations (as calcium chloride) to heated milk causes the rennin to coagulate the milk normally.

*Hydrogen-ion concentration.* The reaction of the milk affects the rapidity of coagulation and the character of the curd formed. Ordinarily when the reaction of the milk is alkaline coagulation does not occur. This is shown by the addition of a small amount of soda to milk before the addition of junket. The optimum hydrogen-ion concentration for rennin activity has been reported to lie in the zone between pH 5.99 and 6.40.

*Character of cations.* In addition to rennin, cations are necessary to bring about coagulation of milk. Because casein and calcium are so closely involved in milk, the cation calcium is important in bringing about coagulation. Hence, Rogers states that it is to be expected that the concentration of both casein and calcium markedly affect both the rate of coagulation and the character of the clot. If milk is diluted with sufficient water, clotting is both delayed and incomplete, the clot being soft. If calcium chloride is added to the water, diluted milk clotting properties are restored, which suggests that the concentration of calcium ions is more important than that of the casein ions.

Rogers states that any metallic ion can replace the calcium in coagulation. However, it is generally accepted that the sodium and potassium salts of paracasein are soluble. Monovalent ions are less effective than divalent ones in replacing the calcium. Rogers reports that all monovalent ions did not bring about coagulation in some instances. The divalent ions were not all equally effective, calcium and barium being more efficient than magnesium.

*Sugar.* Sugar tends to prevent the coagulation of milk by rennin.

**Coagulation of milk by acid.** Kruyt states that there are some proteins that are not sufficiently hydrated to be stable by hydration alone. He cites casein as an example of a protein "which can exist either in acid or in an alkaline solution, but does not dissolve in water, with the consequence that the sol ordinarily flocculates when neutralized." Either the acid produced during fermentation or acids added to milk precipitate the casein. The casein is least soluble at its isoelectric point  $pH$  4.6. If enough acid is added to lower the  $pH$  below 4.6, casein salts, such as casein chloride or casein lactate, are formed. If these salts are soluble, the casein goes into solution. Hence the largest yield of precipitated casein is near the isoelectric point.

**Fermentation of milk.** Fermentation, or the production of lactic acid from lactose by bacteria, takes place in milk that is allowed to stand under favorable conditions. Rogers states that true lactic acid fermentation is brought about by the *Streptococcus lactis* and certain other organisms, lactic acid being the principal end-product, other products being present in only small amounts. In mixed lactic acid fermentation, or when other organisms in addition to *S. lactis* are present, the end-products may include acetic, propionic, lactic, succinic, formic, and butyric acids, carbon dioxide, hydrogen, acetone, and ethanol. As fermentation increases, an acidity is reached at which the action of most bacteria is suppressed. When fermentation is checked at  $pH$  4.8 to 5.0, the bacteria consists chiefly of *Streptococcus lactis*.

The rate of fermentation depends chiefly upon the temperature at which the milk is held. At low temperatures, on account of retardation of bacterial action, it takes place slowly. Rogers states that fermented milk, allowed to stand at a fairly high temperature, undergoes a second lactic acid fermentation brought about by the *Lactobacillus bulgaricus* organisms. Some of these types of bacteria form a high percentage of acid and the hydrogen-ion concentration may reach  $pH$  3.23.

*Changes occurring during acid precipitation.* During fermentation chemical and physical changes occur in the milk. The flavor becomes acid. The calcium caseinate is changed to casein. During this process calcium is split off and forms soluble calcium lactate. In addition some dicalcium phosphate is converted into monocalcium phosphate. Curdling or clotting occurs when the acidity reaches about  $pH$  5.3. During the clotting process the hydrogen-ion concentration does not increase. Milk clotted by fermentation is often called clabbered milk. Its flavor and aroma may vary, depending upon the types of bacteria producing the fermentation. Fermented milk may be used for drinking, for cooking, and for cottage cheese.

Cheese, such as cottage cheese, when clotted by acid coagulation, loses a large proportion of its calcium. The calcium salts become soluble more rapidly than the phosphorus; hence a larger proportion of the calcium than of the phosphorus is lost in the whey. Casein precipitated by rennin retains

most of its insoluble salts, hence has a larger proportion of calcium than the acid precipitated casein.

**Heat Coagulation.** The term heat coagulation refers to the so-called "denaturation" of the protein, by which it is rendered insoluble.

*Lactalbumin.* Lactalbumin has temperatures for heat coagulation similar to that of egg albumin. The lactalbumin forms a flocculent precipitate, whereas egg albumin forms a firm coagulum. Rupp has reported the following amount of lactalbumin coagulated when heated for 30 minutes.

Temperature, °C.	Albumin rendered insoluble, per cent
62.8	0.00
65.6	5.75
68.3	12.75
71.1	30.78

*Casein.* Casein is not coagulated by heat at ordinary temperatures or when heated for short periods, though the heating may alter the casein. Rogers states that it is necessary to heat milk about 12 hours at 100°C. to bring about coagulation. It takes approximately 1 hour at 135°C. and approximately 3 minutes at 155°C. The time and temperature vary somewhat with different milks.

The rate of coagulation depends upon the concentration of the casein as well as the time and the temperature of heating. Rogers states that evaporated milk, containing twice the concentration of solids-not-fat in normal milk, and thus a higher concentration of casein, requires about 60 minutes for coagulation at 114.5°C., 10 minutes at 131°C., and 7500 minutes at 80°C.

Rogers and Palmer both state that, in the evaporated-milk industry, the forewarming of milk prior to processing increases its stability to heat. "Rapid improvement in resistance to heat coagulation results in increase in temperature for prewarming up to 90° to 100°C. Above 90°C. the change is very small, but in some cases can be effected with increases in temperature up to 120°C. for 10-minute periods of forewarming. When time is chosen as the variable, improvement may be noted with increases in the time up to 30 minutes at a temperature of 95°C. At higher temperatures the same improvement may be effected in shorter periods of time."

*Fat.* Rogers states that fat particles in relatively large aggregates may act as nuclei about which coagulation of the casein can proceed. In un-homogenized milk the fat affects the coagulation time and temperature but slightly. But when a milk of higher fat content is homogenized the fat clumps may act as nuclei about which the casein may gather during heating. With increase in homogenization pressure as well as fat content, other conditions being the same, a marked decrease in stability to heat is noted. In homogenized milk it was found that the maximum stability to heat coagulation occurs if homogenization is carried out at 80°.

Rogers adds that the feathering of some homogenized cream when added to coffee may be caused by using too high homogenization pressure, thus reducing the stability of the cream to heat.

*The rôle of salts in heat coagulation of milk.* In heat coagulation of milk, the milk salts play an important rôle, for the salt equilibrium is altered by heat. When milk is boiled precipitation of part of the calcium phosphate occurs. Sommer and Hart have concluded that salts are the main factor in heat coagulation of fresh milk. Electrolytes have a marked effect upon the stability of colloids. In precipitating a hydrophilic colloid divalent and trivalent ions are generally more effective than monovalent ones. In the milk are found the monovalent cations, sodium and potassium; the monovalent anion, chlorine; the divalent cations, calcium and magnesium; and the trivalent anions, phosphate and citrate. Sommer and Hart concluded that the coagulation of milk on heating may be due to an excess or a deficiency of calcium and magnesium. They explain this as follows. "The casein of the milk is most stable with regard to heat when it is in combination with the calcium. If the calcium combined with the casein is above or below this optimum, the casein is not in its most stable condition. The calcium of the milk distributes itself between the casein, citrates, and phosphates chiefly. If the milk is high in citrate and phosphate content, more calcium is necessary in order that the casein may retain its optimum calcium content after competing with the citrates and phosphates. If the milk is high in calcium there may not be sufficient citrates and phosphates to compete with the casein to lower its calcium content to the optimum. In such cases the addition of citrates or phosphates makes the casein more stable by reducing its calcium content. The magnesium functions by replacing the calcium in the citrates and phosphates."

*Heat coagulation of casein endothermic.* Leighton and Mudge have shown that an endothermic reaction accompanies the appearance of visible curds when milk is coagulated by heat. This is accompanied by precipitation of calcium and magnesium as phosphate and citrates.

A similar reaction occurs in custard. In cooking custard, the ingredients of which are milk, egg, and sugar, the temperature drops or does not rise for a period of time during coagulation or setting of the custard, a condition particularly noticeable just before curdling takes place.

**Coagulation of milk by cooking meat or vegetables in it.** Fresh milk is seldom coagulated by heating for home use. The temperature attained in ordinary heating is not great enough to cause coagulation, nor is the milk heated for the long period required for coagulation at boiling temperatures. But with the addition of other foods to milk in food preparation, coagulation often occurs with a very short period of heating. One of the factors in this coagulation is undoubtedly the salt content of the food added to the milk as well as the salt content of the milk. The balance of the milk salts for greatest stability may be upset and coagulation occurs when the food is heated in the milk.



**Cooking of meat in milk.** Ham is often baked in milk. Sometimes pork chops are floured, seared in fat, and then baked in milk. Other meats and fish are sometimes baked or cooked in milk. Often curdling of the milk occurs, and the appearance of the meat, owing to adherence of curds of milk, is not attractive. Thus it is desirable to prevent curdling. Among the causes of curdling are the temperature at which the meat is cooked, the salt content of the food cooked in the milk, the manner in which the milk is added to the meat, and the reaction of the milk.

The higher the temperature at which the meat is cooked the greater the tendency to curdle. Larger curds are also formed at higher temperatures. The temperature to which milk must be heated to bring about curdling is high, so this cooking temperature alone is not sufficient to bring about the coagulation. Even when the meat is cooked in an oven at a high temperature, the liquid portion does not reach a higher temperature than boiling. It is possible that the acidity is increased during cooking, but the resulting pH of the meat-milk broth is changed very little from that of the original milk or from that of the meat broth when the meat is cooked in water. Thus it seems that the heating and the acidity developed during cooking do not alone bring about coagulation.

The salt content of the food cooked in the milk probably influences the coagulation, and this combined with the heating, the temperature of heating, the acidity developed, and the altering of the casein by heat are sufficient to cause curdling. Sodium chloride has some effect, for curdling is more likely to occur when the meat cooked in the milk is a cured or salted one than when fresh meat is used.

Curdling may be prevented by the addition of soda, about 1/16 teaspoon per cup of milk. From this it appears that the reaction has some part in the coagulation. The soda may combine with other salts that tend to bring about coagulation or the coagulation may be prevented by the slightly alkaline reaction. A slightly alkaline reaction also prevents coagulation by rennin and by fermentation.

If a portion of the milk is added to the meat when cooking is first started and the rest of the cold milk added gradually to the meat during the cooking period, curdling is less likely to occur. The addition of acid foods, such as prepared mustard, which may contain vinegar, or apples and pears to be baked with the meat, would tend to increase the tendency to curdle. Evaporated milk has less tendency to curdle than fresh milk, which may be due to the previous heating.

**Cooking of vegetables in milk.** Milk usually does not curdle when cabbage, chard, spinach, or cauliflower is cooked in it. But it is likely to curdle when asparagus, string beans, peas, and carrots are cooked in it. Asparagus usually curdles the milk after a few minutes of cooking. There are several factors that may aid in bringing about coagulation of the milk. The slight acidity of some vegetables combined with the heating of the milk may tend to bring about coagulation, but the acidity is not usually

great enough, nor the boiling temperature high enough, nor the boiling long enough continued for these factors to be very important. The salt and the tannin contents of the vegetables are probably the principal causes of coagulation. Some vegetables contain larger amounts of tannin than others. Tannin is a dehydrating agent and brings about denaturation of hydrophilic sols, like gelatin, starch, and agar-agar. After denaturation the hydrophile is sensitive to small amounts of electrolytes and precipitation occurs readily. Kruyt states that tannins do not bring about dehydration of the protein in an alkaline medium. Hence the addition of soda in small amounts to the milk in which the vegetable is cooked prevents coagulation of the milk. Tannins lower the surface tension, which results in foaming of vegetables containing tannin when they are cooked in water. It is rather interesting that the vegetables that usually foam the most when cooked in water are the ones that have the greatest tendency to coagulate milk.

*Tomato soup.* When tomatoes are combined with milk to make cream of tomato soup, coagulation may occur. The acidity of tomatoes varies somewhat, but is about  $pH$  4.4 to 4.6. If the amount of tomato added to the milk is great enough to lower the  $pH$  of the mixed milk and tomato to 4.8 to 4.6, the casein is precipitated without heating. This may happen if the milk is already fairly acid.

Since a longer time of heating milk increases the tendency to curdle it is preferable to heat tomato soup for only a short time. Heating slowly also increases the tendency to curdle, which may be due to the longer time required. In Experiment 55 in the laboratory outline several different methods of combining the tomato juice and milk are given. The tomato is usually added to the milk by stirring, for in this way the milk is diluted with a smaller amount of acid substance during the first part of the mixing. There is less tendency to curdle when the hot tomato is added to cold milk, than when the cold tomato is added to hot milk. Probably the slight denaturation brought about by heating the milk may partially account for this. Occasionally some milk is acid enough and the tomato is acid enough to cause curdling with all methods of combining unless soda is added. At other times curdling does not occur with any method of combining as outlined in this experiment.

**Fruits and milk.** When cream is added to fruit, clotting often occurs. This is usually due to the acidity of the fruit, but may also be due to an enzyme in it. Raw pineapple contains an enzyme, bromelin, that brings about clotting of milk. However, the pineapple juice not only brings about clotting but also peptization, for after a time the clot formed is less firm and the flavor is similar to that of peptized meat.

### Boiling and Heating of Milk

The physical and chemical properties of the constituents of milk account for the behavior of milk during its use in food preparation. Thus sub-

stances that lower surface tension become concentrated in the liquid/air interface. Proteins lower the surface tension of aqueous sols, hence accumulate in the surface. When milk is heated in an open pan, a scum or skin forms over the surface of the milk. At first this skin is rather thin and mobile but is gradually altered so that it becomes tenacious and tough enough to be removed with a stirring rod or spoon. This scum has been said to contain coagulated albumin and globulin. Tinkler and Masters state that if the scum is removed as formed, the total amount of protein that can be removed exceeds the total amount of albumin and globulin in the milk.

When foods are cooked in milk the milk not only foams readily but the scum tends to hold the steam formed in heating the milk; it is because of this that the milk "boils over" so readily.

### Sugar Reactions with Proteins of Milk

Ramsay, Tracy, and Ruehe investigated the substitution of dextrose for sucrose in sweetened condensed skim milk. They found the objections to using dextrose were (1) a brown discoloration, (2) a physical thickening, and (3) crystallization of the dextrose during storage. The last objection could be remedied by using 50 per cent dextrose and 50 per cent sucrose. The progressive thickening during storage at high temperature was caused by action of the dextrose on the casein and albumin of the milk. During this investigation they found additional evidence that sugars react with proteins. When dextrose, lactose, or levulose was heated with skim milk or freshly precipitated casein, a dark brown color formed in the product. When the sugars were heated in distilled water solutions to 250°F. for 30 minutes no caramelization occurred. Neither did darkening occur when albumin or casein was heated in water solution. But when the milk, albumin, or casein was heated with lactose or dextrose, a brown discoloration occurred. As the temperature was raised the dextrose and casein became so firmly attached to each other that no amount of washing could remove the sugar. Most of the biruet action of the skim milk was lost. The results were explained on the basis that a protein-sugar complex of glucosidal nature was formed.

On heating amino acids with dextrose highly colored products were formed, the reaction probably being a condensation of an amino acid with an aldehyde or ketone group of the sugar. The very stable linkage of the aldehyde group of the dextrose and the ketone group of the fructose in the sucrose molecule is cited to explain the failure of sucrose to form condensation products with casein, albumin, or amino acids. It was found that as the reaction became more alkaline the appearance of the brown color was more rapid. The increased alkalinity was said to favor the change of the sugar from a lactone to a free aldehyde form, the free aldehyde acting with the amino acid or  $-NH_2$  groups of the protein. If the  $pH$  was much

above 7 the milk was almost black. Hence, the sugar used, the reaction, and temperature all influenced the development of the brown color. The length of heating in connection with the temperature was important as relatively high temperatures for a short period gave only slight development of the brown color. It is almost impossible to retain the natural color of fresh milk in the condensed milk products, for some brown discoloration occurs in the unsweetened and sweetened product whether made from whole or skim milk.

Whittier and Benton had shown that the hydrogen-ion concentration increases at a rate which is the function of the lactose concentration and the time and temperature of heating. Or, in other words, when milk is heated for a sufficient time at high enough temperatures the lactose is decomposed with formation of acid products. Hence, when milk is heated with sucrose the increasing acidity inverts some of the sucrose to dextrose and levulose, with the development of a brownish color. One example of this is in the cooking of caramels, more brown color developing with long slow cooking of the sucrose and milk. Another instance where this is used to advantage is in making caramel pudding by boiling, in the can, sweetened condensed milk for three hours or longer. The can and contents are chilled. On opening the can it is found that the contents have developed the brown color of caramelized products and are thickened to the consistency of a pudding.

This combination of sugar with milk proteins to form a thickened product is interesting in view of the fact that sucrose, dextrose, and levulose prevent the heat coagulation of egg albumin.

The housewife also makes use of the effect of acid on sweetened condensed milk. If about  $\frac{1}{2}$  cup of lemon juice is stirred into the contents of a can (about  $1\frac{1}{2}$  cups) of sweetened condensed milk, the mixture thickens to a consistency that can be used for a pudding or pie filling and may be thinned with water to a desired consistency. The explanation of the thickening lies in the action of the acid on the complex sugar-protein combination.

## Cheese

**Definition.** The Food and Drug Administration defines cheese, in the regulatory announcements, as "a product made from curd obtained from the whole, partly skimmed, or skimmed milk of cows, or from milk of other animals with or without added cream, by coagulating with rennet, lactic acid, or other suitable enzyme or acid, and with or without further treatment of the separated curd by heat or pressure, or by means of ripening ferments, special molds, or seasoning."

**Classification of cheese.** Cheese may be classified in many ways as (1) method by which the curd is produced, i.e., acid or rennet coagulation, (2) source of the milk, from cow, sheep, or goat, and (3) the

texture and consistency of the cheese, i.e., whether soft, semi-hard, or hard. Many other classifications might be used but none of them are entirely satisfactory.

Doane and Lawson list and describe nearly 300 cheeses. They state there are probably about 18 distinct varieties of cheese.

For purposes of discussion, Rogers classifies cheese as follows:

<i>Soft</i>	<i>Hard</i>
Unripened	Semi-hard
Cottage	Ripened by molds
Cream	Gorgonzola
Neufchâtel	Roquefort
Ripened	Stilton
Ripened by molds	Ripened by bacteria
Camembert	Brick
Brie	Munster
Ripened by bacteria	Very hard
Limberger	Without gas holes
Liderkranz	Cheddar
	Edam
	Gouda
	With gas holes
	Emmenthal
	Swiss
	Parmesan

**Composition of cheese.** From the standpoint of quantity the principal constituents of cheese are casein, fat, and water. In addition it contains various salts, and unless heated to pasteurization temperatures various organisms such as bacteria and molds. Different types of soft cheese may contain from 40 to 75 per cent of water, hence this type does not keep long. Hard-type cheeses usually average 30 to 40 per cent moisture. The soft types may contain from 13 to 21 per cent of protein and from 0.5 to 50 per cent of fat. Hard types contain from 20 to 45 per cent protein and 19 to 40 per cent fat.

**Coagulation of milk for cheese.** Coagulation may be brought about by rennet or acid. Rennet-formed curds are more elastic, the acid ones more sticky. In acid-formed curds more of the calcium salts are split off from casein, forming calcium chloride which is soluble in the whey. Rennet-coagulated cheeses of cheddar types retain about 80 per cent of the calcium of milk, whereas soft cheeses retain about 20 per cent.

The temperature for coagulation varies with the type of cheese desired. In general, the lower the temperature the softer the curd. Curds formed at 21° to 25°C. are used for some soft cheeses. Cheddar cheese has a firmer curd and the milk is brought to 30°C. before the starter and rennet are added. Temperatures as high as 48°C. may be used for some cheese,

the curd produced being distinctly tough and somewhat rubbery and elastic.

**Making cheese.** The essential steps in making cheese are: blending the particular type of milk desired; bringing the milk to a definite temperature; adding lactic acid culture for types of cheese that need greater hydrogen-ion concentration when the rennet is added (acid cultures are added to cheddar types, but not to Swiss); adding vegetable color, if cheese is to be yellow, omitting if cheese is to be American white; and adding the rennet. After coagulation the curds are cut to the definite size for the type of cheese desired. Small curds retain less moisture within the curd but the whey does not drain so well from the curd. The next step is stirring the curd gently to facilitate draining of the whey. The curd is then ditched, salted, put in molds lined with cloth, and pressed into definite shapes as Longhorns, Prints, Daisies, Flats, Twins, and Cheddars. After being pressed the cheese may be soaked in salt brine or dry salt may be rubbed on the surface. Sometimes no additional salting occurs. Soft unripened cheese is not cured; but after being pressed or molded other types are placed on shelves in caves or specially constructed curing rooms to ripen. In the latter ventilation, humidity, and temperature may be carefully controlled according to the type of cheese. The curing period varies for different types of cheese and for the same type. For example, Cheddar may be cured from 2 or 3 months to 2 years. With longer curing a sharper, richer, and fuller flavor is developed.

Cheese, after being cured, is often blended for uniform flavor, texture, and body.

**Secondary heating of the curd.** A secondary heating of the curd is necessary with most hard and semi-hard cheeses. Making Emmenthal involves heating to about 55° to 58°C. This heating hastens the driving of the whey from the curd, changes its texture, and often alters the bacterial flora. The heating at high temperatures decreases the moisture content and rennet action is checked if not wholly stopped. Various physical changes take place during this period, the curd becoming tough, firmer, and rubbery. In Swiss and Parmesan cheese it also acquires plasticity.

**Ripening of cheese.** In the process of ripening chemical and physical changes occur in the cheese. It loses its tough, rubbery qualities and becomes soft and mellow, sometimes almost crumbly. During this change as much as 50 per cent of the nitrogenous constituents may be converted to soluble forms, though the average for hard cheese is 30 per cent. These changes not only alter the texture and flavor, but also alter the cooking quality of the cheese, the increased solubility of the proteins increasing the ease with which the cheese may be blended with eggs, milk, and white sauce.

Ripening is slower at lower temperatures and more rapid at higher ones. Not only enzymes of the milk, if the milk has not been heated to a temperature to destroy the enzymes, but bacteria aid in ripening of the cheese and hydrolysis of the proteins. Some bacteria, such as lactic acid, produce

enzymes that split the protein. More hydrolysis occurs in the softer center of hard cheese than near the rind. Salting affects the rate of ripening by delaying bacterial growth, the proteins of cheese with more salt becoming soluble at a slower rate. Salt penetrates slowly from the rind to the center and aids in drying the cheese. Changes in the fat in the interior of most cheese are usually negligible.

For the growth of molds and aerobic bacteria, holes must be punched in the cheese to allow oxygen from the air to penetrate.

In the early stages of ripening Emmenthal and Swiss cheeses are soft and become elastic. It is during this stage that the holes or "eyes" are formed from production of gas, principally carbon dioxide, if ripening is normal, but with more hydrogen in abnormal or early ripening. If the cheese becomes too firm before the formation of holes is complete, checks and cracks appear in the cheese.

**Cheddar cheese in cans.** The Bureau of Animal Industry (Rogers) has announced a practical method of canning unripened Cheddar cheese. By this method a one-way or check valve, which holds perfectly against external pressure but with internal pressure allows gases formed during ripening of the cheese to escape, is inserted in the lid of the can. Cheddar cheese has always been pressed in cylindrical forms of varying sizes, but in general rather large. When these large cheeses are cut they lose moisture, so the cut surface dries rapidly. In addition, if the cheese is well ripened, loss occurs through crumbling.

In packing cheese in cans, the cheese, after pressing, is cut into the desired shape. Since hydrogen sulfide is often liberated during ripening of cheese, it is preferable to wrap the cheese in parchment and it is necessary to use a lacquered can, for the hydrogen sulfide tends to form a black product with metals such as iron, copper, or lead.

**Processed cheese.** Rogers states that before the development of the can in which Cheddar cheese may be ripened, the "only commercial method for putting Cheddar cheese into a more attractive and convenient form is the one known as processing. After the rind is removed, the cheese is ground, a small quantity of water and an emulsifier, usually sodium citrate, are added, and the mass is heated with constant stirring until it becomes fluid. The emulsion is run into forms, which in many cases are boxes lined with tinfoil, in which it is sold. The cheese hardens quickly and, as the wrapping adheres closely, there is no trouble from molds. Moreover, as the temperature is high enough to constitute pasteurization, most of the bacteria are killed and the enzymes destroyed, so that ripening is stopped. In this process, much of the original character of the cheese is lost; but, in spite of this objection, the advantage of the package is so great that a large part, possibly one-third, of all the cheese made in the United States is sold in this form."

Templeton and Sommer have investigated various salts that may be used as emulsifiers in processed cheese. They state the purpose of the salt is to

prevent separation of the fat from the cheese and at the same time give the finished product the desired body and texture. They quote Habicht as stating that an alkaline monovalent cation combined with a polyvalent anion, such as sodium citrate, is the ideal emulsifying salt. The physico-chemical explanation is as follows: There is partial saponification between the cation (sodium, if sodium citrate is used) and the fatty acids. The soaps formed are good emulsifiers. In addition the anion, which is a solvent for casein, combines with the casein of cheese so that a film of casein surrounds each fat globule, thus emulsifying it and preventing its escape from the mass. Later we find that the citrate ion is also a good peptizer of egg and flour proteins.

**Loaf cheese.** Rogers states that blending is used extensively for Cheddar and Swiss cheese. In this process the cheese is ground and heated in steam-jacketed kettles, 60° to 70°, and then poured into molds. In the initial heating separation of the fat occurs; but with longer heating the casein becomes plastic and stringy and encloses the fat. Further agitation causes the mass to lose its plasticity and become the consistency of heavy cream. At this time it is poured into the molds.

The plasticity of the cheese is an important part of the process. Once the plasticity is broken it is almost impossible to restore it. The method of manufacture, the degree of ripening, the acidity of the cheese, and possibly other factors influence the degree of plasticity attainable in the heated cheese and the length of time the mass will remain plastic. Sodium and ammonia seem important in the emulsification of the product.

**Cheese spreads.** The term cheese spread may be applied to any packaged form of cheese that can be easily spread with a knife at ordinary room temperature. Templeton and Sommer name the types on the market as: (1) cream cheese, mixed with pickles, olives, etc., (2) processed cheese of such age and moisture content as to be "spreadable," and (3) processed cheese with concentrated whey or skim milk powder added and of such fat and moisture content that the mix will spread easily. They say that, since the composition is quite different from cheese, as defined for Food and Drug regulations, the product cannot be sold as cheese. Actually they are sold as food products under proprietary trade names. The desirable spreading qualities may be due to the moisture content or the fat content or both.

**The use of cheese in cooked products.** All of the factors that affect the plasticity of the cheese when heated for blending, i.e., the degree of ripening, the acidity, and method of manufacture, also affect its blending properties with other ingredients in such dishes as rarebit, cheese soufflé, and macaroni and cheese. To these factors may be added the extent of drying. For the cut or grated surface of cheese may dry rather extensively. Hence, the protein in the surface area really needs soaking for hydration before it will blend with other ingredients, or it may entirely lose its plasticity.

Cream cheese may be combined with eggs, sugar, etc., for cheese cake or



similar cooked dishes. But, in general, whether in its original state after curing, or processed, the Cheddar type is the cheese usually combined with cooked products.

The cheese is combined with white sauce or eggs at low temperatures and by stirring. The temperature should be as low or lower than that used for blending, 40° to 50°C. often being preferable to 60° to 70°C. As the protein becomes plastic the fat exudes. Stirring aids in emulsifying this fat with white sauce and casein of the cheese.

*Cheese soufflé.* A colleague, Plagge, suggested a good method of combining the ingredients for cheese soufflé. The beaten egg yolks were added to the white sauce before the grated cheese, because the addition of the egg yolks cooled the mixture to a greater extent before the cheese was added. However, another advantage of this order of mixing is that the egg yolk aids in emulsifying the fat of the cheese. For the same reason beating with a rotary egg beater as the cheese softens is a good method of blending the cheese with the white sauce, since it more efficiently divides the cheese, thus increasing the surface area for emulsification.

Processed cheese usually combines particularly well with white sauce and egg yolk, because of its added water content and the emulsification of the fat.

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## MILK

### Cream of Tomato Soup

#### Experiment 55.

To determine the best method of combining ingredients in making cream of tomato soup.

##### A. Use:

Milk	$\frac{1}{4}$ cup	60 grams
Tomato juice	$\frac{1}{4}$ cup	60 grams
Salt	$\frac{1}{16}$ teaspoon	

1. Combine by adding tomato juice to the milk. Why? Combine cold tomato juice and cold milk, heat hot enough to serve, and add salt.
2. Repeat 1, but heat slowly in the top of a double boiler.
3. Combine hot tomato juice, hot milk, add salt.
4. Add the hot tomato juice to cold milk, heat, add salt.
5. Add the cold tomato juice to hot milk, heat, add salt.
6. If one curdles badly, repeat, but add first to the tomato juice  $\frac{1}{32}$  teaspoon of soda. If none curdle, prepare 6 by any method desired. What is the effect of soda on the flavor? On curdling? Why may tomato juice cause the milk to curdle? Why may curdling sometimes but not always occur by some methods of mixing?

##### B. Use:

Milk	$\frac{1}{4}$ cup	60 grams
Tomato juice	$\frac{1}{4}$ cup	60 grams
Flour	$\frac{1}{2}$ tablespoon	3.5 grams
Butter	$\frac{1}{2}$ tablespoon	7 grams
Salt	$\frac{1}{8}$ teaspoon	

1. Make a sauce of the milk, flour, and butter; add cold tomato juice, and heat.
2. Repeat 1, but add hot tomato juice to the sauce.
3. Make a sauce of the tomato juice, flour, and butter. Add to the cold milk. Heat.
4. Repeat 3, but add the tomato sauce to the hot milk. Does the addition of flour lessen the tendency to curdle? Can cream of tomato soup be made without the addition of soda?

Results.

### Cooking Vegetables in Milk

#### Experiment 56.

To determine the effect of cooking vegetables in milk. Use green string beans, asparagus, or carrots.

1. To  $\frac{3}{4}$  cup of milk add  $\frac{1}{2}$  pound of string beans. Cook until tender. The beans may be shredded in long strips to hasten cooking.
2. Repeat 1, but have the milk boiling before adding the vegetable.
3. Repeat 1, but add the vegetable to one-third of the boiling milk. Add the remainder of the milk in small portions during cooking.
4. Repeat 1, but add  $\frac{1}{32}$  teaspoon of soda to the milk.
5. Repeat 1, but use cabbage or cauliflower.

Do any curdle? Is there any difference in the size of the curds formed in cooking by the different methods? Why may one vegetable cause the milk to curdle but another vegetable not cause curdling? If you wish to add milk for seasoning to a vegetable like asparagus or green beans, how would you add it to prevent curdling? Is it desirable to use soda?

Number	Curdle	Texture of milk	Comments

Results and conclusions.

### Ham Baked in Milk

#### Experiment 57.

To bake ham in milk.

1. Use mild-cured ham in 1-inch slices. To  $\frac{1}{2}$  pound of the ham 1 inch thick add 1 tablespoon of medium-brown sugar, sprinkling it evenly over the ham. Add  $\frac{1}{2}$  cup of milk and bake at  $125^{\circ}\text{C}$ . ( $257^{\circ}\text{F}$ .) until tender. The size of the dish should be such that the milk barely covers or just reaches the top of the ham.
2. Repeat 1, but prewarm the milk by boiling it before adding to the ham.
3. Repeat 1, but add only one-third of the milk. After baking 30 minutes add the remaining milk in small portions at intervals of a few minutes.
4. Repeat 1, but add  $\frac{1}{32}$  teaspoon of soda to the milk.
5. Repeat 1, but use evaporated milk. Dilute  $\frac{1}{4}$  cup of evaporated milk with  $\frac{1}{4}$  cup of water and add this diluted milk to the ham.
6. Repeat 1, but bake the ham at  $175^{\circ}\text{C}$ . ( $347^{\circ}\text{F}$ .) until tender.

In which experiments does the milk curdle? Are some curdled worse than others? What is the effect of a higher temperature upon curdling? Compare the flavor of ham.

Number	Texture of milk	Texture of meat	Flavor	Comments

Results and conclusions.

The series may be repeated, omitting the sugar and using pork chops or fish instead of the ham. There is less tendency to curdle with the fresh meat.

## Junket

### Experiment 58.

To determine the conditions most favorable for the clotting of milk by rennin.

1. Use  $\frac{1}{2}$  cup of raw milk warmed to  $35^{\circ}$  to  $40^{\circ}\text{C}$ . Add  $\frac{1}{4}$  of a junket tablet that has been powdered and  $\frac{1}{2}$  tablespoon of sugar. Stir to dissolve. Put the junket mixture into a glass container or a Pyrex baking cup. Let stand at room temperature. Keep a record of the time required for setting. Determine when it is set by tipping the container slightly to one side.

2. Repeat 1, but use pasteurized milk.

3. Repeat 1, but set in the refrigerator after adding the junket.

4. Repeat 1, but dissolve the junket in 1 tablespoon of water. Boil, concentrating the water to 1 teaspoon. Add to the milk and sugar.

5. Repeat 1, but boil the milk, then cool to  $35^{\circ}$  to  $40^{\circ}\text{C}$ . before adding the junket.

6. Repeat 1, but dilute the milk with water, using  $\frac{1}{4}$  cup of water and  $\frac{1}{4}$  cup of milk.

7. Repeat 6, but use cereal water instead of water for diluting the milk. The cereal water should be a little thinner than the consistency of a medium white sauce.

8. Repeat 1, but add  $\frac{1}{16}$  teaspoon of soda to the milk.

9. Repeat 8, but increase the soda to  $\frac{1}{4}$  teaspoon.

10. Repeat 1, but double the amount of sugar using 1 tablespoon (12.5 grams).

11. Add 1 tablespoon of grated raw pineapple juice to  $\frac{1}{2}$  cup of milk. Add the sugar but not the junket.

Which ones set? Which do not set? Explain. Compare the firmness of the clot formed in the various experiments.

Number	Clotted	Texture of clot	Flavor

Results and conclusions. .

## Cottage Cheese

### Experiment 59.

To make cottage cheese.

A. From sweet milk.

1. To 1 cup of sweet milk warmed to  $35^{\circ}$  to  $40^{\circ}\text{C}$ . add  $\frac{1}{2}$  of a powdered junket tablet. Leave at room temperature until it has set. Pour into a cloth sack and let drain for a few minutes. Determine the amount of cheese obtained. Compare the texture and flavor of the cheese with that from clabbered milk. What is the yield of cheese?

B. From sour milk.

1. Sour milk that has formed a clot is called clabbered milk. Boil 1 cup of clabbered milk 1 minute. Pour into a cloth sack and drain for a few minutes. What is the yield of cheese obtained?

2. To 1 cup of clabbered milk add 1 cup of boiling water. Determine the temperature. Drain through a cloth sack for a few minutes and determine the yield of cheese obtained.

3. Heat 1 cup of clabbered milk in a double boiler until the whey separates from the curd. Take the temperature. Follow directions under 1.

Compare the resulting cheese in texture, consistency, and flavor. What is the effect of a high temperature upon curd of milk that has been precipitated by souring? What temperature is preferable for heating clabbered milk to make cottage cheese? Which method is preferable? Compare with the cottage cheese made from sweet milk and junket.

Temperature to which milk is heated	Yield	Texture	Flavor	Comments

Results and conclusions.

## Cheese

### Experiment 60.

To determine the effect of heat upon cheddar cheese.

A. The melting point.

1. Place some grated cheddar cheese in a test tube. To determine the melting point place a thermometer in the test tube. Melt the cheese by immersing the test tube in water and heating the water. Compare the melting points of several samples of cheddar cheese. Notice the consistency of each cheese, its dryness, hardness, etc., before and after melting.

2. Repeat 1, but use the Kraft or other varieties of cheddar cheese that have been put in sealed or other types of containers.

B. Effect of temperatures above the melting point.

1. After observing the consistency and texture of the cheese from A1 and A2, put the tubes in warm water and heat to temperatures above the melting point. Notice all changes that occur.

C. Combining the cheese with milk.

1. Combine about 2 level tablespoons (14 grams) of grated cheese with  $\frac{1}{4}$  cup of milk (60 grams). Heat in the upper part of a double boiler. Note the melting point of the cheese. Continue heating and describe the changes that occur in the cheese-like mixture.

Does the dryness, texture, or fat content have any effect upon the melting point? From the results obtained, what would you conclude about combining cheese with other foods? Should cheese be heated directly over or under the fire? If so heated, what temperature should be used? Should cheese be covered

with sauce and bread crumbs in macaroni and cheese before putting in the oven? Why?

Sample of cheese	Melting point	Texture of cheese before melting	Effect of melting and heat	Comments

Results and conclusions.

### Welsh Rarebit

#### Experiment 61.

To determine the most satisfactory method of combining ingredients for Welsh rarebit.

1. Prepare a medium white sauce using:

Milk	½ cup	122 grams
Flour	½ tablespoon	3.5 grams
Butter	½ tablespoon	7 grams

Remove from the fire and cool to 40°C. Add ¼ cup (28 grams) of grated cheese to the sauce. Stir with spoon or beat with rotary egg beater until the cheese is melted and blended with the sauce. Place in top of double boiler and heat slowly to serving temperature.

2. Repeat 1, but add the cheese to the hot sauce.

3. Combine ½ cup of milk and 1 egg (48 grams). Add ¼ cup (28 grams) of grated cheese and stir.

4. Repeat 3, but add the cheese to the milk. Heat in a double boiler until the cheese melts. Add the beaten egg and cook until the mixture thickens.

Compare the results for consistency, flavor, smoothness, and ease of making. Does the consistency of the cheese before its addition to the milk have any influence upon the ease of blending with the milk? What types of cheese blend most readily with the milk? If grated cheese that does not blend well with the milk is soaked in the milk before heating, would this aid the ease of blending?

### Cheese Soufflé

#### Experiment 62.

To determine a satisfactory method of combining and baking cheese soufflé.

Recipe:

Butter	3 tablespoons	42 grams
Flour	2 tablespoons	14 grams
Milk	½ cup	122 grams
Egg yolks	3	54 grams
• Cheese, grated	½ cup	56 grams
Salt	½ teaspoon	
Egg whites	3	90 grams

Directions for mixing:

Melt the butter. Add the flour and salt and blend with the butter. Add the milk and bring to boiling, stirring continuously. Remove from the stove and beat the egg yolks thoroughly. Add egg yolks to the white sauce and blend. Add the grated cheese and mix thoroughly, using a spoon or a rotary egg beater. Fold in the stiffly beaten whites and pour in baking dish buttered on bottom only.

A. The time of baking.

Prepare the whole or  $1\frac{1}{2}$  times the recipe of whatever amount is necessary for the size baking dishes used. After mixing, divide, putting equal portions in three dishes. If possible set all three dishes in a large pan in the oven. Pour boiling water around the dishes and bake. Oven temperature  $175^{\circ}\text{C}$ . ( $347^{\circ}\text{F}$ .). The time of baking may need to be varied, time given being suggestive, because the time will vary with the quantity of water poured around the baking dishes. The soufflés should be baked until little or no shrinkage occurs on removal from the oven.

1. Bake 40 minutes.
2. Bake 50 minutes.
3. Bake 60 minutes.

B. The temperature of baking.

Follow directions given under A. What modification of time will need to be made?

1. Bake one part at  $160^{\circ}\text{C}$ . ( $320^{\circ}\text{F}$ .).
2. Bake a second part at  $175^{\circ}\text{C}$ . ( $347^{\circ}\text{F}$ .).
3. Bake a third part at  $190^{\circ}\text{C}$ . ( $374^{\circ}\text{F}$ .).

C. Compare baking the soufflés in dish surrounded by hot water and without water. Use temperatures and time found best under A and B. What modification of time will need to be made for those baked without water? Which conducts heat more readily, water or air?

D. The method and temperature of combining ingredients.

Bake at temperature and time found best under A, B, and C.

1. Follow directions for mixing under A.
2. Reverse the order and temperatures for adding the cheese and egg yolk. Add the cheese to the slightly cooled white sauce. Mix, then add the beaten egg yolks.

3. Add both the egg yolks and cheese to the slightly cooled white sauce. Mix.

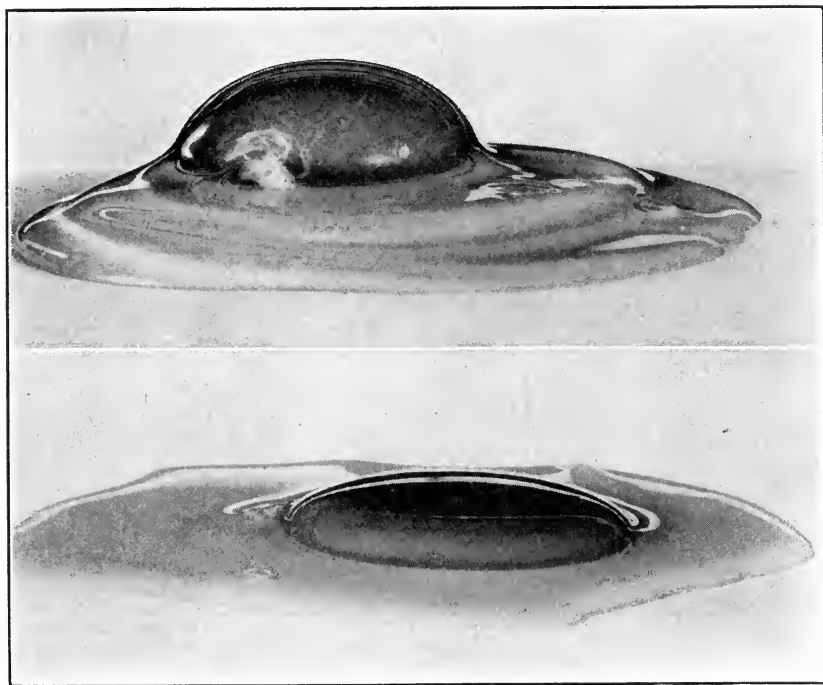
Compare the volume, tendency to shrink, and texture of the soufflés. What temperature should the white sauce be when the cheese is added? Would this vary with different kinds of cheese, that is loaf, processed, and cheddar? Would it vary with degree of ripeness or dryness of the cheese? What is a desirable method of making and baking cheese soufflé?



## CHAPTER X

### EGG COOKERY

**Structure and composition.** The shell forms about 11 per cent of the egg and is largely composed of calcium carbonate with some magnesium carbonate, calcium and magnesium phosphates, and organic matter.



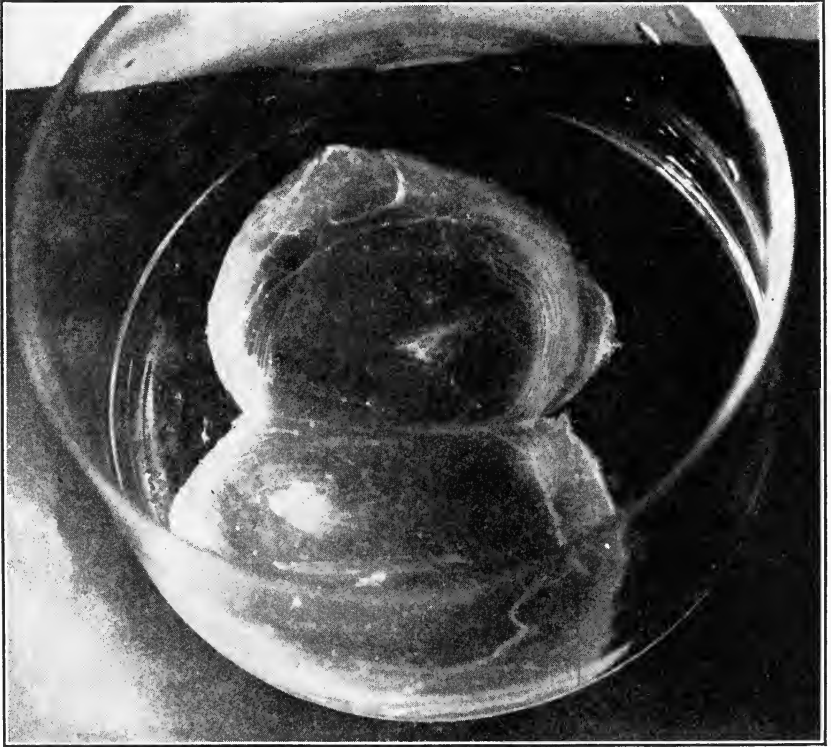
*Century Photos, Inc.*

FIG. 32.—Showing standing up quality of yolk and white of a fresh and a deteriorated egg.

Within the shell is the shell membrane, a thin, semi-permeable membrane made up of two layers, the inner and outer. After the egg is laid, its contents cool and shrink. The air cell at the large end of the egg is formed during this shrinkage by separation of the two membranes.

For cookery purposes the white and yolk are the important parts of the egg. The white is clear, transparent, and jelly-like. It composes about 57 per cent of the weight of the whole egg. The layer next the shell is a thin

soft white, its relative proportion varying somewhat at time of laying. Fig. 32. Next comes a layer of rather thick, viscous white, containing a larger proportion of mucin than the thin white. Beyond this is a small layer of thin white surrounding the yolk. Schaible, Moore, and Davidson say that the thick, "firm white is of laminated structure, composed of concentric layers containing mucin fibers." If a freshly laid egg is broken



*Courtesy of Institute of American Poultry Industries and P. J. Schaible, J. M. Moore, and J. A. Davidson, Michigan*

FIG. 33.—Showing the laminated structure of firm egg white, yolk removed.

into a large quantity of distilled water (the thick white having been slit with scissors on one side to remove yolk) and allowed to stand, the mucin and probably some globulin are precipitated at the edge of the cut surface. Six or more sheets or layers, one over the other, can be distinctly seen. Fig. 33.

The chalazae are dense cord-like strands of white substance, one on each side of the yolk, which anchor the yolk near the center of the egg. They allow the yolk to revolve. Being dense the chalazae are not broken down readily when the egg is beaten, hence they are often caught on the blades or wires of the egg beater.

The yolk forms about 32 per cent of the whole egg. It is separated from the white by a yolk sac, called the vitelline membrane. The yolk is made up of layers. See Fig. 34. The fat is more concentrated around the germ spot; hence its specific gravity is less and when the egg is turned the yolk rotates so that the germ spot is always uppermost. In eggs of average size the white usually averages about 30 grams and the yolk about 18 grams.

*Composition.* The composition of the white is approximately 86.2 per cent water; 12.3 per cent protein; 0.2 per cent fat; and 0.6 per cent

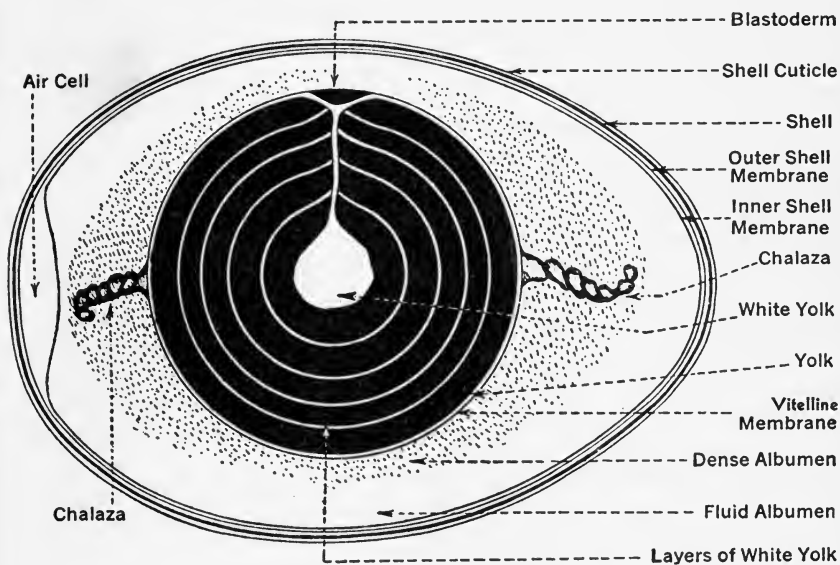


FIG. 34.—Diagram showing internal structure of an egg.  
*Courtesy of Institute of American Poultry Industries.*

mineral. The composition of the yolk is about 49.5 per cent water; 33.3 per cent fats, including lecithin and cholesterol; 15.7 per cent proteins; and 1.0 per cent minerals.

**Color of shell and yolk.** The color of the shell is determined by inheritance, certain breeds laying white, others brown-colored shells. The Barnaveldters lay eggs with nearly chocolate-brown shells.

The coloring matter of the yolk, according to Palmer, Mattikow, and others is xanthophyll, with a small proportion of a carotene-like pigment. The intensity of the yolk color is determined by the amount of xanthophyll in the food of the hen. The color of the yolk may vary from a very pale, almost white yolk, through deeper yellows to orange and finally a deep-red-orange. Some feeds may produce red-colored yolks. Some attempts have been made to work out color charts, giving each shade a number; but most of these are only tentative. It is an advantage for bakers and mayonnaise manufacturers to obtain yolks of uniform color to insure uniformity

of color of their products. A small number of manufacturers at present do specify the color of the egg yolks when they place their contract for them.

**Reaction of eggs.** The egg white is alkaline. Sharp found that the  $pH$  of the white varies from 7.6 to 9.7, whereas the yolk of fresh eggs averages  $pH$  6.0 or slightly lower. The  $pH$  of both the white and yolk increases with age because of the loss of carbon dioxide. Sharp and Powell state that since the loss of some carbon dioxide cannot be prevented before the  $pH$  is taken, that a  $pH$  of 7.6 is probably too high for freshly laid eggs. With further loss of carbon dioxide the  $pH$  may increase to 9.5. Then, probably owing to break down of some of the egg protein, the  $pH$  decreases. The  $pH$  of the yolk may reach 6.8, but changes more gradually than that of the white. When the whole egg is beaten so that the white and yolk are mixed, a  $pH$  intermediate between that of the white and yolk is obtained.

### Egg Quality

The term "quality" as applied to eggs refers ultimately to their desirability for human consumption. When an egg deteriorates its cooking qualities are altered. It is commonly accepted that an egg of high quality is better for poaching, boiling, and frying than one of inferior quality. At present, for trade use, eggs of quality are defined as those having a relatively high percentage of thick to thin white, and a high percentage of yolk solids. These eggs, when broken on a flat surface, do not tend to flatten out as quickly nor to so great an extent as eggs of poorer quality. See Fig. 32.

**Tests for quality.** A candler's grading of the egg is based largely on the size of the air cell and the visibility of the yolk. Perry found that yolk color, ascertained after breaking the egg, influences the yolk shadow and the yolk movement, as determined in candling. The dark yolks cause a darker shadow and increase the apparent movement, though the percentage of thick albumen did not influence the yolk shadow and movement. The air cell increases in size with loss of water from the egg. The less the humidity of the air in which the egg is stored, the greater the loss of water. When water is lost to the outside air the total solids of the egg increase. The changes in the cooking quality of the white and yolk may not be so detrimental as when the water loss is prevented. Since the size of the air cell increases with the loss of water, the humidity of storage rooms is usually controlled to prevent a large moisture loss. But other changes, more detrimental to the quality of the egg than water loss, may occur.

Almquist, Givens, and Klose say that the transmission of light varies for different layers of egg albumen, being lowest for the firmest or gelatinous layers. They find the transmission of light to be correlated with the percentage of mucin in the albumen. In addition it varies with the temperature and  $pH$ , both of which affect the physical condition of the mucin.

At lower temperatures and at lower  $pH$  the translucency of the mucin fibers is lessened.

Wilcke used a torsion pendulum to measure externally the interior viscosity of an egg and from observations worked out an index  $K$ , which was a measure of the combined viscosity of the entire contents of the egg. He found that the  $K$  value increased with increased weight of the eggs, but that the rations used did not affect the  $K$  values of the eggs produced by hens on the rations used in his study. The index,  $K$ , is a characteristic of the individual hen.

*Standing-up quality of the yolk.* Sharp has worked out a system of determining the quality of the egg from the standing-up ability of the yolk. If a fresh egg of good quality is broken out of the shell, the yolk stands up. But as the interior quality deteriorates the yolk flattens out more and more readily until a stage is reached at which the yolk membrane breaks, no matter how carefully handled, when the shell is broken. Both the time the yolk is on the dish and its temperature affect the extent of flattening, the flattening being greater with longer time and a higher temperature. By dividing the height of the yolk by its width a numerical index is obtained that indicates the quality of the egg. The measurements of the yolk, after being freed of the white, taken 5 minutes after it is laid on the Petri dish and at a temperature of  $25^{\circ}C.$ , give an average value of about 0.41 for eggs 3 to 4 hours old. With deterioration of the egg the index becomes less, and breaking occurs when the index falls to about 0.25.

The standing-up ability of the white may also be used to determine egg quality.

*Vitelline membrane strength.* Another method for determining quality is to measure the strength of the vitelline membrane. The average thickness of this membrane has been reported to be about  $64/100,000$  of an inch. In a fresh egg its bursting strength is about 0.065 pounds per square inch. With deterioration the strength of the membrane decreases and the yolk breaks easily when the strength has fallen to a little over half this value.

**Factors affecting quality of eggs.** Fresh-laid eggs vary in proportions and viscosity of the thin and thick white. The yolk membrane also varies in strength. These variations are probably due to feed, the season of the year, the period of the laying cycle, and individual characteristics of the hen. It has already been mentioned that Wilcke found that the rations did not influence the viscosity of the egg in his investigations, but he states his work does not rule out this factor. Lorenz and Almquist report that the percentage of firm white is lowered by higher air temperature during the hours immediately after the egg is laid, resulting in an apparent seasonal variation in internal egg quality. The poorer quality of eggs obtained during summer months is attributed to the higher temperature during this season. The finest quality eggs are claimed to be those laid in the spring, which coincides with the time of greatest production.

**Preservation and deterioration of eggs.** Sharp states that "as soon as the egg leaves the hen it begins to decline in interior quality and the best we can hope to do is to retard these changes as much as possible. They cannot be stopped, they can only be retarded. An egg a week old may have deteriorated more in quality than an egg properly cared for which is a year old."

Eggs are preserved by (1) storing at low temperatures, (2) by freezing, (3) by drying, and (4) by oil dipping.

*Storing at low temperatures.* In commercial storage the temperature, humidity, and air currents are controlled, the last to prevent mold growth. A high moisture content in the storage air lessens the amount of the water evaporated from the egg, but encourages mold growth. The storage temperature is usually maintained at 29° to 30°F. In addition chemical control of the atmosphere is frequently practised in the storage rooms. Stewart and Sharp state that at 30°F., if 0.6 per cent carbon dioxide is used, the  $pH$  of the egg white will be maintained at 8.0 to 8.1. If the concentration of carbon dioxide is too high, the white becomes turbid, but loses this turbidity after loss of some carbon dioxide from the egg on breaking.

Most of the eggs placed in low temperature storage are stored during March, April, May, and June. More than half of the annual supply of eggs is laid during these four months. Withdrawal of eggs from storage usually begins in August, reaches its peak about November, and the supply is generally exhausted by January.

*Frozen eggs.* The use of frozen eggs has increased very rapidly in the last 10 years. The eggs are broken out of the shell for freezing, which gives an opportunity for increasing contamination with bacteria. If eggs are frozen quickly after being broken, little bacterial growth takes place. Swenson and James found that fewer organisms survived quick freezing than delayed slow freezing. They also report that the addition of carbon dioxide to the egg batter just prior to freezing was detrimental to survival of bacteria. Eggs are frozen whole, the whites and yolks being mixed by beating. The whites and yolks are also frozen separately. Freezing alters the physical characteristics of the yolk, as it is more viscous after defrosting. Hence to prevent its becoming so stiff and gummy that it does not mix readily with other ingredients, before being frozen it is beaten and a small percentage of salt, sugar, particularly dextrose, or some suitable edible ingredient is often added. Some of these processes are patented, and the proportion of ingredients added as well as the manner of incorporation are not generally known.

Frozen whole eggs, egg yolks, and egg whites are usually prepared in 30-pound lots, though some 10-pound lots are frozen. A pound of frozen whole eggs is equivalent to about 10 fresh eggs. As yet frozen eggs are not on the retail market.

*Drying.* The use of dried eggs is decreasing in the United States, the frozen eggs taking their place in many products.

*Oil dipping.* Oil dipping, shell treating, or processing of eggs is increasing rapidly. This process consists of dipping the egg in some kind of oil to seal the pores of the egg shell, thus retaining the carbon dioxide within the egg.

Swenson, Slocum, and James report that a special white, odorless, tasteless mineral oil of right viscosity and low enough pour-point (40°F.) has been developed to be applied to the shell at temperatures of 60° to 80°F. They also state that oiling shell eggs, especially by the vacuum-carbon dioxide method, tends to maintain the pH of the egg white at  $7.9 \pm 0.3$ , which is below the optimum for proteolytic activity. Sharp and Wagener state that if eggs are oil dipped fairly soon after they are laid, the white will have a pH value of 8.0 or less at the end of the storage period. If oil dipping is to be of value in preserving the eggs they must be dipped before too much carbon dioxide has escaped.

**Factors causing deterioration.** The causes for deterioration of eggs may be listed as follows: (1) action of the enzyme trypsin, (2) alkaline hydrolysis, and (3) chemical changes and changes due to bacterial action. The changes brought about by these factors may be speeded up or retarded by temperature and reaction.

*Enzyme action.* Balls and Swenson report that trypsin, a proteolytic enzyme, is found only in the thick white. Its action, i.e., protein splitting, which reduces the proportion of thick white in the egg, is speeded up by increase in temperature, its greatest activity occurring near body temperature. Sharp has found that the weakening of the yolk membrane is greater in 2 days at 98.6°F. for eggs stored in air containing ordinary amounts of carbon dioxide and at 80 per cent humidity than after 5 days of storage at 77°, or 20 days of storage at 60.8°, or 100 days of storage at 35.6°F. Likewise a pH of about 9.25 may be reached in 2 days at 37°C., in 5 days at 16°, and in 10 days at 2°C. Or, in other words, carbon dioxide escapes more slowly and enzyme action is also slower at lower temperatures. The reaction of trypsin is also speeded up as the reaction becomes more alkaline, the optimum activity according to Swenson, Slocum, and James occurring at pH 8.4 to 8.8. Thus with loss of carbon dioxide from the egg, the action of the trypsin is increased. Balls and Swenson found that the action of the trypsin is decidedly speeded up by injecting enterokinase into the thick white, which also gives proof that the enzyme is trypsin, since enterokinase activates only trypsin. The thin white contains an anti-trypsin which inhibits the action of the trypsin. Therefore, when the thick and thin white are mixed together the action of the trypsin is inhibited. This mixing of the thick and thin white before freezing may be one reason for the claim made by many users of frozen eggs that frozen eggs are superior to and more uniform in quality than fresh eggs. Balls and Swenson state the amount of trypsin varies greatly in individual eggs of the same lot.

*Alkaline hydrolysis.* Alkaline hydrolysis of proteins, the breaking down of the protein into smaller units, is also speeded up as the egg becomes more

alkaline by loss of carbon dioxide and as the temperature increases. Alkaline hydrolysis of protein occurs independently of enzyme action.

*Chemical changes and changes due to bacterial action.* Slow chemical breakdown may cause off flavors and changes in eggs, but true rotting of eggs is caused by microorganisms.

Eggs which are infected with a large number of molds and bacteria ordinarily do not keep well. Microorganisms cannot always be detected in eggs in the shell, yet the eggs deteriorate in storage. But, in general, eggs with clean shells are comparatively free from bacteria. Reetger found that not over 4 per cent, and usually a smaller number, of eggs with clean shells were infected with bacteria. Egg shells vary in porosity and some eggs have a few very large pores. Infection with bacteria is easier through these large pores. Eggs having dirt on the shell are most easily infected. Bryant and Sharp report that washing of such eggs is not the cause for deterioration, if they are handled properly after washing. The deterioration of washed eggs is caused by bacterial infection of the egg from the dirt on the shell.

**Changes in eggs with deterioration.** The most important changes occurring in eggs during deterioration are: (1) the thick white becomes less viscous and jelly-like, gradually changing to a thin watery white. (2) Water passes from the white to the yolk increasing the size and fluid content of the yolk, thus decreasing the yolk solids. In addition the yolk membrane weakens and, if the weakening has progressed far enough, breaks when the shell is opened. (3) Loss of moisture usually occurs. (4) The egg may absorb foreign or off odors. (5) With continuous loss of carbon dioxide the alkalinity of the egg increases.

### Properties of Egg Proteins

The extensive use of eggs in cookery is made possible by their protein content. The protein coagulates during heating, thus bringing about thickening as in custards or the binding of pieces of food together as in croquettes. The proteins of the egg are good emulsifying agents. The proteins form elastic films when beaten, thus incorporating air, which is used as leavening in such products as angel cakes and soufflés. The elasticity of the egg protein is also important in products such as popovers where the egg stretches with expansion of steam, and later coagulates to aid in forming the framework of the popover.

**The proteins of the egg.** The proteins of the white are ovalbumin, ovoglobulin, and ovomucin. There may be small amounts of other proteins and it is also possible that each protein is made up of component fractions. Hughes and Scott give the relative proportions of the proteins in the three portions of the white as shown in Table 41.

The principal protein of the yolk is ovovitellin. Sell, Olsen, and Kremers



TABLE 41

PERCENTAGE OF THE TOTAL NITROGEN CONTRIBUTED BY EACH OF THE THREE PROTEIN FRACTIONS (*Hughes and Scott*)

	Outer thin layer of egg white	Thick layer of white	Inner layer of thin white
Ovomucin.....	1.91	5.11	1.10
Ovoglobulin.....	3.66	5.59	9.89
Ovoalbumin.....	94.43	89.18	89.29

separated salted egg yolk into a soluble lipid fraction and an insoluble residue. The latter consisted of sodium chloride and the protein-like material of the yolk. This residue they called lecitho-protein. It composed about 32.5 per cent of the yolk. This protein fraction contained nearly one-half the total lecithin of the yolk.

**Solubility of the proteins.** The albumin of egg forms a sol with water and dilute salt solutions. The globulin forms a sol in dilute salt solutions, but not in pure water. The globulin composes about 6.5 per cent of the total proteins of the egg.

Egg-white proteins belong to the group of hydrophilic colloids. Egg white and water are mutually soluble. Usually the addition of 1 tablespoon of water to an egg white, unless it is very watery, increases its extensibility, and when the egg white is whipped a larger volume is obtained. But with increasing quantities of water a stage is reached at which the egg white loses too much of its rigidity and will no longer retain air in small bubbles, the bubbles being large and floating on the more liquid part.

The ovovitellin of the egg yolk is combined with phosphorus and belongs to the phosphoprotein group. It is insoluble in water but is soluble in dilute salt solutions and in dilute alkalis.

**Isoelectric point of egg proteins.** Loeb has reported the isoelectric point of egg albumin as  $pH$  4.8. Some investigators give  $pH$  4.7 as the isoelectric point. Above the isoelectric point the albumin combines with bases to form salts like sodium albuminate; below the isoelectric point it combines with acids to form salts like albumin acetate, citrate, or tartrate. Above the isoelectric point the protein is negatively charged; below, it is positively charged. Since the reaction of the egg white is about  $pH$  7.6 to 9, there will probably be few combinations of egg white with alkalis or alkaline salts in food preparation that will increase its alkalinity. Many combinations are made that increase its acidity. For example, the addition of a teaspoon of cream of tartar, a salt with an acid reaction, to a cup of

egg whites, proportions often used in angel food cakes, increases the acidity and lowers the  $pH$ , often to about 7.5 or 7.0. As the proportion of cream of tartar is increased, the  $pH$  is lowered to a greater extent. The addition of fruit juices and fruit pulp to egg whites to make fruit whip, soufflés, or similar desserts, increases the acidity. When 1 to 2 teaspoons of lemon juice are added to an egg white the  $pH$  is lower than 4.8.

No record could be found in the literature of the isoelectric point of ovovitellin. When lemon juice is added to egg yolk, the mixture is thickest at a  $pH$  between 4 and 5, as if the greatest tendency to curdle is at this point. This might indicate that the isoelectric point of the egg yolk proteins is between  $pH$  4 and 5. This greatest thickening occurs with about 5 cc. of lemon juice to an egg yolk.

The addition of an acid like vinegar or fruit juice to the white and yolk beaten together tends to curdle the mixture. This occurs when the acidity is in the vicinity of the isoelectric point. When sufficient acid is added to lower the  $pH$  below the isoelectric point of the egg proteins, and if the salt formed, such as protein citrate, is soluble, the coagulum dissolves and the mixture becomes smooth. With the exception of salad dressings and a few sauces, there are probably not many instances in which enough acid is added to lower the  $pH$  of the food mixture below the isoelectric point of the egg protein.

**Peptization of egg proteins.** Peptization of egg proteins increases the tenderness of some products. Freundlich states that peptization of proteins is frequently brought about by low concentrations of electrolytes, though to accomplish this the electrolyte must be intimately mixed with the substance to be peptized. The hydroxyl, citrate, acetate, and tartrate ions are effective for peptizing egg proteins. For example, when tomato or lemon juice is added to egg in amounts to bring the  $pH$  of the egg slightly above or about the isoelectric point of egg albumin, the tenderness of omelets is definitely increased. In some instances peptization of the egg proteins is detrimental. An example of this is the thinning of salad dressings, thickened with only egg yolk, when heated above the temperature at which optimum coagulation occurs.

Sugars (sucrose, dextrose, and levulose) through peptization tend to prevent coagulation of egg protein.

**Denaturation.** Denaturation, by which soluble proteins are rendered insoluble, of egg proteins is brought about in a variety of ways, including the action of acids, salts, heat, mechanical agitation, and radiation. Mechanical agitation or beating of egg white, as well as the tendency of proteins in surfaces to form films, causes partial denaturation of the egg proteins. Sugar tends to prevent this denaturation.

The theories for heat coagulation have been considered in Chapter I. But, however the process of coagulation is brought about, the coagulation temperature, the time required for coagulation, and the factors that cause

variation in coagulation temperature are of interest in egg cookery, because they determine the temperature to which certain dishes, such as custards and cooked salad dressings, may be heated. If heated beyond this point, separation into solid and liquid may result and curdling occurs, or the salad dressing may become thinner.

**Coagulation temperature of egg white.** Undiluted egg white coagulates at about 60°C. or becomes jelly-like at this temperature. Coagulation may start at a slightly lower temperature, but the amount coagulated at the lower temperature depends on how long the egg is held at that point. In coagulating, the egg white changes from a clear, transparent mass to a white and opaque one. If the egg white is heated slowly, a point is reached—about 62°C.—at which it will not flow in a test tube. It is still firmer at 64° to 65°C. In cooking, the temperature is seldom held a long time at a definite degree but may rise gradually and often rapidly.

**Coagulation temperature of the egg yolk.** The egg yolk requires a higher temperature for coagulation than the egg white. It begins to thicken at about 65°C. but does not reach a stage at which it does not flow until about 70°. Since the yolk does not change color during coagulation it is more difficult to determine when it is coagulated.

When the white and yolk are mixed by beating and are heated slowly the mass begins to thicken at 65°C. and becomes stiffer not far from 70°.

**Factors affecting heat coagulation of egg proteins.** The following factors affect the coagulation temperature of the egg proteins: (1) temperature, (2) time, (3) concentration of protein, (4) salt content and its concentration, (5) reaction of the egg solution or mixture, and (6) sugar.

*Temperature and time.* The rate of coagulation increases with increasing temperature. At high temperatures it is so rapid that it seems nearly instantaneous. Eggs cooked in boiling water will cook at a much faster rate or in a shorter time than those cooked in water at 70°C. Chick and Martin have found that "heat coagulation is a reaction with a high temperature coefficient, the reaction velocity of which varies considerably with different proteins and according to the acidity and saline content of the solution." They have reported that the temperature coefficient for crystalline egg albumin in water solution and 1 per cent concentration is 1.9 times for 1°C. rise in temperature. The temperature coefficient is greater than 2 for the results of Lepeschkin given below. In cooking eggs or foods containing large proportions of egg, the amount of coagulum formed at a definite temperature depends upon the length of time the food is held at the specified temperature and the number of degrees the specified temperature is above the point at which coagulation may begin. Using filtered egg white, Lepeschkin found that, with water at a definite temperature, a longer time was required before the egg appeared turbid at lower temperatures than at higher temperatures. His findings may be summarized:

°C.	Seconds required for coagulation
57.04	22,600
58.01	9,520
59.03	1,535
60.03	595
61.02	230
62.01	97
63.01	40

As the temperature of milk custards is elevated the firmness of the custard is increased. At a definite temperature, depending on the rate of heating, an optimum consistency is obtained. Heating to a temperature higher than this increases syneresis and porosity of the custard.

Woodruff and Meyer found that by increasing the temperature from 79° to 91° by 4° intervals the strength, when tested by a gel tester of distilled-water-egg custard gels with 0.2 M and 0.05 M sodium chloride and 0.2 M magnesium chloride plus 23 per cent sugar, was increased. But at the higher temperatures the gels were porous and undesirable. The concentration of egg used was approximately 2 to a cup of liquid.

*Concentration.* Robertson states, "The concentration of the protein, and especially the presence of other substances in the solution, very markedly affects the coagulation temperature." This is illustrated in egg cookery. The whole egg coagulates at a temperature not far from 70°C. When 1 to 2 tablespoons of milk or water are added, as in the making of plain omelets, coagulation occurs at a temperature above 70°C. When 1 egg is added to a cup of milk the coagulation temperature is much higher than that of egg alone. It is about 80°C., the amount coagulated at a definite temperature depending upon the rate of heating. If 2 eggs are added to a cup of milk the concentration of egg is greater than when 1 is used, and coagulation under the same conditions for heating occurs at a slightly lower temperature.

*Salts.* The salt content of the egg or of the material with which the egg is combined affects the coagulation of the egg proteins. Lepeschkin has shown that, if egg albumin is dialyzed so that the mineral content is lowered, the albumin does not coagulate on heating. He has also shown that coagulation varies with the salt concentration, that some concentrations cause coagulation and others do not. However, if, to the heated egg albumin that has been dialyzed, salts are added, coagulation takes place, but this often requires a definite concentration for maximum coagulation, higher or lower concentrations not being so effective or failing to bring about coagulation.

The effect of the salt content on coagulation can be shown by combining egg as for custard, but substituting distilled water for the milk, which when heated to 83° to 86°C. does not gel. If to this distilled-water custard a definite concentration of a salt is added, coagulation will occur on heating. Salts which will bring about coagulation are iron lactate, ferric

chloride, calcium chloride, sodium chloride, aluminum chloride, aluminum sulfate, sodium sulfate, magnesium sulfate, sodium acetate, potassium tartrate, sodium potassium tartrate, calcium phosphate (monobasic and secondary), sodium and potassium phosphate. However, some produce a firmer coagulum than others, for with each salt a definite concentration brings about optimum coagulation. If the distilled-water custard is heated to 83°-86° before the salt is added, and the salt is then added, coagulation occurs; but when the mixture is stirred, curdling occurs to a greater or lesser extent. A milk-salt mixture, such as the Sherman or Steenbock formulas used in animal-feeding experiments, in the right concentration forms a coagulum in distilled-water custards that is similar in consistency to that produced by milk custards.

*Concentration and valence of added salts.* If the effect of electrolytes upon hydrophobic and hydrophilic colloids is referred to in Chapter I, the statement is found that the precipitation of the protein is brought about by the ion having the opposite charge from that of the protein. In general, the coagulating power of the ion increases with increasing valence, but there are some exceptions to this rule, some monovalent ions being more effective than some polyvalent ions. In many cases there is a zone of maximum coagulating effect. The effect of the concentration of the salt upon the coagulation of the egg can be shown in the following way. If less than 1/16 teaspoon of ferric or aluminum chloride is added to an egg, a cup of distilled water and 2 tablespoons of sugar, the custard coagulates on heating to 84°C., though the coagulum is not so firm as when milk is used. However, if a larger quantity of ferric or aluminum chloride is added to the mixture, about ¼ teaspoon or more, the custard does not coagulate when heated to 84°C. The reaction of the custard mixture with the small amount of aluminum or ferric chloride given above is slightly acid to litmus, and the larger quantities are decidedly acid to litmus. Hence, the larger quantity of ferric chloride must peptize the egg proteins.

Woodruff and Meyer found that sodium chloride, sodium sulfate, and calcium chloride, when used in 0.2 M concentration, produced gels of approximately equal strength and slightly weaker gels than milk. Magnesium chloride and sodium thiocyanate produced stronger gels than milk. They concluded that the difference in strength of gels formed by various electrolytes seemed to be a specific function of the cation and anion of the salt, and independent of the pH of the solution. Increasing the concentration of each salt gave gels of greater strength until a maximum strength was reached, after which further increases of the salt reduced the gel strength.

*The relation of reaction to setting of custards.* If hydrochloric acid is added to the egg-distilled-water custard, so that the reaction is adjusted to a pH above the isoelectric point of egg albumin, pH 4.8, coagulation occurs within the range of pH 5 to 6. The coagulum is soft and not quite so firm

as when salts are added, but it shows that a definite acidity tends to aid coagulation.

The coagulation of egg-distilled-water custard with added salt is somewhat similar to the jellying of fruit jells in that it occurs at a definite range of  $pH$ .

Coagulation occurs over a wider range of  $pH$  when milk is used with the egg than when distilled water is used. If the  $pH$  is adjusted with hydrochloric acid and sodium hydroxide, it occurs from  $pH$  0.2 to 8.6 or over even wider ranges. The reaction of a milk-egg custard mixture, with no added acid or alkali, is between  $pH$  6 to 7 with an average of about 6.5. This custard mixture was made up in a large quantity, and divided into different portions. To these portions hydrochloric acid or sodium hydroxide was added to adjust the custard to the desired  $pH$ . As the  $pH$  was lowered the firmness of the custard increased, until at about  $pH$  5 curdling occurred. All custards with a  $pH$  below 5 curdled, the curd becoming very fine in texture, and forming a dense layer in the bottom of the container. This layer decreased in amount as the  $pH$  was lowered below the isoelectric point of egg albumin. At a  $pH$  0.2 the custard was badly charred, and the curd was very slight and fine, the custard quite soft. With increased alkalinity above  $pH$  6.5 the coagulum was less firm. The custards could be placed in the order of acidity by the depth of color: the greater the acidity the lighter the color, the greater the alkalinity the deeper the color. The color ranged from light cream, through yellow, to a deep orange-yellow.

*Acids.* Chick and Martin state that acid solution hastens the second part of the heat-coagulation process, that is, the clotting or coagulation, but does not hasten the first part of the process, the denaturation. They have reported that acid accelerates the rate of coagulation. They state that the influence of acid in accelerating the coagulation rate of a neutral solution is at first relatively small, but with each successive addition of acid its influence becomes disproportionately greater. Loeb using isoelectric crystalline egg albumin in a 1 per cent solution at a  $pH$  4.8 found that it coagulated at a temperature not far from  $60^{\circ}C$ . When acid was added and the  $pH$  lowered to 4.39 the coagulation did not occur until about  $80^{\circ}C$ . With  $pH$  4.25 coagulation did not occur at  $95^{\circ}C$ .

Fruits that do not have a high acidity such as dates and figs may be used in custards and tend to give a firmer custard, because they lower the  $pH$  slightly. More acid fruits, such as lemon juice, cannot be used in very large quantities. The addition of quite acid fruit juices tends not only to coagulate the casein and albumin but also to hasten curdling. Custards that are made of milk that is slightly sour will curdle more readily during heating. If the acidity has not reached the stage at which curdling occurs, the custard is firmer.

*Alkalies.* Chick and Martin have found that in alkaline solution the second part of the coagulation process, the aggregation or coagulation of

the protein, does not occur. If after heating the alkali is neutralized with acid, coagulation occurs. Thus, if enough of an alkali or of an alkaline salt is added to a custard to render the solution sufficiently alkaline, the custard will not coagulate on heating. But if acidified after heating the custard will "set."

*Sugar.* The addition of the non-electrolyte sugar to an egg mixture elevates both the setting and curdling temperatures. In large enough quantities it tends to prevent both coagulation and curdling. Its effect in preventing coagulation appears to be proportional to the amount added, the greater the amount added the greater the difficulty in bringing about coagulation. Bancroft and Rutzler state that a "15-per cent egg white sol was not prevented from coagulating by the addition of 0.25 gram of dextrose to 10 cc. of the sol. However, when the sol was saturated with respect to dextrose heating in boiling water caused no coagulation."

Woodruff and Meyer found that 10 per cent of sucrose reduced the gel strength of egg-milk custards heated to 83°C., approximately one-half. Adding 30 per cent of sugar practically prevented coagulation. Adding sugar also increased the translucency of the custard.

In the salad-dressing recipe given in Experiment 65, increasing the sugar from  $\frac{1}{2}$  to 11 tablespoons (140 grams, about 30 per cent) elevates the temperature for optimum thickness about 4° to 6°C. Here in spite of the fact that the acid tends to lower the coagulation temperature the effect of the large quantity of sugar is still greater and the mixture must be cooked to a higher temperature for optimum thickening.

*Coagulation by other means.* Flosdorf and Chambers found that audible sound, frequencies (1000-15,000), coagulated solutions of egg albumin and synthetic plasterin almost instantly at 30°C.

Jellinek placed a raw egg between two condenser plates connected to a short-wave radio transmitter. After power of 1000 watts had been applied for 5 minutes, the egg yolk was coagulated and hard, as if it had been cooked, but the white was scarcely affected. The temperature of the yolk at the end of this period was 140°F., that of the white was 176°F.

### The Applications of Factors Affecting Heat Coagulation to Preparation of Food Products

*Custards.* As can be deduced from the foregoing discussion, custards containing a high proportion of sugar may not thicken satisfactorily for serving purposes. A small amount of salt aids setting but too much increases the tendency to curdle.

*Pie fillings.* One question often asked is why butterscotch fillings for pies which are of a consistency for serving sometimes become thin and runny after standing for a short time. This of course is different from the instances in which thickening does not occur. There may be various factors that bring about this result, but the effect of the sugar in elevating the temperature

at which egg coagulates is one explanation. The proportion of sugar in butterscotch fillings in different recipes varies from about 15 to 25 per cent, or 15 to 25 grams per 100 grams of filling. A usual procedure is to cook the sugar, cornstarch or flour, and scalded milk until thick. This mixture is often added to the beaten yolks by stirring the hot mixture into the yolks. Sometimes it is considered that the hot milk mixture will coagulate or cook the egg yolk sufficiently. However, if the temperature drops below 80°C. during this procedure and the mixture is not reheated the egg yolks will not be cooked sufficiently. The filling appears thick at the time, but on standing it becomes runny. If sugar is added to uncooked egg yolks, mixed, and left to stand for a few minutes the mixture appears thinner and more runny. If the yolks are not cooked sufficiently they act in much the same way, the sugar dissolving in the uncooked yolk and the filling becoming runny. This has never been observed by the author if the mixture is heated to a sufficiently high temperature after the egg yolks are added. The same thing may occur in chocolate and lemon pie fillings, although this in some instances is due to not using enough starch, the action of the acid on the smaller amount of starch lessening the stiffness of the filling. Another possible cause is the tannin of the brown sugar, because the tannin has a dehydrating effect on many sols. But to date it has not been possible to obtain thinning in the butterscotch filling by adding slightly more tannin than might be found in the sugar.

*Baked products.* The addition of sugar to egg in baked products also tends to delay coagulation or peptize the egg proteins and will be discussed further under angel cake and cakes containing fats.

### Cooked Salad Dressings

Vinegar, lemon juice, or a mixture of the two, is used in cooked salad dressings. The two acids do not behave alike, particularly in regard to curdling. The lemon juice contains citric acid and salts. Vinegar contains acetic acid, and cider vinegar contains salts. If mustard, sugar, and salt are kept constant in the recipe given in Experiment 65 with 72 grams of egg yolk and a total of a cup of liquid, results similar to the following may be obtained, provided the rate of heating is the same in each case. The mixture is cooked in the upper part of a double boiler, 12 to 15 minutes being required for the cooking process.

		Water	pH about	Coats spoon °C.
Vinegar	1/8 cup	7/8 cup	4.2	82 to 85
Vinegar	1/4 cup	3/4 cup	3.9	78 to 80
Vinegar	1/2 cup	1/2 cup	3.6	76 to 78
Lemon juice	1/8 cup	7/8 cup	3.6	82 to 85
Lemon juice	1/4 cup	3/4 cup	3.3	78 to 80
Lemon juice	1/2 cup	1/2 cup	2.8	76 to 78



One-fourth cup of either the vinegar or lemon juice gives a stiffer or thicker dressing than  $\frac{1}{8}$  cup;  $\frac{1}{2}$  cup of vinegar or lemon juice gives a thicker dressing than  $\frac{1}{4}$  cup. These results seem to agree with those of Chick and Martin that acid aids coagulation. Increasing the quantity of acid lowers the temperature at which the consistency for serving is reached. The optimum dressing for serving is obtained at a temperature slightly higher than the temperature for "coating the spoon." The salad dressings become thinner after heating above this optimum temperature for serving; the ones with lemon juice are thinner than those with the vinegar. Another peculiarity is that if a portion of these salad dressings is cooked to as high a temperature as  $92^{\circ}\text{C}$ ., all those made with vinegar may or may not curdle. The ones with lemon juice may not curdle, or those with the smaller quantity of lemon juice may curdle at about  $85^{\circ}\text{C}$ ., but when heated to a higher temperature the curds may partially or entirely disappear. In all these instances the reaction of the dressings is probably below the isoelectric point of ovovitellin. If heated only to the temperature at which the dressings are thickest, the thinning is not noticeable if the dressing is stored.

If 92 grams of whole egg are substituted for the egg yolk, the  $\rho\text{H}$  remains practically the same, but the dressing when cooked contains fine curds, those in the dressings made with lemon juice being finer than those in the ones made with vinegar. Increasing the proportion of salt produces a thicker product at a slightly lower temperature but one which curdles at a lower temperature. Increasing the sugar in the recipe slightly elevates the temperature at which the best texture for serving is obtained.

The explanation for the salad dressing's becoming thin and nearly its original consistency when heated above the temperature at which the optimum thickening occurs is that the acid and continued application of heat bring about peptization of the protein. It is probably an illustration of a partial or complete reversibility of heat coagulation and one of the most common occurring in food preparation. It is probably the reason that usually only one or no recipe for boiled salad dressing containing only egg yolk as the thickening ingredient is given in most cook books. Too many cooks have had the salad dressing return to its original consistency.

*Salad dressing containing starch.* If maximum thickening of both starch and egg is desired when these two ingredients are used together in a boiled salad dressing, the starch and all, or a part, of the liquid should be heated to  $95^{\circ}\text{C}$ . or boiling before the egg is added. The maximum thickening of cornstarch does not occur below  $91^{\circ}$  and of wheat starch below  $95^{\circ}\text{C}$ . Since the maximum thickening of the egg in the presence of vinegar or lemon juice occurs at temperatures of  $76^{\circ}$  to  $85^{\circ}\text{C}$ . and thinning occurs at higher temperature, this suggests that the thickened starch paste should be added to the cold beaten egg and then heated to a temperature that gives maximum thickening of the egg.

On the other hand, there is the possibility that part of the egg protein

may not coagulate in the presence of starch, hence not thicken the salad dressing. Bancroft and Rutzler, quoting Berlinsson, state that "albumin is prevented from coagulating even in boiling water by the presence of starch." However, this appears contrary to observed results in food preparation. Possibly there needs to be a certain concentration of starch before coagulation is prevented or peptization of the egg protein may occur when heated above the temperature for coagulation of the egg protein. It will, at least, be an interesting point to investigate.

### Eggs Cooked in the Shell

**Effect of coagulation at low and high temperatures.** Eggs cooked in water held at 70°C. are not firm like those that are cooked in boiling water. The white cooked at 70°C. is very soft and jelly-like in consistency. The yolk held at this temperature for an hour or longer has the appearance of an uncooked yolk, but is more viscous, more waxy, thicker, and does not flow like the uncooked yolk. The color also remains more like that of the uncooked yolk, a deeper orange, instead of the yellow which is developed in eggs cooked at higher temperatures. The white of an egg cooked at least 12 minutes in boiling water is rather firm and may be tough. Eggs cooked at temperatures between 70° and 100°C. have textures intermediate between the ones described above, i.e., they are firmer than the former and usually more tender than the latter.

By cooking for a short time at a higher temperature the outer edge of the white may be firm to a depth depending on time of cooking, a portion near the yolk may be unchanged, and the yolk may be unchanged or the outer portion may be slightly cooked.

The softer coagulum at the lower cooking temperature has been explained as due to the effect of low temperature. Robertson suggests that it may be due to only partial coagulation of the protein at the low temperature.

The white of some eggs is often more tender than that of other eggs cooked in the same lot. Perhaps this may be explained by the reaction, those which are more alkaline coagulating less readily. There is also the possibility that the white of eggs cooked an extremely long time may become more tender.

Barmore mixed egg white thoroughly and placed it in a cement briquette mold. The mold was immersed in water of the desired temperature and left 40 minutes. The tensile strength and the depth a steel ball and rod would penetrate were determined. Below 77.5°C. the samples were too tender to handle. The three tests all indicated a decided increase in tenderness as the temperature of coagulation was reduced with the exception of the steel ball at 93° and 101°C. Here the data indicated that the change may have decreased instead of increasing the toughness. The other tests gave opposite results at these temperatures.

**Rate of heat penetration.** The higher the temperature of the cooking water, the more rapid is the rate of heat penetration. As the temperature of the egg and water become more nearly equal the rate of heat transference is very much slower, but the temperature at the center of the yolk even after cooking in boiling water for 4 hours or longer is never quite as high as that of the water, but is a fraction of a degree lower.

**Time required for cooking eggs in water.** Since coagulation takes place at a definite rate, which increases with a rise in temperature, both the length of time the egg is left in the water and the temperature of the water affect the coagulation rate, and thus the time necessary for cooking. At a temperature just a little above the temperature at which coagulation of the white occurs, 60° to 65°C., a very long time is required to coagulate the mass of the egg white. If the cooking temperature is 70° or a little higher, more than an hour is required to coagulate the white and yolk. At a cooking temperature of 85° to 90°C. from 25 to 35 minutes are necessary to have the yolk the same consistency throughout. A shorter time leaves a portion of the egg yolk an orange color, instead of the uniform, powdery yellow. At the temperature of boiling water about 12 minutes are required to complete the cooking of the yolk uniformly. With increase in height above sea level these times are lengthened.

The exact time of cooking at any given temperature depends upon the temperature of the egg when placed in the water, the quantity of water in relation to the size of the egg, and the rate of heating the water.

### Poached Eggs

Fresh eggs are usually considered better for poaching than eggs in which the physical quality has deteriorated, i.e., eggs with watery whites. Class results substantiate this popular opinion, for eggs with thick viscous whites can be poached satisfactorily with far less care than those with thin whites. In poaching eggs it is desirable to have the temperature of the water near the boiling point when the egg is added. Thus the outer portion of the egg is coagulated in a short period of time. If desired, the cooking can be completed at a lower temperature.

Since both the white and yolk tend to flatten on standing after being broken out of the shell, poached eggs of better appearance are usually obtained if the egg is broken just before it is added to the poaching water. St. John and Flor have reported that the thin portion of the white coagulates as satisfactorily as the thick portion if  $\frac{3}{4}$  teaspoon of salt to a pint of boiling water is used. The salt aids in coagulation. Eggs with about the same proportion of thick and thin parts of the white are firmer when poached in salted than in unsalted water. But for what food teachers call standard products, eggs poached in unsalted water often have a better appearance than those poached in salted water. The ones cooked in salted water are usually not so shiny. Occasionally the reverse is true. The added salt aids

in coagulation, so that the thin portion of the white is less readily detached from the thicker portion. But the appearance of the thin portion after cooking in the salted water is often more puckered, wrinkled, and ruffled, or is in voluminous folds around the thicker coagulated part. This detracts from the appearance. Either a very hard water or a softened water is used for poaching eggs in class work. It is possible that the natural salt content of the water may effect coagulation, so that thin watery whites cooked in Ames's water do not give as good appearing products as those obtained by St. John and Flor.

### The Formation of Ferrous Sulfide in Cooked Eggs

When an egg has been cooked in hot water for 15 minutes or longer a dark greenish color may be formed on the surface of the egg yolk. If the egg is immersed in cold water immediately after cooking, the green color is not produced or is less apparent than when the egg is left in the hot water to cool slowly.

The yolk contains most of the iron of the egg, about 85 times as much as the white. According to Sherman, the sulfur content of the white is slightly higher than that of the yolk, the white containing 0.214 per cent and the yolk 0.208 per cent. The sulfur of the white is more labile and more easily split off by heat than the sulfur of the yolk. Marlow and King say that the sulfur in egg whites and yolk is organically bound and that nearly all of it can be accounted for by the cystine and methionine sulfur.

Tinkler and Soar have shown that the green color is due to the formation of ferrous sulfide at the surface of the yolk. The white with prolonged heating at high temperatures evolves considerable quantities of hydrogen sulfide. The hydrogen sulfide combines with the iron of the yolk to form ferrous sulfide which produces the green color. The amount of hydrogen sulfide evolved depends on (1) the time of heating, (2) the temperature reached, and (3) the reaction of the egg. In a short cooking period little hydrogen sulfide is evolved. Likewise at a lower temperature a smaller amount of hydrogen sulfide is formed. Tinkler and Soar have also shown that the formation of ferrous sulfide takes place very, very slowly until the yolk reaches a temperature of 70°C. It is very seldom formed in eggs cooked for 1 to 1¼ hours at 70°C., or in eggs cooked 30 to 35 minutes at 85°C. Thus both the temperature attained by all or a portion of the egg white as well as the time held at this temperature influence the amount of hydrogen sulfide formed. In addition, as the reaction becomes more alkaline, the sulfur is split off more readily. Therefore, the extent of deterioration of the egg also affects the amount of hydrogen sulfide formed. This explains why some eggs have more ferrous sulfide formed than other eggs when cooked at the same time and cooled in the same manner. Tinkler and Soar have reported that the uncooked yolk is acid in reaction but upon being heated above 70° becomes alkaline.

**Effect of rapid cooling upon formation of ferrous sulfide in cooked eggs.** Hydrogen sulfide is a gas. When the egg is placed in cold water immediately after cooking the lowering of the temperature at the surface of the egg lowers the pressure there. One of the things learned in connection with the gas laws is that the pressure increases with increasing temperature. Since the white near the shell reaches a certain temperature more rapidly than the white near the yolk, more hydrogen sulfide is split off near the shell. But, since the temperature near the yolk is lower, hence has less pressure than near the shell, the hydrogen sulfide diffuses through the white towards the yolk. However, if the egg is placed immediately in cold water after cooking, the hydrogen sulfide diffuses to the surface of the egg, owing to the reduced pressure, but if left in hot water, or to cool in the air, the gas does not diffuse so quickly to the surface and ferrous sulfide is formed at the junction of the egg white and yolk. Tinkler and Soar have found that eggs cooked 15 minutes in boiling water and cooled slowly have some green color at the surface of the yolk; if cooled quickly, none or very little green color develops. Cooking in boiling water for 30 minutes gives a great deal of green color, no matter how the eggs are cooled. Since the yolk contains iron and a fairly large quantity of sulfur, they wondered why the entire yolk did not turn green when cooked as long as 7 hours. They found the sulfur compounds in the yolk were more stable and less easily broken down to form hydrogen sulfide. Thus even with long cooking the color of the interior of the yolk is not changed.

### Custards

In custards, eggs are combined with milk and sugar. The chief protein of cow's milk is casein, which is not coagulable by heat. Milk contains some albumin and a small proportion of globulin, which are coagulable by heat. Zoller states that the protein coagulable by heat is about 0.75 per cent of cow's milk. In the mixed milk and egg, the egg furnishes the larger percentage of the heat-coagulable protein. As the egg, milk, and sugar mixture is heated, coagulation occurs, and the thickened mixture is known as custard. If the temperature of the custard is carried a little higher than the coagulation point, a point is reached at which the custard begins to show syneresis, or the liquid separates from the curd. This is called the curdling point.

**Baked and soft custards.** Custards may be cooked in two ways. They may be cooked without stirring. This type is usually baked in the oven and is called baked custard. The other type of custard is stirred continually while it is cooked and is called soft custard. If the proportion of ingredients in the custard are the same the one cooked without stirring is firmer in texture and appears to be in one piece or clot. The soft custard has a softer texture and is not in one piece but is a viscous fluid.

The stirred custard also tends to curdle more readily than the baked

custard. In part, this is undoubtedly because of the effect of mechanical agitation and is similar to the separation of fibrin of blood when beaten.

Milk for custards is often heated before mixing with the egg and sugar. Forewarming of the milk may tend to prevent curdling of the milk, but the greatest advantage is probably in shortening the cooking period.

**Coagulation temperature of custards.** The temperature at which a custard begins to coagulate or thicken is higher than the temperature at which the egg alone coagulates. The exact point at which coagulation starts is more difficult to ascertain than in the egg white, since the coagulation must be determined from the thickening of the custard. But not much occurs below 80°C. at ordinary rates of heating nor below 78°C. at slower rates of heating. As the soft custard coagulates, a thick layer will cling to a spoon that is dipped into the custard. In cookery this is known as "coating a spoon" and is one method of estimating when the custard is sufficiently cooked. The temperature at which coagulation starts varies with the varying proportion of ingredients of the custard and the rate of cooking. In class results, the coagulation of a custard made of 1 cup of milk, 2 tablespoons of sugar, and 1 egg has never been perceptible below 78°C. and not at this temperature except when the rate of cooking is very slow. Occasionally a custard is heated slowly enough so that the best serving consistency occurs at 80°, provided the eggs are fresh so that the reaction has not become quite alkaline.

It is possible to heat a cup of custard mixture in a double boiler from room temperature to the curdling point in less than 3 minutes. With this rapid rate of heating the custard is too thin to serve at 85° or even at 87° to 89°, and generally curdles about 89°, often after the temperature has remained stationary at 89° for a time. It may reach 91° or 92° and then drop back to about 89°, the curdling occurring before a serving consistency is attained.

When the custard is cooked more slowly, and particularly if the heating is slow after 75°C. is reached, thickening is quite perceptible at 80°, it has a consistency for serving from 80° to 84°; that cooked more slowly being thicker at the lower temperature. A slower rate of cooking is preferable to the rapid one. With the slower rate of cooking the thickening is evident for considerable time before the curdling point is reached. With the rapid cooking, the custard requires very close watching and rapid work to remove it from the heat before the curdling temperature is reached. Curdling may occur at 84° if the temperature is raised very slowly, but in ordinary cooking it is more likely to occur between 85° and 87°C.

Coagulation and particularly curdling in custards is accompanied by absorption of heat. In the custards heated slowly the temperature is usually stationary for a considerable period before curdling occurs. In the rapidly heated custards the temperature often reaches 90° to 92° and then drops as curdling occurs.

The temperatures given in the following discussion are for custards

requiring 12 to 20 minutes from the time cooking is started to reach the curdling point.

**Concentration of egg and coagulation.** If the proportion of egg in the custard is increased, thus increasing the concentration of the protein, coagulation starts at a slightly lower temperature, a firmer custard being obtained at a definite temperature as the proportion of egg is increased.

**Sugar.** If the proportion of sugar to 1 egg and a cup of milk is increased, the coagulation temperature is elevated and coagulation begins above 80°C. The elevation of coagulation temperature is proportional to the amount of sugar added. If the custard is saturated with sugar, coagulation does not occur at boiling temperature.

**Yolks.** If two yolks are substituted for 1 whole egg the coagulation temperature is higher than for the whole egg.

**Whites.** If two whites are substituted for the one whole egg the coagulation temperature is lower than for a custard made of the whole egg. With both the yolks and whites the coagulation temperature varies with the proportion of sugar used.

**The optimum temperature for cooking custards.** Williams has reported that the curdling point for a custard made of 1 egg, 1 cup of milk, and 1 tablespoon of sugar is 83.5°C. When the proportion of ingredients is varied the curdling point varies. If the proportion of egg is increased the curdling point is lowered; increasing the sugar elevates the curdling point.

The temperatures given previously and those reported by Williams are for soft custards. Baked custards may be cooked several degrees higher than soft custards without curdling. This lower curdling temperature for soft custards is probably due to the stirring, which increases the tendency for separation of the custards into curds. Hence, it is important in making soft custards to prevent heating after a certain temperature has been reached. This can be accomplished by putting the cooking pan in cold water or by pouring the custard into another utensil.

Between the temperature at which coagulation starts and the curdling point is a temperature at which the custard has the best texture and flavor for serving.

Williams has reported that the optimum temperature for custards made of 1 egg, 1 cup of milk, and 1 tablespoon of sugar is 82.5°C. When 2 yolks are substituted for the whole egg the optimum temperature is 83.5°, and when 2 whites are substituted for the whole egg the optimum temperature is 82°.

**Custard pie.** In cooking custard pie one of the major difficulties is to prevent soaking of the crust. Increasing the proportion of egg helps, as the custard then coagulates at a lower temperature. Thus 1½ eggs to a cup of milk is better than 1 egg. Prewarming the milk before adding it to the other ingredients shortens the time before coagulation takes place.

One way to prevent soaking of the crust is to cook the pastry and the

filling separately. Bake the pastry on the bottom side of a pie pan with sloping sides. Bake the custard in a pie pan of the same size as the one used for the crust, setting the pan in hot water and using as low an oven temperature as desired. After baking the custard, cool it until the pan feels warm but not hot to the hand. At this temperature it has set sufficiently to hold together, yet will not break so easily as when cold. Run a knife or spatula around the edge of the custard and, tilting it at about a 45-degree angle, shake and slide it out of the pan into the crust.

### Whipping Eggs and Egg Whites

When an egg is whipped with an egg beater, or similar utensil, its volume increases, owing to incorporation of air. The egg white because of its low surface tension and the stability of its surface films readily forms a foam.

The essentials for a stable foam have been discussed in Chapter I. They are a low surface tension, a low vapor pressure, and a tendency for the substance in the surface to solidify, hence giving rigidity and permanence.

**Stages of stiffness in beating egg whites.** With slight whipping the incorporated air bubbles are large, the egg white appears foamy yet transparent, is very runny, and will flow readily. With longer beating the air cells in the egg white become smaller, the appearance of the egg white is less transparent and more white. It still flows if the bowl is partially inverted. The egg white becomes stiffer with continued beating. The stiffness is due, in part at least, to the finer division of the air bubbles, and thus the amount of egg white utilized in forming films is greater. Many small air bubbles with their fine cell walls may be stronger and more rigid than a few large cells. As beating is continued the egg becomes very white, begins to lose a little of the moist, shiny appearance, and is stiff and rigid. If the bowl is inverted, the egg white does not flow but remains in the bowl and the end of peaks stand up straight. If the egg is left to stand, the watery fluid collects at the bottom of the bowl more slowly. With longer beating the egg white appears dry, loses its shiny appearance, and small white patches that look like small curds may appear. This is the stage called dry in cook books. At this point the white is very rigid and rather brittle so that with a whisk beater it is easily thrown out of the bowl in which it is whipped.

*Methods of testing stiffness.* There are several ways in which the stiffness may be tested. For household use the tests are (1) appearance, (2) the height of peaks and the extent to which the point bends over when the egg beater or some utensil is lifted out of the beaten white, and (3) the rate of flow when the bowl or plate in which the white is beaten is partially inverted. A skillful operator working constantly with egg white soon learns to judge the degree of stiffness by these common household methods, and the degree of proficiency that can be attained is surprising. But for



experimental purposes the same degree of stiffness probably could not be duplicated in another laboratory from the description. In the home the height of the peaks, and particularly the extent the point falls over, is the best criterion for judging stiffness. The rate of flow is not quite so good unless the same quantity of egg white is always used, for a large quantity must be beaten stiffer to flow at the same rate as a smaller quantity.

For laboratory purposes, (1) specific gravity, (2) foaming power, and (3) the amount of drainage during a definite time are used to test the stiffness and stability of the foam. Specific gravity is determined by dividing the weight of a given volume of egg white by the weight of the same volume of water at the same temperature. Barmore reports that foams with specific gravity of 0.15 to 0.16 yield good angel cakes. Bailey calculated foaming power by means of the formula:

$$F = \left( \frac{1.04V}{W} 100 \right) - 100$$

where  $F$  = foaming power of egg white,  $V$  = volume of dish in cubic centimeters, and  $W$  = weight of foam in grams. The specific gravity of the original egg white was taken as 1.04.

The stability of a foam may be tested by putting a given weight of foam in a funnel of known capacity and bore. The funnel is covered to prevent evaporation. If the funnel is placed in a graduated cylinder, the drainage may be read in cubic centimeters or the weight taken at the end of a definite time, usually 30, 40, or 60 minutes. When the egg white is not beaten sufficiently both the unbeaten egg white and the foam drain from the funnel. After a certain stage of beating is reached little drainage occurs. With still longer beating Barmore states the drainage increases. Work of students in the author's laboratory, Keltner, Hoskey, and Loaft, though not extensive enough to be conclusive, indicates that better angel cakes are obtained if a certain percentage of drainage occurs, the exact amount varying with different types of egg beaters.

**Salt and the whipping of egg whites.** It is traditional that a small amount of salt added to egg white is an aid in increasing foaming and stiffness. This could easily be tested but so far as the writer knows its effect on stability has not been reported. It has been found that electrolytes are necessary for heat coagulation of proteins. They may also aid coagulation by mechanical means or surface denaturation. The more likely explanation is the one previously given for protein solutions and electrolytes. The protein lowers the surface tension but the addition of salt lowers it still more, thus causing a greater concentration of the protein at the air/liquid interface, hence a slight stiffening. The addition of salt may result in a slight salting-out effect and a stiffening of the membrane around the air bubbles. This would have the same result as in emulsions. For, by the last mechanism a certain amount of salt would bring about maximum stabilization

of the emulsion or foam, but too large a quantity would have the tendency to break the emulsion or the foam.

**Acids and stability of egg white foams.** Barmore in his last publication states that when acid substances were added in sufficient quantity to adjust the egg white to  $pH$  8 the stability of the foam was practically the same for acetic and citric acids and for cream of tartar. But at  $pH$  6 the cream of tartar produced the most stable foam. The acid substances increased the stability of the foams.

The addition of the acid delays the formation of the foam, i.e., if beaten for a definite time the foams containing acid are not as stiff as those containing no acid. This is particularly true for both acetic and citric acids.

**The addition of sugar to egg white foams.** Adding sugar to the egg white increases the stability of the foam, for less drainage occurs when the egg is beaten to a definite stiffness. However, a longer time is required to beat the egg white, if the sugar is added before the beating is completed, but this also makes it difficult to overbeat the foam. Because sugar retards denaturation of the egg white foam, it is a good practice to add sugar to the egg white as soon as beating is started when whites for angel cakes are whipped at high speed on a machine. It would also appear that less leakage might occur in meringues for pies if the sugar is added by beating it into the white as the white is beaten.

**Egg white is partially coagulated during beating.** In whipping the egg white is finely divided, so that from the physical subdivision it is far more rigid and stiff. But the beating has brought about other changes in the egg white. In speaking of the methods by which coagulation may be brought about, Ostwald states, "When egg white is beaten to a foam, a part is regularly coagulated in the walls enclosing the air bubbles. A decrease in degree of dispersion to the point of inducing coagulation can also be brought about through centrifuging, etc. These belong to the mechanical methods of producing coagulation."

**Effect of temperature upon whipping of eggs.** Since a low surface tension is one essential for the formation of a foam, it follows that a lowering of the surface tension will aid its formation. Eggs that are taken from the refrigerator and beaten while still cold do not whip up as readily or quickly as those at room temperature. Surface tension is lowered with increased temperature so that it is probably one factor in bringing about this result.

The Bakery Research Department of Procter & Gamble Company have reported that "regardless of the length of time of beating, a given sugar and egg mixture, when whipped at  $60^{\circ}F.$ , will never become as light as will a mixture of the same proportions beaten at the same speed and at a temperature of  $110^{\circ}F.$ "

St. John and Flor found that a greater volume was obtained at room temperature, about  $21^{\circ}C.$ , than at refrigerator temperature,  $13^{\circ}C.$  A still better volume was obtained at  $30^{\circ}C.$ , but they report that while drying

the whites to measure the volume the liquid part from those beaten at the highest temperature separated more readily.

**Season and age of eggs and whipping.** The whipping quality of eggs varies, according to the season in which they are produced. Nemetz has reported experiments in which whole eggs that had been broken and frozen in April, July, and September were used. The eggs were used in sponge cake and cream puffs. With all mixing and baking conditions standardized, the April eggs gave a 15 per cent increase and the September ones a 10 per cent increase in volume over the July eggs in sponge cake. Similar results were obtained in cream puffs.

Burke and Niles found that egg whites from eggs produced during the season when eggs are considered less desirable beat to a stiffer foam when beaten the same length of time than the whites from eggs produced early in the spring.

Nemetz states that if fresh or frozen eggs are used in a similar mix under identical conditions, greater volume and greater yield will be obtained from frozen eggs.

Bakers also claim that egg whites do not whip as well if used the next week after being frozen as when they have been frozen at least three months.

Barmore states that the older the eggs, when whites were beaten for equal lengths of time, i.e., 1, 2, and 3 minutes, the less stable the foam. However, when eggs were beaten 4 minutes the stability was practically the same for all ages of egg used, e.g., fresh, 3, 6, and 9 days.

**Egg beaters.** Egg whisks or whips are made with wires of varying thickness. The thick wire does not whip or divide the egg white as easily as the finer wire. The air cells are larger than when a whisk with finer wires is used, though the size of the enclosed air bubbles decreases with longer beating with any type of beater. Whisks with thicker wires may require two to four times as many strokes to beat an egg white to a definite stiffness as one with finer wires. Some egg whisks beat the egg quickly, dividing it into many very fine cells without giving an excess of the curdy-looking precipitate within the whipped white. Some produce a greater curdled appearance than others, even when the egg does not appear to be beaten to the same stage of stiffness. With the type of whisk that produces the very curdled appearance of the egg white, the cell walls of the omelet or soufflé are more likely to collapse during baking, and, by many cell walls running together, a very coarse texture is obtained or the product falls. The above statements regarding whisks also apply to egg beaters of the rotary type. There is some variation in the width and the curvature of the blades of these beaters.

If the quotation concerning emulsifying apparatus, from Clayton, in the chapter on emulsions is changed to read, "It is quite reasonable to believe that for any given egg beater there exists an optimum speed or degree of agitation or beating, and an optimum time of beating, whereby the most

perfect beaten egg white is obtained for a definite use," the statement may apply equally to egg beaters.

Longer experience only emphasizes the importance of the foregoing quotation from the chapter on emulsions. For instance, in the Foods Laboratory a procedure had been worked out whereby excellent angel cake is made by beating the egg white and adding the sugar, using high speed on the Kitchen Aid. The beating must be timed to the second, because with several hundred r. p. m. a few seconds too long makes a tremendous difference.

When Peet and Lowe began work on starting baked products in cold and preheated ovens, it was necessary to mix six times the angel cake recipe at one time. But it was found that the time of beating the egg whites on an institutional, large-sized Hobart mixer had to be increased over the time used with the Kitchen Aid to have the same stage of stiffness.

Bailey obtained larger volume from the thick portion of the white than from the thin part when whipped on a Hobart type mixer, but results were opposite on an electric Dover type.

Barmore states that with hand rotary beaters there was more reduction in viscosity for the corresponding reduction in specific gravity than with the electric beater used in his experiments. It has been the experience in this laboratory that Barmore's hand beaters 1 and 2 are poor types.

Hand-operated rotary beaters may be turned at varying speeds. But fast initial beating of egg white gives a larger volume to the egg white.

The gear ratio for hand-operated rotary beaters is about 1 to 5, i.e., one turn of the handle gives about 5 revolutions of the blades. If the handle is turned 120 r. p. m., the blades would turn about 600 revolutions. The speed of electric mixers, depending on the particular mixer, the speed, and for some mixers the load or stiffness of material used, may range from 300 to 2400 r. p. m.

**Wire whisks or rotary beaters.** One question that is constantly asked regarding the whipping of egg whites is whether it is better to beat them with a whisk or rotary beater. A great deal depends upon whether the egg whisk or rotary beater is a good type of its class or a poor one. If the eggs are whipped so that the cells in the cake are the same size there seems to be little difference in the finished product. Whisks sometimes give a larger volume than rotary beaters in angel cake.

**Combination of egg albumin with metals.** Sometimes in beating egg white a pink color develops. This is due to a combination of the egg albumin with a metal like copper or iron. The color develops more frequently when the acid cream of tartar is added, as in beating egg whites for angel cakes, but it may develop without its addition. Some egg beaters have blades of copper that are plated. After the plating is worn off the copper is exposed. The pink color has often been noticed when folding sugar into the beaten egg whites with a spatula. Probably some other factor than the presence of the metal alone is necessary to bring about the color change,

for the color does not always develop when the egg whites are beaten with such beaters or when spatulas are used.

### Meringues

Meringues vary in the quantity of sugar added and in their use. Only soft and hard ones will be considered here.

**Soft meringues.** One general use for soft meringues is for pies. The factors determining to the greatest extent whether a desirable meringue is obtained are: the extent of beating the egg white, the adding of the sugar, the baking temperature and time, and an optimum proportion of sugar to egg white. Good meringues have been obtained by many methods, but the following method is successful for a majority of the experimenters. Beat the sugar into the egg white—preferably during the latter half of beating, but it may be added at the start—with a rotary egg beater, until the whites are stiff and shiny. The peaks are fairly stiff and the tip end only slightly rounded.

The sugar stabilizes the egg-white foam. Greater stabilization seems to be attained when the opportunity for solution is greater, i.e., in beating instead of folding. Since adding the sugar during beating increases the time required for obtaining a definite stiffness, there is less danger of over-beating. In some class problems less leakage of the meringue has occurred when the sugar was added in the above manner.

Since leaky meringues give undesirable moistness and slipperiness to the top of the pastry filling and make cutting difficult, how to prevent this leakage is a question frequently asked. The Institute of American Poultry Industries states that there seems to be no advantage in adding a small amount of water to the meringue. Although water increases the volume, there seems to be a tendency for the meringue to leak a short time after baking.

Insufficient beating of the egg white, especially if the sugar is folded instead of beaten into the meringue, after the sugar is added is sometimes a factor in causing leakage. Over-beating of the egg white before sugar is added may also increase the tendency to leakage.

Too small an amount of sugar to each egg white tends to give a less fluffy, less tender meringue and one lacking in sweetness. Too much sugar tends to give a gummy crust or one containing sugar crystals, though the amount of sugar that can be used to obtain a desirable meringue depends on the fineness of the sugar and perhaps on its rate of solution. In general, 2 tablespoons of fine or berry sugar per egg white give the best results. With ultra-fine crystals, as many as 3 tablespoons of sugar per egg white can be used; whereas with coarser granulated sugar, hitherto used more than at present, less than 2 tablespoons per egg is desirable. Powdered sugar containing starch is usually not satisfactory in meringues. Honey, sirup, or jelly may be used in meringues, but only 1 tablespoon per egg

white. Red jellies often give a blue rather than a pink tinge to the meringue.

Baking necessarily requires a longer time at a lower temperature. All of the following temperatures have been used successfully, though a majority of the students working on meringues as special problems preferred 425° and 400°F.: 425°F. for 6 minutes, 400°F. for 8 minutes, 350°F. for 12 to 18 minutes, and 325°F. for 18 to 25 minutes. With temperatures below 325°F., the time is long, the meringue often shrinks after being removed from the oven, and dries too much.

**Hard meringues.** Hard meringues contain a larger proportion of sugar than soft meringues. Because of the high sugar content they have a fairly smooth, somewhat crystalline, crisp crust. They are usually puffy in appearance and are used for accompaniment to, as a foundation for, or as a dessert.

The optimum amount of sugar appears to be 4 to 5 tablespoons per egg white, the smaller quantity probably being preferable. Since acid increases the tenderness of egg white, its addition is desirable. About 1 to 2 cc. of vinegar per egg white may be used; but, since cream of tartar produces a more stable foam than acetic acid, the use of cream of tartar may be preferable. About 1½ per cent of cream of tartar, or between ⅛ to ¼ teaspoon of cream of tartar per egg white, is satisfactory.

The sugar is added in the same manner as for soft meringues, but, because of the larger quantity added, better results are usually obtained if it is added gradually.

Bake on heavy paper at as low a temperature as possible, 225° to 275°F., for 40 to 60 minutes, the time depending on the temperature and size of the meringues. If the meringue is eaten shortly after baking, the soft centers, if not entirely dried in baking, are not objectionable. However, they may be removed. If the meringues are to stand over night, the Institute of American Poultry Industries recommends letting them stand in the oven until cool, after the heat is turned off, in order to dry the centers.

### Omelets

There are several types of omelets. They are designated in various ways as plain, French, and foamy omelets. Some have a white sauce or tapioca basis. In others, bread crumbs are used to absorb a part of the moisture. The type of omelet that has the egg yolk folded into the beaten white is sometimes called a foamy omelet. This is the type that requires the most skill in making and is the one mentioned here.

**Method of mixing foamy omelet.** The yolk is beaten until foamy and then folded into the stiffly beaten egg white. The cooked omelet should be light, tender, and foamy, and it should not collapse or fall after cooking, though some shrinkage usually occurs. Whether the product obtained fulfils these conditions depends to a great extent upon the amount of beat-

ing of the egg white, the mixing of the egg white and the yolk, and a proper cooking temperature. The egg whites for omelets need to be whipped nearly or quite stiff enough to stay in an inverted bowl. Unless they are sufficiently stiff there is a tendency for the liquid to drain to the bottom of the bowl or cooking pan. After the yolks are mixed with the whites this tendency is increased. Sometimes the liquid portion does collect in the bottom of the cooking pan and coagulates there while cooking, forming a thick compact layer. This is due to insufficient beating of the whites, or insufficient mixing of the yolk with the white, so that the yolk is not sufficiently blended through the white to be held up by the framework or physical structure of the whipped white, or it may be due to standing too long after mixing before cooking is started. The pan into which the omelet is poured should be hot enough to start coagulation of the egg, but not hot enough to form a hard crust. However, over-mixing and rough handling cause loss of too large a portion of the air incorporated into the egg white. Over-beating of the egg white before the yolk is added results in loss of extensibility, and the volume of the omelet does not increase as much as it should during baking. It is also drier and sometimes powdery. But with omelets it seems better to err a little on the side of over-beating rather than under-beating.

**Formation of ferrous sulfide in omelets.** The green color develops on the bottom of the omelet only when some of the egg has separated and drained to the bottom. It is due to the formation of hydrogen sulfide from the white and its combination with iron of the yolk. It may be prevented by sufficient beating of the egg white, by thoroughly blending the yolk and white, or by starting cooking promptly. The color may develop in omelets cooked on top of the stove, or in those cooked in Pyrex, but occurs more often in baked ones, for the baking requires a longer time.

**Effect of addition of a liquid to a foamy omelet.** A tablespoon of water for each egg is usually added to the white or to the yolk. If to the white of the egg, it may be added before the white is beaten or after it is beaten enough to become frothy but not stiff. The volume of the beaten white with the addition of the liquid is usually greater than an egg white without the added liquid. Sometimes other factors due to size of the egg, its deterioration in quality, or other causes affect its beating qualities and a poor volume is attained. It has already been stated that increasing alkalinity tends to prevent coagulation. Thus very old eggs may not beat as well as fresher ones. The hydration of the white increases the tenderness of the omelet as well as its elasticity. The white being more elastic, a larger volume is obtained during cooking. If too much water is added to the egg a point is reached at which the white becomes too tender and too many cells break when the air expands during cooking. Evidently the addition of water to egg white retards coagulation by beating, for a longer time is required to beat the white to a definite stage than when no

liquid is added. This retardation of coagulation may be due to the lessened concentration of the egg white.

**Kind of liquid in omelets.** The liquid added to foamy omelets may be water, vegetable juice, tomato juice, or a mixture of one-third lemon juice and two-thirds water. If a tablespoon of milk is added to an egg white it will not form a foam. If added to the beaten white the volume is quickly reduced and the foam is destroyed. Dizmang and Sunderlin investigated the effect of milk on the whipping quality of egg white. Their results are given in Table 42, and indicate that the fat of the milk is responsible for breaking the foam. But the size of the fat globules is also important, smaller particles having less effect.

TABLE 42  
THE EFFECT OF MILK ON WHIPPING QUALITY OF EGG WHITES  
(*Dizmang and Sunderlin*)

Substance added to egg white	Largest number of drops added to one egg white, permitting formation of foam stiff enough to stay in an inverted bowl
Cream (20% fat) . . . . .	1-2
Whole milk . . . . .	2-3
Sterilized whole milk . . . . .	8
Reconstituted powdered whole milk . . . . .	50-70
Cream (20% fat) homogenized, 3000 lbs. . . . .	70
Evaporated milk . . . . .	50-350
Separated milk . . . . .	400-446
Whole milk, homogenized, 2500 lbs. . . . .	400-450
Whole milk homogenized at 3000 lbs. . . . .	1000
Reconstituted powdered separated milk . . . . .	1600

The addition of 1 teaspoon of lemon juice and 2 teaspoons of water to an egg white brings the reaction to about  $pH$  4.8, the isoelectric point of the egg albumin. It may be higher or lower, depending on the original  $pH$  and perhaps the size of the egg. The addition of a tablespoon of tomato juice to an egg white does not lower the  $pH$  to 4.8. The addition of tomato juice and the lemon juice results in a more tender omelet, and one of greater volume, if the conditions of mixing have been standardized, if the liquid is added after the egg white is partially beaten, and if beaten to the same degree of stiffness. Tomato juice requires longer for whipping than the water, and the mixture of lemon juice and water requires still longer than the tomato juice. The addition of the acid tomato and of the lemon lessens the alkalinity of the egg white. Bogue has reported that the foaming properties of gelatin are greatest at the isoelectric point. If the foaming properties of egg white are also greater at the isoelectric point, a greater



volume might be expected at  $pH$  4.8. This greater volume is usually obtained, with the addition of tomato or lemon juice, but a longer whipping time is required. Tomato and lemon both contain citric acid. The greater tenderness with the use of tomato juice and lemon juice probably results from a peptizing effect of the citrate ion on the egg protein. If lemon juice is merely added to egg white without whipping it, coagulation of the egg white is produced, but with beating the lemon juice is thoroughly mixed with the egg white. A better volume is usually obtained if the egg white is beaten until frothy before the lemon juice or tomato juice is added.

**Temperature for cooking omelets.** Omelets are usually cooked above heat, but baking them in the oven is an easy method to secure uniform temperatures for class work. A temperature of  $160^{\circ}$  to  $165^{\circ}C.$  is a good one to use. If the temperature is too low the omelet tends to separate while cooking, the liquid portion collecting in the bottom of the cooking utensil and forming a solid mass with the foamy part on top. Too high a temperature for cooking leaves the inside of the omelet too moist unless the outer portion is over-cooked and thus toughened. In cooking over the heat the omelet needs to be covered. The omelet can be placed under the broiler to brown the top quickly.

### Angel Cake

Angel and sponge cakes are included under egg cookery because they logically belong here and not under batters and doughs. The texture of the finished cake depends chiefly upon the manipulation of the egg, and the cooking temperature corresponds to that used for egg cookery.

**Review of literature on angel cake.** Excellent work has been reported from different laboratories on angel and sponge cake and a review of this literature seems rather imperative.

Hunt and St. John separated the thick and the thin portion of egg whites. The average volume of the cakes from the thin portions was greater than for the cakes made from the thick portions. They have also reported that the volumes of angel food cakes made from egg whites beaten at room temperature,  $21^{\circ}C.$ , were larger than cakes made from similar whites beaten at  $5^{\circ}C.$  The grain of the cakes made from whites beaten at room temperature was finer and the cakes more tender than those from whites beaten at  $5^{\circ}C.$

Hedstrom, in studying the effect of the consistency of the egg white on the volume and texture of angel cakes, found the percentage of thin white increased, as did the  $pH$ , with increased age of the eggs. The effect of age of the eggs on the volume of the cakes is shown in Fig. 35. It is obvious that there are some discrepancies in these results. Nevertheless, they are given here, for further work, which is not complete, appears to substantiate these results in that cake volume decreases with increased age of the eggs.

Barmore's results of investigating the influence of chemical and physical factors on egg-white foams are as follows: stability of the foams was determined by beating the egg white with an electric food mixer and photographing the foams 2 and 10 minutes after beating had stopped. The specific gravity of foams was determined. Stability of the foams was further determined by placing the egg-white foam in a funnel and determining the drainage at definite intervals.

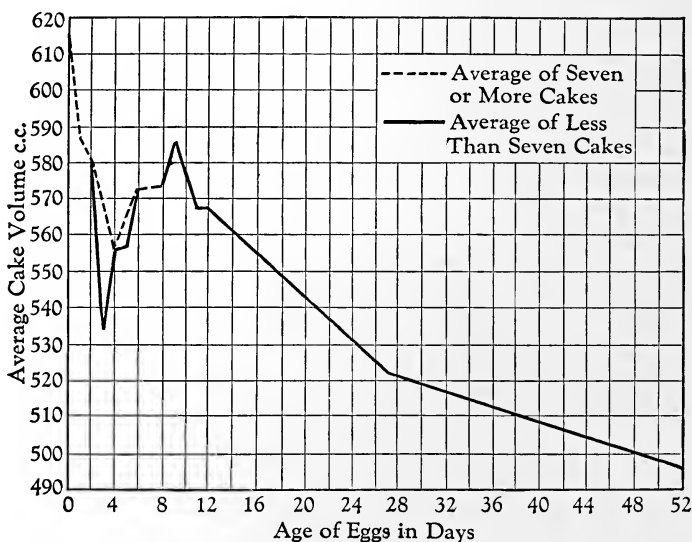


FIG. 35.—Relation of angel cake volume to the age of the eggs. (Hedstrom.)

It was found that the older the eggs, the lighter the specific gravity of the foam after beating for a definite period of time. The addition of potassium acid tartrate, citric, and acetic acid increased the stability of the foams. The longer the foam is beaten, the less stable it becomes so that its stability is inversely proportional to its specific gravity.

Stanley states that the thin white beats up to a larger volume than the thick white. But the volume of the cake made from the thick white is larger than that made from the thin white and cakes made from the thick white have greater elasticity.

Barmore reported from his investigations on baking angel cake at various altitudes that increasing the egg or flour, or both, in an angel cake increases its tensile strength. Conversely, increasing the sugar decreases the tensile strength or increases the tenderness. Barmore says that his formula,

$$F - .43S - .41A + 24.5 = 0,$$

gives all the possible, successful recipes for this type of flour mixture for

any habitable altitude.  $F$  represents flour in grams;  $S$ , sugar in grams; and  $A$ , altitude in thousands of feet. The egg white was kept constant at 210 grams and the flour should be not less than 40 nor exceed 80 grams for this proportion of egg white. For 1 gram of egg white this allows 0.19 and 0.39 gram of flour respectively.

King, Morris, and Whiteman investigated "some methods and apparatus used in measuring the quality of eggs for cake making." The physical and chemical measurements made on the eggs were carbon dioxide content of the white and the yolk,  $pH$  and total solids on white, yolk, and magma, and viscosity of the magma. They say more work should be done on the relation between  $CO_2$  content and  $pH$  before it can be said that the increase in  $pH$  of the white is due entirely to a loss of  $CO_2$ . The lifting power of the eggs was based on measurements of specific gravity and  $pH$  of the cake batter and on volume, tensile strength, and compressibility of the sponge cakes. They report that the chemical and physical properties of the eggs so far measured have shown no definite relation to the various cake measurements.

Barmore determined "the influence of various factors, including altitude, in the production of angel food cake." He concludes that the whites of fresh eggs should be beaten with 1 to 2 per cent of cream of tartar to a specific gravity of not less than 0.15 and not more than 0.17. Part or all of the sugar should be added before the addition of any of the flour, for the addition of the sugar strengthened the egg-white foam; whereas the volume of the batter decreased considerably more when the flour was added with the sugar than when it was added by itself, after the sugar had been beaten into the egg foam. A summary of Barmore's extensive investigations follows:

At  $pH$  8 the stability of the egg-white foam was practically the same for acetic and citric acids and cream of tartar. But at  $pH$  6 the cream of tartar produced the most stable foam.

Cakes baked at  $178^\circ C.$  for 30 minutes had larger volume, were more moist and more tender, probably because of larger volume, than cakes baked at  $163^\circ$ ,  $152^\circ$ , or at  $138^\circ C.$  The last required 100 minutes for baking. Baking at the highest oven temperature produced an interior temperature about  $2^\circ C.$  higher than in cakes baked at the lowest temperature, though the difference in oven temperature was  $40^\circ C.$

Eggs several days old made poorer cakes than fresh eggs. The reason suggested for this is hydrolysis of the egg proteins rather than increased proportion of thin whites.

No moisture was lost by evaporation by any portion of the cake farther from the outer edge than 1 cm. "Cake baked at the low temperature appeared to contain less moisture, because the center of the cake felt and tasted much drier than that baked at a higher temperature for a shorter

time. The data show that one was just as moist in the center as the other. The difference in feel was apparently occasioned by the difference in the condition or location of the moisture. Perhaps in the low-temperature cake the moisture had been more completely removed from the sugar solution and absorbed by the starch or protein, because of the greater length of time the cake was maintained at a high temperature."

In studying the influence of acid and sugar on the initial coagulation temperature of egg white (different proportions of sugar and acid added to egg white, placed in test tubes for heating) it was found that sugar increased but acid lowered the initial coagulation temperature of the egg white. Adding both sugar and acid in proportions used in cakes raised the temperature at which coagulation of the egg white started. However, in spite of the lowered initial coagulation of the egg white by the addition of acid, its addition increased the tenderness of the egg white. In the test with egg white coagulated at various temperatures it was found that the lower the temperature at which coagulation occurred the more tender the egg white.

"With increases in altitude it has been shown that the amount of expansion during baking increases; the cake becomes more tender; the final cake volume changes and is related to tenderness; the amount and rate of evaporation increases; the maximum internal cake temperature decreases; the volume of the vapor escaping increases; and the color of the crust becomes lighter."

Peet and Lowe baked angel food cakes in six ranges, three electric, two gas, and one kerosene. Cakes were baked in ranges cold at the start and in preheated ovens.

The results of analysis of scores showed that the judges did not differentiate among cakes baked in the different ranges for total score, texture, and eating quality. However, for these same points the judges thought the cakes baked in the preheated ovens were superior to those baked in the same ranges from a cold start. Furthermore, these differences, as shown by analysis of variance, were highly significant.

The scores for moistness were higher for cakes baked in preheated ovens but these results were not analyzed statistically.

Tenderness was tested in two ways, one subjective and one objective test. The analysis of scores for tenderness indicated that the cakes baked in some ranges were more tender than cakes baked in other ranges. The statistical analysis showed that these results were significant. The judges, as indicated by scores, considered there were still greater differences in tenderness of cakes baked from a cold and from preheated starts, than for cakes baked in different ranges. These results were highly significant, the cakes started in preheated ovens being tenderer than those baked from a cold start. The analysis of data obtained by tensile strength measurements also indicated significant differences in tenderness of cakes baked in dif-

ferent ranges and highly significant differences between cakes started in cold and preheated ovens, those started in preheated ovens being more tender. The correlation coefficient between the two methods of testing tenderness was  $-0.4014$ , which was significant. This indicates that in general there was agreement in the two methods of testing tenderness.

The volumes of cakes varied in the different ranges, the results being significant, i.e., cakes of larger volume were obtained in some ranges than in others. The volumes of cakes baked in preheated ovens were greatest, and the differences were significant.

Burke and Niles made angel food cake on the same day of the week throughout the year, from eggs of the same age, produced by the same flock on controlled feed for the duration of the experiment. The quality of the cakes, at first fairly good, decreased to a low in November. After a slight rise in December there was again a decline in January. A noticeable increase in quality occurred in February and March. They state that the egg-white foams during the "low" and "high" periods seemed to differ in the time required to beat to the stiff stage. During the "low" period the whites seemed much stiffer and less tender than those in the "high" when beaten for the same length of time. They state that perhaps, if the amount of beating were standardized according to some factor other than time for beating, excellent cakes could be made during the "low" months as well as the "high."

One cake each week was baked at  $350^{\circ}\text{F}$ . for 45 minutes, and three cakes at  $325^{\circ}\text{F}$ . for 1 hour. Consistently throughout the year the moisture loss was less and the volume usually noticeably larger for the cakes baked at the higher temperature. The average moisture loss for the year was 11.2 and 9.6 per cent, and the average volume 7.79 and 7.85 cm., respectively, for cakes baked at  $325^{\circ}$  and  $350^{\circ}\text{F}$ .

King, Whiteman, and Rose investigated the effect on the cake-making quality of some egg-production factors. The physical and chemical measurements of eggs, cake batter, and sponge cake were the same as those reported for King, Morris, and Whiteman, with the exception that elasticity or recovery of the cake crumb is added in the present study. They found that five different diets of the hens did not affect the properties of the eggs or the quality of the cake made from them. Most of the eggs used were obtained over a period of seven months (December-June), beginning about three months after the hens started laying, and were collected and dipped in mineral oil saturated with carbon dioxide. They found no progressive change in the properties of the eggs or the quality of the cakes over the period in the laying cycle of the hen or the seasons of the year studied. As in the earlier study they found no apparent relationship between the physical and chemical properties of the eggs studied and the quality values of the cakes.

"There was a relationship between the specific volume, elasticity, and compressibility of the sponge cakes, and between the pH and specific gravity of the batter from which the cakes were baked.

"Findings of an earlier study which indicated that there is no relationship between pH and CO<sub>2</sub> content of egg white were confirmed."

**Formulas for angel cake.** Because formulas mean more to many cooks than equations, the data in Table 43 have been compiled.

TABLE 43  
FORMULAS FOR ANGEL FOOD CAKE

Formula	Egg white		Sugar		Flour		Cream of tartar	Amount of salt
	Meas. Cups	Wt. Gm.	Meas. Cups	Wt. Gm.	Meas. Cups	Wt. Gm.		
I . . . .	1	244	1¼	250	1	100	1 t.	¼ t.
II . . . .	1	244	1½	300	1	100	1 t.	¼ t.
III . . . .	1½	366	1½	300	1	100	1½ t.	½ t.
IV . . . .	1½	366	1¼	250	4/5	80	1 t.	¼ t.
V . . . .	1¾	427	1½	300	1	100	2 t.	½ t.
VI . . . .	1	244	1	200	1	100	1 t.	¼ t.
VII . . . .	1	246	2⅙	266	⅙	90	1 t.	¼ t.
VIII . . . .	1	246	1⅔	169	½	48	1 t.	¼ t.
IX . . . .	1	246	1½	222	⅙	90	1 t.	¼ t.

Only the first five formulas have been made in class work at 900-foot elevation. Excellent cakes may be made from these five formulas, though II is less likely to be successful. The last three formulas are from Barmore's tables; VII and VIII are for 1000-foot elevation with the largest and smallest amounts of flour advocated, respectively. Further analysis of these formulas is found in Table 44.

Since sugar tends to prevent coagulation of the egg white, there is an amount of sugar which, if exceeded, will prevent coagulation to such an extent that the cake is so tender it will fall. It is desirable to use an amount that will just prevent the cake from falling. However, this particular amount of sugar will depend somewhat upon the amount of flour. The flour increases the toughness of the cake. Hence there is a ratio of sugar to flour, so that, within certain limits, as the sugar is decreased the flour must also be decreased. For the formulas given the ratio of sugar to flour is 3 to 1 in four of the recipes and 2.5 to 1 in the standard recipe.

The illustrations are all for angel cakes which were baked from the same quantity of material, one-sixth of the recipe. The pans were small ones so that the photographs are nearly actual size. Thus the illustrations

TABLE 44

AMOUNT OF SUGAR AND FLOUR PER GRAM OF EGG WHITE AND RATIO OF SUGAR TO FLOUR (ANGEL CAKE)

Formula and source	Egg white Gm.	Sugar Gm.	Flour Gm.	Ratio of sugar to flour
I Standard.....	1	1.02	0.41	2.5
II .....	1	1.23	0.41	3.0
III Thirteen egg.....	1	0.82	0.27	3.0
IV Cedarquist.....	1	0.68	0.23	3.0
V Prize (I. A. P. I.)*.....	1	0.70	0.22	3.1
VI Hunt and St. John.....	1	0.82	0.41	2.0
VII Barmore (1000 ft.).....	1	1.08	0.36	2.9
VIII Barmore (1000 ft.).....	1	0.69	0.20	3.5
IX Barmore (5000 ft.).....	1	0.90	0.36	2.5

\* Institute American Poultry Industries.

show the comparative volume of the cakes, and the cells are nearly actual size.

**Beating the egg whites for angel cake.** The beating of the egg whites is one of the important steps in making angel cake. For the best results, the whites should not be beaten quite as stiff as for foamy omelets and soufflés. The probable reasons for this are the stabilizing influence of sugar on the egg-white foam and the absorption of moisture by the flour.

If the egg whites are not beaten a cake of small volume and very soggy texture is obtained. When the egg white is beaten the volume of the cake increases with the degree of stiffness of the whites, until a stage is reached at which the greatest volume is attained. Continued beating of the egg white after that to produce the maximum volume gradually reduces the volume of the cake, the reduction in volume being in proportion to the amount of over-beating of the egg white. The influence of the extent of beating the egg white on the volume of the cake is shown in Figs. 40 and 41, Experiments 69,C and E.

*Result of insufficient beating of the egg white.* The egg whites for the cakes in Fig. 40, Experiment 69C, were all beaten together. One-third of the total weight of the egg white was removed for cake 1 after the egg whites were beaten until they flowed when the bowl was partially inverted. The volume is less than when the whites were beaten to flow very slowly for cake 2. When the egg whites are whipped too little, not as much air is enclosed and the film of egg white surrounding the air bubbles is not as thin as it is with longer beating. If the egg white is beaten still less than for the illustration, the volume is still smaller. With very little beating, the egg white is quite runny and the cake is tough and compact.

Occasionally a gummy layer is found in the bottom of the baked cake. It is often difficult to give an explanation for this, but it may sometimes be due to insufficient whipping of the egg whites.

*Maximum beating of the egg white.* The whites for the cakes in Fig. 37, for cake 2, Fig. 40, and for cake 1, Fig. 41, were beaten until the tip end of peaks was slightly rounded and fallen. The cakes are more tender and have a larger volume than when the whites are not beaten sufficiently. The appearance and stiffness of the egg whites for a maximum volume in the cake vary slightly with the type and kind of egg beater used.

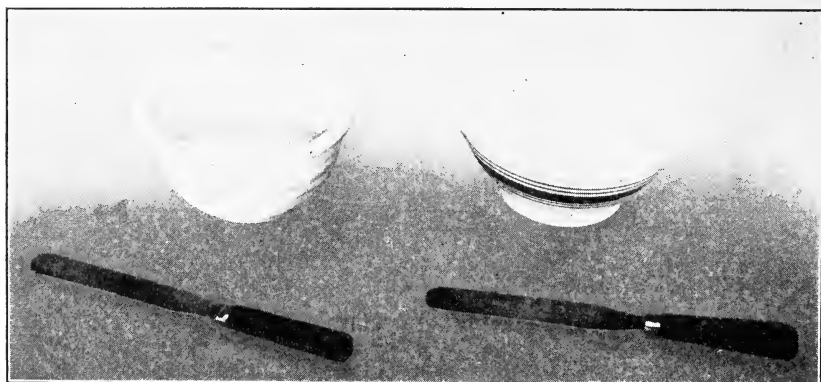


FIG. 36.—The bowl on the right with the sloping sides is a good type for mixing and folding.

The bowl on the left has sides that are too straight for efficient folding.

The spatula on the right has a round handle that fits the hand.

The spatula on the left has 4 edges that tend to blister the hand with long folding.

With a maximum volume of the cake the cell walls are thinner, which tends to produce a more tender cake.

*Effect of over-beating the egg white.* For cake 3, Fig. 40, the egg whites were beaten until quite stiff. The volume is decidedly less than for cake 2. Longer beating results in a still smaller volume, see cake 3, Fig. 41. The smaller volume with over-beating is due to excess coagulation of the egg white by beating. This lessens the elasticity of the egg white; hence, when the air bubbles enclosed in the beaten egg white expand from the heat during baking, some of the cell walls rupture instead of expanding. When a number of the cells rupture during baking, several cell walls coalesce, the cell walls are thicker, and the volume is reduced.

**Mixing angel cake.** After the egg whites are beaten the other ingredients are folded into the cake. The water, cream of tartar, and the salt are added to the partially beaten egg whites. The flavoring may also be added to the egg white at the same time as the cream of tartar. This eliminates extra folding after the sugar and flour are added. For directions for folding, see Experiment 68; and for types of bowls, Fig. 36.



*Sugar.* The sugar may be folded into the egg whites after they are beaten or whipped with the whites. The latter is sometimes called the meringue method. A certain amount of folding of the sugar with the egg white results in a cake of the best texture and tenderness. Too little folding does not blend the sugar sufficiently with the beaten whites; then the flour does not fold in readily and heavy spots may be found throughout the cake. They may be quite small, but soggy and thick, and sometimes they contain just a trace of dry flour in the thickened spot. Such a spot is shown in Fig. 37, cake 1. The cakes usually increase in volume with longer folding of the sugar, reaching a maximum with about 60 strokes; then a slight decrease occurs with longer mixing. Sometimes the maximum volume occurs after folding about 40 strokes and sometimes after about 80 strokes. The tenderness of the cakes usually varies more with longer folding of the sugar than the volume.

When the sugar is whipped into the whites, it may be added before whipping is started but this materially lengthens the time for whipping. The preferable time for adding the sugar is after the cream of tartar and salt are added. The sugar is added gradually for hand beaters and the whites beaten until stiff and shiny. The peaks stand up with slight rounding or bending of the tip ends.

The meringue method is particularly good to use with an electric beater, for the rapid revolutions can soon over-whip the whites to the dry stage. Adding the sugar during whipping of the whites increases the time for beating but also tends to prevent mechanical coagulation and tends to prevent leakage, thus stabilizing the foam.

In class work about nine times out of ten better results are obtained if all or at least half of the sugar is added to the egg white before any of the flour is added. Barmore reports the same result. Yet one person that the writer knows who makes excellent angel cakes always mixes all the sugar and flour together and then adds it to the egg white. It illustrates a point that constantly impresses all who have a chance to observe different people work with foods. There is no one method that always produces the best result. It seems best to give the method or methods successfully used by the majority.

However, adding about three-fourths of the sugar to the egg whites and sifting the remainder with the flour make the flour easier to incorporate. Hence, the flour can be added with less folding with the result that toughness is not increased from long folding and the volume of the foam is not materially reduced. Mixing the sugar and the flour before adding to the egg white has not produced as satisfactory results as folding the sugar first. As one student remarked, "The addition of the sugar to the egg white seems to prepare the egg for blending with the flour."

*Flour.* The flour is folded into the mixed sugar and egg white. Here the amount of mixing also affects the volume and tenderness of the cake. Too little mixing does not blend the flour sufficiently with the sugar and

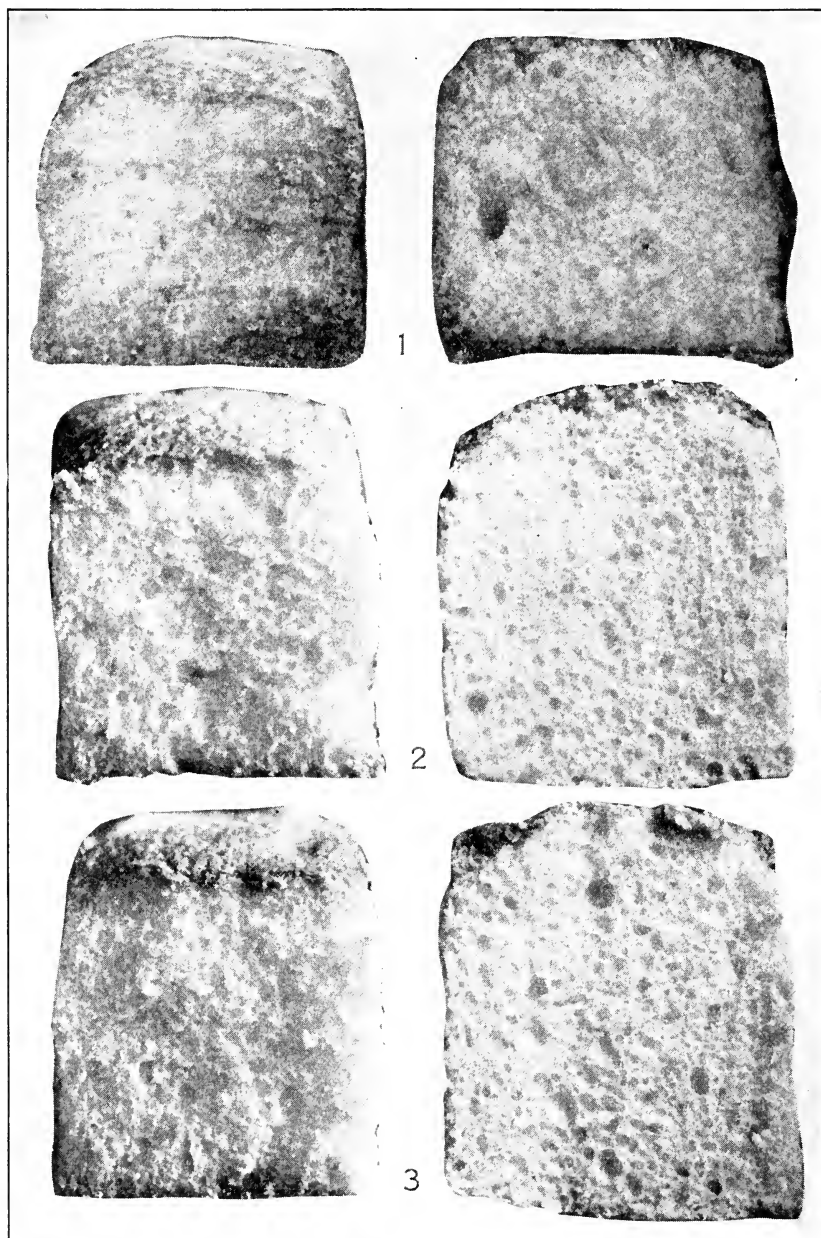


FIG. 37.—Angel cake. Showing effect on the volume and texture of varying the folding of the sugar with the egg white. Cake flour used. Experiment (69,A). As shown in the illustration the cakes are about five-sixths actual size.

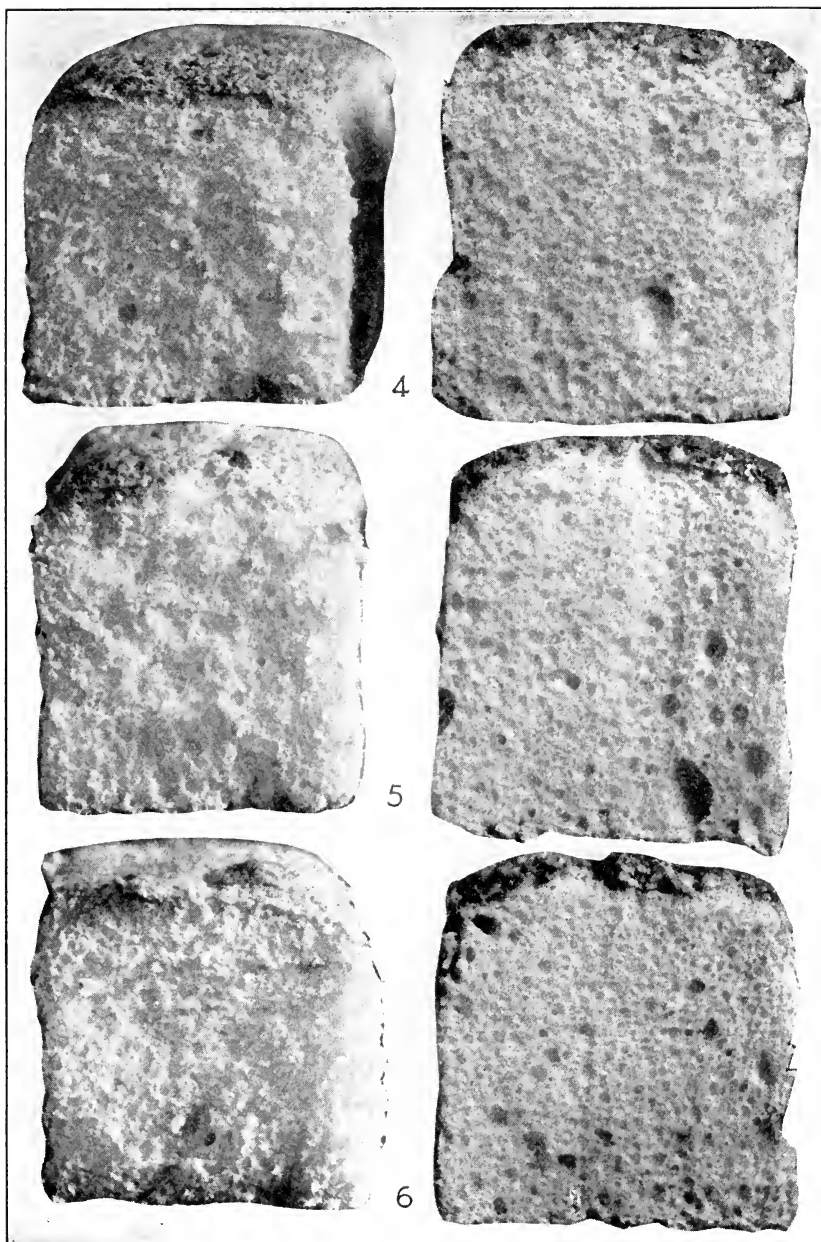


FIG. 37.

1. The sugar folded 20 strokes.
2. The sugar folded 40 strokes.
3. The sugar folded 60 strokes.
4. The sugar folded 80 strokes.
5. The sugar folded 120 strokes.
6. The sugar folded 180 strokes.

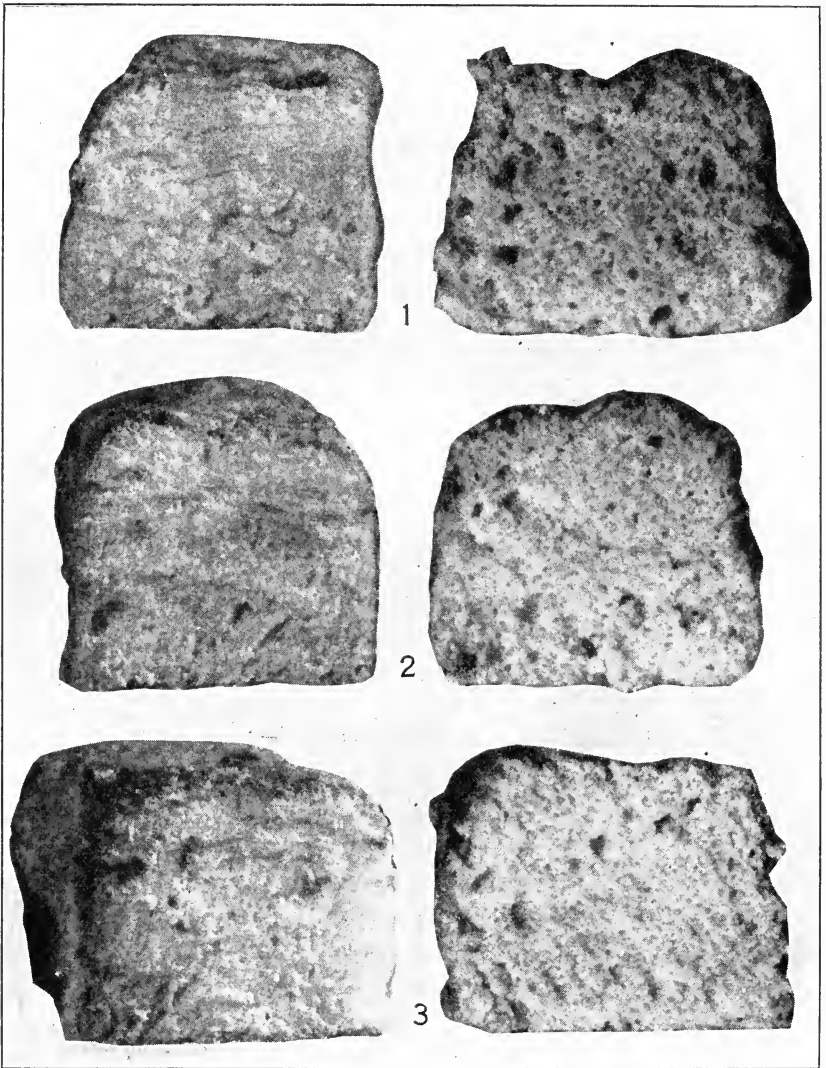


FIG. 38.—Angel cake. Showing effect of substituting bread flour for cake flour in Fig. 37. Experiment (69,E).

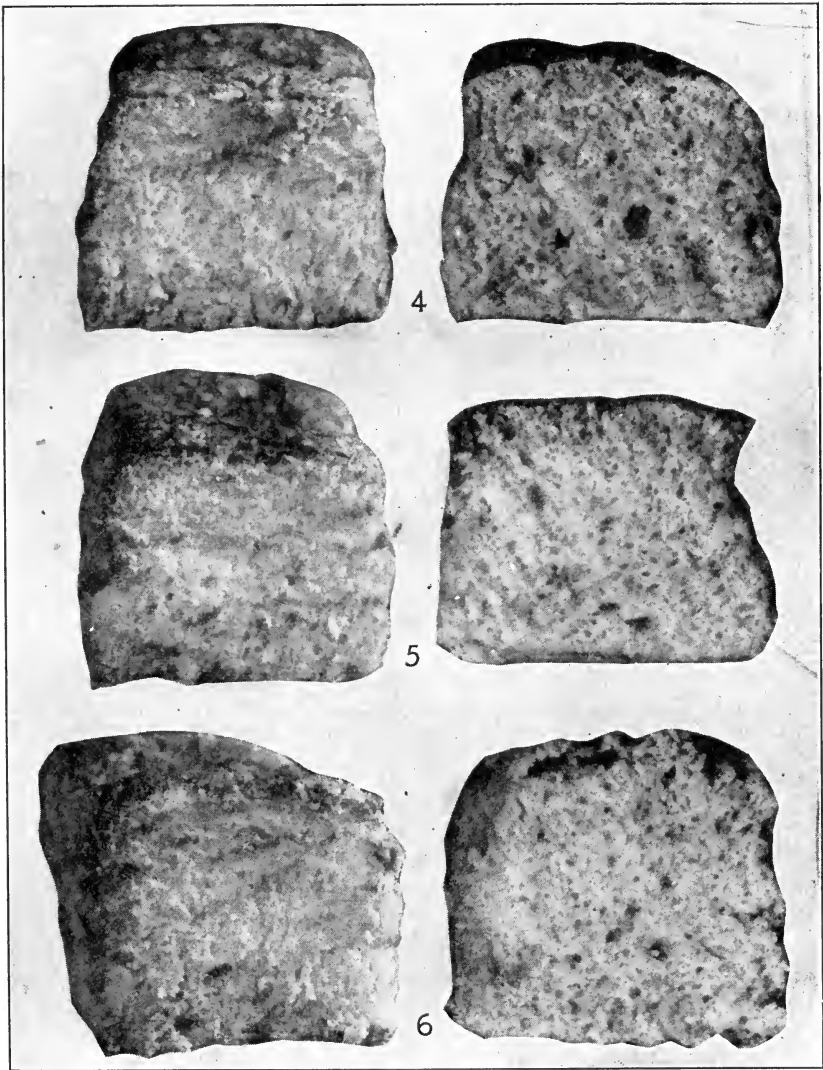


FIG. 38.

1. The sugar folded 20 strokes.
2. The sugar folded 40 strokes.
3. The sugar folded 60 strokes.
4. The sugar folded 80 strokes.
5. The sugar folded 120 strokes.
6. The sugar folded 180 strokes.

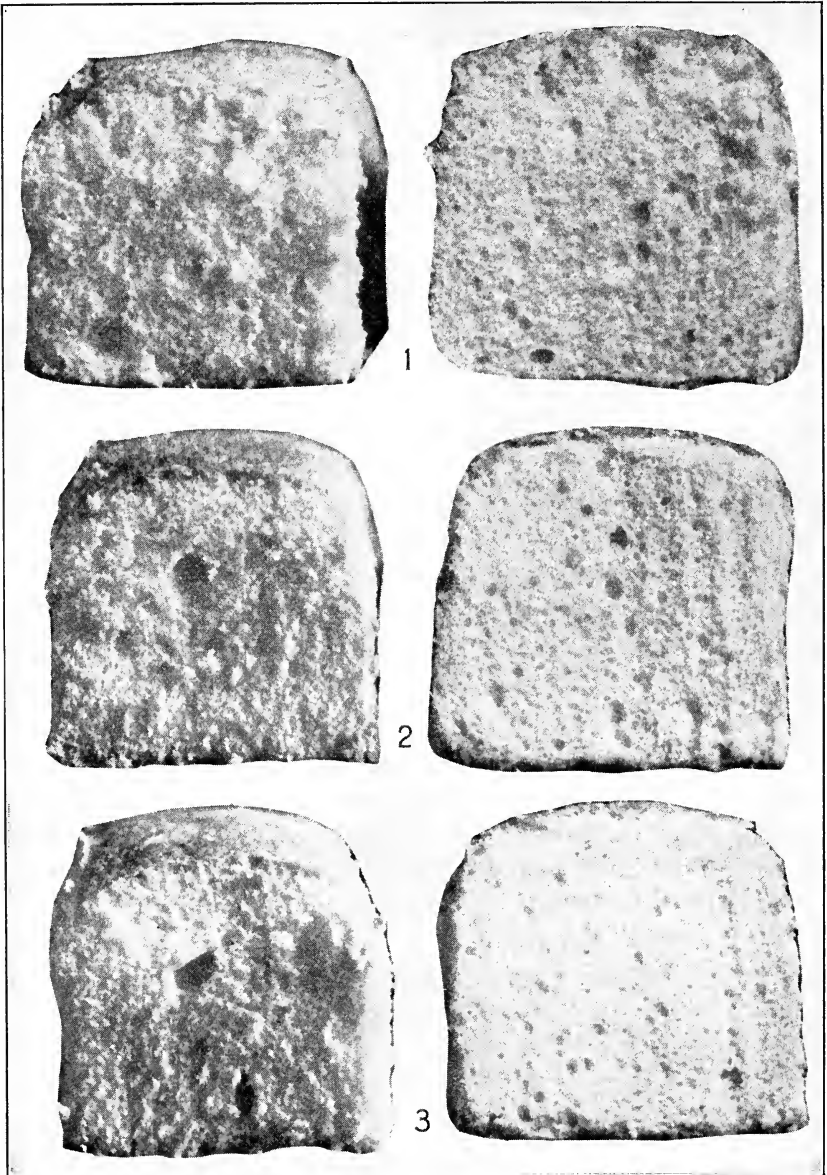


FIG. 39.—Angel cake. Showing effect on volume and texture of varying the extent of folding the flour with the sugar and egg white. Experiment (69,B). As shown in the illustration the cakes are about five-sixths actual size.

1. The flour folded 40 strokes.
2. The flour folded 60 strokes.
3. The flour folded 80 strokes.

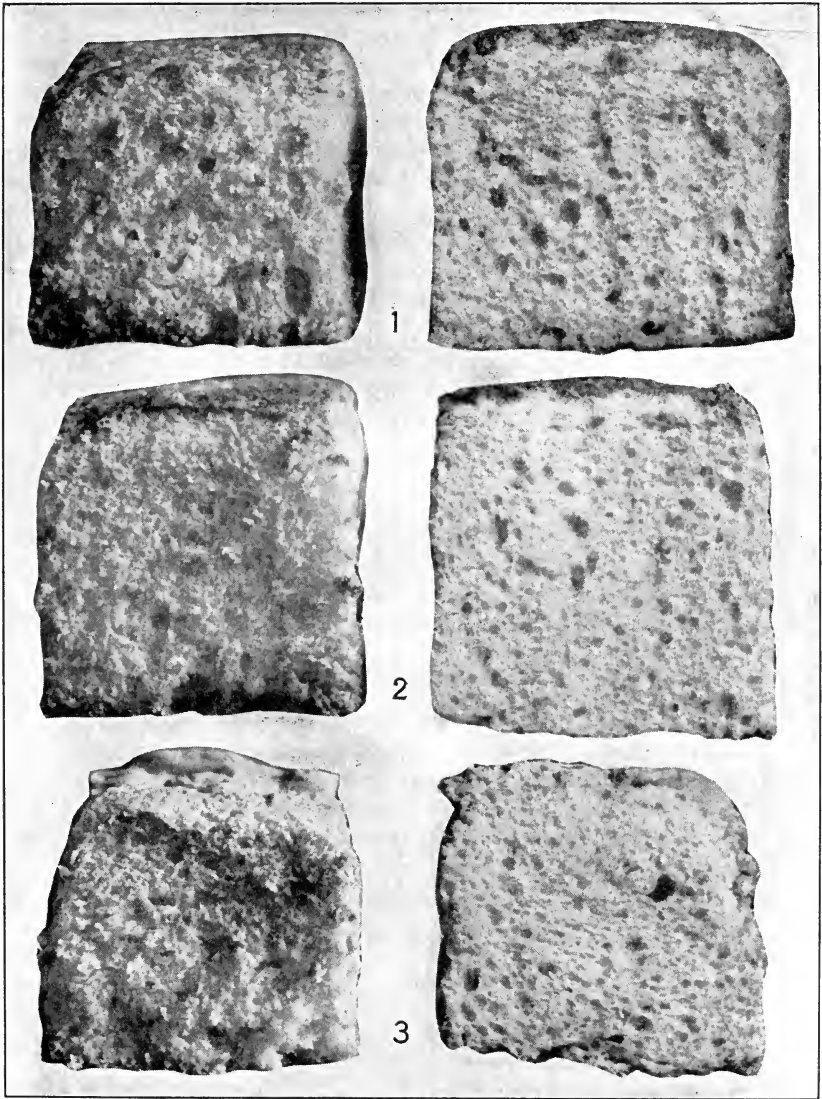


FIG. 40.—Angel cake. Showing effect on the volume and texture of beating the egg white to different stages of stiffness. Experiment (69,C). As shown in the illustration the cakes are about five-sixths actual size.

1. Egg white slightly under-beaten.
2. Egg white beaten sufficiently.
3. Egg white slightly over-beaten.



egg white mixture, and the grain is coarser. Spots of flour may occasionally be found. These are more likely to occur when the sugar has not been sufficiently mixed, or when all the flour is sifted over the cake at one time, or if too thick a layer is used, which increases the difficulty of incorporating the flour, as it tends to pile and roll up in balls. Longer mixing of the flour with sugar and egg white tends to produce a fine grain and small cells. See Fig. 39, cakes 2 and 3. The longer mixing of flour also has a tendency to toughen the cake, which may be due to development of the gluten of the flour and to the thicker cell walls caused by combining several cells through loss of air by mixing. An amount of mixing of the flour just to blend it well with the egg white and sugar usually produces the best results.

**Texture.** The texture and grain, also the volume and tenderness, of angel cake are influenced by several factors: (1) The mechanical treatment, which includes the kind of beater used, the degree of whipping of the whites, the method of and extent of mixing the ingredients; and (2) the ingredients used, their amount and kind.

The factor determining the size of the cells to the greatest degree is the type of beater used and the extent to which the egg white is beaten, which has been considered. Longer whipping produces more and smaller air bubbles so that the cells are smaller, the grain finer. Rotary and electric beaters, in general, give finer grain than whisks.

Beating the egg whites to obtain the possible maximum cake volume usually produces the most tender cake, for with a maximum volume the cell walls are stretched to the greatest extent, hence are thinnest.

The method of folding or mixing also affects the grain of the cake. After egg whites are whipped, the folding and mixing should be done gently and to retain as many of the air bubbles as possible.

Longer mixing of the sugar with the egg whites tends to give a finer grain (see Fig. 37), but not to the extent that the folding of the flour does. Thus the grain or texture of the cake may vary to a certain extent, but a cake with thin cell walls and medium-sized cells that is so tender that it "melts in your mouth" is preferable to one that has a fine grain but is less tender.

**Ingredients used in angel cake.** *Flour.* The amount of flour per gram of egg white may vary from 0.2 to 0.4 gram. The smaller amount tends to give a more moist and tender cake, the larger a more dry and less tender one. Cake flour produces a more tender cake than bread flour. It contains gluten that is not so tenacious, and therefore yields a cake that is more tender and of greater volume. The cakes made of bread flour shrink and pull away from the pan as they finish baking and while cooling. See Fig. 38, which is a reproduction of the manipulation and proportions for the cakes in Fig. 37. It is possible to obtain a fair cake from bread flour, but it is not as tender as with cake flour. Better results are obtained with bread flour if the sugar is increased by about 2 to 4 tablespoons or the



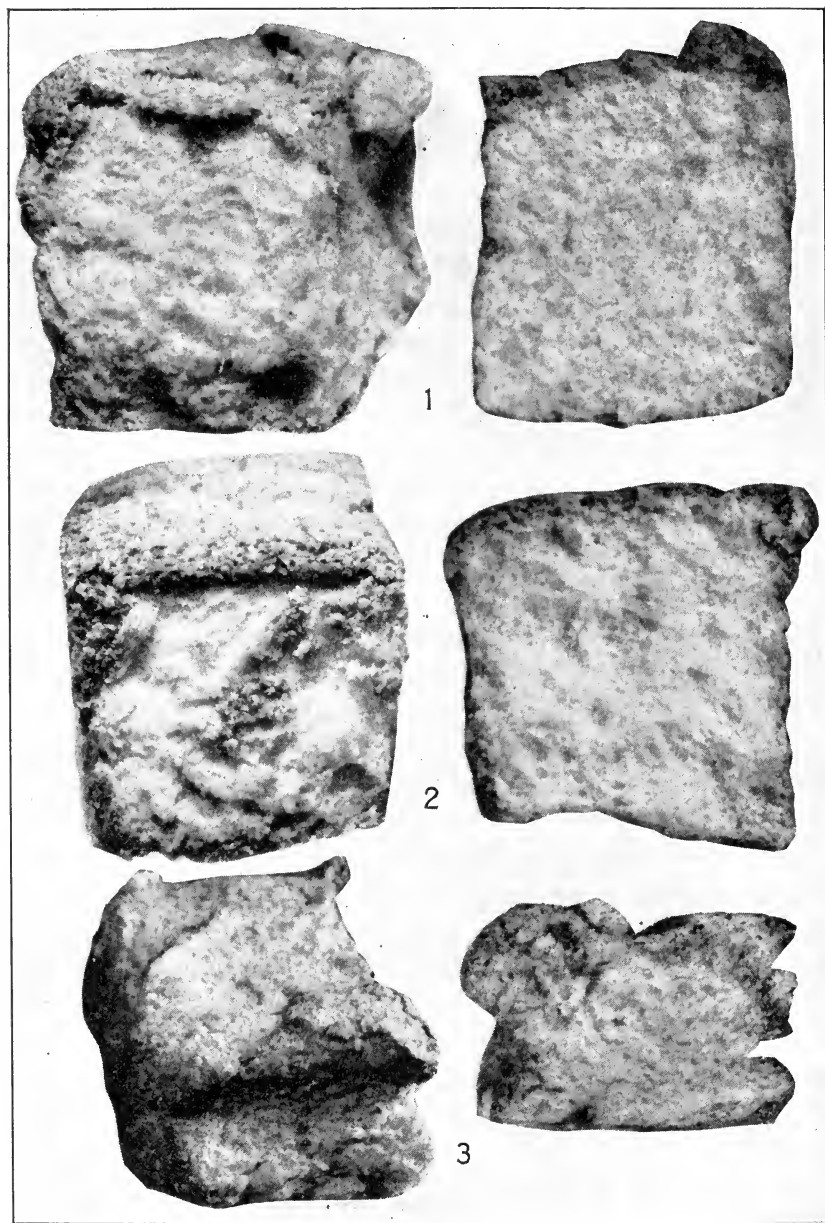


FIG. 41.—Angel cake. Showing effect of increasing the sugar from  $1\frac{1}{4}$  to  $1\frac{1}{2}$  cups. Typical sugary crust. Experiment (69,F). As shown in the illustration the cakes are about five-sixths actual size.

1. Egg white beaten to flow slowly in a partially inverted bowl.
2. Egg white beaten stiff enough to stay in an inverted bowl.
3. Egg white beaten until very dry and flaky.

flour reduced by about 2 to 4 tablespoons. There is also a greater tendency for drops of sirup to collect on the surface of the crust when bread flour is used.

*Liquid.* There does not seem to be any advantage in adding about 30 cc. of water to the egg white.

*Cream of tartar.* Angel cake made without cream of tartar is cream colored. The cream of tartar produces a very white cake on account of the effect of the acid salt on the flour. The flavone pigments of flour are cream colored when slightly alkaline but white when the reaction is acid or neutral. Also the addition of cream of tartar produces a more tender cake. Evidently the tartrate ion brings about peptization of the egg or flour proteins, or both. Increasing the quantity of cream of tartar beyond the amount used in the recipe produces a more tender cake and one that is more moist and tart in flavor. Barmore recommends that the amount of cream of tartar should be 1 to 2 per cent of the weight of the egg white. The amount given in the standard recipe is about 1.5 per cent.

*Sugar.* A fine crystalline sugar, such as fruit or berry sugar, which dissolves rapidly is excellent to use in angel cake. The maximum amount of sugar per gram of egg white is about 1 gram. At higher altitudes this must be decreased. At sea level, or up to 1000 feet above sea level, the sugar can be increased to 1.25 grams of sugar per gram of egg white provided the maximum amount of flour is used. But it must be handled carefully. See Fig. 41. Cakes with large proportions of sugar have a typical sugary crust.

**Temperature of baking angel cake.** Reports of recent investigations of baking temperatures for angel cake indicate that higher temperatures than those commonly used are preferable. Barmore reports that cakes baked at 178°C. (352°F.) had a larger volume, were more tender (probably because of larger volume), and appeared more moist, though a moisture analysis showed no cakes lost moisture farther from the edge than 1 cm. Burke and Niles have reported a larger volume, more tender cakes, and less moisture loss for cakes baked at 350°F. than for those baked at 325°F. Peet and Lowe have reported a larger volume, more tender cakes, and more moist cakes when the cakes were baked in preheated ovens of electric, gas, and kerosene ranges than from a cold start in these same ranges.

Whether still higher temperatures will be more desirable has not been reported. At present it appears that oven temperatures of 175° to 180°C. are preferable to 150° or 160°C.

### Sponge Cake

Sponge cake, like angel cake and foamy omelets, depends chiefly upon the extent of whipping the egg whites, the mixing, and good proportions to produce a tender cake.

Probably the most common fault in making sponge cake is insufficient beating of the egg yolks and sugar. These two ingredients, plus the liquid, if water or lemon juice is used, can be beaten until they are extremely light and foamy. This is most successfully done with rapid beating, preferably by an electrically operated beater or a rotary beater rather than a whisk. Excellent sponge cakes may be made from only the yolks, provided some water is added and the yolks and sugar are beaten rapidly until very light. In the type of sponge cake recipe given in Experiment 70, when the flour is mixed too long with the sugar and egg yolks the cake is more compact and tough. But in some types of sponge cake in which considerable water is added, that is, the ones called water sponge, it is often necessary to beat the flour and egg yolks a long time to obtain a cake with thin cell walls and a uniform texture. In other words, this can be interpreted to mean that, for each recipe in which the proportion of ingredients varies from those in another recipe, the amount and the kind of manipulation to produce a cake of the best texture vary.

Different methods of combining the ingredients may be used in mixing sponge cake. Several are suggested in Experiment 70. Excellent sponge cakes may be made by any method of mixing. The method of adding the water and lemon juice to the sugar, given in Experiment 70,3, produces rather uniform results when used by many different students.

Platt and Kratz have reported means of measuring and recording some characteristics of test sponge cakes, which can also be used with angel cake. These include measuring tensile strength, volume, and specific gravity.

Whether the temperature for baking sponge cake like that for angel cake should be increased has not been reported. It has been shown in the author's laboratory that sponge cake made from egg yolks only is more desirable when baked at 350°F. than at 325°F. It is likely that most sponge cakes should be baked at the same temperatures as angel cake.

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## EGGS

### Cooking Eggs in Water

#### Experiment 63.

##### I. In the shell.

A. To determine the effect of coagulation at different temperatures on the texture of the white and yolk.

1. Cook an egg in water. Do not let the temperature of the water go above  $72^{\circ}\text{C}$ . It is easier to control the temperature, if a large quantity of water is used and the heat is turned low after the desired temperature is reached. Cook from 1 to  $1\frac{1}{4}$  hours.

2. Cook an egg in water the temperature of which does not go above  $85^{\circ}\text{C}$ . Cook 30 to 35 minutes.

3. Cook two eggs in boiling water. Cook 12 to 15 minutes.

a. Cool one egg slowly, leaving it in the water in which it was cooked.

b. Cool the other egg rapidly, letting cold water from faucet run over it until cold.

Compare with the eggs from 1 and 2 in texture and firmness of the white and yolk. Which gives a tender and desirable product for eating? For slicing? Do any have a green layer at the junction of the white and yolk?

Texture		Tenderness		Comments
White	Yolk	White	Yolk	

Results and conclusions.

B. To determine the effect of cooking for varying lengths of time at a high temperature upon the texture and consistency of egg white and yolk.

Cook in boiling water.

1. Cook 2 minutes.
2. Cook 3 minutes.
3. Cook 5 minutes.
4. Cook 7 minutes.
5. Cook 10 minutes.

Compare the consistency of the white and yolk cooked for varying lengths of time. Compare with results obtained in A.

II. Out of the shell.

A. To determine the method of obtaining a desirable poached egg.

Use a pan deep enough so that water will entirely cover the egg. Add a pint of water. Use more water if necessary, but all should use the same quantity. A film of fat rubbed over the bottom of the pan before the water is added seems to help prevent the egg from sticking to the pan. Have the water boiling when the egg is added. Keep the water bubbling very slowly. (For edible purposes it is better to keep the water below the boiling point after the egg is added, but the temperature of the water in different pans may vary widely. Hence, keeping the water boiling very slowly serves for comparative purposes.) Cook 3 minutes. Start with fresh water for each experiment. Break the egg into a sauce dish just before adding to the water. Slide it carefully into the water. Study the structure of one egg after it is broken out of the shell. Note the proportion of thick and thin white, for this will vary with different eggs. If very different in some individual eggs, cook and repeat one part of the experiment, to see if you get the same results the second time. Note the chalazae. Do any spots appear on the yolk?

A. Fresh eggs.

1. Cook in plain water.
2. Add  $\frac{3}{4}$  teaspoon of salt per pint of water.
3. Add 1 teaspoon of vinegar per pint of water.
4. Decide which of the three experiments above gives the best-appearing product, then repeat it; but swirl the water around the pan, dropping the egg in the center.

B. Eggs deteriorated so that they have a larger proportion of thin white.

1. Repeat A1.
2. Repeat A2.
3. Repeat A3.
4. Repeat A4.

C. Repeat A1, using a ring placed in the bottom of the pan in which the egg is placed. Or use any type of cup made for poaching eggs.

Which coagulates better, the thick or thin portions of the egg white? What is the effect of adding salt? Vinegar? Would the technic in swirling the water make any difference in the result? Why not swirl too hard? If eggs are cooked at a lower temperature, should the time be increased?

Do you wish to try changing the proportion of salt? The time and temperature of cooking?

White		Yolk		Comments
Extent of coagulation	Texture	Extent of coagulation	Texture	

Conclusions.

### Custards

#### Experiment 64.

To determine the factors that affect the coagulation and curdling of custards.

Recipe:

Milk	1 cup	244 grams
Egg	1	48 grams
Sugar	2 tablespoons	25 grams

A. To determine the effect of rate of coagulation upon the texture and consistency of custards.

1. Prepare 2 times the recipe, then divide into equal parts; use part one for A1, and part two for A2. It is better for two or more students to work together for this experiment. Combine all the ingredients and mix thoroughly. Put one part in the upper part of a double boiler. The boiler should be rather deep to have the custard sufficient to cover the thermometer bulb when portions of the custard are removed. A double boiler holding a quart and about 4 inches in depth is satisfactory. Add a pint of cold water to the lower part; then put the upper portion of the double boiler into the lower. Make a record of the temperature of the custard mixture and the time. Put over the fire and heat. The heating may be rapid until the custard mixture reaches a temperature of 70°C. Then the heat should be regulated so that at least 1 to 1½ or more minutes will be required to elevate the temperature 1°C., i.e., about 3 minutes should be required for the temperature of the custard to go from 80° to 82°. One student may hold the thermometer and read the temperatures; a second can record the time and temperature. Record the time every 5° during the first period of heating, i.e., 30°, 35°, etc. But record the time for 1° rise after 78° is reached, i.e., at 78°, 79°, 80°, 81°, etc. A third student may stir the custard and a fourth can remove portions of the custard. It is easier to let the bulb of the thermometer touch the bottom in the center of the double boiler. Use a wooden spoon for stirring. Have dishes ready to put the custard in. Bend the bowl of an old metal spoon until it is at right angles to the handle. Use it for removing portions of the custard, taking out 2 tablespoons at each temperature. Remove portions of the custard at 78°, 80°, 82°, 84°, 86°, 88°, and when curdled.



2. Repeat A1, but have the pint of water in the lower part of the double boiler boiling when the upper part is added. Regulate the heat to keep the water boiling very rapidly. Cook as quickly as possible, but not more than 6 minutes should be necessary. Record the temperature of the custard and the time just before putting the custard over the boiling water. If possible, record the temperature as under A1. The stirring should be rather rapid for the cooking is rapid. It will also take rapid work to remove the custard at the desired temperatures. Remove portions of the custard at temperatures given under A1.

Note the temperature before and during curdling of the slowly and rapidly cooked custards.

Does the temperature lag or drop in some instances? Prepare a time-temperature chart, showing the period of time required for custard for different groups and time intervals as follows. It will be found that the consistency of a given custard at a definite temperature, say 80°C., is directly proportional to the time required to heat it from 76° to 80°C. Compare thickening of custard for different groups, noting time required for each custard to reach a definite temperature. Also note curdling temperature and highest temperature reached.

	Time to reach 76°C. Min.	Time from 76° to 78° Min.	Time from 78° to 80°, etc. Min.
A. Group 1, etc.			
B. Group 1, etc.			

Compare the consistency of the custards at each temperature. What is the effect of the rate of coagulation upon the amount coagulated at a definite temperature? Would you advise the rapid or the slow cooking? Why? Compare with baked custards heated to the corresponding temperatures.

B. Baked custards.

Prepare 2 times the recipe. Combine all the ingredients and mix thoroughly. Divide into 5 portions, using equal parts in each cup. Put all the cups in a large, flat pan. Set the pan in the oven. By supporting on an oven rack above the custards insert a right-angled meat thermometer, so that the bulb of the thermometer is at the center of one custard. Place a second thermometer so that the temperature of the water can be read. Start heating the oven and then pour boiling water around the custard cups until it comes as high as the custard in the cups. If the oven has a regulator so that a low temperature, 125° to 150°C. (250° to 300°F.) is maintained, the custards can be cooked without adding the water to the pan. Record the time and the temperature of the custard every 3 minutes if the oven has a glass door, otherwise

every 5 minutes. Remove one custard of each series at the following temperatures: 82°, 83°, 84°, 85°, and 87°C.

C. To determine the effect of varying the proportion of ingredients in baked custard.

Follow directions under B. If possible, bake all the custards under B and C in the same pan. Prepare 2 times the recipe.

1. Use 1 egg, 1 cup of milk, 2 tablespoons of sugar, or use the custards from B for a control.

2. Use 1 egg, 1 cup of milk.

3. Use 1 egg, 1 cup of milk, 4 tablespoons of sugar.

4. Use 1½ eggs, 1 cup of milk, 2 tablespoons of sugar.

Are all the custards for the same experiment of the same thickness or consistency? How might you account for this? Are the custards removed at 83°C. all of the same consistency? Compare the time required for cooking. Does the increased egg result in a thicker custard than when 1 egg is used? Compare the stiffness of custards made with the whites and the yolks. What is the effect of increasing the sugar? Which proportion of sugar is desirable for serving? Are any of the custards curdled? What is the optimum temperature for serving each custard?

Time of cooking

Consistency of custard at

To reach 80°C.	From 80° to 87°C.	Consistency of custard at				
		82°C.	83°C.	84°C.	85°C.	87°C.

Conclusions.

D. To determine the effect of substituting yolks or whites for the whole egg.

Follow directions under B. Prepare 2 times the amount given below.

1. Use 2 yolks (36 grams), 1 cup of milk, 2 tablespoons of sugar.

2. Use 2 whites (60 grams), 1 cup of milk, 2 tablespoons of sugar.

Beat the whites only slightly before adding the milk. If beaten stiff they float on top of the milk and do not blend well with it. Also fill the cups to the same height as those containing the egg-yolk custard. Otherwise the larger quantity of egg-white custard will heat more slowly than the egg-yolk custard.

When egg yolks are substituted for the whole egg in the custard, compare the stiffness of the custards with those made from the whole egg cooked to the same temperature. Compare the flavor. The color. Compare with custards made of egg white.

E. To determine the factors that affect coagulation.

Prepare ½ the recipe, using only 1 custard cup.

1. Use 1 egg, 1 cup of distilled water, 2 tablespoons of sugar.

2. Use 1 egg, 1 cup of distilled water, 2 tablespoons of sugar. Dissolve ½ teaspoon of calcium lactate in the distilled water before adding the egg and sugar.

3. Use 1 egg, 1 cup of distilled water, 2 tablespoons of sugar. Bake until the temperature at which D2 sets is reached. Remove from the oven and add  $\frac{1}{3}$  teaspoon of calcium lactate that has been moistened in a tablespoon of distilled water. Stir. What happens?

4. To 1 egg, 1 cup of distilled water, 2 tablespoons of sugar, add about  $\frac{1}{16}$  teaspoon or less of aluminum or ferric chloride. Mix the ferric or aluminum chloride with the distilled water; then add the beaten egg and the sugar. What happens when the egg is stirred in the mixture? Continue stirring for a few seconds.

5. Repeat E1, but add  $\frac{1}{3}$  teaspoon of aluminum or ferric chloride. Does the custard coagulate during cooking? Test the custards with litmus paper.

6. To 1 egg, 1 cup of distilled water, and 2 tablespoons of sugar, add  $\frac{1}{4}$  teaspoon of salt.

7. Repeat E6, but omit the salt and add  $\frac{1}{3}$  teaspoon of a milk-salt mixture used in feeding rats.

8. To 1 egg, 1 cup of distilled water, and 2 tablespoons of sugar, add  $\frac{1}{2}$  teaspoon of lemon juice.

9. To 1 egg, 1 cup of distilled water, and 2 tablespoons of sugar, add 1 teaspoon of lemon juice.

F. To determine the effect of beating on thickening power of the egg.

1. Use  $2\frac{1}{2}$  eggs. Beat in a bowl either by hand or with an electric mixer until the yolks and whites are well blended. Weigh out 48 grams and combine with 1 cup of milk and 2 tablespoons of sugar.

2. Beat the egg remaining from part F1 until thoroughly beaten. The egg can be beaten as long a period as desired. Weigh 48 grams of the egg. Discard the remaining egg. Combine the 48 grams with 1 cup of milk and 2 tablespoons of sugar. If the egg was beaten with an electric mixer, put milk in the mixer bowl and combine with the mixer. Does the egg tend to float on top of the milk? Bake according to directions under B.

3. Beat 1 egg slightly, so that the yolk and white are not well blended. Add to 1 cup of milk and 2 tablespoons of sugar.

What is the effect of increasing the egg upon temperature of coagulation? Of varying the proportion of sugar? Does the distilled-water custard set? What is the effect of adding calcium lactate? Salt? What is the reaction of the custard containing the small proportion of aluminum or ferric chloride? The one with the larger proportion? Does either set? Unless the proportion of ferric or aluminum chloride is small enough, E4 may not set.

Time of cooking	Coagulation temperature	Texture	Flavor	Comments

Results and conclusions.

G. Soft custards.

The series under C and D may be repeated and cooked as soft custards, or the baked custards may be omitted and the soft custards prepared instead. Prepare once the recipe and follow directions under A for cooking.

## Salad Dressings

## Experiment 65.

To determine the effect of acid upon coagulation of egg in cooked salad dressings.

*Recipe:*

Egg yolks.....	4	72.0 grams
Sugar.....	$\frac{1}{2}$ tablespoon	6.2 grams
Liquid total.....	1 cup	240.0 grams
Mustard.....	$\frac{1}{2}$ teaspoon	
Salt.....	$\frac{1}{4}$ teaspoon	

A. Cook in a double boiler. Follow directions under Experiment 64A for cooking. It is not necessary to cook as slowly as under Experiment 64A, but the time for each degree rise in temperature should be the same in all the experiments.

Remove portions of the salad dressing at the following temperatures: 76°, 78°, 80°, 82°, 85°, and 92°C. Note the temperature when the salad dressing coats the spoon.

1. Use  $\frac{1}{8}$  cup of vinegar,  $\frac{7}{8}$  cup of water.
2. Use  $\frac{1}{4}$  cup of vinegar,  $\frac{3}{4}$  cup of water.
3. Use  $\frac{1}{2}$  cup of vinegar,  $\frac{1}{2}$  cup of water.
4. Use  $\frac{1}{8}$  cup of lemon juice,  $\frac{7}{8}$  cup of water.
5. Use  $\frac{1}{4}$  cup of lemon juice,  $\frac{3}{4}$  cup of water.
6. Use  $\frac{1}{2}$  cup of lemon juice,  $\frac{1}{2}$  cup of water.
7. Repeat A1, but add 1 tablespoon flour, 7 grams.

At which temperature is the most desirable texture for a salad dressing obtained with the different proportions of acid? Which proportions of acid give the thicker salad dressing? Does curdling occur at the higher temperatures? From results with custard, what would be the result of increasing the proportion of salt? Which produces the clearer salad dressing, vinegar or lemon juice?

76°	78°	80°	82°	85°	92°

## Conclusions.

B. To determine the effect of varying the ingredients and the proportion of ingredients in salad dressings.

1. Repeat 65,2, or 65,5, but increase the salt to 1 teaspoon.
2. Repeat B1, but increase the sugar to 2 tablespoons.
3. Repeat B1, but substitute 72 grams of whole egg for the egg yolk.
4. Reduce the egg yolk to 36 grams and add 2 tablespoons (14 grams) of flour.

Hollandaise Sauce

Experiment 66

To determine the factors affecting the smoothness of Hollandaise sauce.

*Recipe:*

Butter.....	½ cup	112 grams
Egg yolks.....	2	36 grams
Hot water.....	⅓ cup	
Vinegar.....	1 tablespoon	
Salt.....	¼ teaspoon	
Paprika.....	few grains	

1. Melt the butter in the top part of a double boiler. When melted remove from the heat and add the well-beaten egg yolks, stirring until blended with the butter. Add other ingredients and return to the double boiler. Heat slowly and stir continually. Remove samples at the following temperatures, 72°, 74°, 76°, 78°, and 80°C. If mixture has not separated at 80°C., continue to remove samples until curdled.

2. Repeat 1, but do not beat the egg yolks before adding to the butter.

3. Repeat 1, but increase the egg yolks to 4.

4. Repeat 3, but omit the water and increase vinegar to 2 tablespoons.

5. Substitute lemon juice for any of the above. Compare smoothness and consistency of the different sauces. Compare the flavor.

Omelets

Experiment 67.

To determine the factors that affect the texture of omelets.

*Recipe:*

Egg.....	1	Salt.....	⅛ teaspoon
Liquid.....	1 tablespoon 15 cc.	Butter.....	½ tablespoon 7 grams

*Directions for mixing and baking.*

The first omelets should not be used for comparisons for experiments. The omelets should be made over several times if necessary to acquire the technic and the manipulation necessary to make a good omelet.

Separate the white and the yolk of the egg. Beat the yolk until it will mix well when folded in the white. Beat the white until it is frothy and add the liquid; add the salt and continue beating until it is quite stiff. It should be beaten until it will stay in an inverted bowl.

Mix the beaten white and yolk by folding. Use a spatula for folding. The spatula should have a flexible blade near the end but should be rigid where it joins the handle. Fold by holding the blade of the spatula parallel to the right side of the bowl. Move to the bottom of the bowl, at the same time pressing so that the spatula scrapes the material from the bottom of the bowl. Bring up with the blade parallel to the left side of the bowl. As the spatula is brought across the top of the material turn it upside down. Turn

the bowl occasionally, and about every fifth stroke bring the spatula up through the middle of the material for better mixing. Fold white and yolk until well blended. They should not be mixed until a large portion of the air is lost from the white, but they must be mixed enough to prevent separation of the white and yolk. Count the number of strokes used in mixing the yolk and white. The number needed will vary with the size and kind of utensil, usually about 20 to 25. The same number of strokes should be used in mixing for all the experimental work and also the same size and kind of utensils. If desired, different makes and styles of egg beaters and whisks can be used. Count the motions required to beat the egg whites to the same degree of stiffness. The butter is put in a frying pan or an omelet pan of the proper size for a one-egg omelet. Melt the butter in the pan. Add the omelet and cook over a medium flame for about  $\frac{1}{2}$  minute before placing in the oven. Have the temperature of the oven  $160^{\circ}$  to  $165^{\circ}\text{C}$ . ( $320^{\circ}$ - $330^{\circ}\text{F}$ .). Oven baking is not necessary but it gives a uniform temperature for class work. Bake 25 minutes. If necessary, increase or decrease the time of baking. See Fig. 36, p. 362.

A. To determine the effect of omitting the liquid and the effect of using different liquids.

1. Omit the liquid in the recipe.
2. Use water for the liquid in the recipe.
3. Use milk for the liquid in the recipe.
4. Use tomato juice for the liquid in the recipe.

5. Use 1 teaspoon of lemon juice and 2 teaspoons of water for the liquid in the recipe.

Which omelet gives the greatest volume? Which is the most tender? What happens in 3?

No. of strokes used for mixing	Volume	Texture	Tenderness	Flavor

Results and conclusions.

B. To determine the effect on the volume and the texture of omelets of combining the liquid with the egg yolk.

Repeat the series under A1, but combine the liquid with the beaten yolk.

C. To determine the effect of cooking at different temperatures.

1. Repeat A2, and bake at  $160^{\circ}\text{C}$ . ( $320^{\circ}\text{F}$ .).
2. Repeat A2, and bake at  $140^{\circ}\text{C}$ . ( $285^{\circ}\text{F}$ .).
3. Repeat A2, and bake at  $180^{\circ}\text{C}$ . ( $355^{\circ}\text{F}$ .).

Which cooking temperature gives the best results?

Results.

D. To determine the effect of beating the egg white to different stages of stiffness on the texture and the volume of omelets.

1. Repeat A2, for a control.
2. Repeat A2, but beat the egg white until very dry and flaky.

3. Repeat A2, but beat the white until it will flow if the bowl is inverted and is not as stiff as for D1.

Results,

### Meringues

#### Experiment 68.

To determine some of the factors affecting the desirability and texture of meringues.

*Recipe:*

Egg whites	2	60 grams
Sugar	4 tablespoons	50 grams
Water (may be omitted)	2 teaspoons	
Salt	$\frac{1}{8}$ teaspoon	
Vanilla	$\frac{1}{4}$ teaspoon	

*Directions for mixing.*

Beat the egg white until foamy, 50 turns of handle of rotary beater. Add the water, salt, vanilla, and beat an additional 100 turns with rotary beater. Add sugar and beat 50 turns with rotary beater. (*Note.* The sugar may be added gradually. If added in this manner, the amount of beating after addition of salt should be shortened. Ask instructor for directions. Change or adapt the extent of beating to suit the type of beater used, whether water is added, and the consistency of the egg white.) The above quantity of meringue should give enough for 4 pies about 6 inches in diameter. The meringues should be between  $\frac{3}{4}$  and  $1\frac{1}{2}$  inches in depth. Bake pastry. Fill shells with chocolate, lemon, or butterscotch filling as desired. Spread the meringue carefully over the filling to the edge of the crust, leaving it somewhat rough over the top. The meringue may be placed on a hot or cold filling. However, if added to a cold filling the time for baking will be longer, especially at the lower temperatures. When possible keep portions of the pie over night to observe the extent of leakage of the meringue.

A. Temperature of baking.

1. Bake at 230°C. (446° or 450°F. may be used) for 4 minutes.
2. Bake at 215°C. (420° or 425°F. may be used) for 6 minutes.
3. Bake at 200°C. (392° or 400°F. may be used) for 8 minutes.
4. Bake at 185°C. (365°F. or 375°F. may be used) for 12 to 15 minutes.
5. Bake at 170°C. (338°F. or 350°F. may be used) for 15 to 20 minutes.
6. Bake at 155°C. (311°F. or 300°F. may be used) for 25 to 30 minutes.

B. Amount and kind of sugar.

Bake at temperature found best under A.

1. Use 1 tablespoon (12.5 grams) sugar per egg white.
2. Use  $1\frac{1}{2}$  tablespoons (18.5 grams) sugar per egg white.
3. Use 2 tablespoons (25 grams) sugar per egg white.
4. Use  $2\frac{1}{2}$  tablespoons (31 grams) sugar per egg white.
5. Repeat B3, substituting powdered sugar for the granulated sugar.
6. Use 1 tablespoon honey or sirup per egg white.

C. Extent of beating after sugar is added.

Bake at temperature found best under A and use amount of sugar found best under B.

1. Beat 25 turns of handle of rotary beater after sugar is added.
2. Beat 50 turns after sugar is added.
3. Beat 75 turns after sugar is added.
4. Beat 100 turns after sugar is added.
5. Fold in sugar with spatula, using 50 folds.

D. Time of adding sugar to egg white.

Bake at temperature found best under A and use amount of sugar found best under B. Beat until foamy, add sugar and cook as indicated.

1. Add sugar and water (if used) at first and beat until shiny and stiff. Beat 200 turns of beater handle. Remove  $\frac{1}{4}$  of mixture for D1.

2. Beat the mixture remaining from D1 250 turns of the beater handle. Remove  $\frac{1}{4}$  of original mixture for part 2.

3. Beat the meringue remaining from D2 300 turns. Use  $\frac{1}{4}$  of the original mixture for part 3.

4. Beat the remaining meringue 300 turns.

Repeat the above series. Beat egg white until foamy. Add water (if used) and start adding sugar gradually. Beat until stiff.

E. Amount and kind of liquid.

Bake at temperature found best under A.

1. Do not add liquid to egg white.
2. Use 1 teaspoon of water for the full recipe.
3. Use 2 teaspoons of water for the full recipe.
4. Repeat E2 using lemon juice.

## Angel Cakes

### Experiment 69.

To determine the factors that affect the texture of angel cake.

*Standard recipe:*

Egg whites . . . . .	1 cup	244 grams
Sugar . . . . .	$\frac{1}{4}$ cups	250 grams
Cake flour . . . . .	1 cup	100 grams
Cream of tartar . . . . .	1 teaspoon	3.6 grams
Salt . . . . .	$\frac{1}{4}$ teaspoon	

*Directions for mixing and baking.*

Bake  $\frac{1}{6}$  of the recipe for each experiment. Beat the egg whites until frothy, then add cream of tartar and salt. Continue beating until they are the desired stiffness. The peaks formed when the white follows the lifted beater stand up fairly stiff and the tip end is slightly rounded. Sift the sugar to remove lumps and large crystals so that it will dissolve readily when mixed with the egg white. The sugar is sprinkled over the top of the egg and then folded in with a spatula. See Experiment 67 for directions for folding. The class should use spatulas of the same size. An egg beater can be used to fold in the sugar, but if used all members of the class should use one, and the number of strokes may need to be changed according to the size of the egg



beater. The flour is sifted to remove all lumps so that it folds in readily with the mixed whites and sugar. If the sifter is a coarse one, sift the flour several times. The flour is sifted over the eggs, then folded in. Flavoring is omitted in the above recipe so that the flavor of ingredients is more distinct. When used it may be added with the cream of tartar, thus preventing excess folding. To better compare the effect of other factors it is preferable to beat the egg whites together and then divide after they are beaten. Pans  $2\frac{1}{2}$  by  $2\frac{1}{2}$  by 5 inches will hold  $\frac{1}{6}$  of the above recipe. It is better to bake the whole recipe in a pan with an opening in the center to facilitate baking, but small portions bake well in a loaf. Let the baked cakes hang inverted in the pans until cool.

A. To determine the amount of mixing of sugar to yield the best texture and volume.

#### I. Standard method.

Beat enough whites at one time for the whole recipe. Add the cream of tartar and salt. Divide into 6 parts, using 38 grams of the beaten white for each  $\frac{1}{6}$  of the recipe. Bake at  $175^{\circ}\text{C}$ . ( $347^{\circ}\text{F}$ .). There should be several girls in this group. One girl should beat and weigh the egg whites. Each girl should do the same manipulation on each cake. Thus if one girl folds the first  $\frac{1}{4}$  of the sugar, she should do this operation on each cake, but no more, and pass it on to the next girl. Two girls can fold the flour, the first adding  $\frac{3}{5}$  and the other the remainder.

1. Add approximately  $\frac{1}{4}$  of the sugar, sprinkling it over the top of the beaten egg. Fold 5 times with a spatula. Repeat for each  $\frac{1}{4}$  of the sugar. This gives a total of 20 strokes for folding in all the sugar.

Sift approximately  $\frac{1}{5}$  of the flour over the egg and sugar mixture. Fold with 5 strokes of spatula. Add another  $\frac{1}{5}$  of the flour and fold a total of 10 strokes with the spatula. Add  $\frac{1}{5}$  of the flour and fold a total of 15 strokes. Add  $\frac{1}{5}$  of the flour and fold a total of 20 strokes. Add the last  $\frac{1}{5}$  of the flour and fold a total of 40 strokes.

2. Repeat 1 but fold each  $\frac{1}{4}$  of the sugar 10 times with the spatula.

3. Repeat 1 but fold each  $\frac{1}{4}$  of the sugar 15 times with the spatula.

4. Repeat A1, but fold each  $\frac{1}{4}$  of the sugar 20 times.

5. Repeat A1, but fold each  $\frac{1}{4}$  of the sugar 30 times.

6. Repeat A1, but fold each  $\frac{1}{4}$  of the sugar 45 times with the spatula.

What is the effect on the size of the cells and cell walls when the sugar is sufficiently mixed? When it is over-mixed? When it is insufficiently mixed? Can the flour be blended well if the sugar has not been sufficiently mixed? What is the effect on the texture and tenderness of longer mixing?

#### II. The meringue method.

Follow the same procedure as for A1, but do not beat the egg whites quite so stiff. The peaks should be soft and the tip end should round over readily. It may be necessary to decrease or increase each of the following parts by 5 or more strokes, depending on the stiffness to which the egg white is beaten. If desired  $\frac{1}{4}$  of the sugar may be sifted with the flour. Follow directions under A1,1 for folding the flour. Weigh out 38 grams of white for each part.

1. Add  $\frac{1}{4}$  of the sugar to be beaten in the egg white. Beat the sugar into the egg whites using 10 turns of handle of rotary beater or 10 strokes of whisk for each  $\frac{1}{4}$  of the sugar.

2. Repeat 1 but use 15 turns of rotary beater handle or 15 strokes of whisk for each  $\frac{1}{4}$  of the sugar.

3. Repeat 1 but use 20 turns of rotary beater handle or 20 strokes of whisk for each  $\frac{1}{4}$  of the sugar.

4. Repeat 1 but use 25 turns of rotary beater handle or 25 strokes of whisk for each  $\frac{1}{4}$  of the sugar.

5. Repeat 1 but use 30 turns of rotary beater handle or 30 strokes of whisk for each  $\frac{1}{4}$  of the sugar.

6. Repeat 1 but use 35 turns of rotary beater handle or 35 strokes for each  $\frac{1}{4}$  of the sugar.

Character of crust	Volume	Crumb					
		Size of cells	Size of cell walls	Tender-ness	Color	Moist-ness	Flavor

Results and conclusions.

B. To determine the amount of mixing of flour to give the best angel cake.

Beat enough eggs at one time to make  $\frac{1}{2}$  of the full recipe. Add cream of tartar and salt for  $\frac{1}{2}$  the full recipe. Divide the beaten egg white into three parts using 38 grams for each part. Use either the standard or meringue method of adding the sugar, with number of strokes found best under A. Divide the work so that each girl does the same manipulation on each cake.

1. After adding the sugar, add the flour. Fold in with 40 strokes. Follow directions for folding flour under A1,1.

2. Repeat B1, but use 10 strokes to mix each  $\frac{1}{5}$  of the flour and a total of 60 strokes.

3. Repeat B1, but use 15 strokes to mix each  $\frac{1}{5}$  of the flour and a total of 80 strokes.

What is the effect on the grain, the volume, and the tenderness of the cake when the flour is mixed too long? Can less than 35 strokes be used?

C. To determine the effect of beating the egg whites to different stages of stiffness on the texture of the angel cake.

Beat enough egg whites at one time to prepare  $\frac{1}{2}$  of the full recipe. Add cream of tartar and salt for  $\frac{1}{2}$  the full recipe. The first portion is to determine the effect of too little beating of the white so that the egg white can be weighed with as little beating as desired. Weigh out 38 grams of the beaten white and use the remainder for 2 and 3. Divide the work so that each girl does the same operation on each cake.

1. Add  $\frac{1}{4}$  of the sugar. Add each  $\frac{1}{4}$  of the sugar with the number of strokes and method found best under A. Fold the flour with the number of strokes found best under B.

2. Continue beating the egg white from C1, until it is about the same stiffness as that used under A and B. Weigh out 38 grams.

Add the sugar and the flour as in C1.

3. Beat the remaining egg white from C2, until it is very stiff, dry, and flaky. Weigh out 38 grams. Add the sugar and the flour as in C1.

Would longer mixing of the egg white in C1 partially overcome the lack of sufficient beating of the egg whites?

D. To determine the effect of varying the proportion of cream of tartar used in angel cake, and the method of adding the cream of tartar.

1. Prepare 1/6 of the recipe for a control. Add the sugar by method and number of strokes found best under A and the flour with the number of strokes found best under B.

2. Repeat D1, but omit the cream of tartar.

3. Repeat D1, but increase the cream of tartar to 2 teaspoons for the full recipe.

4. Repeat D1, but omit adding the cream of tartar to the egg. Sift the flour and the cream of tartar together 2 or 3 times, before adding the flour to the egg and sugar mixture.

E. To determine the effect of increasing the proportion of sugar used in the cake. (Formula II.)

1. Increase the sugar for the full recipe to 1½ cups. Beat enough egg whites for ½ the full recipe. Add salt and cream of tartar for ½ the full recipe. Beat the egg whites by method and amount found best under A, but leave them slightly under-beaten. Add the flour with number of strokes found best under B.

2. Beat the remainder of the egg whites from E1, the amount used in other experiments. Weigh out 38 grams and repeat E1.

3. Beat the remainder of the egg white from E2, until very dry and flaky. Weigh out 42 grams. Repeat E1.

When the sugar in the recipe is increased, should the egg white be beaten longer to coagulate a larger proportion, thus giving greater rigidity to hold the added sugar, or does over-beating lessen the rigidity of the egg white? What would be the effect of increasing the mixing of the sugar and the egg white? May the flour be increased to 107 grams when the sugar is increased to 1½ cups?

F. To determine the effect of reducing the proportion of flour in the standard recipe.

Reduce the flour for full recipe to 90 grams. Prepare 1/6 the recipe. Use meringue or standard method or both for beating eggs, beating an amount to give a desirable cake. Add flour as found best under B. If you think it advisable repeat the experiment reducing the flour to 80 grams.

G. To determine the effect of different baking temperatures.

Prepare ½ the full recipe following directions under F and using amount of flour found most desirable. Divide the batter into 3 equal portions. Bake one cake at 160°C. (320°F.), the second at 175°C. (357°F.), and the third at 190°C. (375°F.).

H. Use formula III, p. 360. Use any or all methods that may yield a palatable cake. Compare volume, texture and tenderness with cakes from the standard recipe.

I. Repeat H, using formula IV, p. 360.

J. Repeat H, using formula V, p. 360.

## Sponge Cake

## Experiment 70.

To determine the factors which influence the texture of sponge cakes.

*Recipe:*

Sugar.....	1 cup	200 grams
Pastry flour.....	1 cup	100 grams
Lemon juice.....	1 tablespoon	15 grams
Water.....	2 tablespoons	30 grams
Eggs.....	6	288 grams, yolks 108 grams, whites 180 grams
Lemon rind.....	1 tablespoon grated	
Salt.....	$\frac{1}{8}$ teaspoon	

## A. Method of mixing.

1. Prepare  $\frac{1}{6}$  of the recipe. Bake at  $160^{\circ}\text{C}$ . ( $320^{\circ}\text{F}$ .). Beat the egg yolk. Add the sugar, the lemon juice, the grated lemon rind, the water, and the salt. Beat until light, foamy, and lemon colored. Add the flour. Keep a record of the number of strokes used for mixing the flour. Beat the egg whites until they flow slowly when the bowl is partially inverted. Combine by folding the beaten whites into the egg and flour mixture. Keep a record of the number of strokes used for folding the egg whites in the flour mixture.

2. Beat the whole egg until light and foamy. Add the sugar gradually, then the lemon juice, lemon rind, water, and salt. Beat until light. Sift a portion of the flour over the top of the egg mixture and fold in. Continue until all the flour is used. Keep a record of the number of strokes used in folding the flour.

3. Add the lemon juice, lemon rind, water, and salt to the sugar. Stir until well mixed. Add the unbeaten egg yolk to the sugar and beat until light and lemon colored. Add the flour. Keep a record of the number of strokes used in mixing the flour. Beat the egg white until it flows slowly when the bowl is partially inverted. Add to the flour mixture, keeping a record of the number of strokes used for folding the egg whites.

4. Prepare  $\frac{1}{2}$  of the recipe. Make a sirup of  $\frac{1}{2}$  cup of sugar and  $\frac{1}{2}$  cup of water. Cook to  $118^{\circ}\text{C}$ . and pour slowly over the beaten egg whites. Beat the egg white while adding the sirup. Cool. Beat the egg yolks, adding the lemon juice, lemon rind, and salt to the yolks. Fold the beaten yolks into the egg white. Keep a record of the amount of folding used for the egg yolks. Sift a portion of the flour over the egg mixture. Fold in. Continue adding the flour until it is all folded into the egg mixture. Keep a record of the number of strokes used for folding the flour. Omit the 2 tablespoons of water in the recipe.

## B. Variations in amount of mixing the flour and the egg white.

Repeat the series under A, but increase or decrease the number of strokes used in folding the flour and the sugar so as to obtain the best texture in the cake.

## C. Vary the baking temperature.

## CHAPTER XI

### FLOUR AND BREAD

The composition of wheat may vary with several factors, such as varying rainfall, temperature, and other climatic conditions, irrigation, texture and composition of the soil, and the use of fertilizers. Bailey reviews all these factors and others in "The Chemistry of Wheat Flour."

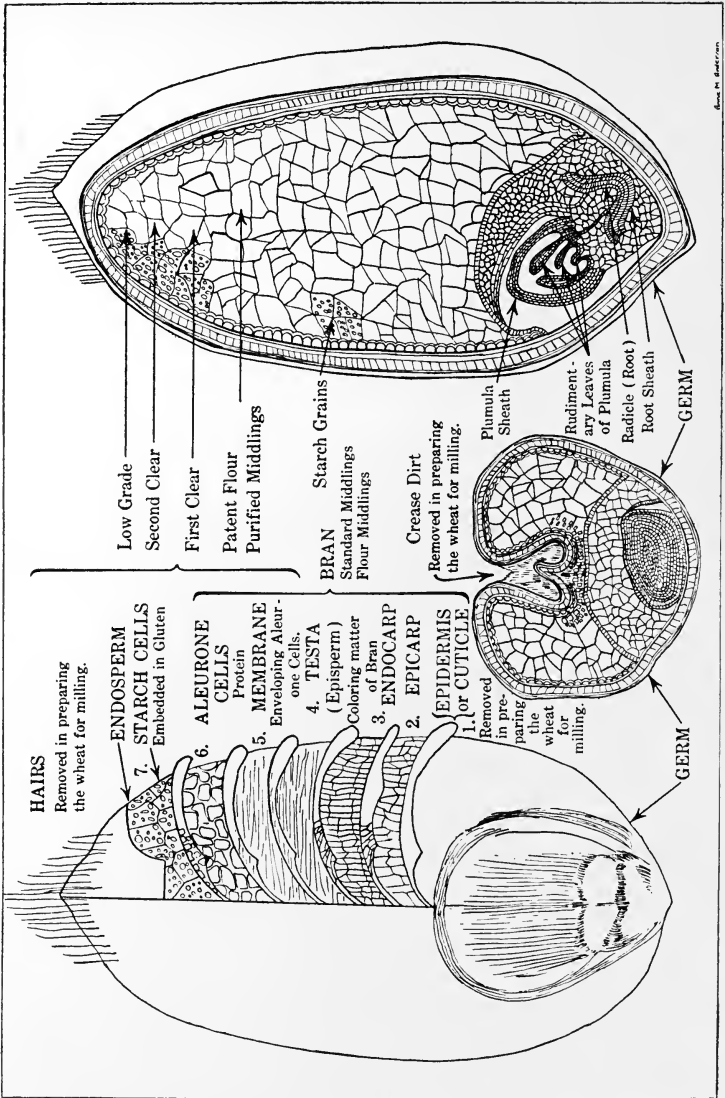
The kind of flour and to a great degree its composition depend upon (1) the milling process, (2) the classes of wheat from which the flour is milled, and (3) the purpose for which the flour is intended. Flour is also made from rye, buckwheat, barley, corn, rice, potatoes, bananas, lima beans, cottonseed, and soybeans, but the term flour refers to wheat flour when no grain or product is mentioned.

**The milling process and the structure of wheat.** The wheat kernel may be divided into three main parts: the bran, the germ, and the endosperm, the relative proportion of each part of the entire kernel being respectively about 14.5, 1.5, and 84 per cent. Milling is the process of separation of the endosperm from the bran and germ. When no separation is made, or all the flour streams are reunited, the flour is known as whole-wheat flour, but otherwise the completeness of separation determines the resulting grade of flour. If the separation is so complete that only the heart of the endosperm is used, the resulting flour may be called a "fancy" or "short" patent. In general, only about 72 to 75 per cent of the endosperm is obtained in white flour, the remainder constituting bran and shorts. Between the two extremes of flour, whole-wheat and fancy patent, are many other varieties.

The steps in the milling process may include the following: cleaning, tempering, breaking, sifting, or separating the primary products, purifying, reducing, bolting, flour blending, and bleaching.

The structure of the wheat berry is shown in Fig. 42. Layer No. 1, sometimes called the bee's wings by millers, the hairs, and the dirt on the berry, particularly that in the crease, are removed in the cleaning operations preparatory to milling. Layers No. 2 to No. 6, shown in the surface drawing, and the longitudinal and cross sections constitute the bran coats.

The gross appearance of a cross section of a wheat berry varies somewhat with the type of wheat and the ripening conditions. Hard wheats are more flinty and vitreous than soft wheats. The proportion of gluten is usually higher in hard than in soft wheats, and the gluten forms a continuous matrix in which the starch granules are imbedded. When the grain contains a large proportion of gluten, the starch granules, as it dries out in



Courtesy of International Milling Company, Minneapolis

FIG. 42.—The structure of a wheat kernel. The bran layers are shown peeled back from the kernel. The portion from which the different flours are obtained is shown in the longitudinal section.

ripening, are more firmly cemented to or held in the gluten matrix. In milling the vitreous wheats naturally tend to yield coarser particles and less free starch granules than soft wheats, unless the hard wheats are deliberately ground fine. If the weather is hot and dry after flowering of the wheat, a larger proportion of gluten and less starch are laid down in the kernel. It is known that vitreous barley has smaller starch granules than soft barley, and it is probable that this also applies to wheat.

In contrast to hard wheats, the soft wheats have air spaces throughout the endosperm. The endosperm is quite friable and naturally breaks into smaller particles in milling.

Tempering consists of adding a definite amount of water at a certain temperature to wheat berries, the proportion of water added depending on the moisture content of the wheat and other factors such as relative plumpness and hardness of the kernels. In tempering wheat the water is usually not left in contact with the wheat long enough for moisture to be absorbed by the endosperm. Thus the pliability and toughness of the bran coats are increased so that they are more easily separated from the endosperm. Sometimes, to prevent the endosperm from breaking into very fine particles, the water is added in two portions, part of the first addition being absorbed by the endosperm.

The germ because of its high fat content is easily flattened or flaked and is removed by bolting from the other constituents of the wheat berry during milling. The endosperm constitutes about 80 per cent of the wheat berry. The starch is more concentrated in the immediate vicinity of the germ and in the interior of the endosperm. The concentration becomes less and less towards the outer layers of the wheat berry. The starchy endosperm being drier and more friable tends to shatter more readily when the berries are fractured or broken between rollers.

In the first breaks, the wheat kernels are mostly broken into large fragments by the corrugated rollers. The coarser fragments, which are separated from the finer ones by sifting, are returned to the next set of break rolls of which there are 5 or 6. Other things being equal, a larger proportion of fine particles is obtained from soft wheat than from hard wheat during the first breaks.

Bolting or sifting, which occurs after each break, is the separation of the coarse particles, which are reground, fine granules of flour, which are not reground, and intermediate particles, which are sent to the purifier.

Purifying refers to a part of the milling process whereby particles pass over a sloping, vibrating sieve. At the entrance the meshes of the sieve are fine but gradually increase in size to the discharge end. As the particles travel down this sieve they are separated according to size. During this process controlled air currents lift out the flakier and more fibrous particles. The remainder of the particles, known as purified middlings because they are freer from branny, fibrous material, yield a more highly refined flour after reduction.

The purified middlings are ground between smooth iron rollers to reduce them to the desired fineness. Since the flour bolted from the first grinding of any stream of purified middlings is more highly refined, because it is freer of fiber than that produced by subsequent grinding of the coarser residues, it is often used in making the so-called "short" patent flours.

In separating the endosperm from the rest of the wheat berry and reducing it to flour, some small bran particles are broken from the bran coats. As these particles are formed they are separated from the flour stock and may be graded according to size and included in the various feeds. As it is impossible to prevent some flour particles' being removed with the bran, these flour particles may also be graded according to size and may become part of the feeds. The other portions into which the wheat berry may be separated, in order as the percentage of bran particles increases, are First Clear, Second Clear, Red Dog, Flour Middlings, Shorts, and Bran.

**Classes of wheats used for flour.** Wheats are classified in five main groups as follows: (1) white, (2) hard red spring, (3) hard red winter, (4) soft red winter, and (5) durum. Since the composition of the wheat varies with climatic and soil conditions to which it has been subjected in growing, it is natural that many variations in composition occur within each class. The sections in which the different classes of wheat are grown overlap to a greater or less degree. The major portion of the hard red spring wheat and durum wheat is grown in the North Central States of the United States and in Canada, whereas hard red winter wheat is grown chiefly in the South Central and Middle Central States. This class of wheat leads all others grown in Iowa, Nebraska, Kansas, Oklahoma, Texas, and Colorado. At present twice as much acreage is planted in hard red winter wheat as in any other class of wheat. Soft red winter wheat is grown in Missouri and the eastern half of the United States. It is also grown in some Western States, particularly Oregon, Washington, and Idaho. White wheat is grown to a limited extent in the northeastern part of the United States and in Michigan, New York, and on the Pacific Coast.

**Flour terminology.** Flour terminology had become confusing but as a result of the work of the committee on terminology of the Millers' National Federation, in cooperation with the U. S. Department of Agriculture, definitions for labeling have been worked out and progress has been made in clarifying the terminology. It has been suggested that grade be used to refer to the type of flour as determined by the milling process, whereas the word class be used to designate the kind of wheat from which the flour is milled. According to such a plan, grades of flour would be patent, clear, etc.; classes would be durum, hard- and soft-wheat flours.

*Definition of flour.* The definition of flour is from the Definitions and Standards for Food Products of the Service and Regulatory Announcements of the U. S. Department of Agriculture, issue of 1933.

"Whole-wheat flour, entire-wheat flour, graham flour, is the product



made by grinding wheat, and contains, in their natural proportions, all of the constituents of the cleaned grain."

Harrell and Benson state that whole-wheat flour may be of coarse, medium, or fine granulation.

"Flour, wheat flour, white flour, is the fine-ground product obtained in the commercial milling of wheat, and consists essentially of the starch and gluten of the endosperm. It contains not more than 15 per cent moisture, not less than 1 per cent nitrogen, not more than 1 per cent ash, and not more than 0.5 per cent fiber."

*Straight flour.* Straight flour (100% flour) is a milling term indicating that all the bolted wheat meal has been recovered from the wheat after removal of the feeds. It is not generally on the market and all commercial flours are derived from straight flour.

*Patent flour.* Patent flour may be made from any class of wheat and is the more refined portion of the wheat meal from which all or a portion of the clears have been removed. (How "long" or "short" a patent is depends on how much of the total flour is included. In general, most patent flours include about 85 per cent of the total flour obtained from the wheat. But a very "short" patent used in fancy cake flour may include only 25 per cent of the total flour.)

*Clear flour.* Clear flour is the less refined bolted portion of the wheat meal recovered in the manufacture of Patent flour. According to trade practise or demand, clear flour may be divided into First and/or Second Clears.

First Clear is the better portion of the Clear when separated into two parts.

Second Clear is the remaining portion of the Clears when First Clear is removed.

**The purpose for which the flour is intended.** *Hard-wheat flours.* Practically all durum wheat is used for the manufacture of semolina, which in turn is used for macaroni products.

In general bread flours are made from hard wheats, although suitable soft-wheat flour is used for baking bread in some sections. Bread flour is a term indicating a "strong" flour that has the capacity to make loaves of good volume texture and grain. The term "strong" indicates that the gluten has tenacity, cohesiveness, and elasticity. Bread flour usually contains more gluten and less starch, and the granulation is usually coarser than in either pastry or cake flour.

All-purpose, General-purpose, or Family flour are synonymous terms used for a flour which is suitable for most kinds of baking. It may or may not be a blended flour. It may have as a basis either hard- or soft-wheat flour. Hence, there are two types of all-purpose flours, and which is obtainable in a certain section depends on whether hard or soft wheat predominates in that section.

*Soft-wheat flours.* Since soft wheats usually contain a smaller quantity of

gluten than hard wheats, the flours from these wheats are generally more desirable, and particularly if the gluten is of fine quality, for cakes and pastry products than hard-wheat flours.

Pastry flour is a term indicating a flour usually milled from soft wheat, which is of fine granulation and has a low or moderate amount of gluten. It differs in baking quality from both bread and cake flours.

Cake flour is milled from soft wheat. It is a "short" patent. The granulation is very fine and uniform, the protein content is low but may be of fine quality. Cake flours are usually better grades of flour than pastry flours.

Cracker flour is milled from soft winter wheat. Micka states that because it constitutes nearly 90 per cent of the cracker it is largely responsible for the general character of the finished product. A desirable cracker flour differs from bread flour in color, absorption, and fermentation capacities. Because of the long fermentation period the inside color of crackers is quite uniform but the color of the flour affects the outside color and bloom of the cracker. A cracker flour has a lower water-absorbing capacity than bread flour and, since little sugar is added, the flour must itself furnish the necessary fermentative material.

The geographical areas in which the different classes of wheat are grown determine to a great extent the type of flour that predominates in local retail markets in these areas. For example, in Iowa it is very difficult to obtain soft-wheat flour, except in the specially prepared cake flours, the bread and all-purpose hard-wheat flours being found on the local markets. In Alabama it is just as difficult to obtain hard-wheat flours. In some sections or states both soft- and hard-wheat flours are readily obtainable.

*Bleaching of flour.* Bleaching can occur through aging or gradual oxidation of the carotene, but a large portion of flour is bleached at the mills in a short time. Nitrogen peroxide or chlorine, benzoyl peroxide or nitrogen trichloride, or a combination of two of these, is used for bleaching.

### Rye Flour

The Service and Regulatory Announcements define rye flour as "the fine-ground product made by bolting rye meal, and contains not more than 13.5 per cent moisture, not less than 1.36 per cent nitrogen, and not more than 1.25 per cent ash."

Bailey has reported formulas and methods for testing the use of rye flour in bread. There are five classes of rye flour, based largely on the color: white, light, medium, dark, and extra dark.

### Composition of Flour

Flour contains pigments, enzymes, cellulose, moisture, fat, mineral salts, carbohydrates, and proteins. All the constituents of flour are important in

that all affect the baking qualities of the flour and thus the product in which the flour is used.

### Color of Flour

Bailey states that the color of flour is due to five factors: (1) Granulation or size of flour particles, which affects the appearance of the flour and not that of the dough. Large granules appear darker than small ones. (2) Color changes due to mixing with water in contact with air at elevated temperatures are caused by enzymes found principally in the bran. (3) Dirt and foreign matter, as weed seeds, if highly pigmented, may become pulverized and color the flour. (4) A reddish-brown pigment is present in small quantities in flour made from "red" wheats. Highly refined flours from those wheats show less of these small bran particles containing the pigments.

(5) **Carotinoid pigments.** Flour contains the pigment carotene which gives it a creamy or yellow tint, the depth of color depending upon the amount of the pigment present. Because of the fineness of division of the flour particles its bulk includes a large proportion of air. The carotene is bleached by oxidation; thus, in aging, natural bleaching of the flour occurs. Markley and Bailey have reported that flour contains the following fat-soluble pigments: carotene, xanthophyll, and an unknown pigment.

(6) **Flavones.** The flavones are water-soluble pigments. Markley and Bailey state that flavones have long been known to exist as glucosides and from their study it appears possible that they will be found as esters of the fatty acids. The flavones are colorless in acid or neutral mediums but develop a greenish yellow tint in alkaline reactions.

### Enzymes

Wheat and flour contain many enzymes, some of which are important because of their action during fermentation of cracker and bread doughs. Others become active in the sprouted grain, hence affect bread making only rarely when some sprouted grain is included with sound wheat in milling. Of the numerous enzymes, the diastases or amylases and the proteinases are the most important from the standpoint of baking.

**Diastases.** Andrews and Bailey state that the chief function of the starch enzymes of wheat and flour is changing starch to sugars. In sound normal wheat and flour the diastatic activity is due primarily to the action of beta-amylase. When wheat germinates, a second "diastatic factor," termed alpha-amylase, is produced. Accompanying the activation of alpha-amylase are the phenomena of dextrination and liquefaction. Both amylases convert starch to reducing sugars, the alpha-maltase yielding alpha-maltose and the beta-amylase producing the corresponding beta sugar. The maximum

activity of beta-amylase occurs at  $pH$  4.5 to 5.1, whereas that of alpha-amylase is at  $pH$  5.6 to 5.8.

**Proteinases.** Until lately little was known about the proteolytic enzymes of flour except that they brought about hydrolysis of flour proteins. Balls and Hale have not only reported a method for estimating the proteolytic enzymes in flour but also the action of these enzymes. They state alteration of flour that takes place in bleaching and storage in air is due to a diminution of the proteolytic activity, brought about by the oxidation of the activator of the flour proteinase. Jørgensen states that wheat flour contains powerful proteolytic enzymes which are usually latent but activators such as glutathione or yeast-water stimulate these proteinases of flour. Such substances as  $KBrO_3$  and ascorbic acid, because they depress the activity of the proteinase, have been found to be good improvers of baking strength of wheat flour. Jørgensen has applied for a patent in the United States for such a use of ascorbic acid.

### Cellulose

The greater part of the cellulose of the wheat kernel is removed in milling, so that the amount in white flour is small.

**Bran.** Bran contains considerable cellulose and cellulose absorbs water slowly. Rahn describes the Schlueter process by which bran is steeped in hot water and treated for some time with moist heat. During this treatment the cellulose membranes are sufficiently hydrolyzed so that the cell contents are more readily digestible. The bran is then dried and put through a crusher and a fine grinding mill. In contrast to ordinary bran, the treated bran is said to keep indefinitely and absorbs water more readily and in larger quantity.

### The Moisture Content of Flour

Flour has been considered adulterated with water, under the federal standards of the United States, if the moisture content exceeded 13.5 per cent. Recently this standard has been changed to 15 per cent. It has been found by careful experiments that, when the moisture is determined by the water-oven method, 13.5 per cent is equivalent to 15 per cent by the new vacuum method.

Sanderson, in determining the variations in moisture content of flour during storage, decided that the moisture loss of flour varies less with 11.0 per cent of moisture. From different reports 11 to 13 per cent of moisture seems to be a normal content of flour over a large section of the United States.

Bailey states that flour responds more readily to changes in humidity than the wheat kernel, because of its fineness of division of particles and the greater exposure in handling it in sacks.

**Hygroscopic property of flour.** The starch of flour takes up and lets go of moisture very quickly. This affects the proportion of moisture needed for baked products such as bread and cake. Browne in determining the hygroscopic moisture of carbohydrates has reported that anhydrous starch ranked first in the amount of moisture absorbed at 60 per cent humidity in 1 hour. Over longer periods the starch did not absorb as much moisture as some of the sugars. Kent-Jones states that English flour has a moisture content  $\frac{1}{2}$  to 1 per cent higher than American flour on account of the higher humidity of the English climate.

### The Fat Content of Flour

The percentage of fat in white flour is low, since most of the fat is found in the germ which is removed during milling. But though present in a small quantity, the lipid content of flour is important. Some lipid constituents improve, whereas others injure the baking quality of flour.

Working has reported that "The gluten of low grade flour increased in tenacity when the phosphatide was removed by washing. The addition of phosphatides to flour in small quantities injured the gluten as determined by the feel of the hand washed gluten, the viscosity as measured by the viscometer, and by baking tests." Working suggests that the effect of phosphatides on gluten is similar to that of oil on rope. Lubrication of the strands of the rope lessens its strength and tenacity.

In a later paper Working reported that a small amount of phosphatide, such as the normal amount present in a good patent flour, may improve the baking quality.

Sullivan, Near, and Foley report that it is well known that increasing percentages of wheat germ in flour harm the baking quality of the flour. They investigated the effect of fat from wheat germ and of each fat fraction and its hydrolytic products on normal sound patent flour as judged by gluten washing and baking tests as well as by the Farinograph and Fermentograph. Fat from the fresh germ was not found to be deleterious to the baking quality.

They say: "The only germ-fat constituents which were found to be injurious were the unsaturated fatty acids which develop upon aging due to hydrolysis of the triglycerides and, what is much more important, the subsequent oxidation products of these unsaturated acids.

"Higher saturated fatty acids (which may occur in small amounts in any wheat product as a result of hydrolysis of the triglycerides) have only a very slight 'shortening' effect on the flour-water curves. Unsaturated fatty acids (oleic, linolic, and linolenic) cause a decided change in the shape of the curves and produce 'short' tough glutens when added to patent flour. These unsaturated acids, however, are only slightly detrimental to the baking quality of a flour. The bake is not harmed as much as one would expect from the feeling of the gluten."

The effect of unsaturated fatty acids on flour is in direct correlation with their increasing number of double bonds. The oxidation products of these unsaturated fatty acids have a significant damaging effect on the baking quality of flour.

In addition, these investigators have shown that extracting fat from flour with ether injures the baking quality of both strong and weak flours. The addition of flour fat brought the quality of the ether-extracted flour back to normal but the addition of germ fat did not. They concluded that this indicated that flour fat contains some constituent or groups of compounds necessary for good baking quality of flour, which are absent in the germ lipoids.

### The Ash Content of Flour

Sullivan found that the total ash content of wheat averaged 1.86 per cent. In general the ash content of a flour increases as more of the wheat kernel is used. Whole-wheat flour contains all the ash of the wheat, and patent flour contains the smallest percentage of total ash. Patent flour may contain as low as 0.25 to 0.3 per cent of total ash. Sullivan gives the inorganic constituents present in relatively larger quantities in flour as shown in Table 45:

TABLE 45

INORGANIC CONSTITUENTS PRESENT IN RELATIVELY LARGER QUANTITIES IN WHEAT, PATENT FLOUR, AND BREAD

(Sullivan)

Inorganic constituent	Wheat <sup>1</sup> %	Patent flour %	Bread %
Total ash.....	1.86	0.45	2.77
Potassium.....	0.571	0.168	0.200
Phosphorus.....	0.428	0.113	0.140
Sulfur.....	0.194	0.165	0.192
Magnesium.....	0.173	0.029	0.040
Chlorine.....	0.055	0.051	1.005
Calcium.....	0.048	0.016	0.080
Sodium.....	0.009	0.003	0.660
Silicon.....	0.006	0.005	0.005

<sup>1</sup> Calculated to dry basis.

Phosphorus is found in inorganic combination and in organic combination in phytin, nucleic acid, and lipoids.

Sullivan states that potassium probably has some direct bearing in the

translocation of sugars and starch formation and that a potassium deficiency influences the respiration rate of plants and may have some rôle in the activity of diastatic enzymes.

Magnesium is found in excess of calcium in plants, whereas the reverse is true of animal tissues. It is present in chlorophyll and Sullivan states that it takes some part in the transfer of phosphoric acid through plant tissues. It may exist in the wheat pericarp as the magnesium salt of inositol phosphoric acid. It is found in larger quantity in stronger wheats than in weaker wheats, and there is a correlation between the percentage of magnesium and protein content.

Calcium is essential for the growth of plants. It is present in both inorganic and organic combination. Sullivan states plants deficient in calcium are unable to assimilate nitrates and accumulate carbohydrates in large quantities. Sullivan and Near have reported the potassium, calcium, magnesium, and phosphorus content of glutens in three grades of flour. Their investigation shows that the calcium content is highest in glutens of highest strength, and potassium and magnesium increase as the tenacity of the gluten decreases.

Calcium acid phosphate is often added to soft-wheat flour and sometimes to high grades of flour. This practise is very common in the South. A great deal of this flour is used in quick breads like biscuits. The addition of the calcium acid phosphate is said to improve the volume, quality of crumb, texture, and color of biscuits.

Sullivan states that the inorganic constituents—iron, manganese, copper, zinc, boron, cobalt, iodine, flourine, and nickel—all play a significant rôle in plant physiology. The addition of certain of these rare minerals, in as little concentration as one part per million, to nutrient solutions in which plants are grown permits normal growth and production, although too great a concentration of some of these elements has undesirable effects.

Gericke studied the effect on bread scores of supplying to wheat grown in liquid media the following salts during the latter part of the growth period:  $\text{NH}_4\text{NO}_3$ ,  $\text{Ca}(\text{NO}_3)_2$ ,  $\text{KNO}_3$ ,  $\text{Mg}(\text{NO}_3)_2$ , and  $\text{NaNO}_3$ . He decided the physical state of the protein was determined by the nature of the salt solution surrounding the protein during its synthesis and translocation in the grain. Quality in bread varies with the quantity and quality of the protein in the flour. Bread from flour of wheat grown in  $\text{Ca}(\text{NO}_3)_2$  scored exceptionally high. The order in decreasing desirability of scores for bread was:  $\text{Ca}(\text{NO}_3)_2$ ,  $\text{KNO}_3$ ,  $\text{NaNO}_3$ ,  $\text{Mg}(\text{NO}_3)_2$ , and  $\text{NH}_4\text{NO}_3$ , though there was little difference between sodium and magnesium. However, the ammonium nitrate was definitely the lowest-scoring bread.

Gericke found that the effect of chloride salts supplied to wheat grown in liquid media on bread scores was in the following order, the highest being given first:  $\text{CaCl}_2$ ,  $\text{NaCl}$ ,  $\text{MgCl}_2$ , and  $\text{KCl}$ . The best bread was obtained from the wheat supplied with  $\text{NH}_4\text{Cl}$ , but this was the only salt

supplying nitrogen and hence the only wheat which gave a flour with a high protein content.

### Sugars

**Sugar.** Flour contains small amounts of sugars. The content of maltose is from  $\frac{1}{2}$  to 1 per cent. The amount of sucrose averages approximately 1 per cent but may reach 2 to 3 per cent. Dextrose may not be present in the flour but is found in bread dough. Dextrin is present in the flour in very small quantities.

### Starch

**Uses.** Starch, either alone or in flour, of which it may compose as much as 75 per cent and averages 65 to 70 per cent, is used in cookery: for thickening, as in soups and sauces; to form molded gels, i.e., cornstarch puddings and similar desserts; and, because hydrated starch has adhesive qualities, as a cementing or binding material for holding pieces of food together in the sauce base of croquettes and in the framework of such baked products as muffins, biscuits, cakes, and breads. Hence its characteristics of special interest in food preparation are its gel-forming properties. Alsberg (*Wheat Studies*) has given an excellent review of the rôle of starch in bread making.

**Sources of starch.** Most of the starches and starchy foods used in food preparation are obtained from the cereals: rice, barley, rye, corn, and wheat. Starch is also obtained from tubers, potatoes and sweet potatoes being the principal sources. In addition tapioca, arrowroot, cassava, and some other starches are used to a limited extent.

Starch from different sources varies in size, shape, and properties. Some starches are more suitable for some purposes than others. Some of these differences are in thickening capacity, adhesiveness, ease and rate of hydration, and rate of hydrolysis by diastase. Samec states there are two possible explanations for these differences. (1) It may be supposed that starch is a homogeneous substance existing in many different colloidal conditions and (2) it may be assumed that starch is a heterogeneous system built up from a polysaccharide (or several kindred polysaccharides) together with inorganic or organic substances which accompany it. Under the first condition the properties would result because of different colloidal conditions and under the second condition the components with the starch would modify its properties.

**Size and shape of starch granules.** Sjoström has published excellent photomicrographs of the natural and gelatinized starch granules. Butcher gives excellent descriptions, and Scott gives both descriptions and illustrations. Starch is laid down as discrete particles called granules. Many



granules are compound, i.e., composed of aggregates of 2 to 25 or more granules. Some starch granules have a characteristic black spot called the hilum, which is an air space visible microscopically as a black spot. The hilum, even in varieties in which it is a definite characteristic, is not always present in all granules. In some starches distinct concentric markings or striations occur which are visible because certain portions of the granules contain less water and thus are denser than other portions. Naturally the size and to a certain extent the shape will vary with the growing conditions, so that sizes reported in the literature vary considerably.

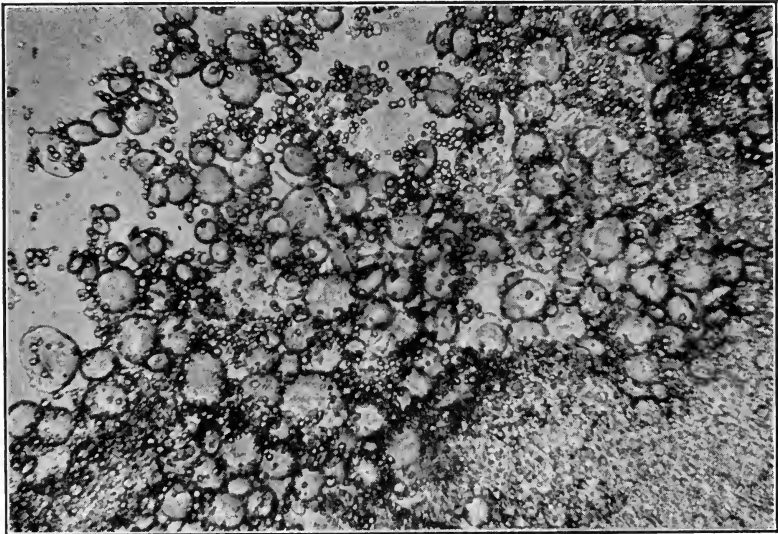


FIG. 43.—A photomicrograph of flour with enough water so that it will stick to the slide. Note that the starch granules are both oval and round. Magnification approximately  $\times 100$ .

Wheat granules are of two shapes and sizes. They are embedded in a more or less continuous matrix of gluten, a relatively larger number of the granules being free or not embedded in the gluten of soft-wheat than in hard-wheat flours. Larger granules average 25 to 35 microns in diameter and are oval and lenticular (bun shape, being flatter on one side). The small granules are circular and average about 3 to 5 microns. The hilum may show as a circular spot, and striations if present are faintly visible in large granules only.

Rice starch is composed of aggregates of granules, though the polygonal (angular) granules are all small, 3 to 8 microns. No striations are visible and the hilum is stellate and visible only at high magnification.

Cornstarch granules are, according to the variety, polygonal or round. The size averages 10 to 25 microns and few aggregates are found. The

hilum is stellate and in the center, and sometimes shows as a crack. Striations are very indistinct.

Potato starch granules vary in size, the large ones being egg or oyster-shaped, the small ones usually circular. The diameter is usually 60 to 100 microns but may vary from 15 to 100 microns. The hilum is an annular or circular spot at the narrow end of the granule. The striations are usually very distinct in large granules, somewhat ring-shaped with wider spacing at the broad end.

**Constitution of starch.** A perusal of the literature of starch chemistry shows no unanimity of opinion in regard to the naming of the starch components, their number, nor some of their properties. However, it should be remembered that starch, as it is found in the plant tissues, is only one of many other components. It is separated from these other components by physical means and often, when the chemist starts to work with it, is a modified starch, the modification occurring through physical or chemical treatment.

Starch may occur as free starch or combined with phosphoric acid, with phosphorus and protein, or with free fatty acids. Samec states silicic acid is always present in starch. Many of the properties and characteristics of starch vary with its constitution.

*The starch molecule.* There seems to be agreement that cellulose is composed of beta-glucopyranose units, whereas starch is composed of alpha-glucopyranose units linked into a continuous chain. The terminal units of such a chain differ, because of their position, from one another and from the other units in the chain. One terminal unit should have reducing powers, just as glucose has reducing power; but the greater the number of glucose units combined as in starch, the less the relative reducing power should be. There is no agreement as to the number of glucose units constituting starch. Haworth states that he believes the chemical unit of starch to be composed of about 30 glucose units. However, he adds that these chemical units must aggregate to form physical units of much larger size. Richardson, Higginbotham, and Farrow have reported that the average chain length of starch varies from 460 to 1470 glucose units. Still longer chains than these have been reported.

In general the longer the starch chain the less its solubility. Very short chains broken from a long starch chain, i.e., glucose and maltose, or short chains of these units, are completely soluble. Dextrins, which according to Haworth may be composed of 12, 16, 17, or 18 glucose units, are more soluble than starch and give reddish colors with iodine. The paste- or gel-forming characteristics are also affected by the chain length, shorter chain products having less and less ability to form pastes.

*Alpha- and beta-amylase.* Generally starch is said to be composed of two substances, though sometimes more are listed, a soluble portion and a more insoluble one. Samec says there is a continuous transition between the soluble and less soluble portions. The nomenclature used for these two

substances is varied and confusing both in the earlier and in the present-day literature. Thus at present the terms most often used for the more insoluble fraction are alpha-amylose, amylopectin, and amylo-cellulose, whereas the soluble portion is designated as beta-amylose or just amylose. The proportion of alpha- and beta-amylose varies in starches from different sources, and even in different samples from the same species. In addition, different methods of separating the two fractions and different pre-treatment of the starches would undoubtedly lead to varying relative proportions' being reported by different investigators. In starch pastes or solutions the beta-amylose often changes back to the insoluble form, a process called retrogradation. Richardson, Higginbotham, and Farrow state that natural or "unmodified starches contain chains of varying lengths and it appears plausible to suggest that the shorter, more easily soluble chains constitute the amylose (beta-amylose) fraction, whereas the longer chains make up the amylopectin (alpha-amylose). The amylose retrogrades because the original separation has been made on material not in equilibrium or at such a temperature that on cooling or concentrating its solutions the solubility of some of the chains is exceeded and precipitation must follow. Amylopectin does not retrograde because it is already precipitated, though heavily hydrated." Thus differences in starch gels might be expected at boiling and room temperatures because the solubility of the soluble starch increases with higher temperatures.

There is evidence that in natural or unmodified starches not more than 20 per cent of the starch and often less is soluble, though this varies with the source of the starch.

Many investigators have reported that alpha-amylose is the starch component to which paste-forming properties of starch gels are due, but others have reported that beta-amylose imparts the mucilaginous qualities.

*Phosphoric acid.* Samec states that in some species of plants both alpha- and beta-amylose are combined with phosphoric acid; in starches from other species these two components are linked with nitrogen and phosphorus. Other investigators have reported that the phosphorus is combined with only the alpha-amylose fraction. Alsberg states that in wheat starch the phosphorus is found only with the alpha-amylose fraction.

Alsberg states that Fernback found that small granules of potato starch contained a larger proportion of phosphoric acid than the larger granules, but this proportion has not been determined for wheat and some other starches.

Samec states: "Esterification with phosphoric acid, thus introducing a group with ability to ionize, greatly increases the hydration capacity and does not essentially decrease the tendency to association.

"If a starch paste be heated under pressure to 120°C., the high viscosity of the paste, the proportion of the undialysable phosphoric acid, the quantity of substance which can be transported by the electric current in a given time, and the precipitability by alcohol diminish, whilst the electrical con-

ductivity of the solution rises but the magnitude of the molecular aggregates does not change in the same degree."

Therefore Samec believed there was some correlation between the phosphoric acid content and the high viscosity of starch pastes. Hence he tried phosphating potato amylose with the following result:

	P <sub>2</sub> O <sub>5</sub> content	Relative viscosity of a 1-per cent solution	Color with iodine
Amylose . . . . .	0.00	1.008	Pure blue
Phosphated amylose . . . . .	2.06	43.1	Pure blue

From these results it appears that phosphoric acid may have some relation to the viscosity of starch pastes. Other factors affecting viscosity will be discussed later.

*Fatty acids.* Taylor and Morris make a further distinction between the two starch fractions from the fact that the insoluble residue carries certain high molecular-weight fatty acids combined with its carbohydrate. This insoluble fraction is called alpha-amylose and the soluble fatty-acid free portion is designated as beta-amylose. In potato starch pastes or solutions all the starchy material may be dispersed and, because potato starch contains no fatty acids, Taylor and associates question the existence of alpha-amylose in potato starch as it exists in cornstarch. They state that because the beta-amylose retrogrades on standing to a residue which resembles alpha-amylose except in its fatty-acid content, many investigators report the presence of alpha-amylose in potato starch.

The fatty acids may be split from the carbohydrate by long acid hydrolysis or with lipase-free amylase. Taylor and associates report that unsaturated fatty acids are liberated before the saturated ones.

Samec states that "careful researches concerning the colloidal changes which occur because of esterification of the starch substance with fatty acids are not as yet available, but we assume that the hydration capacity will thereby be decreased since longer chains of C-H<sub>2</sub> are introduced into the molecule. The hydration capacity is also decreased by compounds containing phosphorus and nitrogen."

Cereal starches contain a relatively higher percentage of fatty acids. Potato starch contains no fatty acids but has a relatively high phosphorus content. Wheat also has a relatively high phosphorus content. Taylor states that roughly, those starches having a relatively high fatty-acid content may have a relatively low phosphoric-acid content and *vice versa*.

**Starch paste.** Starch granules added to cold water swell slightly. According to Alsberg the axes may increase as much as 15 per cent. Such swelling is not like that in hot water inasmuch as there is no change in structure observable under the polarizing microscope. If the starch is dried rifts may appear in the granule, and the dried starch granules are deprived of their power to reassume their former volume when wetted. When a small quantity of starch is mixed with cold water, a thin, milky, non-

viscid suspension is formed. If left standing, the starch granules settle to the bottom of the container and the supernatant liquid appears clear. If the starch suspension is heated a change takes place. It becomes thick, forming a paste which is opaque or transparent. The viscosity of the warm paste is far greater than that of the water suspension, but on cooling it loses some of its fluidity, becoming less plastic and more viscid, firm, or stiff. Alsberg has suggested that the reason for the loss of plasticity of the cool paste is that it regains some of its former rigidity at lower temperatures and that the surface of the granules may be more sticky at the lower temperature, thus preventing one granule from moving or flowing so easily past another. It has also been suggested that some of the starch is less soluble at the lower temperature.

When cornstarch is heated with water the resulting paste is clear or transparent. When flour is used the paste is opaque. It is for this reason that a clearer color is obtained when cornstarch is used with colored fruit juices than when flour is used. Samec ascribes the opaque color with wheat starch pastes to the combination of the wheat starch with phosphorus and protein. In another reference he says, "Pastes from wheat starches are white, cloudy, and a little slimy. The starches of cereals do not contain as large quantities of phosphorus, but contain fatty acids. Pastes from starch of such starch are 'pasty' and not 'pectinous.'" Elsewhere it has been stated that combination of starch with phosphorus increases, whereas fatty acids decrease, the hydration capacity, which may have some effect on the translucency of the paste.

*Granule injury.* If starch granules are injured or ruptured in milling or in their separation from other material, some soluble starch is found dispersed in cold solutions; and with increasing proportions of soluble starch the unheated solution becomes more viscid, the heated solution correspondingly less stiff or viscous. Long grinding appears to break some of the starch chains into shorter units.

**Gelatinization.** The change upon heating a cold water starch suspension, so that a transparent or opaque, plastic, viscid product that forms a gel results, is known as gelatinization. Gelatinization depends upon the starch's being heated to a definite temperature, but the temperature at which gelatinization starts depends upon (1) the length of time the granule is wet before it is heated, (2) the kind of starch, (3) the size of the granule, and (4) possibly the salts in the water or combined with the phosphoric acid of the starch.

During gelatinization some starches tend to disperse, that is the physical units become smaller or the granule may disintegrate. With other starches most of the granule may remain intact but may assume a typical hydrated shape. Thus the photomicrographs of Woodruff and of Sjostrom indicate that wheat starch when hydrated tends to become kidney-shaped.

Gelatinization occurs and extends over a wide range of temperature. Swelling may start and the paste becomes more viscid at a fairly low tem-

perature, but complete swelling and maximum stiffening ability may not occur until the starch is heated to a much higher temperature.

Samec says that, if starch granules have been wet or soaked for some time before heating, gelatinization begins at a lower temperature. This gives at least a partial explanation for the shortened cooking period of soaked cereals.

*The kind of starch.* Richardson, Higginbotham, and Farrow state that potato starch gelatinizes more readily than sago or cornstarch. They found that cornstarch gelatinizes slowly in water at temperatures up to 100°C. and in pastes prepared by heating for 30 minutes at this temperature the granules, although swollen, are far from completely dispersed in the solution. The gel formed on cooling such a paste is quite distinct in type from that of potato, in which the granules are dispersed to a much greater extent. A sago gel may be regarded as intermediate in type between those of potato and cornstarch.

Alsberg and Rask report that wheat and maize starches change little until a temperature of 65°C. is reached, when they begin to thicken slightly, thus increasing the viscosity.

Woodruff and Nicoli heated 5-per cent starch suspensions by weight in a water bath at such a rate that 38 minutes were required for the paste to reach 90° and 22 minutes longer to reach 99.5°C. They found the translucency increased quite suddenly at a temperature specific for each starch, this temperature not being sharp but covering a range of 1° to 2°. Heating a longer time to a higher temperature did not increase the translucency. This temperature was as follows: Corn, 86-87°; wheat, 87-88°; rice, 84-85°; potato, 60-70°; arrowroot, 79-80°; and cassava, 74-75°C. It was necessary to heat each starch to 90° or higher for maximum gelatinization.

*The size of the starch granules.* Alsberg states that Nägeli found that larger granules of potato starch begin to gelatinize at 55°C., whereas the smallest granules do not begin to gelatinize until a temperature of 65°C. is reached. Suggested reasons are that the walls of the larger granules may be thinner or that large granules in swelling necessarily develop greater internal pressures per unit of granule surface than small ones.

The effect of large granules gelatinizing at lower temperatures and swelling more rapidly than small ones is indicated by Alsberg. Large granules in gelatinizing first swell and absorb more water which may affect the plasticity of the baking dough. "If the average granule size is small, this effect would come later than if the average size is large." Other things being equal, the longer the dough remains plastic, presumably, the greater will be the volume of the baked loaf. The size of the starch granules might also apply to textures and volume obtained in cake.

*Effect of salts.* In studying flocculation of starch pastes Samuel investigated the effect of different metallic salts and found their action to be varied. Some lowered the gelatinization temperature considerably.

**Viscosity of starch pastes.** Viscosity of pastes made from the same concentration of starch vary (1) with different starches, (2) with its phosphoric acid content, (3) with the phosphorus salt content, (4) with the temperature to which it is heated, (5) with the degree of injury or grinding of the granule, (6) possibly the proportion of beta- and alpha-amylase, and (7) with the length of the starch chain. Chain length may in turn be affected by application of dry heat, by boiling with water, or by acid and enzyme hydrolysis.

*Different starches.* It has long been known in food preparation that starches from different sources need to be used in different concentrations, if the product to be served is stiffened to the same degree.

Woodruff and Nicoli determined the stiffness of starch gels from 5 per cent concentrations of starch. The results, arranged in order of decreasing stiffness are: corn, wheat, rice, potato, arrowroot, and cassava. Other differences noted were: Of the three cereal starches, rice was the most translucent and tender when cut; corn was the firmest, the cold gel being chalky white; and wheat was intermediate between these two. For the other starches, the potato paste was ropy and too gummy to leave the mold well so that it gave a poorly formed gel, although quite transparent; arrowroot gave a still softer and more transparent gel; and cassava starch gave only a viscous fluid. It was necessary to heat the gels to 90°C. for maximum stiffening, but heating of any one starch to 90°, 95°, 99.5°C. gave gels indistinguishable from each other.

*Phosphoric acid.* Samec's results showing the increased viscosity of phosphated starch have been given in the discussion of phosphoric-acid content of starch. From these results he concluded that the viscosity of starch pastes could be reduced in two ways: (1) by removing the phosphoric acid and (2) by reducing the size of the molecule. In general, paste formation increased with increased phosphoric acid content, but this did not hold for wheat starch. Samec believes this discrepancy may be explained on the basis that phosphoric acid in wheat starch may be present as a compound with the proteins.

In general smaller granules gave richer or stiffer pastes than larger granules, which Samec ascribes to the relatively higher phosphorus content of the smaller granules.

*Phosphorus salt content.* In separating starch by electro dialysis Samec states the amylophosphoric acid isolated in this way proved to be a dibasic acid. The solutions of various amylophosphoric acid salts not only gave pastes with differences in viscosity but also affected other properties. Thus copper and iron amylophosphate paste separated badly, the calcium amylophosphate tasted like chalk, magnesium and ammonium caused a slight burning and pricking sensation on the tongue, respectively, and sodium and potassium were reminiscent of wheat flour.

*Temperature to which the starch is heated.* Although the starch may swell to a certain extent at lower temperatures, it may not reach its maxi-

imum stiffening power until a higher temperature is reached. Thus Alsberg and Rask found the maximum viscosity of wheat starch occurred at 95°C. Woodruff and Webber have shown that a 5 per cent wheat starch paste must be heated to at least 90°C. before the resulting gels will form moldable gels, such as would be served for puddings. Furthermore, rapid heating to this temperature gave a better-formed gel than did slow heating. But temperatures of 95°C. or above gave the firmest gels obtained with this concentration.

For cornstarch paste Alsberg and Rask found the maximum viscosity at 91°C., but Richardson, Higginbotham, and Farrow's results indicate that maximum swelling of some cornstarch pastes does not occur until a temperature of 100°C. is reached.

*Degree of grinding.* Samec states: "The capacity of a starch to form paste decreases with continued grinding of the starch and the grinding also peptizes the starch to such an extent that it can pass through ultra-filters." Alsberg found that in flour ground until the granule walls are broken a larger percentage of the starch is dispersed. A higher percentage of such flour is required to produce a paste of definite thickness. His explanation of this is that starch from the broken granules passes into solution and does not thicken as much, hence a greater quantity is needed to produce a paste, for there are fewer whole granules to swell and occupy the volume of the suspension and thus produce stiffening or thickening. During gelatinization starch may absorb about 30 times its weight in water. The smaller the number of granules broken or dispersed, the smaller the percentage of starch required to produce a paste of definite stiffness.

*The proportion of alpha- and beta-amylose.* Samec says that paste formation depends on having a proper balance between the tendency to associate and to hydrate. With potato starch, and starches from similar species, this relationship is attained by the presence of both amylo-amylose and erythro-amylose, and by esterification of the polysaccharid with phosphoric acid.

*Length of the starch chain.* Richardson, Higginbotham, and Farrow state that Staudinger has shown that for many types of long-chain polymers there is close correlation between the chain length and the viscosity of the solution. This relation was found to hold with sago starches but with other starches the relation was not found, so that it was suggested that other factors, such as distribution of length, rate of gelatinization, and degree of hydration of the chain molecules are as important as chain length in determining viscosity. Natural starches contain chains of varying lengths and it may be that the average chain length is greater for some species of starches than for others. However, it is known that dextrins have shorter chain lengths than starch, and they have little or no paste-forming properties.

When starch is dextrinized by heat or broken into shorter chain lengths by hydrolysis, either by diastase, acid, or other means, the stiffening power is decreased. Thus more of browned flour is required for thickening gravies and sauces than of the unbrowned flour.



*Acid.* When starch pastes are treated with acid, hydrolysis of the glucoside linkages takes place and shortening of the molecular chain occurs. Richardson, Higginbotham, and Farrow suggest that the attack occurs at random along the starch chains, so that in any paste of acid-modified starch there is a wide distribution of chains of varying length. As hydrolysis proceeds an increasing number of shorter chains is produced, the reducing power is increased, and the stiffening power decreased. Hydrolysis with acid is more rapid as the temperature increases, which gives an explanation for adding lemon juice to the partially cooled gel of water, cornstarch, sugar, and egg yolk. Hydrolysis is also speeded by increasing the concentration of the acid.

*Boiling and enzyme hydrolysis.* Hydrolysis is also brought about by diastatic enzymes and by boiling with water, the last more rapidly under pressure at temperatures above boiling.

*Commercial soluble starch.* The commercial soluble starches should not be confused with soluble starch occurring naturally in food products. Commercial soluble starches have been treated, usually with acid, and although they are more soluble, their properties, such as stiffening power, are also modified.

The effect of acid upon the thickening power of starch has been known for a long time. If cornstarch, lemon juice, and water are boiled together, the resulting paste is not as thick as one made with the same amount of cornstarch and liquid, but without the acid.

*Sugar and starch.* Woodruff and Nicoli have reported that pastes made from 5 grams of corn, wheat, rice, potato, arrowroot, or cassava starch and 95 grams of water required heating to 90°C. or higher before the cooled gels were strong enough to retain the shape of a mold. When 10, 30, 50 or 60 grams of sucrose were added to the above quantities the three root starches formed increasingly softer gels with increasing amount of sugar, the 50 and 60 grams giving a sirup. Although the three cereal starches showed increasing transparency and tenderness with increase of sugar, a gel that would not mold was not obtained until more than 50 grams of sucrose were added. A sirup was obtained with 60 grams of sugar and the cereal starches.

### The Results of Fine or Over-Grinding upon Flour

Bakers have known for a long time that flour ground too finely does not produce so good a quality of bread as flour that has not been over-ground. Alsberg and Griffing have reported the following for over-ground flour. Before over-grinding, the starch granules clumped together under the microscope; in the over-ground flour they were scattered. Over-grinding injured the starch, and as previously stated the greater the degree of injury the more the starch was dispersed. Diastase acted on the whole granule rather slowly, but with many injured granules and the increase in

cold water extract the action of diastatic enzymes in converting starch to maltose was more rapid; as a result, the rate of fermentation in bread making was increased. Alsberg has suggested adding some over-ground flour to flour reported low in diastase. Since the injured granules swell in cold water they absorb a larger proportion of water. Alsberg states that in the very severely over-ground flours the swelling may resemble heat gelatinization. Thus in severe over-grinding the baking quality is reduced although the hydration capacity of the flour is increased. Usually increased hydration capacity means increased baking quality. Moderate over-grinding did not affect the gluten but evidence was found that severe over-grinding injured the gluten.

### Effect of Aging on Flour

It is commonly accepted that aging, particularly during the first 4 or 5 weeks, improves the quality of flour for making bread. Dunlap has reported that he has always obtained better results with aged than with fresh flour. Some of his results are given in Table 46.

TABLE 46

THE EFFECTS OF INITIAL  $\rho$ H OF FLOUR UPON BAKING RESULTS (*Dunlap*)

	$\rho$ H	Acidity	Total minutes fermentation	Volume cc.	Color, per cent	Texture, per cent	Value, per cent
Fresh.....	6.12	0.139	215	2160	100	100	100.0
Matured I.....	5.90	0.158	198	2250	103	102	103.0
Matured II.....	5.69	0.178	186	2300	104	103	104.5
Matured III.....	5.48	0.198	173	2400	105	104	106.7
Matured IV.....	5.29	0.216	153	2520	106	105	100.2

Sherwood and Bailey report that loaf volume, color, and absorption improve during the first few months of aging, but the loaf volume may diminish after extended storage, even though the color and hydration capacity continue to improve. They found that proteolytic activity gradually decreased in storage, sprouted wheat flours retaining their activity in storage for a few years. The improvement in baking quality with aging has been ascribed to the increasing acidity, the increase in free fatty acids, and the diminution of proteolytic activity.

**Acidity.** The acidity of flour increases in storage, the  $\rho$ H of aged being lower than that of freshly milled flour. However, Bailey believes that the increased acidity is not the only factor responsible for improve-

ment in baking strength, for, if this were the case, the baking quality could be improved by the addition of acids to doughs from fresh flours.

**Free fatty acids.** Kozmin attributes the improvement with aging to the development of free fatty acids. The removal of free fatty acids rejuvenated the flour, its bread-baking properties returning to their original state. In turn, the addition of free unsaturated fatty acids produces the same effect as natural aging. Unsaturated fatty acids had more effect than saturated ones. Aging or the development of free fatty acids occurred more rapidly as the storage temperature increased.

Sullivan, Near, and Foley state that their results agree well with those of Kozmin, with the exception that American flours do not show the improvement which European flours do with the presence of free, unsaturated fatty acids. It was found, however, that after oxidation of the unsaturated acids had occurred that the baking quality was seriously damaged.

**Proteolytic enzymes.** Balls and Hale state that the changes that take place in the quality and behavior of flours after bleaching or storage in air are due to the diminution of proteolytic activity.

### The Proteins of Flour

Osborne in his classical work on the wheat flour proteins reported only a small fraction soluble in water. This fraction contained leucosin and albumin, plus proteose or non-protein nitrogen. A small fraction was extracted by dilute salt solution and this globulin fraction constituted about 0.6 per cent of the wheat kernel. Gliadin, a prolamins, constituting about 40 per cent of the total protein, was soluble in alcohol. The remaining protein, called glutenin, was found to be insoluble except in dilute acids or alkalies.

But later work has shown that the terms "globulin" and "albumin" have little meaning in connection with flour proteins and that neither "gliadin" nor "glutenin" may be an individual chemical entity. Blish in "The Wheat Flour Proteins" says, "It seems that as we have become increasingly familiar with the behavior and properties of flour proteins, we have found ourselves progressively more and more hesitant in the matter of making dogmatic assertions and published statements relative to their nature, their identities, and their individualities."

**Effect of salts on protein extracted.** Gortner, Hoffman, and Sinclair found that N/1 solutions extract the following average percentages of the total wheat flour proteins: KF 13, KCl 23, KBr 37, and KI 64. They showed that the amount of protein extracted varied not only with the nature of the salt used but also with its concentration.

Gortner, Hoffman, and Sinclair have found that for increasing peptizing effect on wheat proteins the following anions arrange themselves in a lyotropic series:  $F < SO_4 < Cl < \text{tartrate} < Br < I$ . The cations have a

less distinct effect on solubility of the flour proteins but give the following order of peptization:  $\text{Na} < \text{K} < \text{Li} < \text{Sr} < \text{Mg} < \text{Ca}$ .

Mangels and Bailey in studying the gelatinizing action of reagents on starch noted a Hoffmeister series as follows:  $\text{Cl} < \text{B} < \text{I} < \text{CNS} < \text{salicylate} < \text{OH}$ .

Rich has shown that the amount of protein extracted or peptized by  $\text{N}/2 \text{ MgSO}_4$ , 10 per cent  $\text{NaCl}$ , and  $\text{N}/4 \text{ NaCl}$  solutions varies directly with increasing ash content of the flour. In general, the maximum peptization occurred with  $\text{N}/4$  solutions. A further increase in salt concentration causes dehydration and eventually salting out of the protein micelle.

**Is gluten a single protein?** McCalla and Rose say that the most soluble 10 to 15 per cent of the gluten protein is probably distinct, but the remainder is a single protein complex which can be divided into a great many progressively different fractions. They suggest the terms "glutenin" and "gliadin" should be discarded.

Rich states that it is "apparent that the protein of wheat is a single individual and that knowledge of the nature of differences in protein 'quality' between 'strong' and 'weak' flours can best be solved by studying the protein as a whole instead of splitting it into arbitrary fractions and studying each fraction separately." He believes that if the dispersing agent or the method of isolation is changed, even slightly, there is no established limit as to the number, quantities, and character of the protein fraction that can be isolated.

**Is gluten composed of distinct groups or individual proteins?** The greatest difficulty in fractional precipitation of the flour proteins can be traced to the agents used to disperse them, for no solvent has been found from which all the protein can be recovered without loss or irreversible change in original properties. Blish says that "irreversible and destructive hydrolytic changes occur almost at once, and proceed at a relatively high rate when gluten is dispersed in weak alkali." On the other hand, in dilute acetic acid, an appreciable amount of hydrolysis is detectable after a few hours standing, but at ice temperature hydrolytic changes are slow. Addition of an equal volume of alcohol to dilute acetic acid protects against hydrolytic change, but may split off other components. Urea is used for peptizing proteins, but because it gelatinizes starch must be used on washed gluten.

Salicylate is one of the anions in the lyotropic or Hoffmeister series causing greatest peptization of flour proteins. Sodim salicylate appears to peptize the flour proteins with no observable hydrolysis or denaturation.

Blish states that it is probable that only a few components or component groups constitute the flour proteins and that they may be precipitated as mixtures containing progressively varying proportions of these few components. "We can merely summarize our *present* viewpoint, which is as follows: There is a considerable portion of flour protein that does not enter into the formation of gluten, but it is not yet possible to distinguish a sharp

and definite boundary-line between the gluten and non-gluten portions. With reference to gluten, itself, we recognize a definite fraction consisting of approximately 10-12 per cent that is extremely resistant to dispersion. We recognize the 'gliadin' fraction, which accounts for 50 per cent or more of the gluten, and which may or may not be a mixture of components having very similar properties. The remaining portion we regard as doubtful, but until proven otherwise we prefer to look upon it as a mixture of a 'glutenin' and a lipid-protein complex." Work with flour proteins "is peculiarly a problem in which any new discovery is likely to invalidate much that has gone before and to necessitate an entire re-examination of the whole situation."

**Lecithio-protein.** Flour may contain a lecithio-protein somewhat similar to that found in egg yolk. Blish says that alcohol added to acetic acid solutions in fractioning flour proteins may cause irreversible splitting off of an important gluten component, a "lecithio-protein" or some similar lipid-protein complex. Blish adds that he suspects the "lecithio-protein" is a very important gluten constituent and that its importance and amount in flours have been underestimated. "At present we feel that a thorough study and understanding of the nature and properties of the lipid-protein complex will contribute greatly to the solution of several flour problems that are of the greatest fundamental interest and importance."

**Gliadin.** Gliadin, either as a multiple protein, or as a component of the gluten complex, is soluble in 60 to 70 per cent alcohol. In water it swells to a sticky mass, being least soluble at its isoelectric point about  $pH$  6.5. With increasing acidity it becomes more soluble, reaching a maximum with a  $pH$  range of 2.0 to 3.0. With hydrogen-ion concentration greater than  $pH$  2 the solubility decreases gradually. With increasing alkalinity, the solubility of gliadin increases more rapidly than on the acid side, up to  $pH$  13.1, the most alkaline of the solutions used by Tague.

**Glutenin.** It is the glutenin, classified as a glutelin, that gives the desirable baking qualities to wheat flour, qualities not possessed by any other cereal. Glutenin is insoluble in water, but is increasingly soluble in dilute acids and alkalies. Sharp and Gortner state that the maximum solubility occurs on the acid side at  $pH$  3.0 and on the alkaline side at  $pH$  11. The isoelectric range, as determined by Sharp and Gortner, is from  $pH$  6.0 to 8.0, and by Bungenberg de Jong as  $pH$  5.6. Glutenin swells in water. If prepared with sodium salicylate it is said to resemble gluten in its coherence and tenacity.

## Gluten

The characteristics of gluten gain in importance because it is the protein of the flour as a whole, regardless of whether it is composed of one, few, or many components, that gives the baking quality to flour. When water is

added to flour, the proteins gradually absorb about 200 per cent of their weight in water.

When flour is made into a stiff dough and kneaded for a short time, the starch can be washed out, leaving a small part of the original dough which is known as gluten. Gluten is rubbery, tenacious, and elastic. It is usually a light gray or slightly yellowish color. A large part of the gluten is composed of the proteins gliadin and glutenin. In addition to the protein, the gluten as washed from the dough contains some starch which is entangled in the gluten, some lipoids, mineral salts, and water. The amount of all these constituents of gluten varies with the manipulation in washing, the kind of water used, and the character of the flour itself. The physico-chemical properties of gluten have been extensively studied and applications made to baking bread.

Since gliadin and glutenin have about the same isoelectric point, ranging around  $pH$  6.5 to 7.0, Bailey states, "it might be anticipated that maximum coherence and extensibility of gluten and dough should be encountered in about the same range."

**Heat coagulation of gluten.** Gluten seems to have no definite coagulation temperature. Alsberg and Griffing have reported that heating the gluten decreases its power to swell in acid solutions, the swelling power decreasing during heating from  $50^{\circ}$  to  $80^{\circ}C$ . Except at the temperatures  $60^{\circ}$  to  $65^{\circ}C$ . no information was obtained that indicated a definite coagulation temperature. They state that denaturation takes place over the whole range from  $50^{\circ}$  to  $80^{\circ}C$ . The swelling power was not impaired but probably increased at temperatures from  $30^{\circ}$  to  $50^{\circ}C$ .

**Gluten quality.** Different flours vary in their baking qualities. Millers and bakers speak of those having poor baking qualities as "weak" flours, and those having good baking qualities as "strong" flours. The definition of good baking quality commonly accepted by millers and bakers is the one suggested by an English worker, Humphries: "Strong flour is one capable of making large well-piled loaves." This definition excludes flours "that produce large loaves, but do not rise satisfactorily." Thus strong flours and good baking quality are synonymous to a certain extent. A weak flour does not have good baking qualities, but there is no distinct line between weak and strong flours. A flour may also be too strong for good baking qualities. Such a flour is called gluten "bound."

Gortner and Sharp have reported that weakness of flour may be divided into three classes as follows:

1. Weakness due to an adequate quantity of gluten but of inferior quality.
2. Weakness due to an inadequate quantity of gluten of good quality.
3. Weakness due to factors influencing yeast activity, diastatic and proteolytic enzymes, hydrogen-ion concentration, etc.

Even though flour may have an adequate quantity of gluten for good

baking qualities, if the quality is inferior it does not produce a good loaf of bread.

**Gluten quality and growth of wheat.** In the flour the protein may be thought of as a partially dried hydrogel. When proteins are dried to contain little or no water, less than 5 per cent, they may lose the power of swelling in water. If they contain 10 to 15 per cent of moisture they may retain the power of swelling in water. Flour contains 10 to 13 per cent of moisture, so that the swelling property is not destroyed. However, the moisture content of flours varies somewhat; but of more importance to the quality of the protein is the rate of dehydration of the protein when it is deposited in the wheat kernel. It is well recognized in colloidal chemistry that the past history of a colloid influences its future reactions. The conditions during the growth of the wheat influence the later reactions of the protein. In the sap of the wheat the protein is in the form of a sol; later as it is deposited in the wheat it is found in the form of a gel. With ripening and further dehydration of the protein, dried hydrogel is formed. The speed at which this takes place, depending upon climatic and moisture conditions, affects the quality of the protein. The mineral salts and the lipid content of the flour also influence the quality of the gluten, which has been discussed under ash.

**Gluten quality and colloidal state.** Gortner and Doherty suggest that the size of the gluten particle is a factor in determining its properties. They emphasize that strong flours give glutes with nearly "perfect colloidal" gels with highly "pronounced physico-chemical properties," whereas weak flours give glutes whose properties are less colloidal; or strong flours contain gluten in a less dispersed state, and weak ones contain gluten more highly dispersed.

### Gluten and Dough

Bungenberg de Jong states that gliadin is a protein that swells easily in water, is readily peptized to a colloidal solution by dilute alkali or acid and in water forms a sticky mass that can easily be stretched into threads. Glutenin in water is a flaky mass without much coherence which swells in, but is difficult to peptize in dilute acid. It peptizes easily in alkali.

Bungenberg de Jong suggests that the plastic and elastic properties of gluten are partially due to the two proteins' adhering to each other because of opposite charges throughout a definite  $pH$  range. If this is true, he says that at the  $pH$  at which the charge on each protein is the same either a maximum or minimum in physical properties should occur, i.e., turbidity, coherence, farinogram curves (which is a measure of consistency of the dough). The point at which this maximum occurs might be altered by the presence of other proteins, such as albumin and globulin with isoelectric

points much lower than that of glutenin, hence would be negatively charged at the pH range at which the gliadin-gluten complex occurs. He also discusses the possibility of salts altering the maximum point. Jong represents this maximum or minimum range schematically. See Fig. 44.

Gliadin, below its isoelectric point pH 6.4, is positively charged, this charge increasing as the pH is lowered. However, about pH 5.6, the isoelectric point of glutenin, the glutenin is negatively charged. In Bungenberg de Jong's experiments maximum turbidity occurred at pH 6.1.

**Gluten quality and proteolytic enzymes.** Balls and Hale ascribe part of the quality of gluten to the action of the proteolytic enzymes. They state that the proteolytic enzymes change the colloidal character of wheat proteins, the effects of which are shown in the gluten. "Proteinases usually

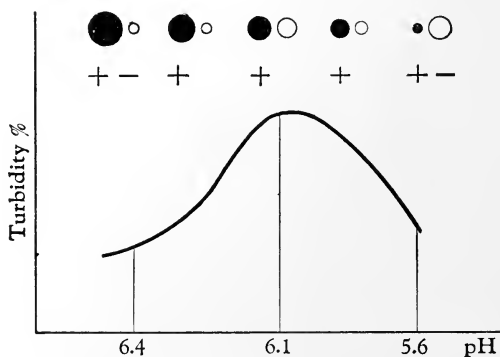


FIG. 44.—Bungenberg de Jong's representation of effect of charge on gliadin and glutenin on gluten properties. The charge of components is represented by positive and negative signs. *J. Soc. Chem. Ind.* 52: 391T, 1933.

produce first a coagulation of the protein; later the coagulated material is broken down and perhaps ultimately dissolved. If this rule holds for flour, in the first phase of proteinase action the gluten would probably become more tenacious; in the second phase it would be broken down to a thinner, more nearly liquid material." They add that a small amount of proteinase may be beneficial, a larger amount harmful. "Usually there is too much, rather than too little."

The baking qualities of gluten are determined largely by its hydration capacity, its power of cohesion, and its elasticity. The hydration capacity results in a larger or smaller volume when mixed with water. With a larger volume the particles of the gluten form a greater surface for contact with each other, thus increasing the sponge-like character of the dough. Also with increased swelling the gluten becomes more tender and less tenacious; with less swelling the volume is smaller but the tenacity may be greater. The swelling can be so great that there is a limit to the



amount of stretching the gluten will stand before breaking. The cohesiveness of the gluten gives less chance for the gluten particles to be pulled apart; the elasticity permits stretching under pressure or when pulled.

**Hydration capacity.** By hydration capacity is meant the swelling of the gluten in water, whatever the mechanism by which it is brought about, whether by absorption or other means. Gortner and Doherty have reported that a strong gluten has a faster rate of hydration, or imbibition as they express it, and also a higher maximum hydration capacity than a weak gluten.

*Distribution of water in dough.* Alsberg in "Starch and Flour Quality" states that in bread dough about 50 per cent of the water is bound moisture or water of hydration incapable of serving as a solvent for other substances. The starch holds approximately half of this bound water, the gluten the remainder. Starch at room temperature can absorb about 30 per cent of its weight of water, whereas gluten may absorb 200 per cent of its weight. But starch constitutes so great a percentage of the flour that as a result the quantity of water it binds is nearly as great as that bound by gluten. The remaining 50 per cent of the water in bread dough, which may serve as a solvent for other substances and form steam, cannot be separated readily from the dough by mechanical means. It is held in the interstices of the dough by surface and mechanical forces.

*The proportion of water added.* The proportion of water added also affects the character of the dough and baked product. If too little water is added the maximum cohesiveness and elasticity of the gluten is not attained.

*Water-binding capacity of flour, dough, and bread.* Kuhlmann and Golossowa found that the water-binding capacity of the flours they tested was in the following order: Soya, rye, corn maize, durum wheat, soft wheat, and potato. No complete parallelism existed between the protein content of the flours and their water-binding capacity. Rye starch had a water-binding capacity of 78 to 80 per cent, whereas that of wheat starch was 40 to 42 per cent. A direct relationship was found between the water-absorbing capacity of the flour and its water-binding capacity.

The water-binding capacity of bread doughs was about the same as flour, but a sharp increase occurred in bound water during baking so that a dough with a water-binding capacity of 60 per cent changed to about 85 per cent in hot bread.

Kuhlmann and Golossowa found that the factors which increased the water-binding capacity of the dough decreased moisture loss in baking and in drying out or aging of the bread after baking. Both the method of making the dough and materials used influenced the water-binding capacity. Doughs made by a straight-dough method bound more water than those made by the sponge method. When the flour for the sponge method was scalded, the

water-binding capacity was markedly increased over dough or bread made by the sponge method without scalding and slightly higher than dough made by the straight-dough method. The addition of maltose and buttermilk increased the water-binding capacity of the doughs and bread.

The hydration of a gluten and hence its tenacity or cohesiveness, and its elasticity or extensibility, may be altered, that is increased or decreased, by: (1) over-grinding, (2) bringing the dough to a certain acidity or alkalinity and subsequent neutralization, (3) treating with alcohol, (4) salts, (5) alkalis, (6) acids, (7) proportion of water used, (8) added substances, (9) temperature, (10) time of standing, (11) mechanical treatment of the dough, and (12) fermentation.

Over-grinding has been considered. The effect of mechanical treatment of the dough and fermentation upon gluten will be considered with the discussion of bread making. The effect of proportion of water used has been considered and that of added substances will be considered under dough structure.

*Bringing the dough to a certain acidity or alkalinity and subsequent neutralization.* The quality of the gluten can be altered by increasing the acidity or alkalinity. Gortner and Johnson have found that "doughs brought to pH 3.0 or 11.0 by the addition of acid or alkali and in which the acid or alkali has been subsequently neutralized, have lost their baking strength."

*Treating with alcohol.* Gortner and Johnson have found that flour treated with 70 to 85 per cent alcohol, from which the alcohol is evaporated, and the flour dried and remilled, when used in bread has lost its baking quality. They attribute this to a loss in colloidal properties brought about by action of alcohol on the glutenin of the flour.

*Salts.* The imbibition of water by gluten, and thus the swelling, may be depressed considerably by salts. This may be brought about by the salts found in the flour, by the addition of salts like baking powders to flour mixtures, or by the addition of the so-called flour improvers to weak flours. The inhibiting effect may be due to the cation or the anion of the salt. Different salts depress the hydration capacity of the gluten in different proportions, that is, in the order of a lyotropic series. See also the section on proteins.

Bailey and Le Vesconte have reported that the addition of monocalcium phosphate to a dough effected a slight increase in the extensibility of gluten. They find no increase in extensibility of the dough, as measured in the Chopin extensimeter, when calcium sulfate and magnesium sulfate are added in the proportions used in commercial practise.

*Alkalies.* The hydration capacity of gluten on the alkaline side of the isoelectric point reaches its maximum capacity at a pH 11.0. Beyond a pH 11.0 the gluten dissolves very rapidly with increasing alkalinity. Since gluten proteins tend to imbibe water and disperse in a weakly alkaline

medium, doughs with a slight alkaline reaction are sticky. With excess alkali they become yellow and develop a soapy taste. Since the proteins are peptized readily with alkali, a product with a  $pH$  higher than 7 is quite tender. Thus chocolate cakes and gingerbread with excess alkali (soda) are very tender, though the cell walls are very thick.

*Acids.* Acids as well as salts and alkalies markedly influence the hydration capacity of gluten. The hydration capacity of gluten is increased with increased hydrogen-ion concentration until a  $pH$  of 3.0 is reached. With a  $pH$  lower than 3.0 the hydration capacity is decreased. Gortner and Sharp have shown that the various acids produce a maximum hydration at  $pH$  3.0. On the acid side of the isoelectric point the gluten is not dispersed as rapidly as on the alkaline side, so that doughs with an acid reaction are more tenacious, and not so sticky as ones with an alkaline reaction. During fermentation of bread the development of acids gives an acid reaction to the dough, increases the hydration and solubility of the proteins and thus the tenderness of the resulting bread.

*Time of standing.* Bailey and Le Vesconte have reported that time of standing of the dough after mixing influences the extensibility of the dough. The greater part of this increase in elasticity or ease of handling is quite noticeable in many dough products. Pastry and other products are easier to handle if allowed to stand a short time after mixing, before they are rolled or baked.

*Temperature.* Bailey and Le Vesconte have reported that temperature markedly influences the extensibility of a flour and water dough. With increasing temperature the dough becomes more elastic and less tenacious. Kent-Jones in reporting the experiments of Luers\* comments on the influence of temperature on hydration capacity. At a temperature of  $8^{\circ}$  to  $9^{\circ}C$ . the imbibition of water by gliadin was quite low and he speaks of it as almost "an anti-swelling effect." At higher temperatures the gluten becomes more elastic. This is of great importance in baking, for without this quality the cell walls of the dough would break and coalesce before the temperature was reached at which the protein is coagulated. As a result the volume of the product would either not increase or would be lessened during baking.

With higher temperatures of mixing the gluten swells more rapidly and this affects the rapidity with which it develops or becomes attenuated with mixing.

Swanson in his article, "The Theory of Colloidal Behavior in Dough," gives a good description of dough structure. The following account is based upon his article, upon other reading, and upon observation.

Bread dough has two continuous phases: water constitutes one, and gluten the other.

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\* Luers, H., Koll. Zeitschrift, 25: Nov., 1919.

**Starch in dough.** When flour is mixed with water to form a dough the starch granules retain their shape. They also have a certain rigidity and little adhesive power, so that they are not easily pulled or squeezed out of shape and do not adhere to each other.

**Gluten particles in dough.** In contrast to the starch particles in dough, the gluten particles behave as if their shape is very irregular. In the flour the shape may be regular, but it is the shape in the dough that gives the dough part of its distinctive baking properties. On account of this irregular shape the particles have a very large surface area. When swollen with water they can be easily pulled, squeezed, or packed into different shapes.

The protein particles in the flour may be compared to chewing gum, for many of the properties are similar. Anyone who has chewed gum is familiar with its manipulation, so that it makes an excellent illustration. The size of the piece of gum is very much larger than that of the protein particle. The stick of chewing gum when first placed in the mouth may be brittle and crumbly. As it becomes moist it sticks together and develops tenacity, adhesiveness, and cohesiveness. If two sticks of gum that have been chewed are brought in contact with each other they adhere or stick together; if pulled, they stretch. In the literature on dough, this change in shape through hydration, surface contact, and particles adhering to each other is called attenuation. The more the pieces of gum are pulled the more attenuated they become, but if the elastic strands touch each other in large areas they adhere, and when worked more and more, they become matted together in one piece.

When the protein particles in the dough become moist they swell and form gluten. The behavior of the protein particles when moistened is similar to that of the gum. When first moistened they are crumbly and do not adhere together. After the particles become hydrated they become sticky and tenacious. When the dough is stirred the surfaces of the particles come in contact and adhere to each other. The stirring of the dough stretches and pulls the surface contacts so that the gluten becomes attenuated and filaments formed. Attenuation of the gluten is often referred to as developing the gluten or dough.

**Gluten forms a continuous phase in dough.** The protein in the dough forms a continuous network or mesh structure throughout the dough. In this meshwork are the starch granules, the sugar, salts, and water.

The protein particles compose only a portion of the flour content, although after they are hydrated the relative volume that they occupy in the dough is greater than their volume in the flour. If to the chewing gum we add some small round particles that do not change their shape and are about the size of small tapioca a better picture of dough structure

is obtained. The small round particles will prevent the chewing gum from forming one solid mass and will tend to keep the pieces of gum apart, so that manipulation and sliding over the round particles is required to bring different surfaces of the gum in contact with each other. In the dough the whole starch granules do not swell appreciably until a temperature of 60° to 65°C. is reached. Thus in a dough mixed at ordinary temperatures they do not change their volume or shape.

A good quality of gluten adheres strongly to other particles of gluten and forms many strands of network around the starch granules. A good quality of gluten must be elastic enough to stretch around the starch granules, and in addition stretch and retain gas bubbles formed in the dough that make the structure porous. No dough will retain all the gas formed within it, but a gluten of good quality will retain a very large portion of the gas bubbles. A poor quality of gluten will not stretch when the gas is formed but will break in places, and too large a proportion of the gas formed is lost.

There are many different qualities of gluten in different wheats. Some may be very soft and not very tenacious; some may be like the ones described above; and others may be so strong that they are tenacious enough not to stretch without excess pressure. Such glutes are improved by blending with weaker glutes. Flour from the large mills is blended to produce a working quality of gluten that gives similar results when baked in different batches. Strong glutes may be improved by the addition of malt extract, which contains a larger proportion of the proteolytic enzyme proteinase than is found in the flour. Since part of the protein is hydrolyzed by the proteinase there is not such a compact mass left and the remaining gluten is softer and more elastic.

### Effect of Added Substances on Gluten of Dough

**Egg.** In thin batters, to improve the baking quality or to give structure to the finished product, eggs are added. Without their addition only a thickened mass with no increased volume is obtained. The egg protein coagulates when heated and with the gluten retains the gas formed in the batter.

**Fat.** The addition of fat gives a shorter dough or a more tender one. By short, bakers refer to the gluten breaking quickly and not adhering tenaciously. Fat causes the gluten threads to pull or break apart more easily. In other words, it might be stated that when the gluten particles are "greased" or lubricated they adhere less strongly.

**Starch.** Bailey and Le Vesconte have found that the addition of starch to a bread flour results in a decreased extensibility. The addition of 10 per cent of starch decreases the extensibility only a little, but the addition of

larger quantities decreases it to a greater extent. The gas-retaining capacity of the dough and the quality of the bread are also impaired. However, since the added starch is not embedded in gluten and the diastase can act on such starch quickly, Alsberg states that carbon dioxide will be formed more rapidly, with which statement Johnson and Bailey agreed.

Cooked mashed potatoes are sometimes added to bread doughs. Since the starch is cooked, judging from Kuhlmann and Golossowa's results, the water-binding capacity of the dough and bread should be increased; but too large a quantity of mashed potatoes because of the dilution of the gluten may impair the quality of the bread.

**Sugar.** Jago reports that sugar causes a diminution of the amount of gluten that can be washed from a dough. When the sugar was added to the dough and the gluten extracted with alcohol much more gluten was dissolved, from which he concluded that sugar has a solvent action on gluten.

**Baking powder.** Baking powder is added to dough as a leavening agent, that is, to produce carbon dioxide gas to stretch the gluten and produce a porous texture. The ingredients of the baking powder and the residue of the salts formed from the reaction of the baking powder may have either an inhibiting or accelerating effect upon the hydration capacity of the gluten, depending upon the particular cations and anions of the baking powders or their salts.

## Bread

Bread is made of flour, water, salt, fat, and sugar. To these ingredients the yeast plant is added. The right treatment of the whole mass gives a loaf of bread of good volume containing cells of definite structure and size.

Bread is a very complex substance. In addition to organic and inorganic materials it contains three substances that show colloidal behavior: the protein, the starch, and the cellulose. The amount of cellulose is quite small, so that it probably plays a very minor rôle in bread making. The part that different constituents of the flour play in the dough structure has been discussed in the preceding pages. Their part in bread making will not be repeated here, but the proportion of ingredients used, the temperature for handling the dough and for baking, the fermentation, and the importance of manipulation of the dough will be considered.

Chemical and physical tests may be performed on flour and dough, but as yet the only final convincing proof of flour quality for making bread is the baking test.

**Temperature.** Enzyme activity is very slow at low temperatures and the enzymes are destroyed at high temperatures. Thus for optimum enzyme activity and also for yeast growth in bread dough it is important to keep the dough at definite temperatures.

Fermentation is carried out over a wide range of temperature. The evidence indicates that a low temperature is more desirable from the standpoint of flavor and the development of acetylmethylcarbinol. But fermentation is more rapid at higher temperatures. Temperatures from 26° to 32°C. (79° to 90°F.) are used. There is more danger at higher temperatures for growth of undesirable organisms which produce disagreeable flavors.

**Proportion of ingredients used in bread.** The American Association of Cereal Chemists (A.A.C.C.) appointed a committee, headed by Fitz, later by Blish and others, to find the proportion of ingredients used by members of the association in test bakes, and to formulate a standard method of procedure and a definite formula for use by members of the association.

*Flour.* It is customary in computing the percentage of ingredients used in bread to take flour as 100 and compute the proportion of the other ingredients in relation to it. Thus if 112 grams of flour are used and to this is added 65 per cent of water, 72.8 grams of water would be used. It requires about  $\frac{3}{4}$  pound of flour to produce a pound loaf of bread, though the exact amount depends largely upon the hydration capacity of the gluten.

*Yeast.* Two types of commercial yeast may be purchased, the compressed and the dry. A cake of compressed yeast contains many yeast plants in an active state. When it is used the yeast plants multiply rapidly, producing a large quantity of carbon dioxide gas, and the fermentation takes place in a short time.

In dry yeast the yeast is mixed with corn meal and dried. The yeast plants are not active, as they are in a dormant state and they are few in number. The yeast needs to be soaked for a short time in warm water and then made into a sponge to give time for the revival and growth of the yeast plants. Therefore it requires a longer fermentation period than compressed yeast.

In addition to the dry and the compressed yeast, two other types of yeast are used by housewives, chiefly farm women, where yeast cakes or bread cannot be delivered every day. A liquid yeast may be used and also a starter. The starter is a portion of the sponge that is saved to start the fermentation of the next baking of bread. Since the sponge or dough contains numerous yeast plants it is used instead of yeast cakes for the adding of yeast plants to the dough. To this starter sugar is added for food for the growth of the yeast during storage.

After yeast is added to the bread a period of time elapses before the bread is baked. This period, the length of which depends upon the proportion of ingredients and the kind of yeast used, is called the fermentation period. Bakers call it "proofing" and housewives "rising."

*Amount of yeast.* The amount of yeast used in bread may vary in wide proportions. Fitz found that as a general rule bakers use 2 to 3 per cent of

yeast, although the amount varies from 1 to 5.88 per cent. For home or school the amount may be increased according to the length of time allowed for the fermentation period.

The following table taken from the pamphlet "Baking Better Bread" by the Washburn Crosby Company gives the amount of yeast to use for different periods of fermentation for straight-dough process.

TABLE 47

Amount of yeast	Period of fermentation	Temperature
1 cake of yeast to 1½ cups liquid . . .	4 hours 2 hours 1st rising 1 hour 2nd rising 1 hour in pans	80
2 cakes of yeast to 1½ cups liquid . . .	3 hours 1½ hours 1st rising 45 minutes 2nd rising 45 minutes in pans	80
3 cakes of yeast to 1½ cups liquid . . .	2 hours 10 minutes 1 hour 1st rising 15 minutes 2nd rising 35 minutes in pans	80
4 cakes of yeast to 1½ cups liquid . . .	1 hour 25 minutes 1st rising 5 minutes 2nd rising 30 minutes in pans	80

*Water.* Milk may be substituted for water in bread. It is usually scalded to destroy any bacteria or organisms that may produce undesirable flavors or be detrimental to yeast action. Since milk contains about 12 to 14 per cent solids, a larger proportion of it is added than of water. Water in which potatoes have been cooked is sometimes used for a part of the liquid in bread. Because of the development of rope in hot weather, it is often desirable in home-made bread to add the whey of sour milk during the summer.

The best proportion of water varies with the hydration capacity of the gluten in the particular flour that is being used. The proportion as reported in the literature varies from about 51 to 67 per cent. Good bread flours usually require from 60 to 65 per cent of water. Soft-wheat flours, which have weaker glens, require a lower proportion of water.

*Effect of proportion of water used.* The proportion of water used affects the tenacity and extensibility of the gluten and hence the resulting dough.



Bailey and Le Vesconte have found that the extensibility of the dough increased with increasing water content until an imbibition equivalent to 64 per cent of the weight of the flour was obtained. Further increase of water and increased hydration decreased the extensibility of the dough. The following table is from their results with the Chopin extensimeter.

TABLE 48  
EFFECT OF INCREASING WATER IN A DOUGH (*Bailey and Le Vesconte*)

Absorption, per cent	Extensibility	Reading for tenacity, millimeters
59	18.65	125.0
60	18.80	122.0
61	18.90	121.0
62	19.50	117.1
63	19.77	114.7
64	21.00	99.7
65	20.96	94.5
66	20.48	94.5
67	19.66	92.3

Swanson and Working have reported in experiments with mechanical modification of the dough, using 340 grams of flour, that the best loaf of bread was produced when 205 to 215 cc. of water was used. In the proportions of water used by them the 205 cc. is equivalent to 60 per cent of the weight of the flour and 215 cc. to 63 per cent. When a smaller amount of water than 60 per cent was used a loaf of poor volume was obtained.

Harrel has also reported that better bread is produced when the amount of water used is sufficient. Table 49 from his results is self-explanatory.

The hydration capacity of different glutes varies, hence the maximum volume with any flour will be obtained with a definite water imbibition for that gluten. With increased swelling beyond the point at which the maximum volume is obtained the gluten becomes more tender and less tenacious, some of the cell walls collapse and coalesce, thus giving a smaller volume. With less swelling than the amount required to produce the maximum volume the tenacity is greater and a smaller volume results. The hydration of the gluten can be so great that there is a limit to the amount of stretching the gluten will stand and a very poor volume is the result.

*Sugar.* Fitz reports that the average proportion of sugar used by bakers varies from 2 to 5 per cent.

*Shortening.* Fitz has reported that the amount of shortening used by bakers varies from 0 to 3 1/3 per cent. It is not necessary to add shortening

TABLE 49

VARIATIONS CAUSED BY DIFFERENT ABSORPTIONS ON PROPERTIES OF BREAD  
(Harrel)

Absorption	Volume of loaf, cc.	Spring in oven	Color of crumb
50	2550	fair	good minus
55	3100	fair plus	good
60	3275	good	good
65	3300	good	good
70	3150	good minus	good
75	2700	fair	slightly dull

to make good bread, but Whymper states that even a low percentage adds to the keeping quality of the bread, for the bread stales less readily.

*Salt.* Fritz has reported that the amount of salt used by bakers averages from 1.5 to 2 per cent and varies from 1.35 to 2.12 per cent. The use of salt is important in bread making. If it is not added to the dough, fermentation takes place very rapidly and the bread is too porous. If too much is used, fermentation is slow and the bread is firmer and more compact.

*Proportion of ingredients in bread dough.* The committee on the standardization of experimental baking tests of the A.A.C.C. have suggested formulas for baking tests, which are given in the laboratory outline, Experiment 73.

**Methods of mixing.** *Straight-dough process.* Two processes are used in making bread. One is called the straight-dough process or quick method. In this process all the flour and other ingredients of the bread are mixed together in the dough for the whole fermentation period.

*Sponge process.* By this method the salt and a part of the flour are omitted during the first part of the fermentation period. Then the remainder of the flour and the salt are added to make a dough, and from this point the manner of mixing and treatment of dough are the same for the two processes. The sponge method is always used with dry yeast and may be used with compressed yeast.

**Method of mixing ingredients.** The committee on formula and method of mixing, Fitz chairman, have suggested the following procedure. "Thoroughly dissolve sugar and salt in a portion of the water, mix yeast in another. Use water at a temperature to bring dough out at approximately 30°C. Add the solution to the flour, rinsing with balance of water, then add shortening in melted form. Mix thoroughly to a smooth dough. This may require 3 to 10 minutes depending on type of mechanical mixer used. Remove the dough, fold into smooth dough ball and place in battery jar (6 by 8 inches), cover, and place in dough cabinet at 30°C. and let rise until ready to punch." See Experiment 73.

**Effect of mechanical treatment on extensibility of dough.** Bailey and Le Vesconte have reported that prolonged mixing may destroy the cohesiveness of the gluten.

The most extended experiments on the mechanical modification of gluten quality that have been reported are those of Swanson and Working. They devised a machine with a "pack-squeeze-pull-tear fashion." By mixing the dough for a longer time in this bread mixer they found that the bread could be baked at the end of the first fermentation period, thus decidedly shortening the total time for fermentation. The prolonged mixing altered the gluten quality so that less time was needed for fermentation. "The figures for volume, color and texture show a progressive improvement with the length of time of mixing." Dough mixed for 15 minutes produced a loaf better in every way than a loaf mixed 3 minutes and then fermented in the usual way. When the revolutions per minute were increased from 60 to 120, it was found that 7 minutes would produce as good bread as 15 minutes at the slower rate. The following table gives their results. The first figures are for the control fermented in the usual way after 3 minutes of mixing.

TABLE 50

EFFECT OF MIXING FOR DIFFERENT LENGTHS OF TIME ON THE QUALITY OF BREAD BAKED WITH ONLY PANARY FERMENTATION  
(*Swanson and Working*)

Total time of mechanical treatment 60 r.p.m., minutes	Total time of fermentation, minutes	Volume of loaf, cc.	Color score	Texture score
Control 3.....	157	1955	95	94
3.....	61	1690	92	85
6.....	58	1785	94	88
10.....	54	1880	96	90
15.....	54	2045	100	98
20.....	54	2070	100	99
30.....	55	2040	100	99
40.....	55	1990	100	96

**Manipulation of dough.** In the laboratory in experimental cookery, one is constantly impressed by the effect of manipulation and the handling of the food materials in giving results that are not strictly uniform.

Swanson states that it is well known that bread dough must not be squeezed too hard when kneaded just before it is put in the pan, or the cell walls will be thickened. He gives as the reason that during the fermenta-

tion the meshwork of gluten has become separated into fine filaments. If kneaded too hard just before being put in the pan these filaments are packed together and as a result a thicker cell wall is produced.

The experiments of Dunlap are of particular interest. At the Bureau of Chemistry in Washington, he and two other operators mixed dough. The only difference in the mixing was the way the dough was kneaded or punched after the first mixing by the different operators. Dunlap's description follows. "In these experiments the three operators used identical formulas and ingredients in preparing the dough batches. The mixers were all started at the same time, the water and shortening were added at the identical instant, and the extent of the mixing was absolutely uniform. All fermentations were carried out in the same cabinet and at the same time and for the same period. All punches were synchronous and the working or punching of the dough was uniform, that is, the doughs were worked or punched with the hand 40 times after the first rise and 30 times after the second. The doughs went to the same proofing cabinet and at the same time. In fact uniformity so far as was humanly possible prevailed throughout. When the bakes came from the oven, the results were very illuminating for despite the care taken, they were far from uniform." These experiments were repeated several times with the same results.

In later experiments carried on in another laboratory, Dunlap decided he had punished the dough too hard or used too much pressure in punching it, especially for the last working. He states, "Putting this idea to the test and handling the doughs with a degree of gentleness previously unknown in my method of operation, results were produced incomparably better than anything previously obtained."

Applying these results it can be stated that the first mixing and kneading, when the gluten is developed, should be thorough, but may not need heavy pressure, and the second and third kneading should be done with light pressure and should not be continued for too long a period.

The mixing of the bread in the bowl should be continued until the dough forms in a ball and cleans the side of the bowl. If a bread mixer is used it may mix and knead at the same time.

For the first kneading, only a thin film of flour should be used on the board, unless far too much liquid has been added. Inexperienced bread makers usually add too much flour in kneading, for in mixing by hand the dough should be sticky when kneading is begun. After the gluten is developed it no longer sticks to the hands or board. In molding, use very little or preferably no flour, for flour added at this stage may produce streaks in the bread, since this flour is not fermented for the whole period.

**Greasing of bowl and pans.** The bowl that the dough is allowed to rise in should have only a thin film of fat to grease the bowl, or it is not necessary to use any. Heavy greasing may produce streaks in the bread. Harrel found that bread baked in ungreased pans gave a better volume and oven spring than bread baked in greased pans. This indicates that the

dough clings to the sides of the pan during rising, and this adhesion aids in attaining a better volume. But greasing the bottom of the pan expedites removal of the bread.

**Fermentation.** The production of gas in the dough to render the bread porous is known as fermentation. Both yeast and bacteria are used to produce gas, bacteria producing the gas in salt-rising bread, yeast in ordinary bread.

*Microorganisms in breadmaking.* Fuller states that the "microorganisms associated with the production of bread may be divided into three main groups: (1) the yeast *Saccharomyces cerevisiae*, carefully purified and selected strains of which are purposely added to the dough; (2) certain bacteria, which, introduced either purposely or accidentally, assist in the development of the gluten and give rise to characteristic flavoring products; and (3) the unwanted organisms, *B. mesentericus*, torulae, and moulds, which are introduced chiefly from flour, air, and perhaps water, unintentionally either into the dough or onto the baked loaf."

Fuller states that it seems likely that attention has been confined too much to selecting and purifying yeasts in relation to their carbon dioxide producing powers and that side reactions, i.e., bacteria-producing, essential flavoring ingredients have been neglected. He cites the work of a Russian microbiologist who examined the bacterial flora of a number of samples of "leaven." The dominant organism in all was *Lactobacillus panis acidi*, with *Streptococcus lactis acidi* and others in small numbers. Adding *Lactobacillus panis acidi* to yeast gave a bread with flavor superior to that of bread in which yeast alone was used.

*Enzyme action in fermentation.* The yeast contains an enzyme, zymase, that produces carbon dioxide and alcohol from the sugar. During fermentation many changes are occurring in the dough. The flour enzymes as well as the yeast enzymes bring about definite reactions. The chief amylolytic enzyme of the flour, diastase, produces maltose from starch. Flour contains some initial sugar but this is used up in gas production and it is essential for sugar to be formed for new gas production. Yeast also contains some diastase. Sugar is usually added to bread dough. It is not essential, but fermentation is more rapid. Most flours contain sufficient diastase for bread making, but in some the diastatic activity is weak. Commercial bakers may add diastase preparations to dough made of flours weak in diastase to shorten the fermentation time.

Sugar is often added in rather large quantities in home-made bread and it, plus the sugars already present in the flour, plus the sugar formed by the diastase during fermentation, furnish the sugar for the action of the zymase to produce carbon dioxide.

The proteinases hydrolyze a part of the protein, and if very active may cause harmful results. For, if the gluten, which during the first part of fermentation may be too tenacious, becomes too soft or thin the volume of the loaf may be diminished and the texture impaired. Balls and Hale say a little

proteinase is beneficial. Jørgensen states that yeast water stimulates the activity of proteinase.

"Bread improvers." Many and various substances have been suggested and tried as so-called "bread improvers." Malt preparations containing both diastase and proteinase are sometimes added to dough. They are of greater benefit if added to flours low in natural diastase. The rate of diastatic activity may depend upon the relative percentage of starch which is embedded in gluten, the size of the starch granules, and other factors. With many granules embedded in gluten the diastase has less surface on which to act. If the starch granules are smaller there is a relatively greater area for the action of the diastase. However, Markley and Bailey in their investigations found particle size did not determine diastatic activity, but that the rate was affected by humidity of the granule surface, possibly because the granule wall is less resistant.

At present potassium bromate is commonly added to bread dough by commercial bakers. Jørgensen states that it imparts a beneficial action because it diminishes the action of the proteinase. Balls and Hale attribute part of the improvement of bleaching and aging of flour to diminution of proteinase activity. Jørgensen has applied for a patent in the United States for using ascorbic acid as a bread improver, its beneficial effects being attributed to its ability to depress plant-proteinases of the papain-type.

*Imbibition of water during fermentation.* Sharp and Gortner have found that during yeast fermentation the imbibition of water increases to a maximum and then decreases. The increased imbibition during fermentation is due to the increase in the hydration capacity of the glutenin. During fermentation the acidity increases, but Johnson and Bailey have reported that the acids of fermentation cannot alone produce all the changes that occur during fermentation. The proteolytic enzymes by hydrolyzing a part of the protein aid in softening of the gluten. Swanson and Working have suggested that the mechanical action of the expanding gas by stretching the gluten also aids in bringing about a modification of the gluten.

*Dispersion of gluten during fermentation.* Johnson and Bailey in studying the effect of hydrogen-ion concentration on dispersion of the gluten of the flour found that as the acidity increased the percentage of proteins dispersed or the protein in the aqueous extract of the fermented dough increased. It is either very difficult or impossible to collect the gluten from a dough that has fermented sufficiently for baking, by washing it in water. This in itself shows a change in the condition of the gluten.

Johnson and Bailey have reported the following amount of protein dispersed, or in the aqueous extract, during fermentation of a soft-wheat dough, without added salt. At an optimum  $pH$  for baking the bread, more than half the protein was in a dispersed phase.

*Desirable acidity for bread.* As fermentation of the dough progresses its acidity is increased. Johnson has reported that some lactic and acetic acids are formed during fermentation. Bailey and Sherwood have shown that in

TABLE 51

EFFECT OF FERMENTATION UPON DISPERSION OF PROTEINS OF FLOUR  
(*Johnson and Bailey*)

Hours fermented	pH	Dispersed protein based on proteins in flour, per cent
0	5.95	15.14
2	....	17.70
4	....	20.60
6	5.49	31.76
8	5.12	77.22
10	4.60	87.42
12	4.26	89.42
16	3.92	92.14
18.5	3.86	93.70

bread dough the increased acidity is largely due to carbon dioxide. The pH of the baked bread is always higher than that of the dough from which it is baked. For an average gluten a pH of about 5 is desirable. With all doughs, if the fermentation is carried too far the volume of the bread is poor and it has a sour odor and flavor. The following table is from Bailey and Sherwood.

TABLE 52

HYDROGEN-ION CONCENTRATION (IN TERMS OF pH) AND TITRATABLE ACIDITY OF BREAD DOUGH SUSPENSIONS (*Bailey and Sherwood*)

	pH	Dough No. 1 titratable acidity	pH	Dough No. 2 titratable acidity
1. Fresh dough.....	5.76	1.10	5.75	1.10
2. Fresh dough after 5 hours.....	5.24	3.36	5.18	3.50
3. Baked bread.....	5.43	....	5.38	....

**Length of fermentation period.** The total length of the fermentation period depends upon the proportion of yeast used and the temperature at which the sponge or dough is kept. The first rising should double in bulk and should spring back easily when pressed with the finger. It is usually given the longest period and often requires 70 per cent of the total fermentation time. The dough is then punched and worked lightly to

allow the gas to escape. The second rising requires a shorter time than the first one, and the dough may be punched and molded and placed in the pans. Very strong glutes may be allowed to rise a third time before putting in the pan.

Dunlap has reported that, with a high initial hydrogen-ion concentration, or induced acidity, produced by the addition of acid or some substance that increases the acidity, better bread is secured if the fermentation periods are reversed, that is the first rising period is short, and the second longer.

If the dough is baked before fermentation has progressed far enough, the resulting bread has thick cell walls and is decidedly less tender than bread fermented sufficiently. The volume is also smaller. This is because the gluten with the proper length of fermentation becomes more dispersed and tender. If fermentation is carried too far the gluten becomes too soft to retain all the expanding gas bubbles and several cells coalesce, which produces thick cell walls and coarse texture. With extreme fermentation the dough smells sour, and a very coarse, heavy, compact bread of small volume and sour taste is obtained.

*Prevention of crust formation during fermentation.* Drying of the crust may be partially or wholly prevented by covering, keeping in a cabinet with high humidity, or greasing the crust.

A crust formed after the dough is panned gives a dry layer on top that is less elastic. Often a layer of compact grained cells is formed just below the crust because of the drying of the crust, and as a result it is inelastic. The drying in the pan may be prevented in the same way as during rising, or the crust may be moistened with water occasionally.

**Size of pan.** The volume of the loaf and the shape of cells of the bread depend upon the method of panning and the relation of the amount of dough to the size of the pan.

When the dough is placed on one side of the pan so that it has to turn over in rising the volume is reduced and the loaf is likely to crack in the center from pressure. The dough should be placed in the middle of the pan and shaped so that it is uniform. Harrel found that, with conditions otherwise standardized, a loaf placed slightly to the side of the pan gave a volume of 2700 cc. but placed in the middle of the pan gave a volume of 3230 cc.

Lewis and Whitcomb in their investigations on the "Influence of Size and Shape of Pan on Baking Test" concluded that the purpose for which the pan is intended should govern its shape and size. An experimental bake is a test of the strength of the flour; for this purpose a pan should be used that puts a more severe test upon the flour. Their conclusions are as follows. "The shape of the pan exerts a marked influence upon the size and quality of the loaf in both strong and weak flours.

"The proof period varies with different types of pans. It does not correspond closely with volume or height of loaf or quality of bread.

"Deeper pans produce taller loaves, but not the larger loaves.



“The deep type of pan produces a smaller loaf of somewhat poorer quality than the shallow type. Hence a flour that will produce a good loaf in a deep pan can be depended upon to perform well in the bake shop where the shallow type of pan is used.”

The committee on standard formulas and procedure of A.A.C.C. have suggested a pan of the following dimensions for a pound loaf of bread for an experimental bake. Top  $7\frac{1}{2}$  by  $4\frac{1}{2}$ , bottom 7 by  $3\frac{1}{2}$ , height  $3\frac{1}{2}$  inches.

**Temperature and time of baking.** The 1926-27 committee on baking, Blish, chairman, of A.A.C.C. have recommended baking a pound loaf of bread for 35 minutes at a temperature of  $220^{\circ}\text{C}$ . For the small loaf made with 100 grams of flour they recommend 25 minutes at  $220^{\circ}\text{C}$ . Larger loaves of bread will require a longer baking period and better results will be obtained with a lower baking temperature. The baking temperature depends somewhat upon the volume attained during rising. If the volume is great enough the temperature should be high; if the bread is not proofed quite enough a lower temperature will allow it to rise more in the oven.

**Flavor of bread.** Visser't Hooft and de Leeuw have reported that excellent flavor in bread is caused by two factors. One factor is a blend of the flavors of the various ingredients of the bread and the other is diacetyl, an important flavor constituent of butter. Acetylmethylcarbinol is formed in the dough as a by-product of fermentation of sugar by yeast. In the finished loaf acetylmethylcarbinol slowly oxidizes to diacetyl. But the amount of acetylmethylcarbinol formed depends upon many factors. The following are reported to have a favorable influence: high sugar-yeast ratio, diastase preparations, low fermentation temperature, short fermentation time, sponge-dough method, hydrogen acceptors or oxidizing agents, oxygen, and proper yeast selection.

**The use of soft-wheat flour in bread making.** There is a large production of soft-wheat flour in some sections of the United States. Winter wheat, by which is meant wheat planted in the fall, is often called soft wheat. There are two types of winter wheat, one of which produces a soft-wheat flour and the other a hard-wheat flour. The type produced depends upon the place grown and the variety of wheat. Soft wheat is more generally grown in the southern states and soft-wheat flour is used extensively in the South.

Soft-wheat flour can be used in baking bread, but the manipulation required is different from that for strong-wheat flour. The gluten in soft-wheat flour is less colloidal, more dispersed, than in strong-wheat flour. Since fermentation produces greater dispersion of the gluten, which gives greater elasticity, and a more tender gluten, the fermentation period is necessarily shorter for soft-wheat flour than for strong-wheat flour. Better results are also obtained if the proportion of yeast is increased. With increased yeast the sugar is usually increased, as it furnishes a quick food

supply for the yeast. Soft-wheat flours do not have so high a hydration capacity as strong wheat, so that it is necessary to use a smaller proportion of liquid. A shallow pan gives better results than a deep one.

Davis and Cline have reported that the best results are obtained with a short fermentation period. They state, "The best results were obtained by allowing the dough to double its volume for the first rising, the bread is then panned, and allowed to treble its volume in the pan." The trebling of the volume in the pan "overcomes the close, cake-like texture and small volume."

*Liquid.* Davis and Cline state that "To a certain point loaf volume and loaf weight increase with an increase in the proportion of liquid used." A more open porous structure is obtained with increased water; with too high a percentage of water the texture becomes too coarse. With the flour used by Davis and Cline, they have found that 52 per cent of water gives the best loaf and texture. This proportion of water gives a dough so soft that it is necessary to handle it quickly to prevent its sticking to the bread board and hands during the kneading and molding.

*Yeast.* The quantity of yeast used for soft-wheat bread is increased from 2 to 3 times the amount used in the formula for strong-wheat flour. This requires  $1\frac{1}{2}$  to 2 cakes of yeast for a pound loaf of bread.

*Sugar.* Davis and Cline state that increase of sugar with soft-wheat flours gives a loaf with excellent oven spring, with a silky, spongy, moist texture, for the increased sugar seems to have a toughening action on the gluten. The loaf browns better in the oven with the increased sugar. They have decided that 17 grams, about  $1\frac{1}{2}$  tablespoons, for a pound loaf, gives the best results. A larger proportion of sugar, 25 to 35 grams or 2 to 3 tablespoons, yields a loaf of larger volume, but the bread is too sweet.

*Salt.* Salt retards fermentation and depresses the hydration capacity of gluten. Davis and Cline have reported that 5 grams or about 1 teaspoon for a pound loaf produces the best results for soft wheat. Increasing the quantity increases the length of time required for fermentation and gives a more compact, tough loaf.

*Shortening.* Two teaspoons per pound loaf produced good results but Davis and Cline have found that increasing the fat to 1 or  $1\frac{1}{2}$  tablespoons gives an increased volume and sheen but also requires a longer fermentation.

**The staling of bread.** Aside from the organoleptic means of detecting staling, several methods have been used by investigators. Karacsonyi has reported the use of the viscosimeter for this purpose. Platt summarizes these methods and reviews the literature on staling. When soaked in an excess of water stale bread does not swell to the extent that fresh bread does. When viewed with the microscope the starch granules in stale bread have a more distinct outline, and often an air space occurs between the starch and gluten. The water extract from fresh bread contains more

soluble starch products than that from stale bread. Fresh bread is more elastic than stale bread, hence measuring the compressibility is also a means of determining the degree of staling.

Staling includes all the changes taking place during the storage of bread, cake, pastry, etc. These changes include volatile losses, changes that may be due to oxidation, and most important, changes that occur within the product, which Platt terms "inherent staling."

The volatile losses are largely composed of water, but include small amounts of carbon dioxide, alcohol, acetic acid, diacetyl, and other substances, all of which give the distinctive aroma to fresh bread. The moisture loss can be largely prevented.

Stale crackers, fruit cake, and other products often deteriorate in flavor because of the oxidation of the fats they contain.

Even if moisture loss is prevented from a loaf of bread certain changes take place within the loaf which give it a flinty feel and a crumbly texture. Colloidal systems change slowly and temperature may have a decided effect on the change. In baking, as the gelatinization temperature of the starch is reached, the starch swells, absorbing whatever moisture it can obtain; but the gluten may lose moisture. However, as the bread cools part of the starch is precipitated and releases moisture, which may be absorbed by the gluten or become the source of the dampness of wrapped cool bread. The staling process is reversible, i.e., the stale bread when heated again to a high temperature acquires the characteristics of fresh bread. This reversal can be repeated several times or until the bread has lost too large a proportion of moisture. Though both starch and protein play a rôle in staling, more work has been done in studying the part starch plays than that of the protein.

Not all the starch is gelatinized in baking, so that the freshly baked bread is not entirely transparent, but has more of a transparent appearance than stale bread. Bryant has reported the following percentage of soluble extract in one experiment: for dry flour after mixing 9.32 per cent, after proofing 10.52 per cent, 30 minutes after baking 13.82 per cent, 6 hours after baking 13.46 per cent, 24 hours after baking 11.92 per cent, and 70 hours after baking 10.41 per cent. He adds that the effect of fat in bread in preventing staleness is not known, but that salt is supposed to tend to increase the staling in that starch changes more rapidly to insoluble starch if salt is present.

Katz, between 1912 and 1916, made extensive investigations concerning the causes of bread becoming stale and means of preventing staling. He refers to staling as follows: "I concluded that staling may be ascribed to an alteration of the starch, partly gelatinized by the baking process, whereby the water-combining powers of starch are impaired or diminished. As a result, starch and the gluten skeleton are no longer in equilibrium with each other, the gluten taking up a certain quantity of water yielded by the

starch. The individual starch granules shrink somewhat and relax their union with the gluten skeleton which binds the partly gelatinized starch granules into a uniform whole. The loosening of this union is the basic cause of bread crumbling when the latter becomes stale.

"It is known that another change takes place in the bread crumb when staling, namely, a hardening of the crumb. This change occurs even when loss of water on the part of the whole bread is precluded, which of the two processes will predominate, i.e., hardening or crumbling, depends on the nature of the bread."

Katz and Vershaffelt have found that microscopic studies of fresh and stale bread show differences in the appearance of the starch granules. "In the stale bread the starch granules are more sharply contoured. Upon closer examination it was found that they were doubly contoured and that between the two contours there was a fine air bubble. This distinction between fresh and stale bread can be detected invariably in all types of bread."

Katz has also reported that hardening of the crumb occurs before crumbling. For determining hardness of the crumb a special type of tester is used. The hardness is determined from the number of millimeters that a disc of 22.5-mm. diameter penetrated into the bread crumb, when loaded with a definite weight and allowed to act for a definite time.

If the bread is kept at a temperature of 60°C. or above, and if moisture loss and condensation of water are prevented, the bread stays fresh indefinitely. Thus staling is brought about by cooling of the bread. Katz has reported that at 60°C. or above freshness of the bread is retained, at about 40°C. it becomes approximately half stale, at 30°C. it becomes still more stale, and at 17° to 0°C. it becomes totally stale. But although at 0°C. bread stales quickly, more intense cold inhibits staling. Katz recommends intense cold, -8°C. or lower, as one means of preventing staling of bread. The chief objection to its use in bakeries is the cost.

Storing the bread from 40° to 60°C. inhibits staling; the chief objection to storing bread at these temperatures is that bacterial and mold growth may be favored.

Whymper states that "The effect of freshness can be enormously increased and sustained for many days by the addition of small quantities of fat to the bread," and that the effect of fat on staleness is out of all proportion to the amount used.

Whymper also states that staleness is hindered by increasing gluten in bread, or at least the addition of gluten to bread delays staleness. Bread made from milk stales more slowly than that made from water. Whymper suggests that fat and gluten prevent the deposition of starch in much the same way as they oppose the setting of cement.

**Ropy bread.** So-called rope in bread or ropy bread is caused by *B. mesentericus*, accidentally introduced into the bread through the flour or other means. The spores of this bacteria are not destroyed by baking the

bread. Two or three days after baking, and particularly during hot weather, the center of the loaf acquires a peculiar gummy, sometimes crumbly texture, which spreads to the edges of the loaf. The development of rope can be prevented by increasing the acidity of the bread. Thus the whey of sour milk can be used for the liquid in home baking or vinegar can be added. It has been reported that only about 1 per cent of vinegar is required. Other suggestions are to have materials and flour bins scrupulously clean, to increase the amount of yeast, thus shortening the fermentation period, to avoid low temperatures during fermentation, and to cool the baked loaf rapidly.

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## BREAD

### Experiment 71.

To see if gluten can be washed from a batter.

To  $\frac{1}{2}$  cup of flour add slowly while mixing  $\frac{1}{2}$  cup of water. Mix until smooth and free from lumps; then beat for 1 minute. Let stand 10 minutes. Place in a fine sieve. Wash in a stream of water and try to collect the gluten. What happens?

### Experiment 72.

A. To wash gluten from a dough.

1. To  $\frac{1}{2}$  cup of bread flour (56 grams) add  $\frac{1}{6}$  cup of water (40 cc.). Stir 40 times; then knead 80 times. Let stand 10 minutes. Wash under a stream of water to free the gluten of starch. Wash until the water is clear. The product obtained is gluten. What is its weight? What are its characteristics? If desired the gluten balls may be baked and their comparative baked volumes obtained. Bake at 200° to 210°C. (390° to 410°F.).

2. Repeat A1, but use pastry flour. Compare the resulting gluten and its quantity with that from bread flour. Bake.

B. To determine the effect of substituting milk for the water and adding baking powders to the flour.

1. Repeat A1, but substitute milk for the water.

2. Repeat A1, but substitute sour milk for the water.

3. Repeat A1, but sift  $\frac{1}{2}$  teaspoon of tartrate baking powder with the flour before adding the water.

4. Repeat B3, but use a phosphate baking powder.

5. Repeat B3, but use sulfate-phosphate baking powder.

6. Add different proportions of sugar to the flour and try to wash out the gluten. The amount of sugar added can be based on the proportion of sugar to flour used in muffins and different cake recipes.

## Bread

### Experiment 73.

To determine the best proportion of water to use with the kind or grade of flour that is to be used in making bread.

Brand of flour used:

*Recipe:*

Ingredients	Approximate measure	Large dough or large loaf, grams	Small dough or small loaf, grams
Flour.....	3 $\frac{1}{8}$ cups	350.0	100.0
Yeast.....	$\frac{3}{4}$ cake	10.5	3.0
Sugar.....	$\frac{3}{4}$ tablespoon	10.5	3.0
Salt.....	1 $\frac{1}{4}$ teaspoons	5.25	1.0
Fat.....	$\frac{1}{2}$ tablespoon	6.5	0.0

Fermentation

First punch 105 minutes (28–30°C.)

Second punch 50 minutes

Pan 25 minutes after second punch

Proof 55 minutes

Bake 35 minutes (220°C.)

Use the large or small dough for baking. The fermentation time for the large dough or large loaf is 265 minutes or nearly 4 $\frac{1}{2}$  hours. That for the small dough or small loaf is 290 minutes or nearly 5 hours. If a shorter fermentation period is desired increase the amount of yeast used as suggested in Table 47 and decrease the fermentation time for punches and panning accordingly.

Determine the temperature of the water necessary to bring the dough to 28°C. This may be done for the first trial by taking the temperature of the room plus the temperature of the flour and subtracting from 84. The result will be the temperature of water to use, to bring the dough out at 28°C. This will not always bring the temperature of the dough out at 28°C., especially if the temperature of the room is rather low and mixing is continued for some time. To find the temperature of the water to bring the dough out at 30°C., subtract the temperature of the room plus the temperature of the flour from 90.

Sift the flour. Dissolve the sugar and salt in a portion of the water and mix the yeast in another part. Add water and melted fat to the flour and mix to a smooth dough. If a bread mixer is used, mix until the dough is smooth. Keep a record of the time and mix other batches of dough for the same length of time. If mixed with a spoon mix until a dough is formed, then knead on a flat surface until smooth. The length of time for kneading depends upon the vigor and rapidity of kneading. It is better to work out a definite method of kneading and count the punches used. Otherwise the amount of kneading will produce variations and it will then be difficult to determine variations due to other causes. Try 300 punches, unless it is found that,

owing to method of kneading or other factors, more or less kneading gives better results.

For fermentation place in a container of suitable size and cover. To obtain a constant temperature in a cooking laboratory the dough may be placed in a covered bowl or pan and set in a dishpan of water, the water being at the desired temperature for fermentation. Add hot water as needed to keep the temperature constant. The dishpan should be covered to avoid drafts over the top of the bread.

An empty refrigerator makes an ideal proofing cabinet, as it is easy to regulate the temperature by a pan of hot water in the bottom, and it is moist so that there is no tendency for the crust to dry. A china closet, a box, or an oven can also be used.

Leave the dough in the container for the punches and punch just sufficiently to bring the dough to the original volume. Count the strokes used for punching and use the same for all the doughs and the same method of making strokes. For panning, turn out on a smooth surface and knead or fold gently into the desired shape. Use no flour to mold as this flour will not be fermented for the same length of time as that in the dough and may leave streaks in the bread.

Prevent a crust from forming while rising and while in the pan. If necessary, moisten the top occasionally with water.

1. Use 55 per cent of water or 192.5 cc.
2. Use 57.5 per cent of water or 201.2 cc.
3. Use 60 per cent of water or 210 cc.
4. Use 62.5 per cent of water or 218.7 cc.
5. Use 65.0 per cent of water or 227.5 cc.

If preferred a score card may be used instead of the following headings for keeping a record of results of the bread experiments. Write a summary of conclusions of experiments giving applications to cooking.

Volume	Crust appearance	Color	Smoothness	Break and shred	Thickness

Crumb, color	Size of cells	Thinness of cell walls	Elasticity or spring	Tenderness	Odor	Flavor

Results and conclusions.

#### Experiment 74.

To determine the effect of manipulation of the dough upon the volume, the texture, and the tenderness of bread.

- A. The extent of mixing and the pressure used in kneading.

1. Use the proportion of water found best under Experiment 73. If this has not been determined, try 60 per cent. Follow directions for mixing given under Experiment 73. Mix 3 times the recipe used. Knead as in Experiment 73, using 400 punches. Weigh the dough and divide into 3 portions. Put part one in the proofing cabinet to rise. Use the remainder of the dough for 2 and 3.

2. Continue kneading one part of the dough from 74,1, for 15 to 20 minutes or use 1000 punches. For the rest of the operations duplicate the procedure under 1.

3. Put the third portion of the dough from 74,1, to rise. When punching after the first fermentation period use more strokes for punching and more pressure. Knead hard just before molding the loaf to put in the baking pan.

#### B. Method of molding.

Repeat A1, using the regular recipe. When molding the dough for the baking pan pat gently into a long narrow strip that can be rolled for the loaf. Roll around about 2 times and shape and place in pan.

Compare the appearance, volume, texture, and tenderness of the loaves of bread. Compare the shape and direction of cells in the baked loaves. Does rolling compress a part of the dough so that some cells are more compressed than others?

### Experiment 75.

To determine the effect of fermentation on the volume, the texture, and the tenderness of bread.

Mix 2 times the recipe used. Follow directions given under Experiment 73, using the proportion of water that gave the best loaf. If this has not been determined use 60 per cent. After kneading, weigh and then divide into 2 parts. Mold and shape one loaf and place directly in the baking pan. Let rise to the desired height and then bake. The second half of the dough should be fermented and punched in the regular way before molding and baking. Compare the two loaves for volume, appearance, color of crumb, texture, and tenderness.

### Experiment 76.

To determine the effect of changing the proportion of ingredients.

Mix in the usual way, ferment, and bake the usual time.

#### A. Salt.

1. Repeat Experiment 73, using the best proportion of water for a control loaf.

2. Increase the salt to 8 grams.

3. Decrease the salt to 2.6 grams.

#### B. Sugar.

1. Double the sugar in the recipe. Use A1 for a control.

2. Omit the sugar in the recipe.

#### C. Fat.

1. Double the fat in the recipe. Use A1 for a control.

2. Treble the fat in the recipe.

Compare the effect on volume, appearance, texture, and tenderness of bread of changing the proportion of ingredients.

## CHAPTER XII

### BATTERS AND DOUGHS

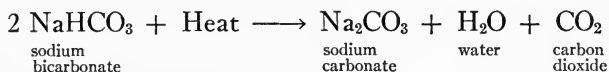
#### Leavening Agents

A leavening agent is a substance that forms bubbles of gas in a batter or dough, thus leavening it or making it porous. During the baking the expansion of the gas produced stretches the batter; then the heat coagulation of the protein of the flour or of the flour and eggs sets the dough structure.

Yeast produces carbon dioxide gas in doughs, but with yeast a period of time is necessary for enough gas to be produced to leaven the dough sufficiently before the product can be baked.

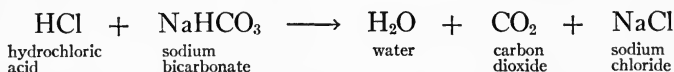
**Steam.** One of the simplest ways of leavening is by steam. One volume of water forms more than 1600 volumes of water vapor, so that steam may have considerable leavening ability. Steam is most effective as a leavening agent in thin batters in which the proportion of water is large, such as popovers and cream puffs. Medium batters, of which griddle cakes and muffins are examples, are partially leavened by steam and partially by the gas produced from the added baking powder. Steam does not aid to such a great extent in leavening the batters and doughs containing little water both because of the small proportion of water used and because of the large amount held by the starch and protein.

**Soda.** Sodium bicarbonate or soda may be used for a leavening agent. When heated it gives off gas as follows:

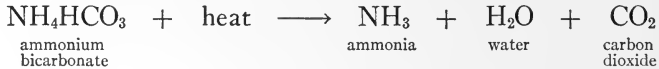


The residue, sodium carbonate, gives a disagreeable taste and produces a yellow color in the baked product. For this reason some substance is used with soda that combines with it to give an end product that does not affect the flavor or color of the food so decidedly as does sodium carbonate.

**Hydrochloric acid.** The following reaction is typical of baking powder reactions in that an acid substance is combined with the soda to produce the gas. According to Hart, the first patent for a baking powder, taken by Dr. Whiting in 1837 in England, was for the formula given below. In the baking powders of today an acid salt, in powder form, replaces the acid of this formula.



**Baking ammonia.** Baking ammonia has been used for years in baked products and is still used in many bakeries for some goods. Baking ammonia is ammonium bicarbonate; when heated it breaks up to form ammonia, water, and carbon dioxide. Since two gases are produced it is a very efficient leavening agent. The chief objection to its use is that, unless



all the ammonium bicarbonate is broken up and all the ammonia gas driven off, the taste and smell of ammonia remain in the baked product. For this reason it is used in baked products like cookies and cream puffs, that are small and thin or have thin walls.

The author was interested in looking over several hundred cooky recipes sent in from all over the United States for a magazine cooking contest in 1927. The surprising thing about them was the length of time some of the recipes must have been used by, or handed down to, a family, for great numbers of them called for leavening agents in common use years ago. There were many that called for baking ammonia, frequently with no definite proportions, for the recipe would state to use three or five cents worth of ammonia.

Baking ammonia is in rather coarse crystals as it is obtained at the drug store, and therefore produces better results if dissolved in the liquid before it is added to the dough.

**Sour milk.** The use of sour milk and soda to produce carbon dioxide gas in baked products antedates the use of baking powder. As the acidity of the milk varies with its age and degree of sourness, the amount of soda needed to neutralize the acidity will vary. Some recipes call for more soda than is needed to neutralize the acid of the milk, thus an excess is left that forms sodium carbonate with its resulting bad after-taste and yellow color. This is probably the reason that many present-day housekeepers do not like to use it. Then some cooks do not learn to vary the proportion of soda to use with the milk.

Slightly sour or "blinky" milk will combine with very little soda, but very sour milk will require a larger quantity. An average amount for ordinary sour milk is  $\frac{1}{2}$  teaspoon of soda per cup of sour milk. This produces gas equivalent to the amount produced by about 2 teaspoons of baking powder. As this does not always produce as porous a texture as is desired, some baking powder may also be added. It is preferable from the color and the flavor obtained in baked and steamed batters to use too little soda to neutralize the acid in the milk, rather than an excess. In fact, sour milk can be used in muffins, biscuits, and cakes with baking powder and no soda, with far less perceptible taste than when excess soda is used.

Many recipes state in the directions to dissolve the soda in a small amount of water. This seems to hold over from the days when soda like

the baking ammonia was coarse and not finely powdered, and the solution in water prevented the formation of brown spots. This is a good method if the soda is added directly to the batter, for it tends to lump in the package. But finely powdered soda such as is used at the present time may be sifted with the flour, though it is true that different brands may differ in fineness of division.

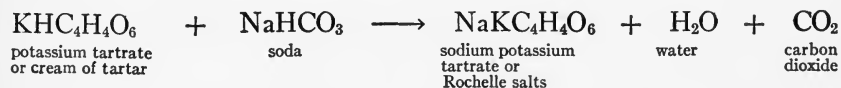
Some recipes state to mix the soda with the sour milk or molasses before combining with the other ingredients. This is not a good practise since gas begins to evolve as soon as the two are mixed and thus a large portion of the gas is useless as a leavening agent.

**Molasses.** Daniels and Heisig have reported the acidity of molasses, honey, and corn sirup. Cooking molasses and sorghum, like sour milk, vary in acidity, so that the amount of soda required to neutralize the acid varies. Some require  $\frac{1}{2}$  teaspoon of soda per cup, others  $\frac{3}{4}$ , and some 1 teaspoon. An average amount is about  $\frac{3}{4}$  of a teaspoon per cup of molasses. However, the strong flavor of the molasses may mask the flavor caused by the excess soda to a certain extent, so that one is often safe in using the amount required for the molasses containing the highest proportion of acid, i.e., 1 teaspoon per cup.

Many old recipes containing molasses, like those containing sour milk, call for excess soda. In the cooky contest previously mentioned, it was not uncommon to find recipes that called for  $\frac{1}{2}$  cup of soda for 3 quarts of molasses and a pint of sour cream or milk.

**Honey and corn sirup.** The acidity of honey as reported by Daniels and Heisig varies. For the samples they tried they report that from  $\frac{1}{2}$  to  $\frac{1}{12}$  of a teaspoon of soda was required to neutralize the acidity of 1 cup of honey. This acidity is so low that it is hardly worth while to add soda for neutralizing. The acidity of corn sirup is very much lower than that of honey.

**Cream of tartar.** Cream of tartar is an acid salt and combines with soda to form carbon dioxide gas. It was used extensively before baking powders came into common use. Many recipes still state to use cream of tartar and soda for the leavening agent, and many of them call for equal amounts of these two ingredients. As the weight of a teaspoon of soda or of cream of tartar is practically the same, an excess of soda is left in the baking mixture when equal measures of the two are used, for by weight 188 parts of cream of tartar combine with 84 parts of soda to form 18 parts of water, 44 parts of carbon dioxide, and 210 parts of sodium potassium tartrate. These proportions by measure are approximately  $2\frac{1}{4}$  teaspoons of cream of tartar to a teaspoon of soda.



### Baking Powder

Hart states that baking powder was first used in England about 1830. It was made of "pearlash and alum, and later of sesquicarbonate of ammonia." When crystalline substances were mixed with soda, a wider use was insured for baking powder, for with the dry salts, reactions of the baking powder did not take place until it was moistened, and the alkaline and acid substances could be kept in the same container.

**The ideal baking powder.** Hart states that "From the standpoint of the consumer, the ideal baking powder (*a*) gives the most gas for the least volume and weight of powder; (*b*) gives the gas slowly when cold and increasingly in the cooking dough, so the dough may be mixed cold and left standing several hours; begins to generate gas in quantity in the oven and ceases to generate when it would rupture the crumb; (*c*) leaves a tasteless and absolutely harmless residue in the bread; (*d*) is cheap; (*e*) keeps well. The chemicals should not react on one another in the can and thus lose strength."

**Carbon dioxide.** Under the United States Food and Drugs Act, the following definition for baking powder was formulated. "Baking powder is the leavening agent produced by the mixing of an acid reacting material and sodium bicarbonate with or without starch or flour.

"It yields not less than 12 per cent of available carbon dioxide."

The principal reason for adding starch to baking powder is for a standardizing agent. To some extent it also absorbs moisture, thus lessening the gas lost during storage by reaction of the ingredients and for a standardizing agent. The federal standard requires 12 per cent of available carbon dioxide, but most of the baking powders made for home use yield 14 per cent of carbon dioxide. Starch is added to each type of baking powder in amounts so that 100 grams of the powder yield 14 per cent carbon dioxide. If the amount of gas produced by a definite weight of baking powder were not standardized there would be great difficulty in substituting some types of powders for others in recipes. For under these conditions the amount of carbon dioxide produced by a teaspoon of powder would vary far more than it does when the powder yields 14 per cent of carbon dioxide.

The carbon dioxide of baking powders is classified as total, available, and residual. The total carbon dioxide is all the carbon dioxide contained in the powder and may be obtained by using acid with it. The residual carbon dioxide is that remaining in the powder after water has been mixed with it and heat has been applied. Available carbon dioxide represents the difference between total and residual and is the amount usually obtained under baking conditions.

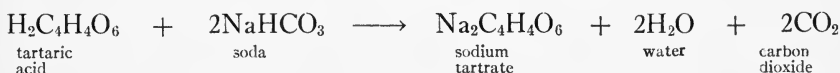
**Types of baking powders.** The alkaline ingredient of all baking powders is soda. The acid ingredient varies, and the names of the various



types of baking powders refer to the kind of compound used for the acid ingredient. The function of the acid salt is the same regardless of the type of salt used. It combines with and releases the  $\text{CO}_2$  from the soda. The types of baking powders are (1) tartrate, (2) phosphate, (3) sulfate, and (4) a combination of sulfate and phosphate.

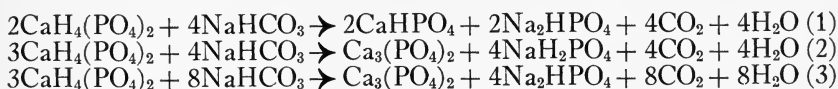
*Tartrate powders.* The tartrate powders on the market consist of cream of tartar or a combination of cream of tartar and tartaric acid. Tartaric acid is not used alone in baking powders. The objections to using it alone as given by Hart are that "Its reaction is rapid and complete in cold water, and its keeping quality correspondingly poor." Cream of tartar reacts more slowly than tartaric acid but keeps and aerates well.

The residue left from cream of tartar and soda is "Rochelle" salts. See the reaction under cream of tartar. Tartaric acid leaves sodium tartrate as a residue.

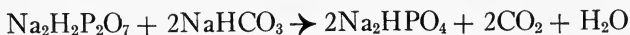


*Phosphate powders.* Three phosphate compounds are or have been used in baking powder. Monosodium phosphate has been used, but so far as the author knows no baking powders on the market at present contain it. Monocalcium phosphate is most frequently used. Lately sodium acid pyrophosphate is being used in considerable quantities by commercial bakers. Phosphoric acid forms three series of salts, such as  $\text{Na}_3\text{PO}_4$ ,  $\text{Na}_2\text{HPO}_4$ , and  $\text{NaH}_2\text{PO}_4$ . The first is not formed in baked products. Davis and Maveety state that the monosodium phosphate ( $\text{NaH}_2\text{PO}_4$ ), disodium phosphate ( $\text{Na}_2\text{HPO}_4$ ), tricalcium phosphate ( $\text{Ca}_3(\text{PO}_4)_2$ ), and dicalcium phosphate ( $\text{CaHPO}_4$ ) are found in the residue after the baking powder has reacted. They state that the reaction is carried to completion with the formation of  $\text{Na}_2\text{HPO}_4$  and  $\text{Ca}_3(\text{PO}_4)_2$  only when an excess of hydroxyl ions is present.

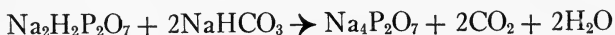
Bailey gives three equations which represent the reactions that may take place under favorable conditions. He adds that equation (3) represents what probably usually occurs.



With sodium acid pyrophosphate Bailey states that there is some question concerning the products of reaction and gives two equations that may represent what occurs.



and



Sodium acid pyrophosphate is at present put up with cornstarch and sold only to bakers. The bakers add the soda, using 2 parts of combined starch and disodium pyrophosphate to 1 part of soda. This proportion yields about 17 per cent of available carbon dioxide. Some of the other baking powders for the bakery trade are also made to yield 17 per cent of carbon dioxide.

*Sulfate powders.* The author knows of no straight sulfate powders on the market at the present time. Sodium aluminum sulfate is the acid salt used in these powders.

*Combination sulfate-phosphate powders.* These powders contain two acid salts in varying proportions. The sulfate salt is sodium aluminum sulfate and the phosphate is monocalcium phosphate. Hart states that sodium aluminum sulfate "has first class keeping quality and has an aerating value about the same as tartaric acid." The reaction of the phosphate salt with soda has been given above. One ingredient of the residue of sulfate powders is aluminum hydroxide. Another is sodium sulfate. The latter in excess produces a bitter taste. The sodium aluminum sulfate is first hydrolyzed with water. The sulfuric acid formed then reacts with the sodium bicarbonate. Bailey states that "Besides the reaction of the phosphate and sodium



aluminum sulfate with soda, there is probably an interaction between the two."

The preceding Graphic Chart by Dr. Chittick shows "the ingredients present in the various types of baking powders, proportioned to produce 14 per cent of gas, which is the average strength of the standard baking powders." It also shows the compounds formed from the reaction of the various baking powders and the percentage or possible percentage of these compounds.

Chittick has suggested calling baking powders containing the sodium aluminum sulfate salt (sometimes known as aluminum or S.A.S. baking powder) sulfate powders, which is a good suggestion. He also suggests that baking powders consisting of a combination of sodium aluminum sulfate and phosphate salts be called sulfate-phosphate baking powder. These changes are shown in the Baking Powder Chart. Because of the number of times names of types of baking powder are used in the laboratory outline, the author has used the abbreviation, S.-P., for sulfate-phosphate powders.

**Temperature and reaction of baking powder.** Sulfate powder reacts slowly at room temperature. Bailey states that at room temperature a tartrate baking powder will react completely, a straight phosphate will yield two-thirds of its gas, but heat is required to liberate the remainder, and a combination powder will liberate from one-fifth to one-third of its

# GRAPHIC BAKING POWDER CHART

L. WATSON, CHEMIST

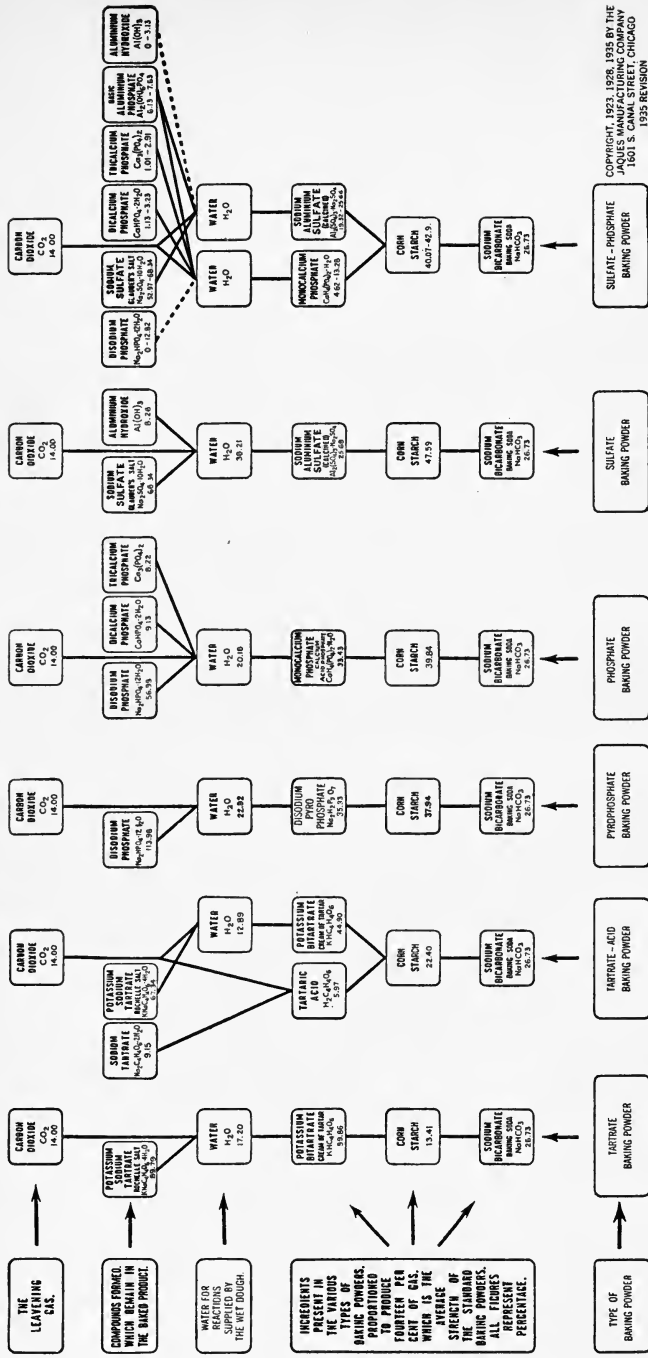


FIG. 45.—Showing the proportion of ingredients in baking powders to yield 14 per cent of carbon dioxide. In the first square at the bottom of the columns is listed the type of baking powder. Next come soda and cornstarch, which are common ingredients in all powders. In the fourth squares are the acid ingredients and the percentage required to yield 14 per cent of carbon dioxide. The next to the last squares at the top give the residues from the reaction of the baking powder ingredients; those on the left of the center of each diagram are soluble and those to the right are insoluble in water.

*Courtesy of Dr. Chittick and Jaques Manufacturing Company.*



gas. The baking powders that liberate a larger proportion of carbon dioxide at room temperature are often referred to as rapid acting; those liberating a small proportion at room temperature are called slow acting. Bailey classes sodium acid pyrophosphate as a slow-acting powder. Barackman states that it may be classed as a rapid-acting powder in water but a slow one in a dough. Sulfate-phosphate is a combination of a rapid- and a slow-acting powder. It can be readily seen that it is possible for some types of powder to lose a larger proportion of gas during mixing than other types of powder. For this reason a smaller amount of the slow-acting powders can be used in many baked products.

**The amount of carbon dioxide lost from a batter.** A smaller proportion of gas is lost from a batter during mixing than from water, owing at least in part to the density and viscosity of the dough mixture. Noble and Halliday have done considerable work with baking powder. The following table from their results shows the comparative loss from water and from a simplified dough mixture after mixing for 40 seconds. They have also determined the amount of carbon dioxide evolved in a simplified batter during 40 seconds' mixing. This was only slightly greater than the amount lost from the batter, as shown in Table 53.

TABLE 53

CARBON DIOXIDE LOST WHEN BAKING POWDER IS COMBINED WITH WATER ONLY, AND WITH OTHER INGREDIENTS INTO BATTERS (*Noble and Halliday*)

Type of baking powder	Average quantity of CO <sub>2</sub> lost when baking powder is mixed for 40 seconds with					Average quantity of CO <sub>2</sub> lost when baking powder is beaten for 20 seconds with flour, fat, and water
	Water	Flour, fat, water	Flour, fat, milk	Flour, fat, sugar, and water		
				4.9 per cent sugar	9.8 per cent sugar	
	per cent by weight	per cent by weight	per cent by weight	per cent by weight	per cent by weight	per cent by weight
Tartrate	10.11	6.77	6.01	6.45	6.78	6.18
Phosphate	9.34	5.56	....	4.71	5.81	4.52
S. - P. 1	5.15	3.25	2.78	2.58	2.60	2.70
S. - P. 2	3.91	2.29	1.76	1.89	2.61	1.27

Barackman states that for baking purposes the carbon dioxide from baking powder may be divided into three divisions as follows: "1. the amount lost from a dough during mixing and standing; 2. the amount causing expansion of the dough; this is called 'bench action' by bakers; 3. the amount of carbon dioxide dissolved and adsorbed and that available from unreacted soda which will be effective as leavening at oven heat." Barackman has determined the carbon dioxide for these three divisions in biscuits and doughnuts. Instead of using baking powder he used acid salts and soda in the dough mixtures. The acid salts used were calcium acid phosphate, sodium acid pyrophosphate, potassium acid tartrate (cream of tartar), and sulfate-phosphate. For convenience dry mixes were made up to which water was later added in a special mixing apparatus. The dry mix for biscuits contained flour, soda 1.5 per cent (flour basis), acid salt, and shortening 10 per cent. The dry doughnut mixture contained flour, soda, acid salt, shortening 5.55 per cent, sugar 22.2 per cent, powdered egg 3.33 per cent, and dry skim milk 10 per cent. When water was mixed with the dry ingredients heat was evolved. This made it necessary to use control doughs containing no acid salt or soda, to correct for the expansion of occluded air in the dough. The doughs all had a final temperature of  $27^{\circ}\text{C.} \pm 0.5^{\circ}$ .

TABLE 54

VOLUME IN CUBIC CENTIMETERS OF CARBON DIOXIDE EVOLVED FROM SODIUM ACID PYROPHOSPHATE AND SODA (*Barackman*)

Time, Minutes	Water solution A	Biscuit Doughs			Doughnut doughs		
		B	C	D	B	C	D
0	0	0			0		
½	84.3	27.0	.....	.....	25.6	.....	.....
1	111.3	42.1	.....	.....	36.0	.....	.....
2	120.4	58.1	14.2	43.9	40.5	4.5	36.0
3	122.9	64.9	18.0	46.9	42.9	6.0	36.9
4	124.2	69.9	21.8	48.1	44.7	6.7	38.0
5	124.9	73.8	25.6	48.2	46.0	7.5	38.5
6	125.6	77.5	28.4	49.1	47.5	8.2	39.3
7	125.9	81.0	30.3	48.7	48.1	9.0	40.1
8	126.5	84.3	33.2	51.1	50.5	9.0	41.5
9	127.2	86.6	35.1	51.5	51.9	9.7	41.2
10	127.6	88.8	37.0	51.8	52.0	10.5	41.5
15	129.4	98.2	43.6	54.6	56.7	12.7	43.0

A. Reaction in water.  
B. Reaction in dough.

C. Dough volume.  
D. Volume of  $\text{CO}_2$  lost.

Barackman's results for the rate of reaction of sodium acid pyrophosphate are given in Table 54.

From the results obtained Barackman concluded that a rapid-acting baking acid caused a larger loss of carbon dioxide from the dough during mixing, whereas a slow-acting acid has a smaller loss and consequently a greater quantity of available gas left in the dough for baking. "Of the gas generated during mixing only 20 to 30 per cent is retained by the doughs. This, plus the gas in the undecomposed soda, is available for leavening in the oven. No appreciable loss of gas occurs after mixing."

In the following tables the specific volume was obtained by dividing the volume of the biscuits or cake by their weight.

TABLE 55

THE PERCENTAGE OF CARBON DIOXIDE LOST FROM BISCUIT DOUGHS COMPARED WITH THE REDUCTION IN SPECIFIC VOLUME OF BISCUITS (*Barackman*)

Acid ingredients	CO <sub>2</sub> available in dough at 2 minutes, per cent	CO <sub>2</sub> lost after 15 minutes, per cent of available	Specific volume of biscuits baked immediately	Reduced specific volume due to standing, per cent loss
Phosphate.....	49	4.0	2.24	8.5
S. A. P. P.....	78	6.5	2.75	9.0
Tartrate.....	70	13.0	2.65	11.0
Sulfate phosphate* ...	76	6.5	2.41	3.0

\* Exception due to effect of acid on colloidal properties of dough.

Barackman's conclusion was that a correlation exists between the carbon dioxide left in doughs after mixing and the volume of the baked product. "The major portion (70 to 80 per cent) of the carbon dioxide generated from baking powders during the mixing of doughs is lost." In the above table the reduced specific volume is due to the biscuits being mixed and allowed to stand 15 minutes before cutting and baking. The controls were baked within 2 to 3 minutes after mixing.

**Fineness of division of baking powder.** The fineness of division of a baking powder may affect the grain and texture of the baked product. With finely ground powders it seems reasonable to expect that the bubbles of carbon dioxide produced will be smaller than with coarser baking powders, and that a finer grain will thus be produced in cakes and other products. Patterson refers to such a result with finely ground baking powders. Sifting the baking powder with the flour aids in mixing the baking powder more uniformly throughout the batter or dough, and prevents loss of gas that would occur if the baking powder were mixed with the liquid.

Brown spots are often produced on the crust of cookies, biscuits, cakes,

TABLE 56

CARBON DIOXIDE CONTENT OF CAKE BATTERS AND THE SPECIFIC VOLUME OF CAKES (*Barackman*)

Acid ingredients	Per cent CO <sub>2</sub> in batter by analysis	Specific volume of cakes	Specific volume increase over control (1.72)
Phosphate . . . . .	23.0	2.73	1.01
S. A. P. P. . . . .	54.0	3.14	1.42
Tartrate . . . . .	41.5	2.90	1.18
Sulfate phosphate* . . . . .	52.5	2.89	1.17

\* Exception due to effect of acid on colloidal properties of dough.

and other products when baking powder is used in them. If the baking powder used contains soda that is not finely ground, these spots are more likely to occur. The spots do not develop in the thin batters because of the large proportion of liquid, for solution of the soda is thus obtained. The brown spots appear in the product when the baking powder has been mixed only a short time with the dough. With longer mixing the soda is dissolved and the spots do not appear. If doughs are allowed to stand before baking, the spots may not develop or a smaller number may form. Since cakes are usually mixed longer than biscuits and cookies, the spots develop more frequently in cakes when the baking powder is added after the mixing of the batter is partially completed.

### The Structure of Batters and Doughs

The texture or structure of the finished product depends partly upon the structure obtained in the batter or dough when it is mixed. The rôle the flour plays in batter and dough products is the same as in bread, but since the batter or dough may contain different proportions of liquid and other ingredients the structure of the baked product is often unlike that of bread.

The factors that affect the texture of the finished product may be grouped as follows: (1) the ingredients used, (2) the proportion of the ingredients used, (3) the kind and amount of baking powder used, (4) the extent of mixing, (5) the temperature of the ingredients when mixed, and (6) the method of mixing or combining ingredients.

Doughs and batters may also be considered in relation to their physical properties. One of the physical properties of batters and doughs which is intimately connected with their structure, and which can be measured, is viscosity. Viscosity of batters and doughs is important enough to repeat the ten factors listed by Ostwald, causing variation in viscosity, which have



been previously mentioned in Chapter I. They are: (1) concentration, (2) temperature, (3) degree of dispersion, (4) solvation, (5) electrical charge, (6) previous thermal treatment, (7) previous mechanical treatment, (8) the presence or absence of other lyophilic colloids, (9) the age of the lyophilic sol, and (10) the presence of both electrolytes and non-electrolytes.

**The ingredients and their proportion.** When factors (1) concentration, (8) the presence or absence of other lyophilic colloids, and (10) the presence of both electrolytes and non-electrolytes, are combined, we have a formula or a recipe, in other words the ingredients and their proportion or concentration. Batters and doughs consist of flour and a liquid. Usually some fat and egg are added, though one or the other may be omitted: fat is seldom used in popovers, and baking powder biscuits contain no egg. The proteins and starch of the flour are lyophilic systems. When eggs or milk are added their proteins add other lyophilic colloids.

As the concentration or the quantity of the different ingredients in the batter is varied, its properties and characteristics vary, which in turn influences the texture of the finished product. A batter with a high concentration of liquid has a greater fluidity; one with a smaller proportion has a greater viscosity. As the proportion of each ingredient is varied, the finished product is altered accordingly, the kind and extent of the alteration depending upon the particular quality imparted to the batter by the ingredient and upon the proportion of it used.

The proportion of liquid used also influences the degree of solvation or hydration of certain constituents of the batter, i.e., the protein and starch.

**The presence of both electrolytes and non-electrolytes.** Baking powder, salt, soda, and cream of tartar belong to the group of electrolytes. Salts affect the imbibition of water by gluten and coagulation by heat. Since baking powders contain different acid salts, it is possible that they may affect, in different degrees, the rate of hydration of the gluten and the total amount of water absorbed.

Sugar belongs to the group of non-electrolytes. Its presence in large quantity in a batter affects the structure and also the extent of mechanical treatment needed to obtain a certain type of grain.

**Mechanical treatment.** The extent of mixing a definite batter or dough may alter its viscosity or fluidity, and the texture of the finished product varies with this variation in viscosity.

In the laboratory outline an effort is made to control the amount of mixing in most of the batter and dough series by counting the number of strokes used to stir the batter, particularly after the flour is added. It has been found that this gives more uniform results when mixing is done with a spoon or similar utensil, than to mix for a definite time. Some girls will use more than twice as many strokes in a stated time as others. To have the strokes more uniform they should all be made across the bowl or all used in a stirring motion. If a very large spoon or one with slots is

used, it may be necessary to mix with a smaller number of strokes than the ones suggested.

When it is possible a mechanical mixer with a definite speed is preferable to use for school work. Here, too, the amount of mixing required depends somewhat upon the size of the mixer and the quantity of material used. With large classes it is not always possible to have enough mixers not to delay the class work. Mixing with a spoon has the advantage of being the method used under most home conditions.

There is an amount of mixing, which partially or completely dissolves the sugar, develops the gluten network sufficiently, and distributes the fat throughout the batter, that gives the best flavor and texture to the finished product. The product is tender and the volume is good. This amount of mixing, which may be called the optimum amount, will vary with each recipe, i.e., with the ingredients and their proportion. One illustration is the kind of flour used, for the optimum amount of mixing is not always the same for bread and pastry flours. It will also vary with the temperature of the ingredients when they are mixed.

**The temperature of the ingredients when mixed.** The temperature of the ingredients when mixed influences the structure obtained, particularly in cakes and doughnuts. The protein particles of flour imbibe water more rapidly at higher temperatures. Sugar is more soluble with increasing temperature. But perhaps the consistency of the fat and its distribution throughout the batter are most affected by temperature. If the temperature is low a fat is firmer, and less plastic. It spreads less readily throughout the other ingredients. The temperature of the other ingredients may be such that fat is rendered more or less plastic, i.e., they may be warmer or colder than the fat. In cake batters, if an oil is used the oil may be partially or wholly emulsified as an oil-in-water emulsion, the flour and egg proteins acting as the emulsifiers and surrounding the spheres of oil. If a fat is melted and added to a cake batter and the temperature of the ingredients is such that they do not harden the fat, a portion or all of the fat may be emulsified as an oil-in-water emulsion and the structure is similar to that produced by oil. This distribution of the oil in a batter as well as adsorption of fat and proteins at interfaces is probably influenced by the electrical charge.

**The method of mixing the ingredients.** Bingham states, "A pure liquid, at a given temperature and pressure, can have but a single fluidity, but in our study of liquid mixtures we have seen that a mixture of liquids may have an indefinite number of fluidities dependent upon the method of mixing, in other words, upon the structure of the liquid. Since colloidal solutions are always heterogeneous, they always possess structure, and therefore we have this variable always entering into our consideration, whereas heretofore we have given it but scant attention. There is, however, every gradation from a pure liquid, to an incompletely mixed solution, an emulsion, suspension or typical gel."

Methods of mixing and order of combination of ingredients have been important in many of the products that have been studied, i.e., gelatin, emulsions, milk, and egg cookery. The methods of mixing are particularly important in the batter and dough series. In some doughs, like pastry and biscuits, the fat is first blended with the flour, and the liquid is then added; in other instances the liquid ingredients are mixed and the flour added to them. Many different methods of mixing may be used with cakes. They will be discussed in more detail later.

A microscopic study of the distribution of the fat by different methods of mixing shows many gradations from the fat distributed in very thin films to that in thick layers. Sometimes the fat or oil is completely emulsified, sometimes only partially. The sugar may be partially dissolved, "an incompletely mixed solution," or completely dissolved. One can see that it is not strange that cakes and other batter products are not always identically alike with different bakings. Different methods of mixing may give different results, but from the previous discussion one concludes that a person cannot state definitely of a muffin, biscuit, or cake, that its texture is due to the method of mixing alone, for the extent of mixing, the temperature of the ingredients, interfacial reactions, and other factors influence the texture obtained.

**The effect of extent of mixing on the flavor of dough and batter products.** The statement that a cake from one-half of a batter after the ingredients are barely mixed does not have the same flavor as a cake baked from the other half of the batter after a longer mixing may seem strange at first. But with longer mixing the sugar is better dissolved, and the other ingredients better blended. To prevent repetition in the discussion of specific batter and dough products, flavor is seldom discussed. But from the standpoint of eating quality, flavor is of great importance, and on a score card the author would rate flavor higher than texture, appearance, or tenderness. However, in the dough and batter series good flavor and good texture are closely related, i.e., if the texture is excellent the flavor is also usually rated high. Of course this is presuming that the ingredients used are of good quality and flavor, and that good proportions are used, i.e., too much salt is not added, etc. Unless otherwise stated, it is considered that the conditions that produce the best texture also give the best flavor.

**The rôle the various ingredients play in batter products.** *Liquid.* The liquid is a solvent for sugar, soluble salts, and proteins. It is through solution in the liquid that the chemical reaction of baking powder is brought about with release of  $\text{CO}_2$ . The liquid hydrates the flour and egg proteins, giving the flour proteins cohesiveness and increasing the extensibility of proteins. Sugar in solution in the liquid comes in closer contact with proteins. The absorption and consequent swelling of starch granules gives them adhesiveness and cohesiveness and aids in forming the framework of baked products.

*Flour.* Flour forms the framework, the backbone, or skeleton of baked

products. This framework is more or less modified by the other ingredients. The gluten forms a continuous network, and the starch granules, which swell to a greater or less extent, depending on the proportion of liquid, become more or less adhesive and are embedded in the gluten network.

*Fat.* Fat renders a product tender or short. It is not soluble but is adsorbed strongly on the surface of other constituents and forms films separating and lubricating them. In this way it is one of the major factors in producing a velvety, soft crumb in cake. Fat adds richness and tends to decrease the volume. If creamed it is a means of incorporating air, thus increasing the porosity.

*Sugar.* Sugar adds flavor. In increasing amounts up to the optimum it tends to increase the volume and tenderness of the product to which it is added. Fat is strongly adsorbed by sugar crystals and is thus distributed throughout the batter. Sugar peptizes egg and possibly flour proteins, elevating the coagulation temperature of these proteins. In increasing amounts it delays solution of baking powder and other salts, so that carbon dioxide is produced more slowly. It is also possible that it may tend to absorb some of the carbon dioxide, thus lessening the amount lost during mixing. Because it is somewhat porous it may be a means of adding more air to the batter.

*Egg.* Egg adds flavor and additional protein for the framework. If the yolk and white are not separated, the egg tends to decrease the volume and increase the elasticity and rubberiness. The lecithio-protein of the egg yolk has strong emulsifying properties and in batters emulsifies all or a major portion of the oil or melted fat. When the white is separated from the yolk it can be used as a means of incorporating air, thus increasing the volume and tenderness of the product. Well-beaten whole egg can also be used as a means of incorporating air, if added quickly to the batter before the air is lost.

*Baking powder.* Baking powder in optimum amounts increases the porosity of products and, by stretching the elastic protein, thinner cell walls, more tender products, and products of larger volume are obtained. It is possible that ions of salts of the baking powder or their residual salts may modify the hydration capacity of the flour proteins and some ions may tend to peptize some proteins.

### Popovers

The amount of liquid used in popovers is large, and thus the hydration of the gluten particles is too great for them to adhere tenaciously to each other. Therefore, the popover batter may be beaten without increasing the compactness and without toughening the baked popovers to any appreciable extent. Egg is added to popovers. It is necessary to furnish additional, extensible protein to hold the steam formed from the liquid and to coagulate

during baking to form the popover walls. If baked with no added egg, popovers do not increase in volume during baking and the texture is very soggy and compact. Except during the period of the year when the baking quality of the eggs is greatest, better popovers are often produced if the number of eggs in the recipe is increased to 3. If the eggs are not weighed and are small in size, better volume is always obtained by using 3 eggs.

The popover batter may be put into hot or cold containers for baking. There seems to be little difference in the finished popovers, whichever way started.

Popovers are probably best baked at rather high temperatures, 220° to 240°C., to form steam rapidly. They need to be baked until they feel firm while still in the oven, for they soften after being taken from the oven, and unless they are quite firm will collapse. The heat may be turned off towards the last of the baking period to prevent excessive browning and the popovers left in the oven to become crisp, for the inside of the popover is hollow and because of the thin batter rather moist.

### Timbales and Cover Batters

Timbales and rosettes should be crisp, and the timbale shell should be thick enough to hold the material that is to be served in it. Usually a cup of flour to a cup of liquid produces a good texture, but a slightly larger or smaller proportion of flour to the liquid also makes a good timbale. The batter should be mixed until free from lumps to avoid thickened places in the finished timbale. If bubbles are formed during mixing or beating of the batter they interfere with the smoothness of the finished timbale and it is therefore better to let the batter stand until these bubbles disappear.

The timbale iron should be heated while the fat is heated in the deep fat kettle so that it will be the same temperature as the fat. If the timbale iron is too cold when it is dipped into the batter, the batter will not cling to it. The fat should be drained from the iron or the surplus wiped off with a paper towel before putting the iron in the batter. Otherwise the batter will not cling to the iron or large holes may be formed in the bottom of the timbale case from the surplus fat.

### Cream Puffs

Cream puffs contain a higher percentage of fat and eggs than popovers, but the proportion of liquid to flour is the same in each. The fat, flour, and liquid are first cooked together until a stiff ball of dough is formed. They are sufficiently cooked when a metal spoon pressed down on the stiff mass leaves a sharp, clear, smooth imprint. Next the eggs are beaten into the batter.

In the stiff batter produced by cooking the fat, flour, and water only a partial oil-in-water emulsion is formed. By staining the fat with Scarlet R

its distribution in the batter can be determined by a microscope. Some of the fat is rather coarsely emulsified, and a good deal is found in layers and pools. Over-cooking of the fat, flour, and water increases the quantity of fat not emulsified. As the egg is added the fat becomes better emulsified, the dispersed spheres becoming smaller. The layers and pools of fat mostly disappear. The secret, and therefore the most important factor, in mixing cream puffs in order to obtain good expansion during baking and a good cavity is to beat the batter while adding the eggs until it is quite smooth, with no suggestions of small lumpy spots. Perhaps this is the reason why some directions for mixing cream puffs advise adding the unbeaten eggs one at a time. Incorporating the eggs one at a time at least insures thorough blending of the first eggs added. However, the eggs can be mixed with the batter as easily or more easily after they are beaten. When the puffs are made in large quantity, more than once the recipe, it is better to cool the paste slightly before the eggs are added because the large amount does not cool as rapidly as a smaller quantity. Some recipes state to cool the dough mixture before adding the eggs. On the whole, much better class results have been obtained by adding the eggs to the dough while it is warm. The probable explanation for this is that the surface tension is lower at the higher temperature and the emulsion forms more readily.

If the proportion of water drops below a certain level the tendency for the fat to run from the dough while baking is increased. This may be due to the fat being more easily emulsified in the thinner batter.

Sometimes the batter is very thin after the eggs are added, and it spreads and does not hold its shape on the baking sheet. When baked, the puff expands in one layer, giving a puff without a bottom or with a layer across the bottom that is too thin to hold a filling. This thin batter can sometimes be partially remedied by cooking and stirring over hot water in a double boiler until the batter is stiff enough to hold its shape when dropped on the baking sheet. The batter should be stiff enough to hold its shape, yet soft enough to appear glossy, and if forced through a pastry tube should retain the imprint of the tube teeth. The formation of the thin batter is not always due to under-cooking, for the flour, fat, and water may form a stiff ball. The fat is emulsified thoroughly enough to prevent its oozing out of the batter, but something happens that prevents the batter from becoming viscous. Usually, when the egg is first added the batter becomes somewhat thinner, but after being mixed the batter becomes increasingly viscous, until incorporation of the egg is complete, just as mayonnaise becomes stiffer as larger proportions of oil are emulsified.

Steam is the leavening agent, and the expansion due to the steam produces the cavity in the puff. Eggs are necessary, for their expansion and coagulation during cooking forms part of the framework of the baked puff. If the number of eggs is reduced and the amount of fat reduced at the same time a fair puff may be obtained. If the number of eggs is reduced the fat is not sufficiently emulsified and oozes from the puff as it bakes. As a

result the volume of the puff is poor. The fat may be omitted and the puffs are then similar to popovers. Cream-puff like popover batter can be beaten as much as desired without perceptibly toughening the finished product. The cooking of the flour with the water and fat coagulates a portion of the flour protein. The starch granules also swell as the flour is cooked with the liquid.

The puffs like the popovers must be baked until very firm or they will collapse after removal from the oven. The best baking temperature is from 220° to 240°C. Cream puffs may be baked as well by starting in a cold oven as in a preheated oven, provided the oven heats quickly enough to reach a temperature of 220°C. in about 25 minutes. The batter may stand some time before baking provided it is left in a bowl and covered to prevent evaporation.

### Griddle Cakes

Griddle cakes are made of wheat flour, or a combination of cereal flours, a liquid, salt, and a leavening agent. They may or may not contain egg, fat, and sugar.

Griddle cakes are partially leavened by steam, but some baking powder is necessary. Both the proportion of flour and baking powder can be altered to secure a thin or a moist thick cake. For example, the consistency of the batter made by using 1 1/3 cups of flour to a cup of liquid can be changed by increasing the baking powder. As the quantity of powder is increased the batter becomes increasingly stiffer so that the griddle cakes are less moist, more porous and tender, and of greater volume. Adding 1 1/2 to 2 teaspoons of powder to 1 1/3 cups of flour gives desirable cakes. This is a rather large amount of baking powder, but thin batters do not retain the gas as well as stiff ones, nor is air incorporated by creaming or by folding in beaten egg white. The kind of baking powder, i.e., one that reacts slowly or rapidly at room temperature, does not seem to affect the results, unless the batter has to stand for a long time before it is cooked. If this is necessary, a larger quantity of rapid-acting baking powder may be used.

The greater the proportion of flour used to liquid, the less the batter should be beaten in order to have a tender cake. With the very stiff batters, the mixing should be continued only until the dry ingredients have barely disappeared. Over-mixing gives a soggy texture, which is apt to contain tunnels. The texture with over-mixing seems to be about the same regardless of the type of baking powder used.

If colored oil or melted fat is used in griddle cakes and waffles the distribution of the fat can be easily seen. It is dispersed in the uncooked batter as small spheres that are large enough to be seen without the aid of a microscope. With the concentration of fat used in these fairly thin batters, this dispersion occurs by stirring the melted fat or oil into the

batter and is the same whether the fat is added first or last. After cooking, a portion of the fat is found in pools or absorbed on the surface of the cell walls of the cooked product.

If 2 or more tablespoons of oil or fat for each cup of liquid are added to the batter, the griddle cakes can be baked without greasing the griddle iron. This is an advantage, for it does away with the fumes of smoking fat while cooking the griddle cakes. Practically all iron skillets and frying pans can be used in this way. Much depends upon the heating of frying pan and griddle in preventing sticking of the batter. If they are too hot they stick as readily or more so than if they are not hot enough. Often they are not heated uniformly, being too hot in some portions and too cold in others. This is likely to happen when a large griddle is placed over a small flame.

### Waffles

Waffles may contain the same ingredients as griddle cakes, though egg is never omitted as is sometimes the case in the latter. The proportion of flour may vary from 1 to  $1\frac{1}{2}$  cups or more per cup of liquid, depending on the type of waffle desired and the proportion of other ingredients. In general, waffles are preferable with less flour than is used in griddle cakes,  $1\frac{1}{3}$  cups to a cup of liquid being a good proportion for plain waffles. They also require less baking powder than griddle cakes.

In mixing waffles the egg whites may be beaten stiff and folded into the batter or the whole egg may be beaten until foamy and added to the batter. The former method generally gives the better results. The stiffer the batter the shorter the mixing period should be, if tender waffles are desired.

One quality that many people desire in waffles is crispness. This depends largely on the length of time the waffle is baked. A plain waffle made from  $1\frac{1}{3}$  cups of flour needs to be baked about 4 to 5 minutes, though the exact time depends upon the temperature maintained by the iron and the depth of batter the iron will hold. However, a batter with a cup of flour to a cup of liquid needs to be baked longer, else the waffle is limp and soggy instead of crisp. Stiffer batters do not need to bake as long, but they are apt to give waffles that are somewhat bready and tough.

The rich waffles, containing a high percentage of fat and some sugar or molasses, that are used for shortcakes or desserts, may be better if baked a little more slowly than plain waffles. Waffles containing a good deal of sugar are often limp when first taken from the iron, but if baked long enough, they become crisp in a short time. Those that are used for shortcake should be baked long enough to remain crisp. Melted fat or oil added to the batter does away with the necessity of greasing an electric waffle iron. However, if the electric iron is too hot or too cold the batter may stick to it.



## Muffins

The proportion of flour in muffins is usually 2 cups to a cup of liquid. For this reason, the extent of mixing has more effect on the structure of the batter and the finished muffins than in thin batters. The gluten with this proportion of liquid is more sticky and glue-like than in the thinner batters. It can be attenuated. Melted fat or an oil is distributed in an uncooked muffin batter in the same manner as in griddle cakes.

**Effect of extent of mixing on texture and appearance.** With just enough mixing to barely blend the ingredients, 30 strokes or less, the batter breaks and separates easily when lifted with the spoon, is lumpy and not smooth in appearance. The top of the baked muffin is rough, though it browns well and is a little shiny and has a glaze. The volume of the muffins is good, its cells rather large and uniform in size, and its cell walls of medium thickness. The muffin is tender. This amount of mixing, usually about 25 strokes, which can be partially determined by the appearance of the batter, is the optimum amount of mixing. It is the amount that is required to just blend the dry flour with the liquid ingredients. See Figs. 46 to 48, muffins number 1.

When the mixing of the batter is continued beyond the optimum amount, the appearance of the batter gradually changes, becoming smoother and less lumpy. It flows more readily, and as it falls from the spoon it tends to cling to the spoon, forming long ribbon-like strands. The muffins also change in appearance, texture, and volume with longer mixing. See muffins 2 and 3, Figs. 46 to 48. The top of the muffin is less rounded and may come to a sharp point or peak. Its crust is smoother, browns less readily, and becomes duller in appearance with less glaze. Up through the center of the muffin are found long holes, which are called tunnels, that end just below the point at the top. Large holes are often found in muffins and cakes, caused by addition of air in mixing, but tunnels are long and rather narrow. When tunnels develop the muffins are less tender. The grain of the muffin becomes finer with longer mixing, the cell walls thinner, the tunnels more numerous, and the muffin is more compact. With extremely long mixing, and particularly with phosphate or tartrate baking powders, the texture of the muffin may be very soggy, the volume small, with few tunnels, the top flat and very smooth in appearance. See muffins 4, Figs. 46 to 48.

**Tunnels.** Tunnels usually start at the bottom of the muffin and converge near the center at the top. They are formed from expansion of gas in the dough. Part of this gas is from steam, for if one watches the baking of muffins through a glass oven door, occasional small jets of steam may be seen to escape from muffins that have been stirred sufficiently so that tunnels develop. With thin batters like popovers, or doughs like baking powder biscuits, tunnels do not develop. When the batter contains the

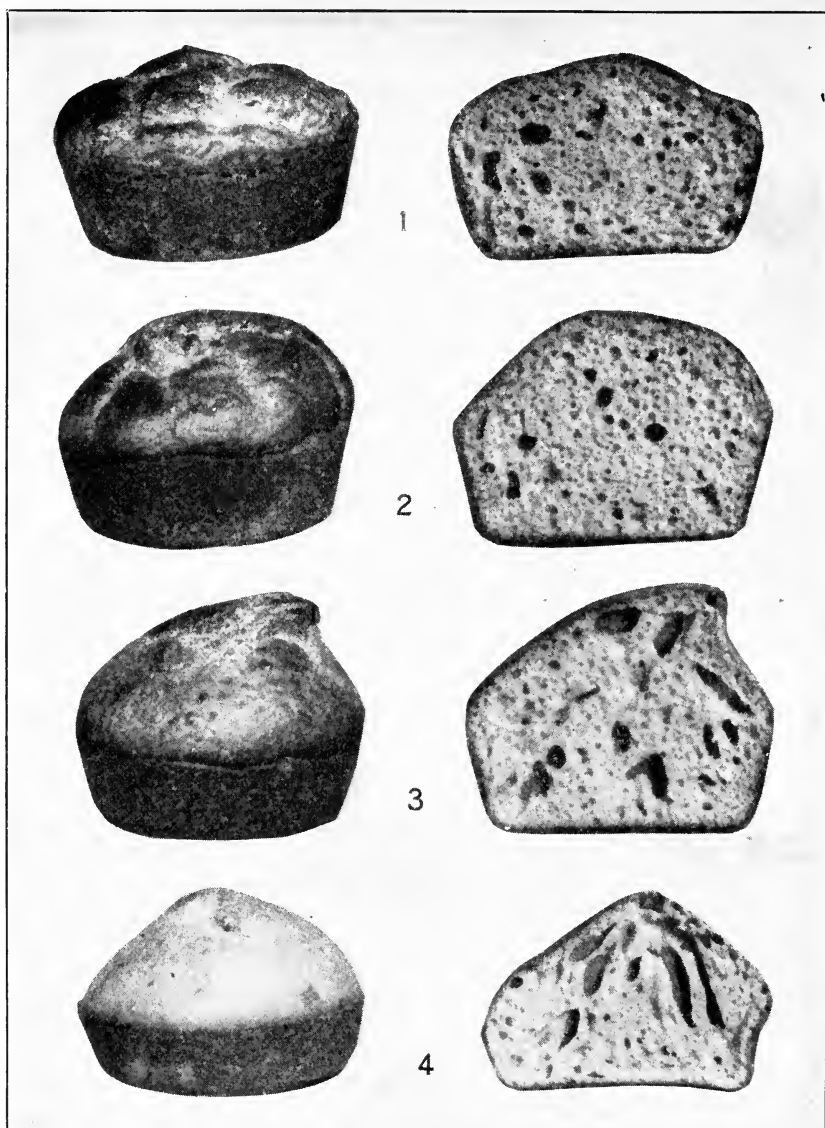


FIG. 46.—Muffins. Showing effect on texture, volume, and shape when the extent of mixing is varied and a tartrate baking powder is used. Experiment (82,A,1). Approximately  $\frac{1}{8}$  of the batter, 60 grams removed after mixing,

1. 30 strokes.
2. 60 strokes.
3. 100 strokes.
4. 300 strokes.

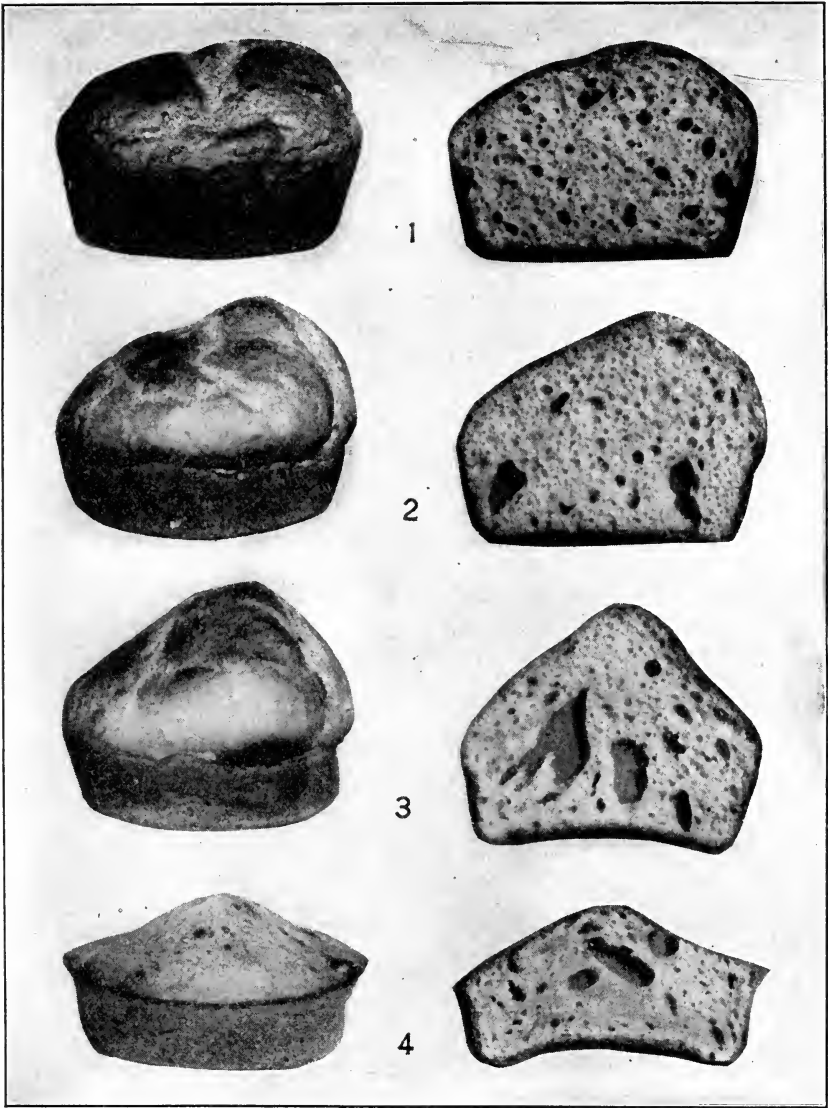


FIG. 47.—Muffins. Showing the effect on texture, volume, and shape when the extent of mixing is varied and a phosphate baking powder is used. Experiment (82,A,2).

Approximately  $\frac{1}{8}$  of the batter, 60 grams removed after mixing,

1. 30 strokes.
2. 60 strokes.
3. 100 strokes.
4. 300 strokes.

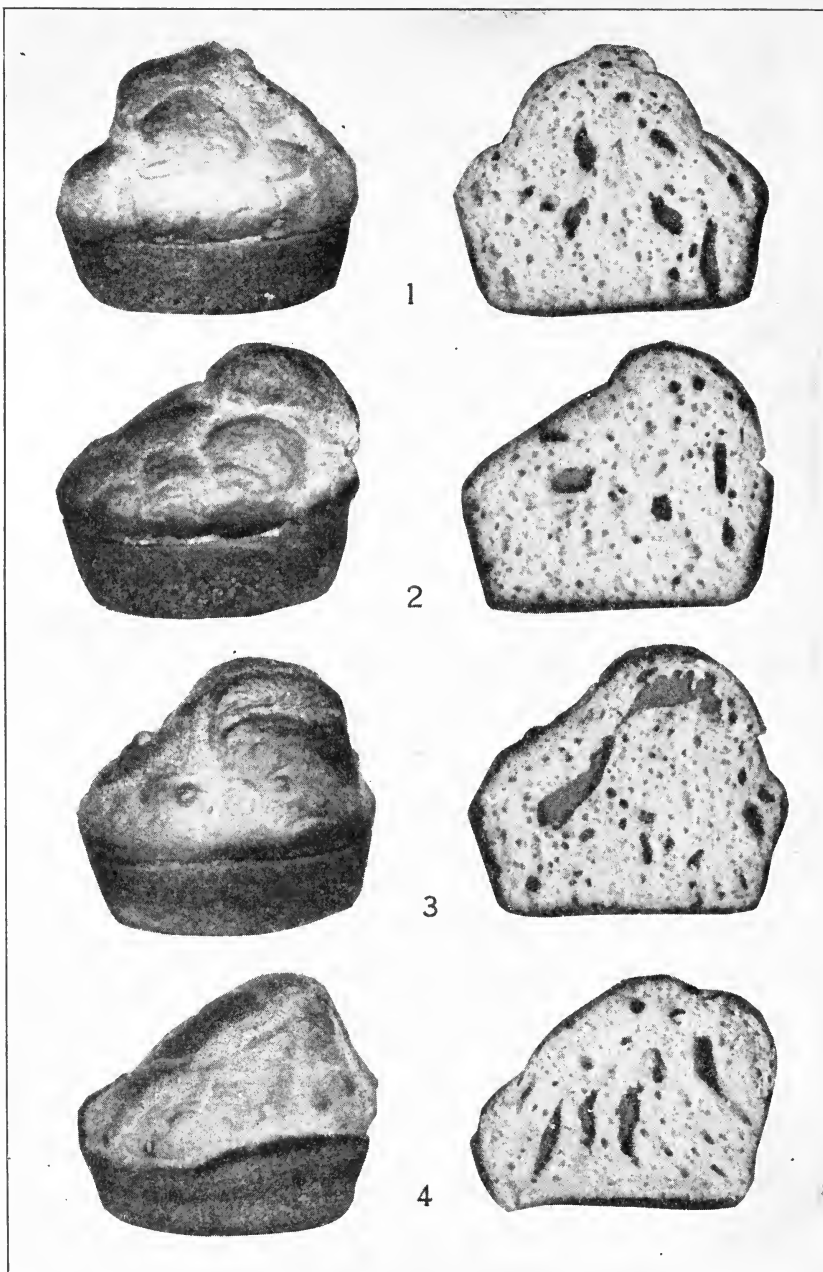


FIG. 48.—Muffins. Showing the effect on texture, volume and shape when the extent of mixing is varied and a sulfate-phosphate baking powder is used. Experiment (82,A,3).

Approximately  $\frac{1}{8}$  of the batter, 60 grams removed after mixing,

1. 30 strokes.
2. 60 strokes.
3. 100 strokes.
4. 300 strokes.

proportion of water that results in a very sticky gluten, and the gluten is attenuated to the point at which it is tenacious and somewhat elastic like rubber, the batter drips from the spoon into the muffin pan somewhat

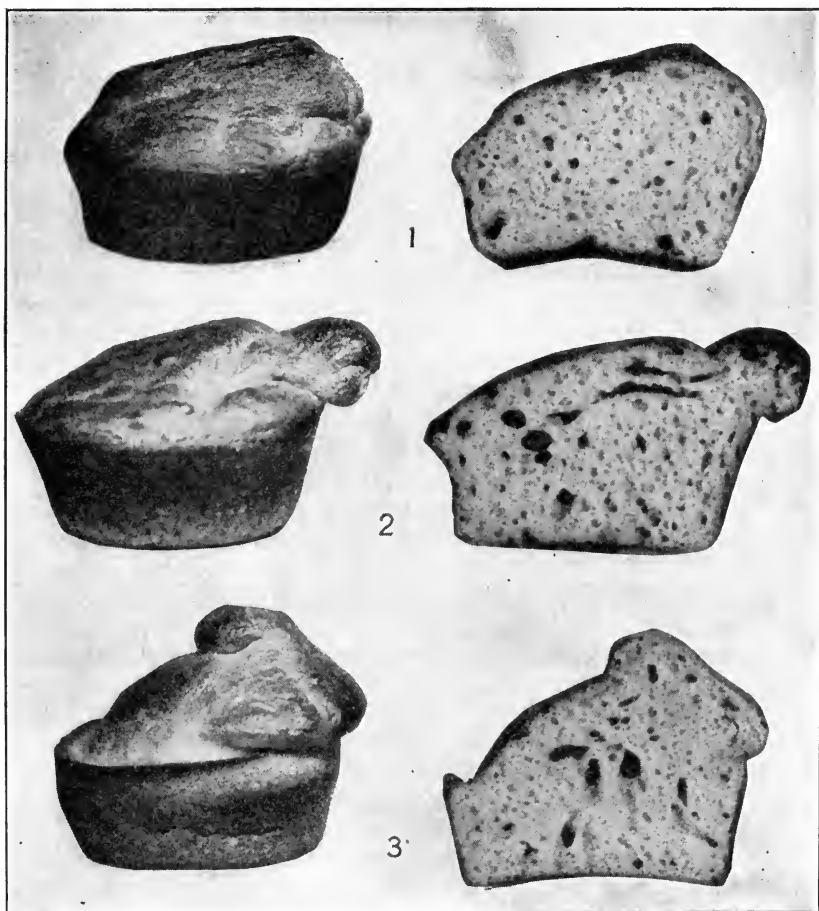


FIG. 49.—Muffins. Showing the effect of stirring the batter 85 strokes; then adding the baking powder and stirring 15 additional strokes. Compare with muffins (3) in Figs. 46 to 48 mixed with 100 strokes.

1. Tartrate baking powder.
2. Phosphate baking powder.
3. Sulfate-phosphate baking powder.

as shown in Fig. 50 at *A*. The gluten strands of the batter are stretched toward the point in contact with the spoon. The manner or direction in which the tunnels form is partially dependent upon the way in which the gluten strands are stretched in mixing and in placing the batter in the

pans. In the baked muffins the tunnels may form as shown in the cross-section diagram at *B*. When the batter from the end of the spoon falls near the edge of the muffin pan the tunnels may converge as shown in *C*, Fig. 50.

Two other factors that influence the formation of tunnels, though their effect is not always consistent, are depth of the batter and the baking temperature. When the batter is mixed just to the verge of tunnel formation, the deeper the batter in the pan the more apt are tunnels to appear. The effect of temperature is still more variable than some of the other factors, but tunnels have been observed in portions of a batter baked at higher temperatures, when other portions baked at lower temperatures did not have them or they were less numerous.

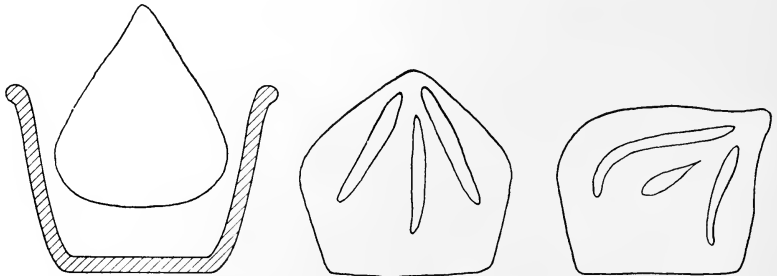


FIG. 50.—A. Cross section of muffin batter that has been mixed until the gluten is well developed, being dropped from a spoon into a muffin pan.

B. Direction of tunnels in baked muffin.

C. Direction of tunnels when the point of dough falls to one side of the pan.

**Varying the proportion of ingredients in muffins.** Too large a proportion of flour or too little liquid increases the tendency to form tunnels, even with a small amount of mixing. If sugar and fat are increased the gluten develops less readily, but the effect is not very great. The omission of egg does not change the muffin structure to a very great extent, although there is less tendency for tunnels to form. The flavor of course is different if the batter contains no egg. Increasing the egg tends to give a tougher, more rubbery, elastic muffin. Egg not beaten sufficiently to blend easily with other ingredients or not mixed sufficiently with the liquid may produce a rather waxy texture with fairly thick cell walls. This texture is often seen in muffins which are not over-mixed.

**Baking powder.** The electrolyte baking powder influences the viscosity and tenacity of the batter. When a muffin batter that contains no baking powder is just mixed, it separates from the spoon without forming strands and may be described as short. With longer mixing the batter becomes smoother, but there is not as definite a change as when the baking powder is in the batter during mixing. If the baking powder is in the batter during all the mixing period the batter is short when just mixed, but after the

baking powder has dissolved, the batter seems more tenacious, and compact with longer mixing. That the volume is less is readily seen by the weight, for 60 grams of the batter is greatest after just mixing and becomes less with longer mixing. This is more noticeable with the phosphate or tartrate baking powders than with the sulfate-phosphate ones.

Fig. 49 shows muffins that have been stirred 85 strokes. Then the baking powder was added and stirred an additional 15 strokes. The knob-like protuberances are characteristic of muffin batter that has been mixed too long. The tartrate and phosphate powders, probably because of their more rapid action at room temperature, are less likely to develop these knobs. However, the sulfate-phosphate powders with over-mixing are more likely to develop these knobs, for less carbon dioxide is lost during mixing, hence more pressure is exerted during the baking.

The amount of mixing required for the best texture in muffins, with the different types of baking powders, is about the same, for the batter can be mixed only about 25 strokes or a little more with either a rapid- or a slow-acting powder.

All the muffins in the illustrations contained the same weight of batter, and were baked in pans of the same size. Thus the effect of mixing on the volume is shown by the comparative size of the picture.

**Baking temperatures for muffins.** A temperature of 195° to 210°C. is good to use for muffins. A very high temperature sets the crust before the batter has time to rise; a very low temperature requires a long time to brown and cook the muffins.

Greasing the sides of the muffin pans lightly or not at all aids expansion of the dough in baking, as the dough can cling more tenaciously to the sides of the tin; but greasing the bottom of the pan heavily expedites the removal of the muffins from the tin.

**Standing before baking.** All muffins and nut breads made with baking powder, but particularly those made with rapid-acting powders, should be mixed quickly and put into the muffin tins as quickly as possible after mixing. This lessens the amount of gas lost. They can stand in the muffin tins for some time before baking, because the dough is stiff and viscous and, if not cut across or through, most of the gas is retained.

The palatability of bran muffins can be improved by soaking the bran in warm milk before the flour and other ingredients are added, or the muffins may be allowed to stand for some time after mixing and before baking so that the cellulose of the bran becomes better hydrated and thus softer.

## Biscuits

The using of the proportion of liquid required by the flour is one important factor in obtaining a desirable texture in biscuits. Since hydration capacity of different flours varies, it is necessary to determine this for the

various brands and grades of flour. The same brand of flour in different sections of the United States is not always from the same kind of wheat. For example, Gold Medal flour in Iowa is an all-purpose flour, but in Alabama or Mississippi it is made from soft wheat, the type used extensively in the southern states.

**Method of combining ingredients for biscuits.** In biscuits, a different method of mixing is used from those heretofore considered in the batter and dough series. Oil may be used. Fats are not melted, and either oil or fat is added directly to the flour. If a colored fat is used it can be readily seen that the fat is distributed in layers or pools and absorbed on the surface of the starch granules. In this dough, with its small proportion of liquid and no egg, there seems to be little tendency for the fat to form an oil-in-water emulsion.

Fat is added to biscuits to give shortness. It is important in making good biscuits to mix the fat and flour sufficiently, but not too much. Using a fine, wired fat mixer, or rubbing lightly between the finger tips, is the easiest and quickest way of mixing the fat with the flour. Some cooks prefer to pick up a portion of the fat and flour, letting it fall gradually back into the bowl while mixing it. In this way the mixture may remain more light and fluffy, because more air is retained. In adding the liquid to the mixture of fat and flour, a two- or three-tined fork is preferable to a spoon, for the dough is packed less during the mixing. Usually about 25 to 35 strokes are needed to combine the liquid and flour. With longer stirring of the dough the biscuits stand up better and the texture is less coarse. The texture of rolled biscuits is improved by folding over and rolling out about 4 times, which gives a very flaky texture, or by kneading a short time in addition to the stirring. For kneaded biscuits the dough is removed to a bread board and kneaded very lightly 10 to 20 times. Kneading tends to develop sheets or layers with a fine texture, which is considered desirable. Excess kneading toughens the dough more rapidly than stirring with a fork. If the proportion of fat used is large, or if a pastry flour is used, the mixing and kneading can be continued for a slightly longer time. The crust of biscuits is less crisp with longer mixing or when they are kneaded. Those who prefer a very crisp crust may like dropped biscuits better than kneaded ones. See Experiment 83.

**Beaten biscuit.** The beaten biscuit of the South is made without the addition of baking powder or soda. While the dough is beaten, it is folded over and over so that it contains air. Since the beating is prolonged the gluten may be modified or softened and becomes more tender. This is similar to the long mixing used by Swanson in modifying the gluten of bread. The amount of beating to give the best texture is indicated by a Negro mammy when she says, "I use 300 strokes for every day, but when I'spectin' company in, I use 500 sure."

**Soft-wheat flour and biscuit.** The addition of calcium acid phosphate to soft-wheat flours improves their quality for biscuit. Alexander states that, "It is almost impossible to sell flours in some districts in the South



unless the sack is marked 'Phosphate added.' " The acid calcium phosphate is acid in reaction. It has a  $pH$  of about 4.0. Alexander states, "We know that the gluten proteins tend to imbibe water, and disperse in a weakly alkaline medium, so that a slightly alkaline dough is sticky. Excess alkali in dough produces a yellow color and a soapy taste."

Alexander reports that dough quality, biscuit volume, crumb, texture, and color are improved by treating soft-wheat flour with 0.5 per cent calcium acid phosphate. Logue and Ranker have reported results similar to those of Alexander.

Smith and Bailey have reported "The Effect of Chemical Leavening Agents on the Properties of Bread." Their conclusions, in part, for the biscuits and their experimental work follow. "Gluten properties, including elasticity and hydration capacity, are affected by baking powder, and by the residual salts resulting from the chemical reaction of baking powder ingredients.

"Disodium phosphate, the residual salt resulting from the reaction of monosodium phosphate baking powder, affects gluten more than the residues from other types of baking powders."

### Cakes

Cake recipes are legion in number, but the underlying principles for making cakes containing a fat are similar, though some variation must be made for different recipes, depending upon the particular ingredients and their proportion.

Cakes containing fat may be divided into two classes. First, the pound cake type, based on the old recipe, which is one pound each of butter, sugar, eggs, and flour, and in which no baking powder or soda is used, the lightness of the cake depending upon the expansion of moisture from the eggs and butter and the air incorporated in creaming and in the beaten eggs. Second, the cup or layer cake types that contain rather small percentages of fat and sugar, in which the lightness depends largely upon added baking powder. Between these rich and lean type formulas are many transitions.

One desirable quality in cake is a certain texture, often called velvetiness. Velvetiness implies softness to the touch, but to obtain this softness it is necessary to have a definite amount of moisture, else the texture is too dry or too soggy. However, the proportion of liquid is not the only factor in developing velvetiness; the proportion of other ingredients and how they are handled are also important. A good cake should have a fine, even grain, with thin cell walls, and should not be powdery or crumbly. It should have a good flavor.

**Pans and preparation for baking.** The cake tends to expand to a better volume if the sides of the cake pans are not greased. But a piece of wax or other suitable paper, cut to fit the bottom of the pan and greased on the side next to the batter, facilitates removal of the cake from the pan.

The depth of batter in the pan also influences the texture of the cake,

so that if a finer, more velvety texture is desired, the size of the pan should be such that the batter is at least 1 inch or  $1\frac{1}{4}$  inches in depth.

Another factor affecting the texture of the cake, and more than might be expected, is the slope of the sides of the pans, straighter sides resulting in better textures.

**Baking cakes.** *Temperatures for baking.* Cakes containing fat are baked over a wide range of temperature, from below  $100^{\circ}$  to over  $210^{\circ}$

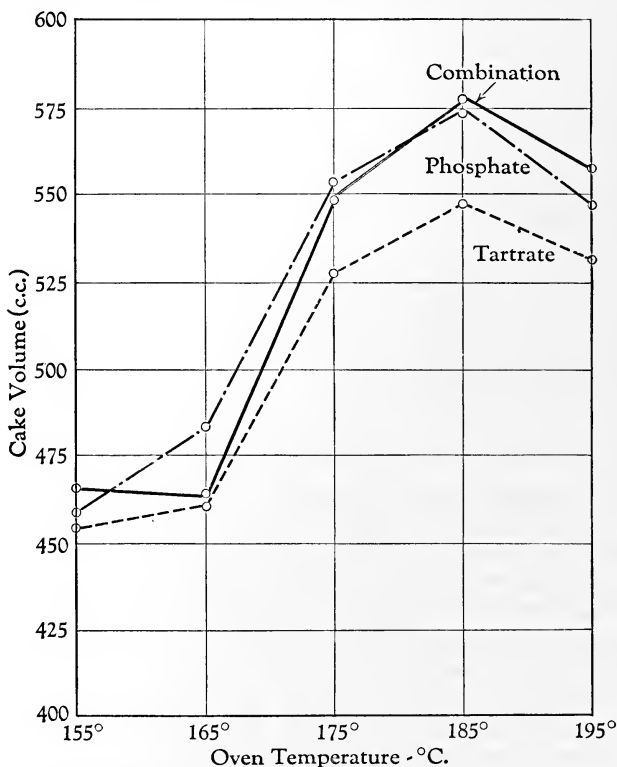


FIG. 51.—The effect of baking temperature on the volume of plain cake, when three types of baking powder were used, sulfate-phosphate (combination), tartrate, and phosphate. (Stone)

being used. For instance, fruit cake may be steamed at  $100^{\circ}$  or baked in the oven from below  $100^{\circ}\text{C.}$  to over  $175^{\circ}\text{C.}$

No very definite information was available as to what temperatures were preferable for baking cakes when using one of the three common types of baking powder. Theoretically, it seemed possible that a powder that released its gas rapidly at room temperature should be baked at a higher temperature than a powder that gave off its gas more slowly. Stone investigated the effect of varying the baking temperature on the volume and scores for plain cake. She used Formula I, with flour reduced to 284 grams and the amount of baking powder found to be optimum by McLean, or

8, 10, and 12 grams of sulfate-phosphate (combination), tartrate, and phosphate, respectively. The cakes for any one series were always mixed together and the batter divided into five equal parts by weight. Hence, any variation in the volume, texture, velvetiness, and eating quality for a set of five cakes was caused by the baking temperature. The time of baking was necessarily shorter as the oven temperature increased. The cakes were

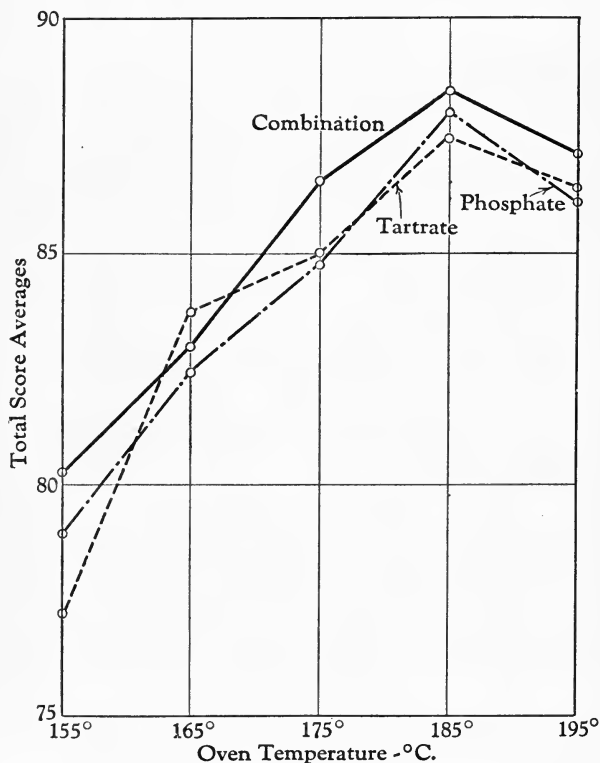


FIG. 52.—The effect of baking temperature on the average cake scores for plain cake when three types of baking powder were used. (Stone)

baked in loaf pans, one-fourth the recipe being used for each cake. The volume was determined by seed displacement. The effect of baking temperature on cake volume is shown in Fig. 51. For the particular formula and amount of baking powder used the optimum baking temperature for all three types of baking powder was 185°C. (365°F.).

The total scores, which were the sum of scores for texture, tenderness, velvetiness, and eating quality, were affected by the baking temperature. These results are shown in Fig. 52.

The texture and velvetiness of the cakes varied with the different baking temperatures. Heat penetration of the cake batter is of course slower at the lower temperatures. The cakes baked at the lower temperature had thicker cell walls, coarser, more harsh, less velvety texture, and were alto-

gether less desirable. The small volume and poor texture at the lower temperature are undoubtedly caused by the cake batter's not coagulating quickly enough in relation to the rate of gas formation. In other words, as the gas formed the temperature was not high enough to coagulate the

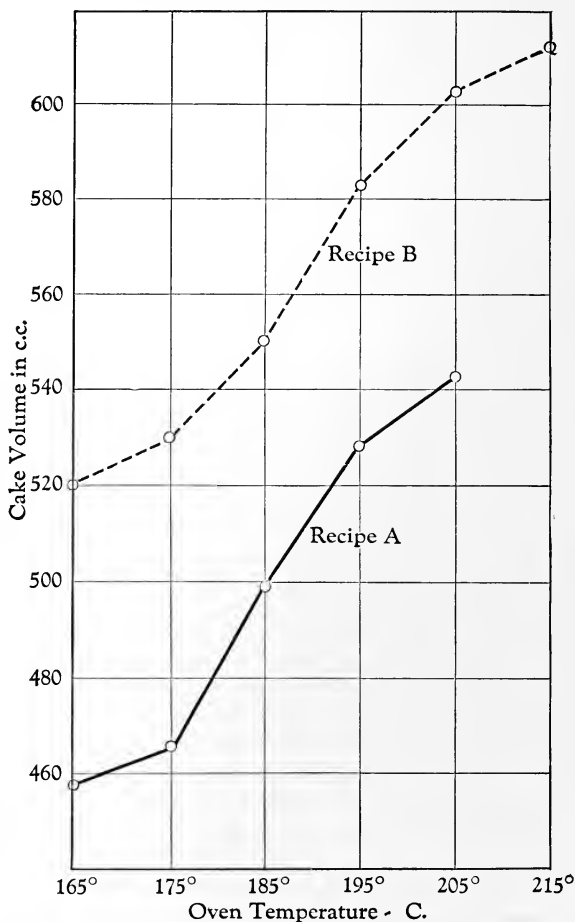


FIG. 53.—The effect of baking temperature upon the volume of a rich (Recipe A) and a less rich (Recipe B) chocolate cake. With exception of lowest and highest temperatures for Recipe B, each point on the graph is an average of scores of 5 judges for 12 cakes. (Rogosheski and Bernds)

egg and flour proteins, with the result that more than the optimum amount of gas escaped and more than the optimum amount of agitation occurred within the cake before coagulation started. For, as gas is produced its expansion agitates to a greater or less degree the cake batter. And if this agitation is continued too long before the crumb is coagulated, coarse textures result. With increase in the baking temperature the eating quality improved, the texture became finer and softer, the volume greater. Above

185°C. the cake became more compact because the crust formed too rapidly, although the texture was still velvety.

*Sugar content and baking temperature.* It is known that sugar is a good peptizer of egg proteins and elevates the coagulation temperature of egg proteins. It is also possible that sugar may affect the coagulation temperature of the flour proteins. From a few isolated observations some evidence has accumulated indicating that the higher the sugar content the higher the baking temperature should be for cake. But the work has not progressed far enough at present to draw definite conclusions.

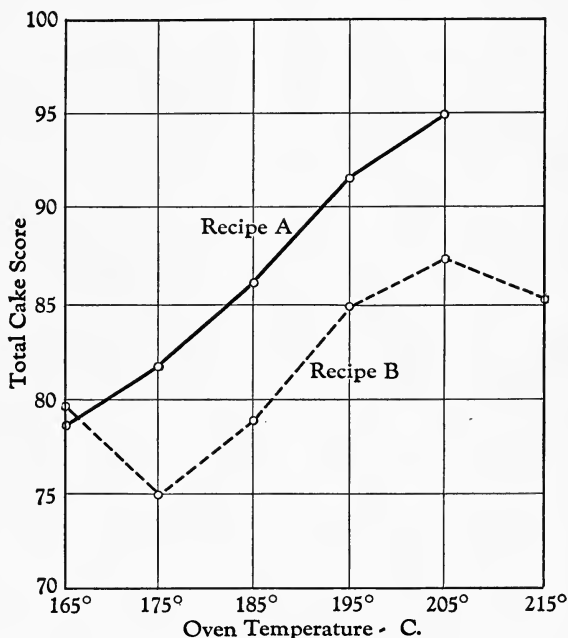


FIG. 54.—The effect of baking temperature upon scores of a rich (Recipe A) and a less rich (Recipe B) chocolate cake. (Rogosheski and Bernds)

*Baking temperatures for chocolate cake.* Rogosheski and Bernds used two chocolate cake recipes, one a very rich cake (*A*), the formula for which is given in the laboratory outline, Experiment 85A. The other recipe (*B*) was identically like Recipe *A* except one-fourth cup less of butter and of sugar were used. The batter for one series of cakes was divided, 250 grams being weighed into each pan.

The effect of baking temperature upon cake volume is shown in Fig. 53, the richer cake giving a smaller volume than Recipe *B*. But for both recipes the volume increased with higher baking temperatures. The relation of baking temperatures to total scores is shown in Fig. 54.

The results should be taken as suggestive rather than final, for only small loaf cakes were used. But since the texture and eating quality improve and the velvetiness of the crumb increases progressively with increase

of oven temperature up to 205°C., it suggests that there has been too much tendency to sacrifice texture for the appearance and shape of the top of the cake.

The shape of the top and the way the cake shrinks from the sides of the pan are characteristic for each temperature. During the last of the baking period and cooling, the cake baked at the lowest temperature shrinks the most, both in height and from the sides of the pan. As the oven temperature is elevated, the shrinking progressively decreases, until none occurs in cakes baked at 195°C.

At the lowest temperature the top of the cake was level or had a slight depression in the center. As the baking temperature increased the top became rounded until at the highest temperature the top punched up in the middle entirely too much for a good appearance. There was a tendency for the cakes baked at 205° and particularly at 215° to become too brown on the edges. If these factors as well as eating quality are taken into consideration, the preferable baking temperature for these formulas appears to be from 195° to 205°C. (Approximately 385° to 400°F.)

Schaal suggests that for bakers' chocolate cakes 380°F. is a good baking temperature. He says, "Bake the goods until they are just barely done. It is a mistake to overbake, since overbaking impairs the flavor just as much as a flashy oven, or an oven at too high a temperature."

*The oven temperature at start of baking.* Peet and Lowe baked plain cake (Formula I) from a cold and preheated start in three electric, two gas, and one kerosene range. The twelve cakes were mixed at one time on an Institutional Hobart mixer. Equal amounts of batter were weighed into the 8-inch square pans immediately after mixing. One-half the recipe was used for each cake. The batter baked in the preheated ovens stood in the pans while that started in the cold ovens was baking. Since a sulfate-phosphate baking powder was used, it was thought the standing was less serious for the tests than to use different mixes. The ovens were all set to maintain a temperature of 185°C., once this temperature was reached.

The cakes started in the preheated ovens were superior in texture, velvetiness, and eating quality to those started in cold ovens. In scoring the cakes the judges found no significant differences in cakes baked in different ranges.

The volumes of cakes baked in different ranges varied, the differences being highly significant. But there was no significant variation in the volume of cakes baked in the same range from a cold and a preheated start.

The texture of the cakes baked from a cold start resembled that of cakes baked at lower temperatures in Stone's study.

*Temperature for removing cake from the pan.* Cakes containing fat have not been given much care in cooling, but Glabau has reported that the cake should not be removed from the pan nor handled until the interior temperature of the cake has reached 140°F. This time varies somewhat with the thickness of the cake and the room temperature but is about 15 minutes or longer. When cakes are first removed from the oven the struc-

ture is fragile. With cooling the critical time for handling passes and the cake becomes sufficiently rigid to withstand the shock of handling.

**Ingredients used in cakes. Flour.** In general, soft-wheat flours give better results than bread flour in cakes. Very tender cakes and cakes of excellent texture are obtained by using specially prepared cake flours. All-purpose flours give good results in the plain cake recipe of the laboratory outline. In the cake recipes in the laboratory outline only 100 grams of all-purpose flour are used for a cup. The smaller weight of flour per cup reduces the total gluten in the cake. Sometimes about 2 tablespoons of cornstarch are substituted for 2 tablespoons of flour in a cup of bread flour. This also lessens the percentage of gluten and the gluten strength of the flour, but too much cornstarch is likely to produce too dry and too powdery a crumb, and the cake does not keep so well; nor does adding cornstarch render the granule size fine and uniform.

Patterson emphasizes the importance of uniform grinding of the flour used for cake, so that the particles are as nearly of the same size as possible. He thinks the uniformity of the particles of flour aids in attaining uniform cells in the cake. He states that in an ideal cake the gas cells should expand to about  $1/16$  of an inch in diameter, and at this point they should rupture slightly, allowing the gas to escape. He also emphasizes the importance of gluten development on the structure of the cake.

**Fat.** Butter is preferable in cakes because of its flavor, the rich, full-flavored, but not rancid, being better than the mild. Oils and melted fats can be used in cakes, but the texture is not as good as when fats that can be creamed are used. Creaming is forming a foam by incorporating air bubbles in a fat by stirring. Creaming fat is somewhat similar to beating eggs or egg whites, in that the enclosed air later aids in leavening. Air is enclosed in the fat more rapidly after some sugar is added, hence creaming is usually done by adding the sugar to the fat, either gradually during the creaming process, or all at one time. The sugar adsorbs a portion of the fat on its surface and is suspended in the fat. If, as suggested in the chapter on meats, adsorption of fat at an interface renders it softer and more plastic than when not adsorbed at the same temperature, a suggestion is given for better creaming after the sugar is added. In addition the sugar crystals aid in supporting the fat in the walls around the air bubbles in much the same manner as the fat globules in whipped cream. See Fig. 31. For a fat to cream or form a foam it must have some body, for if it is too warm so that it is partially or entirely melted it does not cream. On the other hand, a fat that is hard and brittle and not plastic does not cream well. The hard fats like tallow with high melting points are not desirable in cakes. They do not cream well and on account of their hardness after the cake has cooled, they impart a firm, crumbly texture.

Minard and Myers both found that the texture of the fat is important in relation to creaming quality and in obtaining velvety texture in cakes. By the rate of cooling a fat after it is melted, its texture can be controlled so that it is very waxy and firm, soft and smooth, or granular with a lot of

separated oil. Minard found the very firm, waxy lard did not cream well. Myers found a soft, smooth lard creamed best, butter ranked second, and grainy or granular lard was poorest.

Since any fat tends to become harder at low temperatures and softer at higher temperatures, there is a range at which each fat creams best. Martin used hydrogenated lard, Crisco, 44 lards of varying softness and firmness, and butter. The initial temperature of all the fats at start of creaming was 24° to 25°C. All creamed fairly well at this temperature, though in general they tended to cream better at higher temperatures. In general the volume was decreasingly smaller in the order named. A low initial room temperature retarded creaming. Creaming tends to elevate the temperature of the creaming mass, probably from friction, though the butter usually shows an initial drop in temperature. For optimum creaming the firmer fats require a higher temperature than 25°C. The hydrogenated lard creams well at 30°C. or above this temperature, creaming the best of any fat tried on hot days. Optimum creaming temperatures for fats commonly used are 24° to 29°C. (about 75° to 85°F.). In the studies of fats in relation to their use in cake at Iowa State College a highly significant correlation between the volume of the creamed mixture and their temperature has been obtained, which indicates the volume of the creamed mixture is related to its temperature, as expected.

Butter varies in creaming ability. Bakers usually report that it gives a poor creaming volume. Jenkins used three winter butters with Crisco as a control. She used Formula I with 8.4 grams of a tartrate baking powder for the full recipe. The butters were prepared in January by the Dairy Department. The same batch of cream was used for the three butters, but portions were churned when the serum acidity was 0.2, 0.4, and 0.6 per cent. This gave butters with acid numbers of 1.20, 1.40, and 1.70, respectively. The acid number of the Crisco was 0.10. The creaming volume was least from the butter of intermediate acidity, greatest from the most acid butter, and the other two fats gave practically the same volume. It is rather interesting that, regardless of creaming volume, the final volume of all the cakes increased with an increase in temperature of mixing. The final average volumes of the cakes were very similar. But the fat giving the greatest creaming volume does not seem always to yield the greatest cake volume. The temperature of the ingredients when mixed had more effect on the final volume than did the creamed volume of the fat. No indication of the effect of variation in composition of butter on creaming volume was obtained. The composition of butter varies with the season of the year and with the locality in which it is produced. Graham using summer butters obtained results that were very similar to those of Jenkins, but the cakes had smaller volumes. It may seem rather strange that there is no close correlation between the volume of the creamed mixture and the volume of the cake. But studies tend to show this. Both Martin and Buel obtained non-significant correlations between these two factors. Martin obtained a negative correlation which, although not significant, tended to show that, for



4 fats out of 5, smaller cake volumes were obtained with larger creaming volumes. Minard obtained significant, negative correlation for these two factors showing that in her studies cake volume was smaller when the creamed volume was large. The fats studied in these investigations have included several types of lard, butter, hydrogenated lard, and Crisco, though the studies with the last fat were not extensive. From her results, Martin suggested that there may be for each fat a point short of maximum creaming volume, at which the creaming process should be stopped in order to produce a cake of maximum volume.

But what Martin calls creaming quality is important and is closely related to velvety texture and high scores for cakes. By a good creaming quality is meant that a soft, spongy, not too frothy, not a granular, lumpy, or pasty texture is obtained. In other words, there is a particular body and texture in the creamed mass rather difficult to describe that is related to excellent textures in cake.

*Sugar.* Granulated sugar is most commonly used. Finely granulated sugars dissolve more readily than coarse ones. Minton states that, the finer the granulation size, provided it is a natural granulation obtained in the refinery and not a powdered or crushed sugar, the better the creaming quality. The Bakery Research Department of Procter & Gamble Company also state that the fine crystal that has a glossy surface, and is not made by grinding or crushing, gives better creaming volume than the coarse sugars. Brown sugar, because of its flavor, is often used in cake. It is preferable to substitute it by weight rather than by measure.

The transformed sugar, with its irregular surface which holds much air, should not only carry air into the batter, but many films of fat.

*Liquid.* Water or fruit juices may be used for the liquid in cake. When water is substituted for an equal weight of milk, a more moist cake is obtained. Milk contains about 12 to 13 per cent solids.

*Baking powder.* Patterson states that unless the cake cells are very fine and uniform a very fine baking powder should be used, so that small bubbles are formed. With many large bubbles of gas formed at the same time, the cell walls may be subjected to too great a pressure and collapse, producing a fallen cake.

Any of the different types of baking powder can be used in cakes. The main discussion of the use of baking powder in cake is given later in the chapter under "Variation of Proportion of Ingredients."

*Eggs.* Eggs vary so in size that they should be weighed for experimental work. As previously stated, eggs beat up more quickly and to a better volume if they are not too cold, so that it is preferable to have them room rather than refrigerator temperature.

**Methods of mixing cakes.** There are many methods by which cakes may be mixed. Some old cake recipe directions state to mix the fat with the flour. The sugar is next added and lastly the eggs and milk. This old method may give very good cake. In all the batter and dough products that have thus far been considered, with the exception of cream puffs, the

proportion of fat is usually smaller than in cakes. The method of mixing cream puffs is to melt the fat. It is also a common practise, except for biscuit, to melt the fat for the other dough and batter products. These same methods of mixing are used for cakes, but a new method is introduced, one in which a foam is formed with the fat. Certain procedures of mixing are designated by various names, but each of these methods may have many variations.

*Conventional method.* By the conventional method the fat and sugar are creamed until the mixture becomes lighter in color, spongy and fluffy in texture. Fig. 55 is a photomicrograph of creamed butter and sugar. The irregular, large, and intermediate-sized spheres are sugar crystals with an adsorbed layer of fat. It was difficult at first to decide whether the smaller rounded crystals were air bubbles or sugar. This was determined, as is often the case in experimental work, by accident. In using a microprojector to show slides made from colored creamed fats to a class the heat filter was forgotten. After a few seconds the heat from the light used in the projector melted the fat on the slide. One could watch the air bubbles burst on the screen. The remaining particles after the fat was melted were sugar crystals. Many of the air bubbles show in the picture as small, white circles with a very light gray line around them, and are hardly discernible at this magnification. This strong adsorption of the fat at the surface of sugar crystals and at the interface of air bubbles and a liquid is typical and is one means of distributing the fat throughout the batter.

It seems to make little difference in the final product if the fat is stirred for a short period and the sugar is then added gradually, or whether the sugar and fat are combined and then creamed, but air is incorporated more rapidly after the sugar is added. However, creaming by hand is easier and more rapid if the sugar is added gradually because the mixture is not so stiff.

In the conventional method the whole egg is creamed with the sugar and fat or only the yolk is incorporated during creaming and the beaten white is added to the batter. Not as much air can be introduced into the creamed mass if only the yolk is used, but this is compensated for in the cake volume by the air incorporated in the beaten white. Under some conditions there may be advantages in adding the beaten egg white last. Just as good texture is produced if the beaten white is stirred rapidly into the batter as when folded. The texture is also good if the beaten white is added and stirred in with the flour and milk. Considering time, effort, and the cake texture, there is often no advantage in separating the whites and yolks of the egg for plain cake.

Fig. 56 is a photomicrograph of the creamed butter-sugar-egg batter after the egg has been added. Since more of the sugar goes into solution the sugar crystals become smaller after the egg is added. Many of the sugar crystals are larger than those shown in this particular field, as will be noticed when the photomicrograph of the batter is observed.

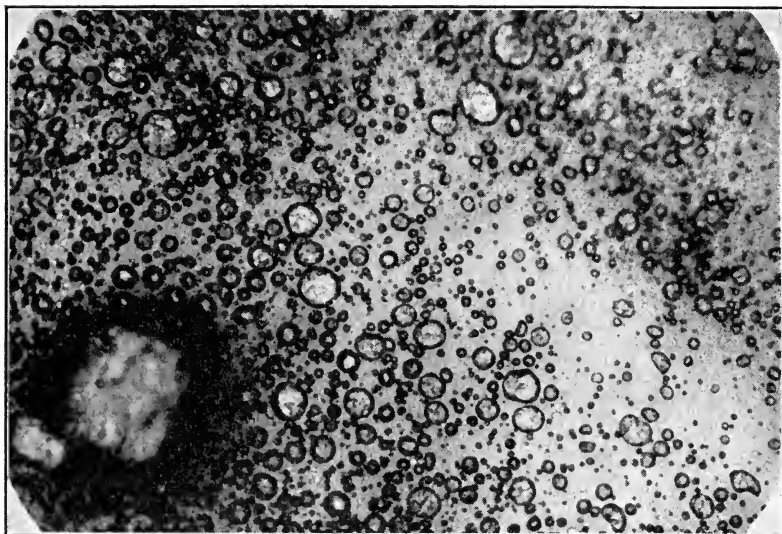


FIG. 55.—Photomicrograph of thoroughly creamed butter and sugar. The butter is stained and shows black in the picture. Note the rounding of the sugar crystals and adsorption of fat at their surface. Magnification approximately  $\times 100$ .

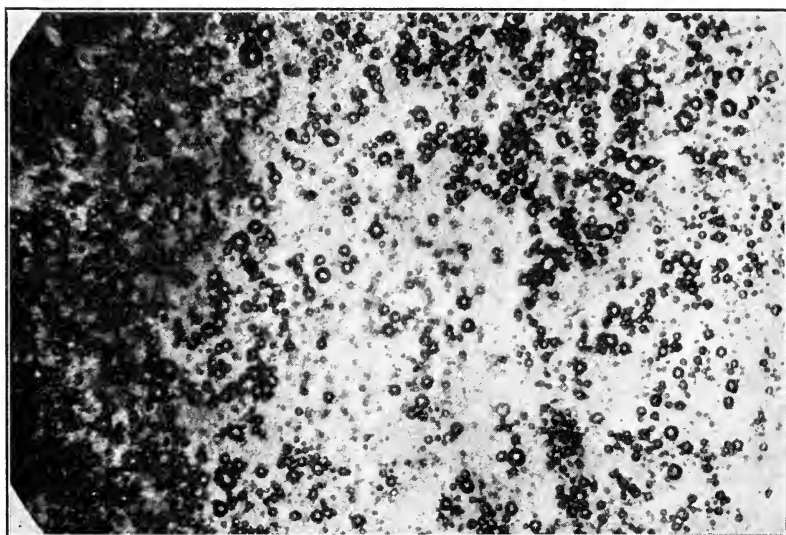


FIG. 56.—Same as Fig. 55 after the addition of beaten egg and thoroughly creaming. The sugar crystals are smaller due to water from egg partially dissolving the sugar. Note the many numerous small air bubbles. Most of them show white, but many show a thin gray line, which is the fat at the interface of the air, butter-egg-sugar mixture. Magnification approximately  $\times 100$ .

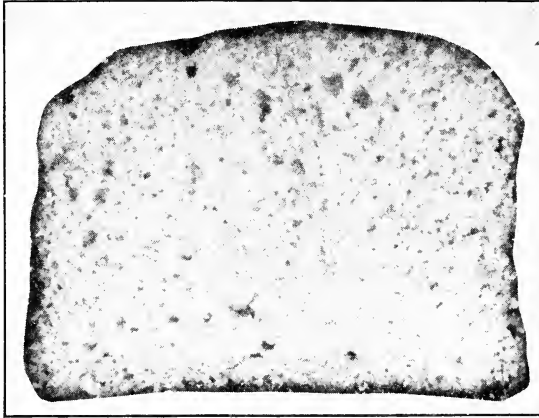


FIG. 57.—Cake made by method of mixing shown in Figs. 55, 56, and 58. The flour and milk were added alternately in thirds with a total of 225 strokes.

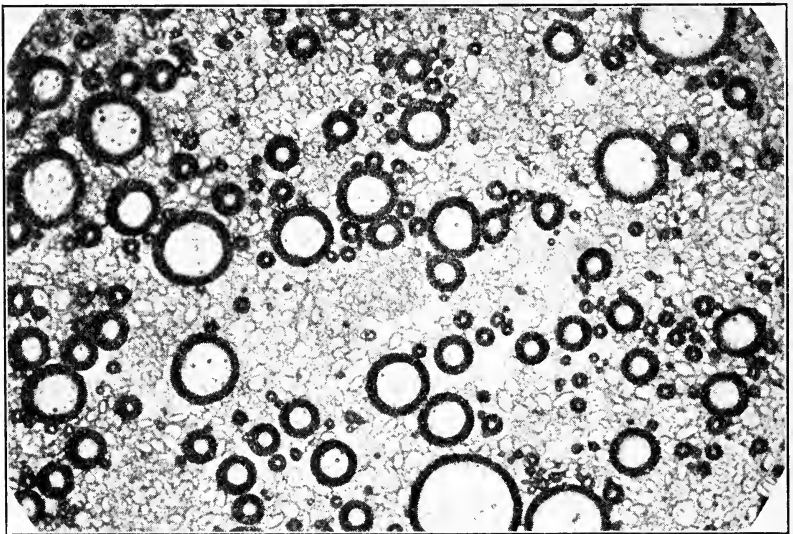


FIG. 58.—Photomicrograph of cake batter. Same as Figs. 55 and 56 after flour and milk are added. There are many large sugar crystals in this field. The sugar crystals and gas bubbles with their adsorbed layer of fat are grouped rather uniformly. The air bubbles do not show at this magnification. If berry sugar is used instead of the coarser granulated sugar used in this illustration, the sugar crystals are smaller and more numerous, the cake texture improved. Magnification approximately  $\times 100$ .

The Bakery Research Department of Procter & Gamble Company have reported that better results are obtained if the eggs are added gradually during 5 minutes, after the sugar and fat have previously been creamed 5

minutes, and the creaming is continued for a total of 20 minutes with a mixer. They state that if the eggs are added after the butter and sugar are thoroughly creamed there is a tendency to break down the creamed mass.

The flour and milk may be added to the creamed mixture as follows: (1) all added at one time, (2) flour added first and last, (3) milk added first and last, and (4) part of the flour and part of the milk added at the same time. Often the statement is given in directions for mixing cakes that a portion of flour should be added first and last to the creamed mixture, as the liquid tends to cause separation of the creamed mass. On the other hand, the Bakery Research Department of Procter & Gamble give for the method of mixing after the fat, sugar, and egg have been creamed, "to add two-thirds of the milk and mix it with just a few turns of the beater. Then the dry ingredients may be added and mixed in, using low speed. After the mixture is quite smooth, add the remainder of the milk slowly and continue the mixing until the dough is thoroughly mixed and very uniform." Judged from laboratory results, the first method is less likely to give an excellent texture, but all the others may give very fine even grain and velvety texture. Adding milk first and last is the quickest and easiest method.

Fig. 58 is a photomicrograph of the creamed butter-sugar-egg mixture shown in Figs. 55 and 56 after the flour and milk are added. All the photomicrographs are from the recipe in which  $1\frac{1}{2}$  cups of sugar were used. The flour and milk were added alternately in thirds, and a total of 225 strokes was used for mixing. In this picture the sugar crystals are shown with an adsorbed layer of fat. In the background are the starch granules of the flour and some very thin films of fat that do not show very well with this magnification. The sugar crystals have a tendency to form in clusters. Fig. 57 shows the cake made by this method. The cakes shown in Figs. 57, 63, and 64 were baked in larger pans than the cakes shown in other illustrations and so cannot be compared on the basis of size. All the ingredients for these cakes were room temperature when mixed. Fig. 59 shows a contrast in creaming to Figs. 55, 56, and 58. The sugar and butter were stirred 10 strokes with a wooden spoon. Then the slightly beaten egg was added and stirred 7 strokes. The flour and milk, Fig. 60, were added in the same manner as for Fig. 58. Fig. 63 shows the cake made from the partially creamed mixture.

*Muffin method.* By this method the beaten egg, the melted fat, and liquid are combined. All the dry ingredients are combined and added to the liquid ones. The advantage of this method is that the batter can be mixed in a short time. If the milk, eggs, and flour are not cool enough to partially solidify the fat, an oil-in-water emulsion is formed of part or all of the fat, and the texture of the cake is not as velvety, nor is it as tender, as by some other methods of mixing. When an oil-in-water emulsion forms in a batter, the batter remains smooth and does not contain flecks or small curds.

*Cake-mixer method.* This method has several different names, and as in

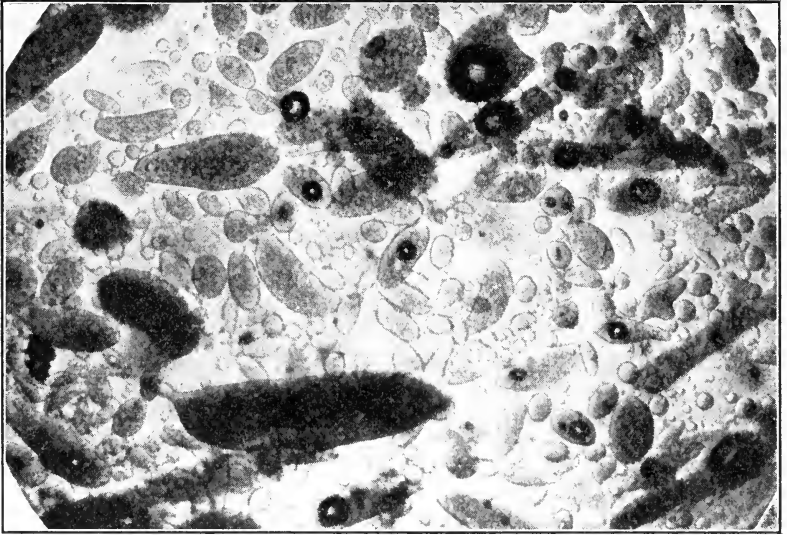


FIG. 59.—Photomicrograph of partially creamed butter, sugar and egg. Magnification approximately  $\times 100$ .

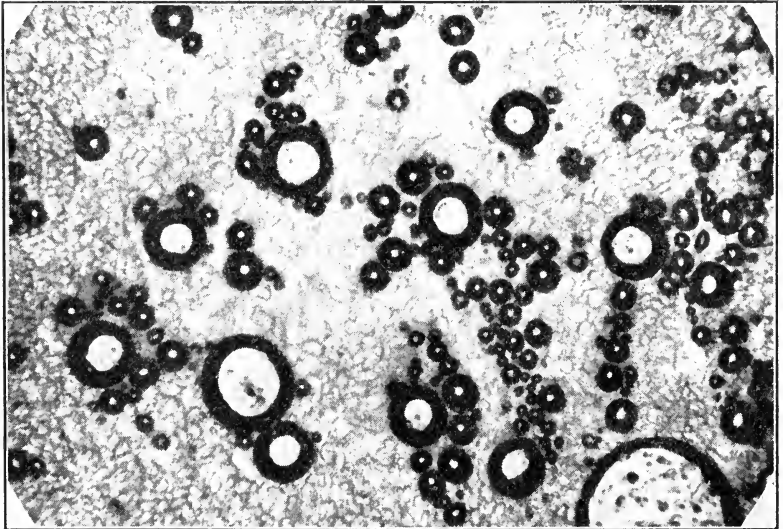


FIG. 60.—Same as Fig. 59 after the addition of the flour and milk. The irregular grouping of the sugar crystals and gas bubbles is characteristic of the coarser texture obtained in the cake shown in Fig. 63. Magnification  $\times 100$ .

the conventional method, the manner of adding the milk and flour may vary. As used in the experimental outline the fat has a temperature of  $22^{\circ}$  to  $28^{\circ}\text{C}$ . It is combined with the sugar and beaten egg. Then they

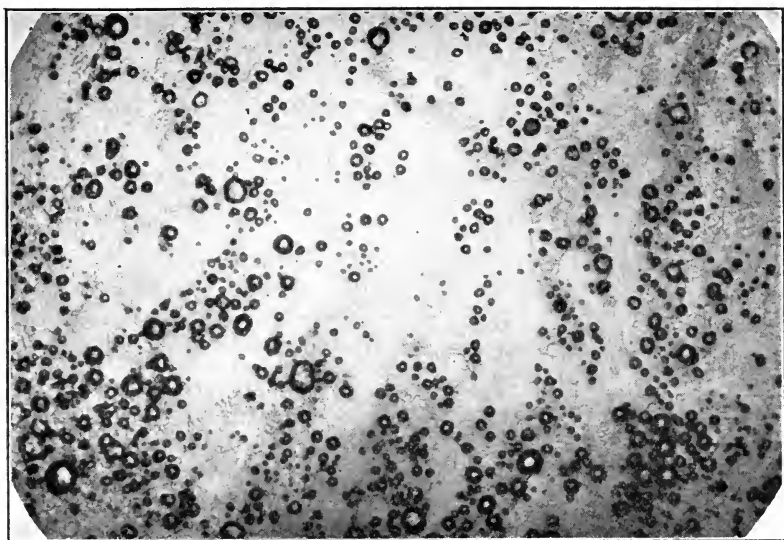


FIG. 61.—The butter, sugar, and beaten eggs are put in the mixing bowl; then thoroughly creamed. The air bubbles are scarcely perceptible as tiny white dots. Temperature of ingredients 22°C. Magnification approximately  $\times 100$ .

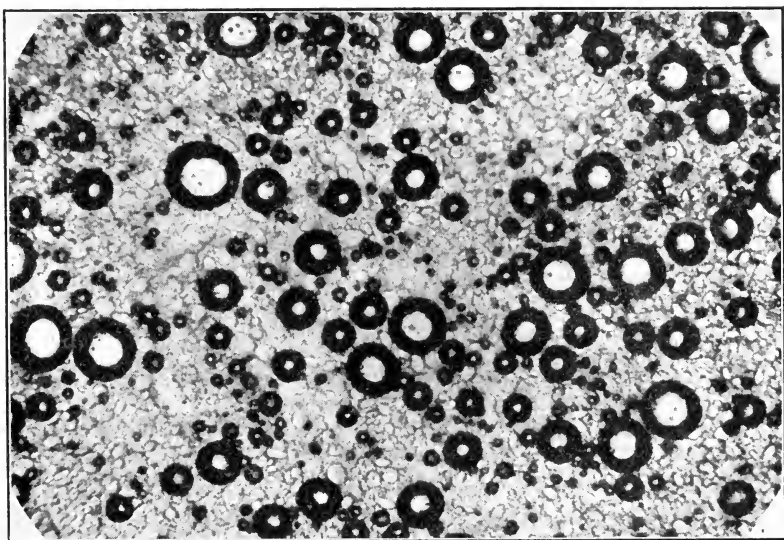


FIG. 62.—Photomicrograph of cake batter. Same as Fig. 61, after adding the flour and milk. Note the very regular grouping of the sugar crystals. All batters, observed microscopically, that have had regular distribution of the sugar crystals have produced excellent textured cakes. See Fig. 64. Magnification approximately  $\times 100$ .

*Figs. 55 to 64 by courtesy of Lora Ruth James.*

are stirred until thoroughly creamed, spongy, and fluffy. When the beaten egg is added to the fat and sugar at the beginning of the creaming process a rotary egg beater may be used until the mass becomes too stiff to turn the beater easily, when a spoon can be substituted. After the fat, sugar, and egg have been stirred they sometimes separate into fine flecks or curds. The flour and milk are added to the above mixture. Sometimes, after the flour and milk are added to the other ingredients, the flecks or curds may continue or may develop later in the batter. They also usually develop with the conventional method of mixing, and at least in some recipes there is nothing detrimental in their formation. In fact, the presence of very fine flecks seems to give assurance of a good texture in some recipes. If the flecks or curds are very large the texture of the cake is not as good as when they are smaller.

James, using Formula I, found that cakes scored higher when the fat, sugar, and eggs were thoroughly creamed than when only partially creamed.

A variation of the cake-mixer method is to put everything in the mixing bowl at once and then combine the ingredients. The texture of the cake thus obtained for any given recipe depends largely upon the temperature of the ingredients when combined. If all the ingredients are at the optimum or ideal temperature for combining, excellent textures may be obtained. Longer mixing is also required than is usual after the flour is added, if the butter and sugar have not been thoroughly creamed.

*Emulsion method.* This method of mixing cake is one evolved in the author's laboratory. If an oil-in-water emulsion is desired in a cake batter, why not mix the batter by a method that will give the most stable emulsion? The oil or melted fat is added gradually to the beaten egg exactly as in making mayonnaise. The sugar is added to the emulsion and next the flour and milk. This method of mixing is a poor one for making cake. The cake is more rubbery and tough when mixed by this method. This is logical, for the fat being dispersed in spheres has proportionally less surface area, and being surrounded by the emulsifying agents, the egg and flour, has less shortening power and hence the cake is more elastic and tough. For the same reason the fat is not as evident to the taste as when the cake is mixed by the conventional or cake-mixer methods. If the emulsion breaks, as it often does with the proportion of fat and eggs used in cakes, the texture of the cake is better than if it had not broken. If the temperature of the ingredients is such that the fat does not remain melted, the oil-in-water emulsion is also likely to break. A better texture is then obtained.

*Conventional-sponge.* Cakes made of oil by the conventional method always have a large portion of the oil dispersed as an oil-in-water emulsion. See Fig. 65. Nearly the same result was obtained when soft, grainy lards were used. Since this distribution of the fat results in a tougher, less desirable cake than when the major portion of the oil or fat forms a thin film at the air/crumb interface, methods of mixing to obtain the latter distribution of the fat seemed desirable. It was noted that a spice cake made



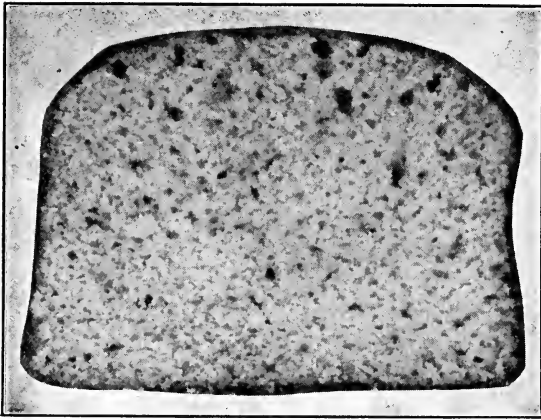


FIG. 63.—The plain cake recipe, Formula I, was used for cakes shown in Figs. 57, 63, and 64. The above cake is made from partially creamed sugar, butter, and egg as shown in Figs. 59 and 60.

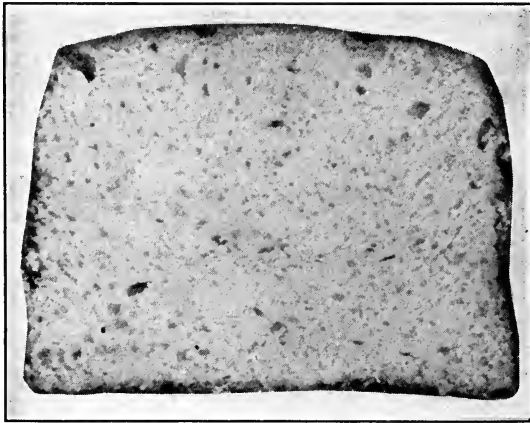


FIG. 64.—The above cake is made by method shown in Figs. 61 and 68. The flour and milk were added in the same manner as for the cakes shown in Figs. 57 and 63.

from soft, grainy lard, but with no egg, had excellent, very velvety texture. Then it was observed that after the egg was added to the cake batter the tendency to disperse the soft fat as an oil-in-water emulsion was increased. From this premise Martin developed several methods of mixing to use with lard in cake. When the egg was thoroughly mixed with the milk and the milk added as usual the texture of the cakes improved. The conventional-sponge method gave still better results.

The conventional-sponge method has been used in a series of studies by McLean, Stone, Buel, Minard, and Myers. The recipe used for this method is Formula I. with  $\frac{1}{2}$  cup of fat and  $1\frac{1}{2}$  cups of sugar. But a good creamed

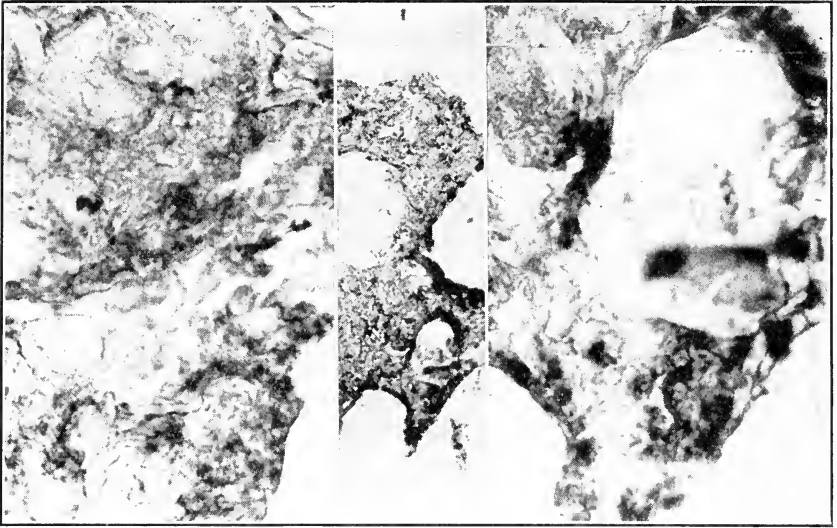


FIG. 65.—Photomicrograph of cake made with oil. Left, conventional; right, conventional-sponge method. Temperature for combining 25°C. There is more tendency for the oil to be distributed at the crumb/air interface by the latter method. Magnification approximately  $\times 350$ , except center, which is  $\times 70$ . Center is same as right. Because of the thickness of the section and the consequent diffraction, the crumb appears fluid at 350 magnification but shows better at 70 magnification.

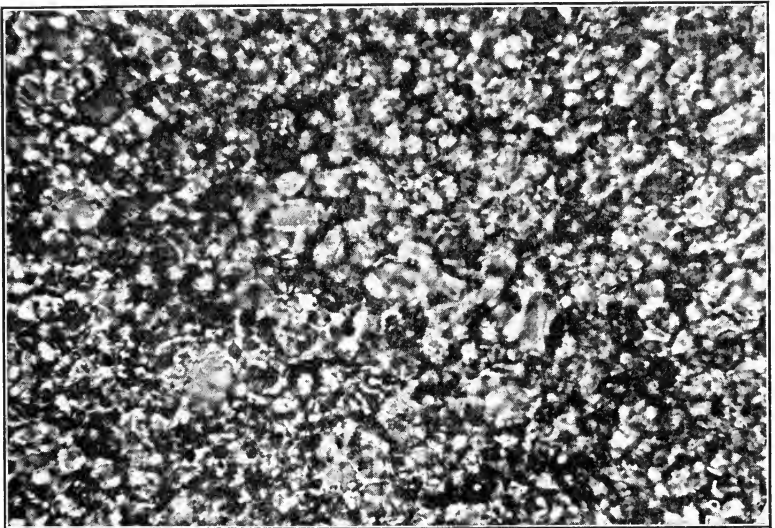


FIG. 66.—Cake batter. The temperature of all the ingredients was 40°C. when mixed. At this temperature the butter was melted. When stirred a partial or complete oil-in-water emulsion was formed. The small dark spheres are butter. Because of the high magnification necessary to show the fat spheres, the layer of batter appears very thick. Magnification approximately  $\times 400$ .

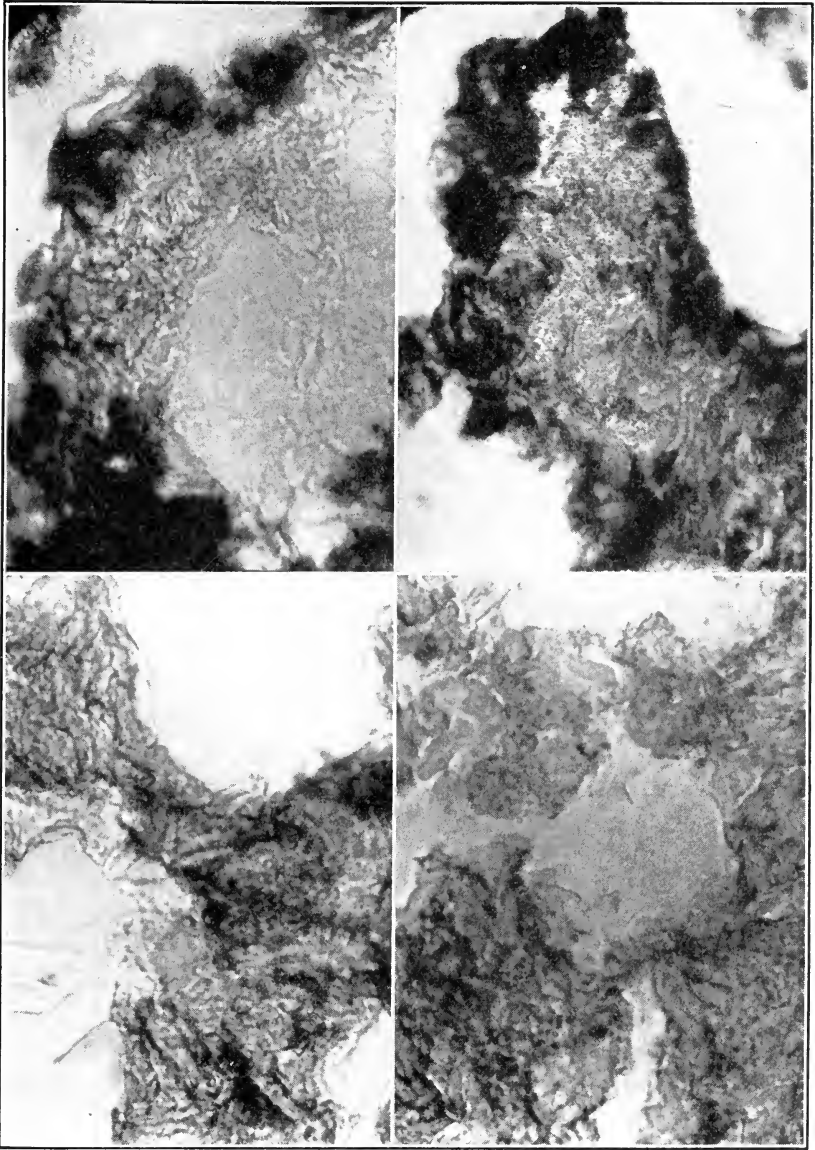


FIG. 67.—Showing the distribution of fat (butter) in cake as influenced by method of mixing and temperature of ingredients when combined. At the lower temperature the fat (black in the photomicrographs) is at the surface of the cake crumb, but the layer is more uneven in the conventional than for the conventional-sponge method. At the higher temperature the fat is softer and is distributed within the cake crumb, which results in a cake of poorer texture. Magnification approximately  $\times 350$ .

Upper left: Conventional method, ingredients mixed at 25°C.

Upper right: Conventional-sponge at 25°C.

Lower left: Conventional at 30°C.

Lower right: Conventional-sponge at 30°C. (*Myers*)

volume is not obtained with these proportions because the ratio of sugar to fat is too large. Hence when Martin creamed the fat with one-half the sugar the volume of the creamed mixture increased. A very small amount of flour was folded into this creamed mixture, then the remainder of the flour and the milk were added in any manner desired. The other half of the sugar was beaten with the whole egg until the mixture was thick, fluffy, and spongy, resembling a sponge cake batter in texture. This was then quickly folded into the cake batter.

The conventional-sponge method is the only method used in the author's laboratory that gives an excellent textured cake when oil is used. Although developed to use with soft lard it has been found equally good to use with butter and hydrogenated fats. The chief advantage of this method is the increased velvetiness of the crumb, which may be related to the fat distribution.

That the method and order of mixing and combining ingredients has an effect on the fat distribution is shown in Fig. 67.

**Temperature of the ingredients when the cake batter is mixed.** At higher temperatures the fat becomes softer, more mobile, and is easier to emulsify. When a temperature at which the major portion of the fat is emulsified is reached, i.e., when very soft or entirely melted, the cakes are poorer in texture and resemble those made from oil by the conventional method. See Figs. 65 and 67.

The extent the batter should be mixed depends to a certain degree upon the temperature of the ingredients. If the ingredients are warm, the flour proteins absorb more water and at a quicker rate than at low temperatures. The sugar dissolves better, and the fat is distributed more readily. Mixing should be shorter when the temperature of the ingredients is high and longer when the temperature is low. But, since the fat creams better at 24° to 28°C., it is preferable to mix the ingredients at these temperatures. When the temperature of the ingredients drops to 18° to 19°C. the texture of the cake is not as nice as at 24° or slightly higher, even if creamed thoroughly on a machine.

A microscopic study of the distribution of fat in cake batters shows that a very important factor in obtaining velvetiness is the way the fat is distributed throughout the batter. If the fat forms an oil-in-water emulsion the cake is not velvety, for the spheres of fat or oil being surrounded by egg and flour cannot impart the softness called velvetiness to the cake. When the fat is distributed in rather thick layers, the cake is not velvety, for there is not the degree of separation of the other ingredients of the cake by the fat to impart this texture. For a velvety texture in the cake the major portion of the fat in the batter is distributed in very thin films or sheets around the sugar crystals, the air bubbles, and between the other ingredients of the batter. The distribution of the fat in thin films is most readily obtained when the fat is most plastic.

Fig. 66 is a photomicrograph of cake batter that shows the butter dispersed as an oil-in-water emulsion. All the materials were incubated at

40°C. and mixed at this temperature. The butter was melted, and during mixing an emulsion was formed. This photomicrograph has a higher magnification than the other photomicrographs used in the illustrations, and shows how well the melted fat may be emulsified by mixing.

Myers studied the effect of two temperatures of ingredients at the time of combining on the fat distribution in the baked cake. The temperatures used were 25° and 30°C.; the methods of combining ingredients, the conventional-sponge and conventional; and the fats used, butter and both smooth and grainy lards. The two lards were from the same source. A sufficient amount of open-kettle rendered lard for the whole experiment was carefully melted and divided into two portions. One part was allowed to cool slowly in an incubator at 25°C. with the result that it was granular or grainy with some separated oil. The other portion was cooled within a kettle set in a container into which tap water at 10°-15°C. was running constantly. More than an hour of constant stirring was required before the lard solidified. The product was then set in the constant temperature box at 25°C. for 12 hours, as suggested by a patent to Procter and Gamble Company. The resulting lard had a very desirable consistency, neither too soft nor too hard and waxy, and was very plastic.

The analysis of variance of total scores shows that the variation due to temperature, method of combining, and fat used were all highly significant. A total of 300 cakes was made and the average total scores are given in Table 57.

TABLE 57

AVERAGE TOTAL CAKE SCORES FOR DIFFERENT TEMPERATURES, METHODS OF COMBINING INGREDIENTS, AND THE DIFFERENT FATS USED (*Myers*)

Variation	Number of cakes	Total average score
Temperature of ingredients when combined, °C		
25.....	150	76
30.....	150	68
Method of combining the ingredients		
Conventional-sponge.....	150	78
Conventional.....	150	64
Fats used		
Butter.....	100	76
Smooth lard.....	100	73
Grainy lard.....	100	64

The smooth-lard group of cakes scored highest at 25°C. for both conventional-sponge and conventional methods, the butter second, and the

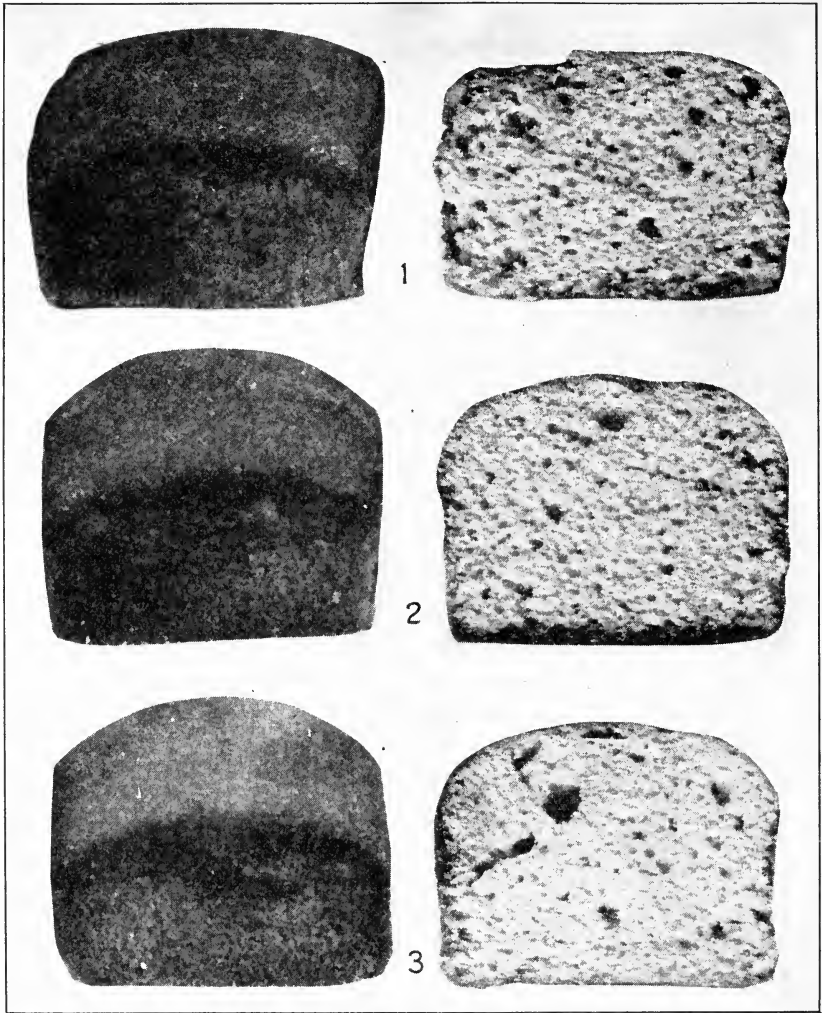


FIG. 68.—Cake. Showing effect of extent of mixing on volume and texture when a tartrate baking powder is used. Experiment 84A. As shown in illustration the cakes are about seven-ninths actual size.

150 grams of the batter removed and baked after mixing,

grainy lard third. But at 30°, butter scored first for both methods of combining, the smooth lard second, and grainy lard third. The distribution of the fat in the cake crumb, which was stained with osmic acid fumes, is shown for the two temperatures and methods of combining in the photomicrographs, Fig. 67.

At 25°, when the fats were firmer when combined, the fat in the cake

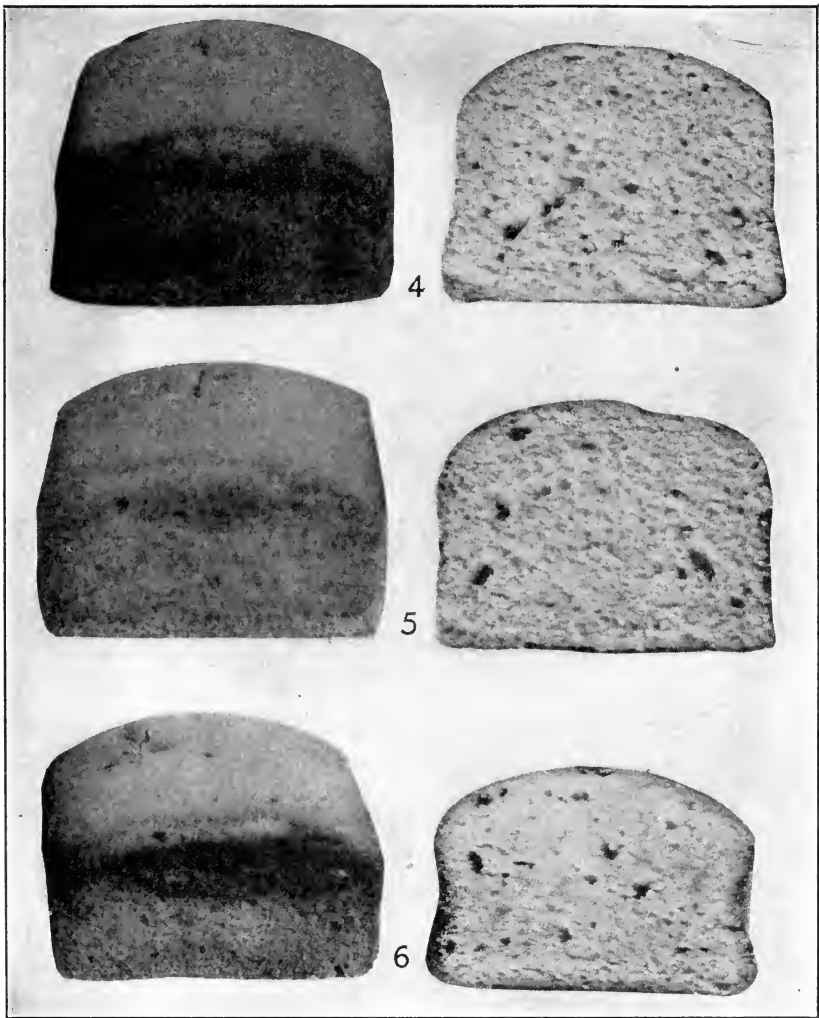


FIG. 68.

1. 50 strokes.
2. 100 strokes.
3. 150 strokes.
4. 300 strokes.
5. 400 strokes.
6. 1000 strokes.

crumb, depending somewhat on method and fat used, is more or less evenly distributed at the air/crumb interface. In general the more even this distribution the higher the scores received by the group of cakes. Of the 12 groups of cakes, those made with smooth lard, by the conventional-sponge

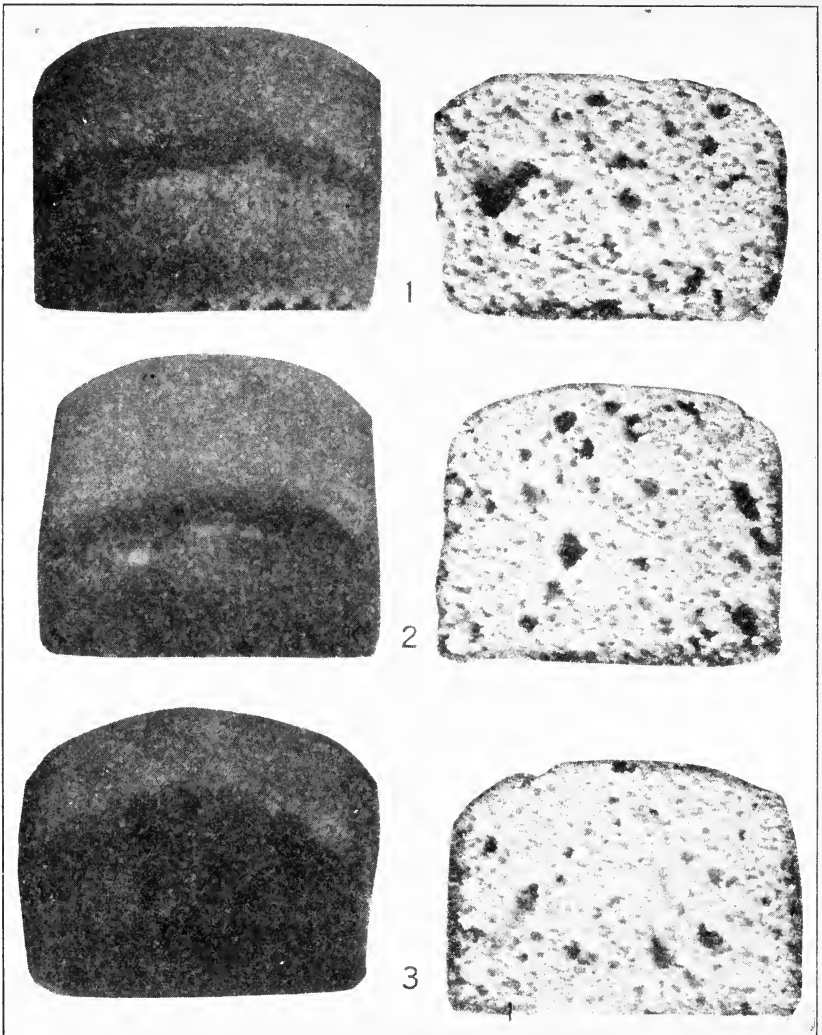


FIG. 69.—Cake. Showing the effect of extent of mixing on volume and texture when a phosphate baking powder is used. Experiment 84B. Illustration is about seven-ninths actual size of cakes.

150 grams of batter removed and baked after mixing,

method at  $25^{\circ}$ , scored highest and as a group had the most even distribution of fat at the air/crumb interface.

At  $30^{\circ}$ , when the fats were softer and more mobile, hence the squeezing effect exerted by the egg in forming oil-in-water emulsions encountered less resistance, the fat is distributed within the crumb, a fairly large portion as



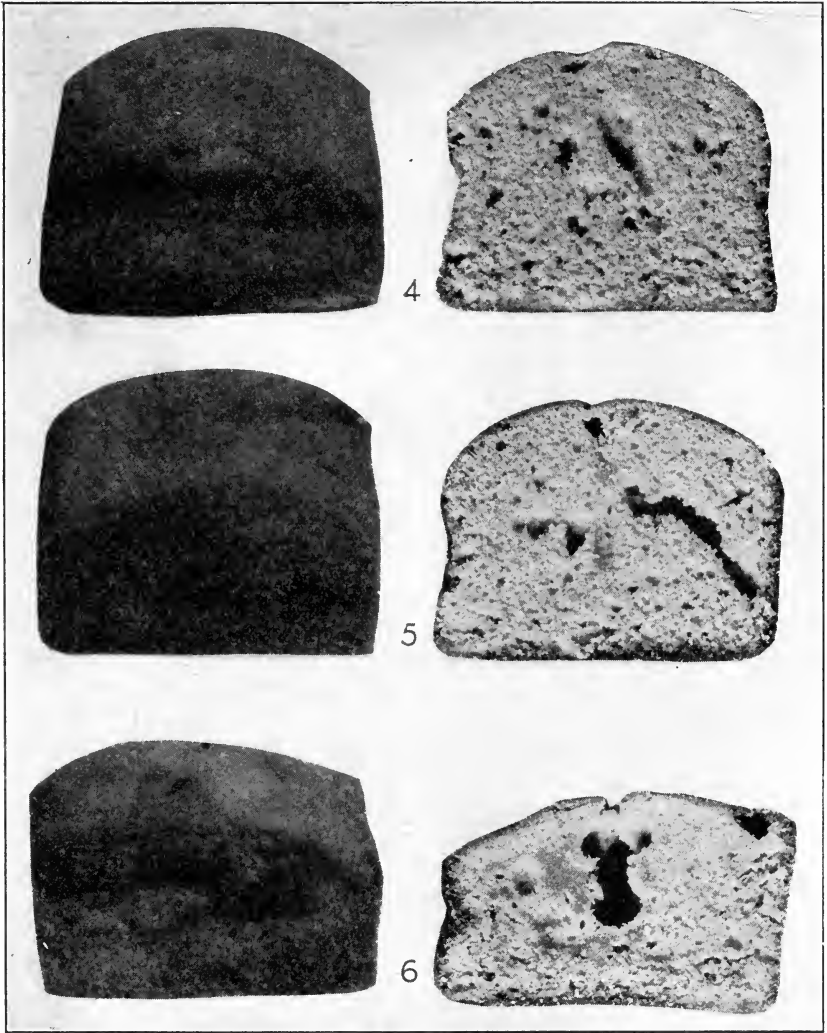


FIG. 69.

1. 50 strokes.
2. 100 strokes.
3. 150 strokes.
4. 300 strokes.
5. 400 strokes.
6. 1000 strokes.

an oil-in-water emulsion. As a result the cakes were less palatable and received lower scores.

**Extent of mixing and its effect on the baked cake.** Several illustrations accompany this part of the discussion of cakes. For the illustrations 150 grams of batter were always used and the cakes were baked in pans of the same size. This small amount of batter was used so that the grain, holes, and imperfections of texture and the volume are shown nearly actual size. As reproduced the illustrations are seven-ninths of the actual size of the cakes. Incidentally, it is difficult to make cake without some irregular holes from enclosed air, and these imperfections show more in the picture than in the cake. The ingredients for the cakes were 23°C. when mixed. The butter, sugar, and beaten egg were creamed only 75 turns with a rotary egg beater and 100 times with a wooden spoon, thus they were not thoroughly creamed, hence a coarser texture was produced. They were also baked at a lower temperature than now considered optimum. The very plain cake recipe, see Experiment 84, is used in the experimental outline because variations in extent of mixing and the proportion of ingredients show very distinctly. For a plain cake recipe for home use most people will prefer the sugar increased to 1½ cups.

*Extent of mixing, its effect upon crust and shape of cake.* With very little mixing, so that the ingredients are just combined but not blended until the batter is smooth (cakes number 1, Figs. 68 to 70, with 50 strokes), the top of the cake is nearly level or slightly rounded. It browns well and is rough. The crust has considerable glaze. As the amount of mixing is increased the crust is less rough, has less glaze, does not brown so well, and is more rounded across the top, until with more than an optimum amount of beating, 300 to 400 strokes in this cake, the crust becomes dull in appearance and quite smooth. There is a tendency for the top to come to a peak instead of being rounded. Small holes may be noticeable. Over these holes there is often a very thin layer of crust that covers the end of a long tunnel that extends up through the cake. With decided excess of mixing, 1000 strokes, the top may be level or only slightly rounded and is very dull and smooth in appearance and nearly white in color. The appearance of the crust of cake made with sulfate-phosphate baking powder, Fig. 70, changes with increased mixing but not so rapidly as in the cakes made with the phosphate or tartrate baking powder.

*Extent of mixing, its effect upon volume.* When the cake is just mixed so that no dry ingredients show, the volume of the cake may be less than when the batter is stirred a little longer, or it may be larger. With more mixing, 100 to 150 strokes, the volume may or may not increase. Continued beating after an amount sufficient to give the maximum volume decreases the volume in proportion to the degree of over-mixing. With more than an optimum amount of mixing the volumes of cakes containing a phosphate or a tartrate baking powder decrease more rapidly than those

of the cakes made with sulfate-phosphate baking powder. See Figs. 68 to 70.

*Extent of mixing, its effect upon texture.* With a definite proportion of ingredients the texture as well as the character of the crust and the volume varies with the extent of mixing. The cakes in which the ingredients are just mixed so as to show no dry flour do not have a desirable texture. See cakes 1 in illustrations. The ingredients of the cake are not well blended, and the crumb has a horny, flinty texture, which is sometimes called bready. The crumb is crumbly. It is not smooth and velvety on the palate. The cell walls are thick and the cells coarse and large in size. A cake made with this amount of mixing dries out and stales in a very much shorter time than portions of the same batter mixed for a longer time. With more mixing the grain of the cake is finer and the cell walls thinner. The crumb is smooth and velvety when tasted, and the ingredients are well blended. With a definite amount of mixing of the plain cake batter, 150 to 400 strokes, which varies somewhat with the kind of baking powder used, the maker's technic, and the temperature of the ingredients, tunnels begin to appear. More mixing than the optimum produces a finer grain, or smaller cells, until a stage is reached, 1000 strokes or more, at which the texture is very compact or even soggy and solid.

Swanson and Working, also Bailey and Le Vesconte, have shown that extended mixing of bread dough modifies the quality of the gluten, and its extensibility is decreased. It seems logical to expect this stage to develop in cakes as well as in bread, although on account of the different proportion of ingredients the amount of mixing to bring this about may vary from the amount required for bread. Several factors may aid in producing the small volume with 1000 strokes. These include the extent of mixing, its effect upon the gluten, the effect of the baking powder upon the gluten, and the loss of carbon dioxide formed from the baking powder.

*Tunnels.* Tunnels in cakes develop in the same way as the tunnels in muffins. Gas expands in a weakened section of the batter. This weaker section is between long parallel strands of gluten which have been stretched and developed in mixing and in putting the batter in the pans. An excess of flour, see Fig. 71, and too much mixing tend to favor the formation of tunnels. An increased percentage of sugar lessens the tendency to form tunnels. A high baking temperature may tend to increase the tendency for tunnel formation, but is quite variable. Tunnels are formed more often when small portions of the batter are baked in small deep pans than when the whole cake recipe is baked in a large or a shallow pan, for the batter for the small cake is usually dropped from a spoon, whereas for the larger cakes it is more often poured into the cake pan. Tunnels do not develop so often if the batter is stirred with a circular motion as they do when the batter is beaten across the bowl. The reason for this is that, if the batter is stirred, the mixing utensil is pulled around and around the bowl and after a definite amount of mixing the appearance of the batter

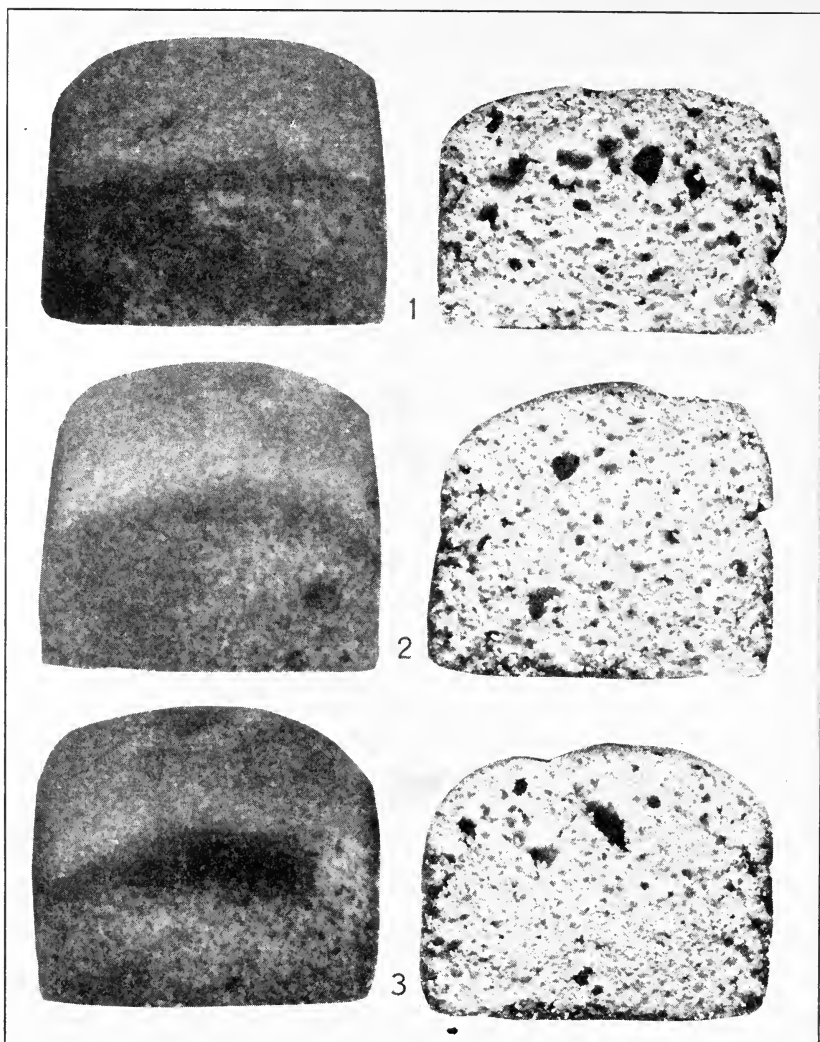


FIG. 70.—Showing the effect of extent of mixing on volume and texture when sulfate-phosphate baking powder is used. Experiment 84C. As shown in the illustration the cakes are about seven-ninths actual size.

150 grams of batter removed and baked after mixing,

is similar to that in Fig. 71. When some of this batter is removed with a spoon to put in a cake pan, the spoon cuts across the strands or ridges developed during stirring, and tunnels are not so likely to occur in the baked cake. In beating, unless the bowl is turned while mixing, the strands or ridges have formed across the bowl instead of around it. If the spoon

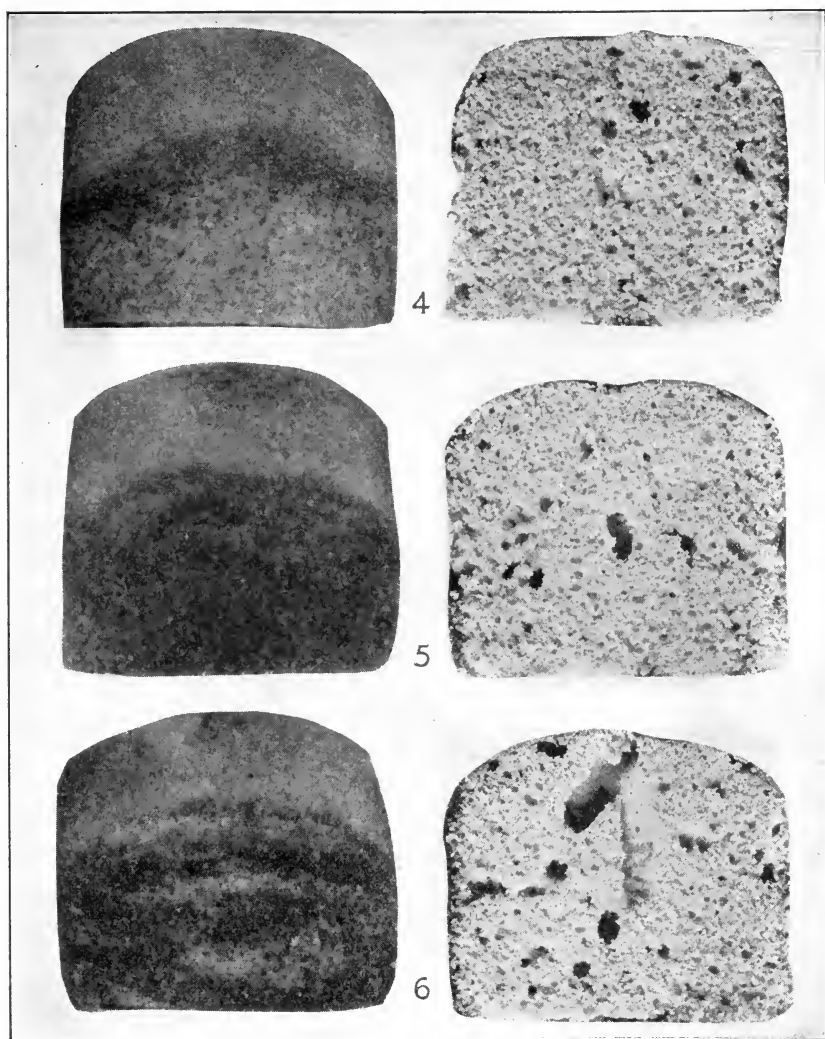


FIG. 70.

1. 50 strokes.
2. 100 strokes.
3. 150 strokes.
4. 300 strokes.
5. 400 strokes.
6. 1000 strokes.

is dipped or the batter is poured in the same direction in which the strands are formed, the tendency to develop tunnels is augmented. If the bowl is turned while the batter is beaten, there is no more tendency for tunnels to form than when the batter is stirred.

*Optimum amount of mixing for plain cake.* In the plain cake the optimum amount of mixing varies with (1) the thoroughness of creaming,



FIG. 71.—Showing the strands formed and their direction in a batter that is stirred.

(2) the intensity of mixing, (3) the temperature of the ingredients, (4) the type of baking powder used, (5) the quantity of baking powder used, and (6) the point at which the baking powder is added. When the butter, sugar, and egg are thoroughly creamed, the optimum amount of mixing may extend over a wider range. Most of these factors have been considered. For the very plain cake recipe, when a phosphate or tartrate powder is used, about 150 to 200 strokes give the best texture, if the baking powder is added with the flour. A sulfate-phosphate powder requires about 250 to 300 strokes for

the best texture. As the sugar in the recipe is increased to give a more desirable cake, the optimum amount of mixing is greater, but is more nearly the same for all the different types of baking powder.

For Formula I, with  $1\frac{1}{2}$  cups of sugar, which is a more desirable plain cake, about 225 to 250 strokes, or sometimes more, are sufficient for mixing the flour and milk with the creamed mixture to produce a good texture.

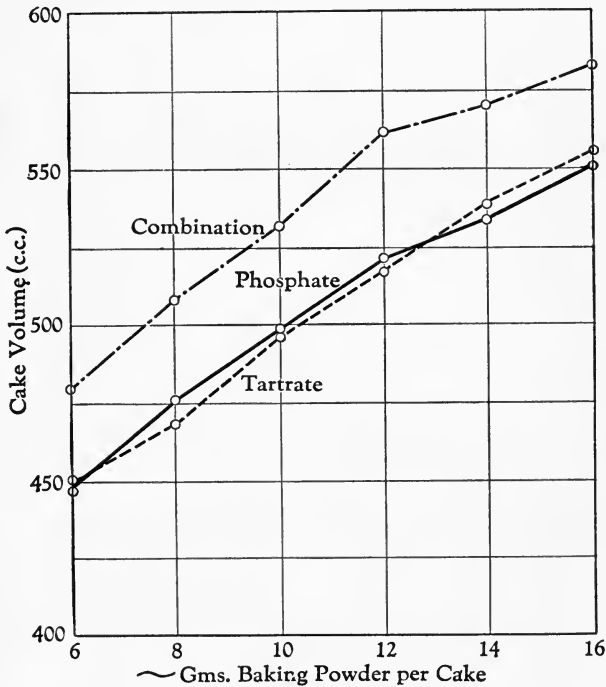


FIG. 72.—The effect on volume of increasing the quantity of three types of baking powder in plain cake, sulfate-phosphate (combination), tartrate, and phosphate. (McLean)

*Effect of extent of mixing on staling.* Olsen used the compressibility apparatus designed by Platt in trying to determine the effect of extent of mixing upon the staling of plain cake. It was found that cakes mixed for different lengths of time could not be compared with each other. Those mixed for a very short period had a loose, coarse, porous texture, which permitted greater penetration of the plunger into the crumb. The cakes mixed for a longer period were compact in texture and offered more resistance to penetration of the plunger. It was found there was a tendency for the cakes creamed a short time to stale more rapidly than those creamed for a longer period. The rate of staling was greatest during the first 24 hours. It was less rapid from 24 to 48 hours and continued at a still slower rate from 48 to 96 hours. Formula I was used for tests.

**Variation of proportion of ingredients.** As the proportion of ingredients used in the cake is varied the appearance of the crust and the top of the cake differs from that of the plain cake. The extent of mixing to give the most desirable texture may also need to be changed.

*The proportion of baking powder.* McLean used varying amounts of three types of baking powder to determine the optimum quantity of each powder for plain cake (Formula I).

The effect on the cake volume of increasing the baking powder is shown in Fig. 72. The volume increases with increased quantity of powder used

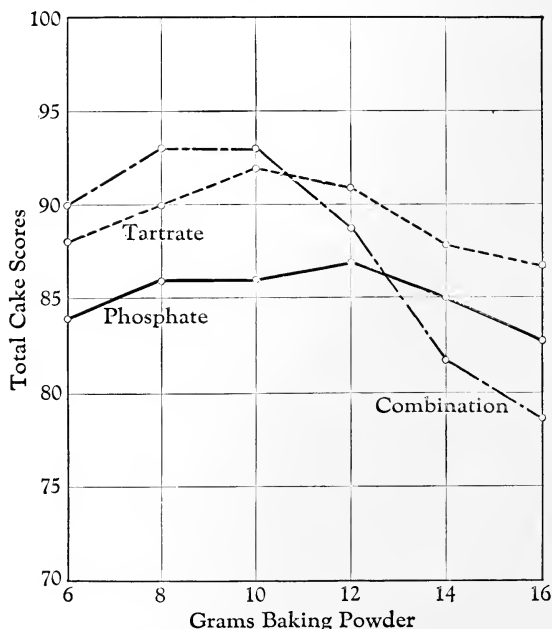


FIG. 73.—The effect on total scores of increasing the quantity of three types of baking powder in plain cake. Each point on the graph is an average of scores for 14 cakes. (McLean)

until a point is reached at which the cake falls, the volume decreasing with still greater increments of baking powder. This decrease in volume occurs with a larger quantity than that shown in the graphs.

From Fig. 73 a comparison may be made of the change in score caused by increasing the weight of a tartrate, phosphate, or a sulfate-phosphate (combination) powder in plain cake and again a comparison may be drawn between the scores for cakes made with an equal weight of the three different types of baking powder. McLean found that the palatability and desirability of the cakes, as shown by the scores, progressively increased with increased weight of the powders until the optimum quantity of baking powder is reached. With a further increase beyond the optimum amount the desirability of the cakes decreased. The decrease in desirability was most



rapid with the powder giving the greatest volume, indicating that it is more detrimental to use too much of a sulfate-phosphate baking powder than of a tartrate or phosphate. For the formula, the method of mixing used, and for the brands of baking powder used in the investigations, the optimum quantity of each powder was as follows: sulfate-phosphate, 8 to 10 grams; tartrate, 10 grams; and phosphate, 12 grams.

An increase in the quantity of a baking powder over and above the optimum amount causes an increasing tendency to produce a coarse, loose texture, crumbliness, a harsh crumb, a lack of velvetiness, and a possible off flavor. With enough baking powder to cause the cake to fall an increasingly gummy, sticky, chewy texture is obtained. Too little baking powder gives a cake that is too compact.

The measure of the optimum amount of each type of powder as determined by McLean is approximately 3 teaspoons, if the average weight of a teaspoon is taken as 3, 3.5, and 4 grams for the sulfate-phosphate, tartrate, and phosphate baking powders, respectively. Since 3 cups of flour were used in the recipe, this would indicate that it is possible to use 1 teaspoon of baking powder per cup of flour for all three types of powders. Since a teaspoon of some brands does not weigh the same as the brands used by McLean, the measure for these brands would vary.

Probably the chief reason for the variation in weight of different types and different brands of the same type is the fineness of subdivision or grinding of the ingredients.

The following weights for a teaspoon of baking powder have been suggested and used.

Type of powder	<i>Halliday and Noble</i> Grams per teaspoon	<i>Woodruff</i> Grams per teaspoon
Phosphate	4.00	3.52
Tartrate	3.67	3.07
Sulfate-phosphate	3.70	2.85

The weights by Woodruff were determined by finding the average weight of a cup of the powder and taking 1/48 of this for the weight of a teaspoon. From the above weights it can readily be calculated that 3 teaspoons of the sulfate-phosphate powder by the Halliday and Noble scale are equal to about 4 teaspoons by the Woodruff scale. When measured by teaspoons rather than by cups the averages of Woodruff are low.

The weight of a teaspoon of baking powder can vary considerably even when a standard measuring spoon is used. For accurate experimental work the baking powder is weighed, but the housekeeper usually measures the ingredients for her cakes. Dipping the measuring spoon into the can and leveling off the surplus tends to loosen the powder. Thus the weight of the second or third teaspoon of powder will vary, depending on whether it is secured from the loosened or the more compact portions in the can. As the powder stands in the can it tends to become more compact. The averages for about 400 teaspoons of each type of powder, secured by leveling off the surplus powder after dipping the spoon in the can, have been about

3.0 grams for one brand of sulfate-phosphate, about 4.0 grams for a second brand, about 4.0 for the phosphate, and about 3.5 for the tartrate.

Of course the optimum amount of baking powder, in addition to (1) the type of baking powder, varies with (2) the formula, (3) the thoroughness of creaming, (4) the method of mixing, (5) the extent of mixing, (6) the kind of flour used, (7) the technic of the operator, (8) time of adding the beaten egg white, and (9) the altitude.

In general, formulas with high proportions of sugar seem to require slightly more baking powder than those with smaller proportions.

The more thoroughly the butter and sugar, or the butter, sugar, and eggs, are creamed, the more air incorporated and the less baking powder needed. Of course, no more than a maximum amount of air can be incorporated in any given mixture.

Methods of mixing like the conventional-sponge in which a great deal of air is incorporated in the egg-sugar mixture may need slightly less baking powder than the conventional method.

There is a limit to which cake batters can be stirred or beaten without affecting the tenderness of the product. In general, the sulfate-phosphate types can be mixed longer than the other types of powders.

Because of the tenacity of the gluten, more baking powder is needed with bread or all-purpose than for pastry or cake flours.

If the beaten egg whites are added to the batter last, either by folding or stirring, a smaller proportion of baking powder produces a more desirable texture.

As the distance above sea level increases, the atmospheric pressure is decreased. Consequently, because of the reduced pressure, a given quantity of baking powder has greater leavening ability at higher altitudes. Hence a smaller amount of any type of powder is needed at higher altitudes. Peterson has developed recipes for high altitudes.

That baking powder has an effect on the viscosity of the batter is shown clearly by adding varying amounts of baking powder (Experiment 84D) to a particular cake recipe. A much stiffer, thicker batter is secured with the larger quantity of baking powder.

*Varying the proportion of egg.* With increased egg the cell walls become thinner and the cells smaller and regular in shape as the mixing is continued. When the egg is increased the crumb is very elastic, the cake more rubbery, tough, and compact. Increasing the egg imparts a glaze to the crust, but the appearance is different from, and less crystalline than, that produced with increased sugar. The plain cake recipe with increased egg and no other changes is not so desirable as the original recipe. If egg is increased, a better texture is obtained if the white is beaten separately and added last.

*Varying the proportion of sugar.* Sugar is added for sweetening. But it also affects the texture of the product. With larger quantities of sugar the batter must be mixed longer even when baking powders that react rapidly at low temperatures are used. The sugar competes with the gluten and

other ingredients for the liquid and prevents the development of the gluten so that longer mixing is necessary. When the sugar in the very plain cake recipe is increased from 1 to  $1\frac{1}{2}$  cups a sweeter cake is obtained and one with a better-balanced formula, so that a better texture and volume are obtained. The amount of mixing to produce the best texture with  $1\frac{1}{2}$  cups of sugar is from 225 to 300 strokes when a tartrate or phosphate baking powder is used, if the powder is added with the flour. When the proportion of sugar is increased to 2 cups, Fig. 74, a decidedly different texture is obtained from that when the flour or egg is increased. With slight mixing the top of the cake is sunken or fallen; see Fig. 74, cake number 1, mixed with 50 strokes, Experiment 84F,4. Sometimes the cake bubbles up over the top of the pan and then falls. The top is rough, shiny, and has a crystalline appearance. The cell walls are very thick and the cells are large and coarse. The cake browns readily. It is gummy and chewy when tasted. As the amount of mixing is increased the texture of the cake is improved. The number of strokes required to produce a fine grain is very much greater than in the plain cake. The texture with 1000 and 1500 strokes, cakes numbers 5 and 6, Fig. 74, is very much better than in the cakes just slightly mixed. The most desirable texture is sometimes obtained with 400 strokes, sometimes with 1000, and occasionally with 1500. The cakes with increased sugar used in the illustrations were made with a tartrate baking powder.

*Varying the proportion of fat.* Increasing the fat results in a more tender cake. The fat in the plain cake recipe can be increased from  $\frac{1}{2}$  cup to  $\frac{3}{4}$  cup and a good texture obtained, but the volume of the cake is smaller. The cake is better if the sugar and eggs are increased at the same time. The appearance of the crust of a cake with a large amount of fat is rather smooth. It browns readily, but not so easily as with sugar.

*Varying the proportion of flour.* If the flour is very dry a better texture is obtained when the flour is reduced. If the proportion of flour in the plain cake is increased the tendency to tunnel is increased. The cake is drier and more solid. The volume is good. When the flour in the plain cake recipe is increased to  $3\frac{1}{2}$  cups, Experiment 84F,7, Fig. 75, the tenacity of the batter becomes very great. As the gluten is developed by mixing, long strands show in the batter when the mixing spoon is pulled through it. Often after mixing 1000 strokes ribbons of batter from  $\frac{1}{4}$  to  $\frac{3}{4}$  inch in width and over a foot long will form when the batter is allowed to drop from the spoon.

**Balancing cake formulas.** Various ways and means are suggested for balancing cake formulas. The single variation of the plain recipe in the experimental outline that usually gives the most acceptable cake is to increase the sugar from 1 to  $1\frac{1}{2}$  cups. This recipe is Formula I in Table 58.

Bakers have different rules for balancing cake formulas, but they state there will always be exceptions to these rules. They also mix larger quantities in one batch than the housewife, often 20 to 50 pounds or more at one time. It is well known that in large-quantity cookery the propor-

tion of liquid must be decreased, or if a very small portion of the recipe is made, the liquid must be increased. In many instances the rules given in bakery trade journals sift down to the following or similar suggestions.

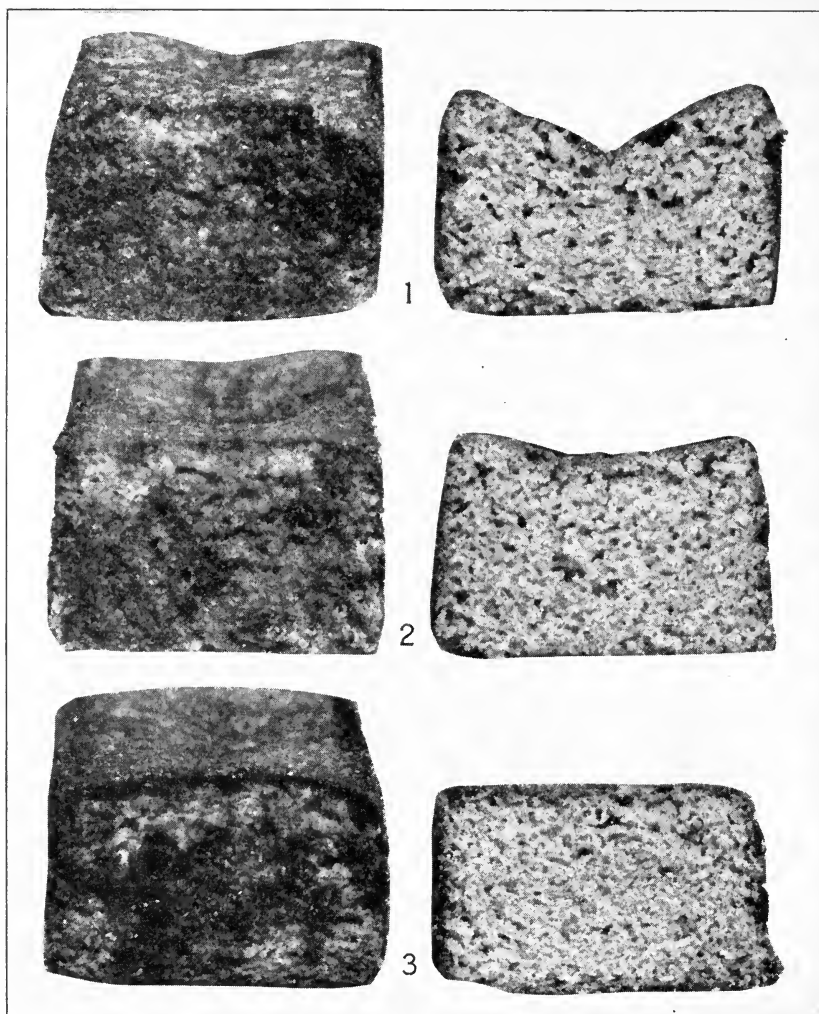


FIG. 74.—Cake. Showing the effect on texture of increasing the sugar in the plain cake recipe from 1 to 2 cups. Experiment 84F,4. As shown in the illustration the cakes are about seven-ninths actual size.

150 grams of the batter removed and baked after mixing,

1. The weight of the fat should not be over one-half the weight of the sugar.

2. The weight of the fat should not exceed the weight of the eggs.

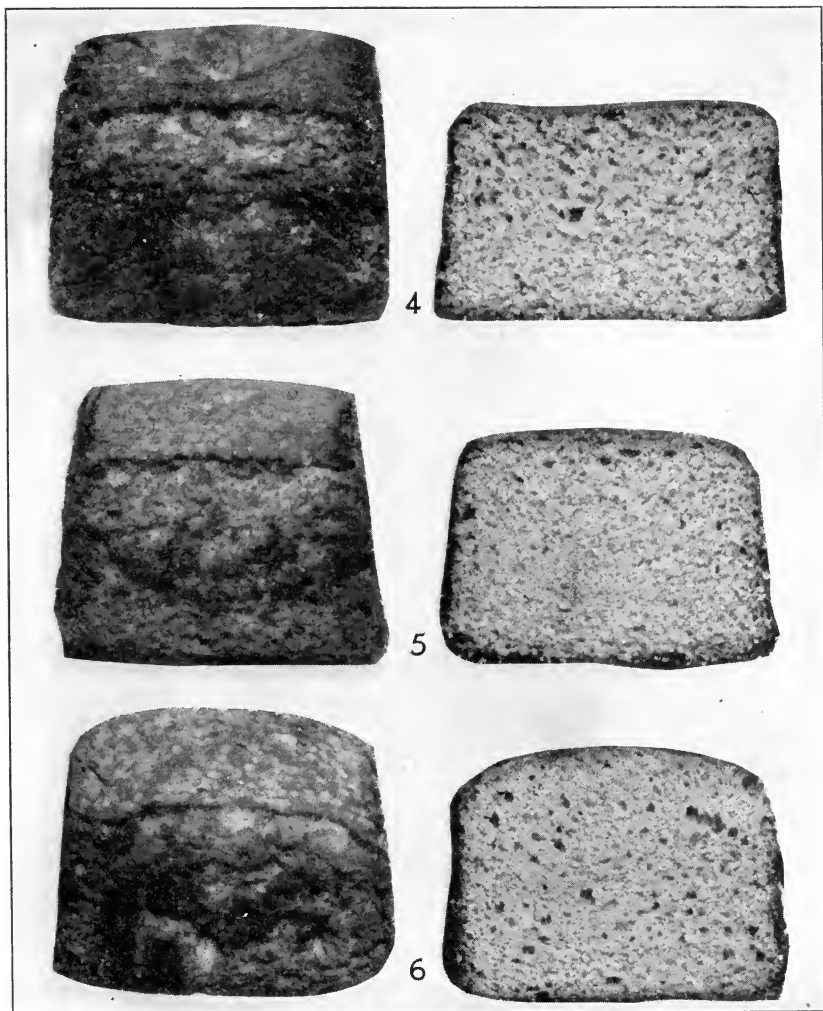


FIG. 74.

1. 50 strokes.

2. 150 strokes.

3. 300 strokes.

4. 400 strokes.

5. 1000 strokes.

6. 1500 strokes.

3. The weight of the sugar should not exceed the weight of the flour.

4. The weight of the liquid (milk plus eggs, not weight of dried milk or eggs) should equal the weight of the flour.

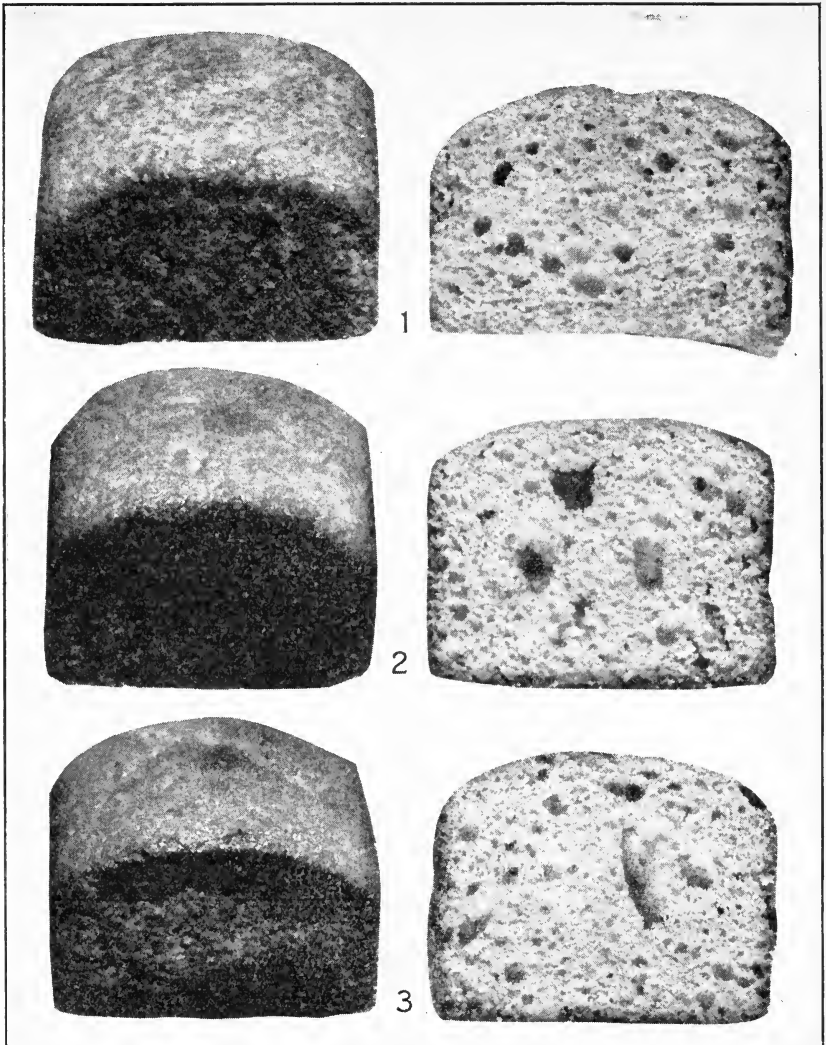


FIG. 75.—Cake. Showing effect on texture and volume of increasing the flour in the plain cake recipe from 3 to  $3\frac{1}{2}$  cups. Experiment 84F,7. Illustration is about seven-ninths actual size of cakes.

150 grams of the batter removed and baked after mixing,

Table 58 gives four formulas. The first is a recipe commonly used for plain cake. In the second the only change is the reduction of the liquid to accord with the rules given above. In the third the fat, eggs, and milk are changed to the nearest most easily measurable quantities for a richer cake.

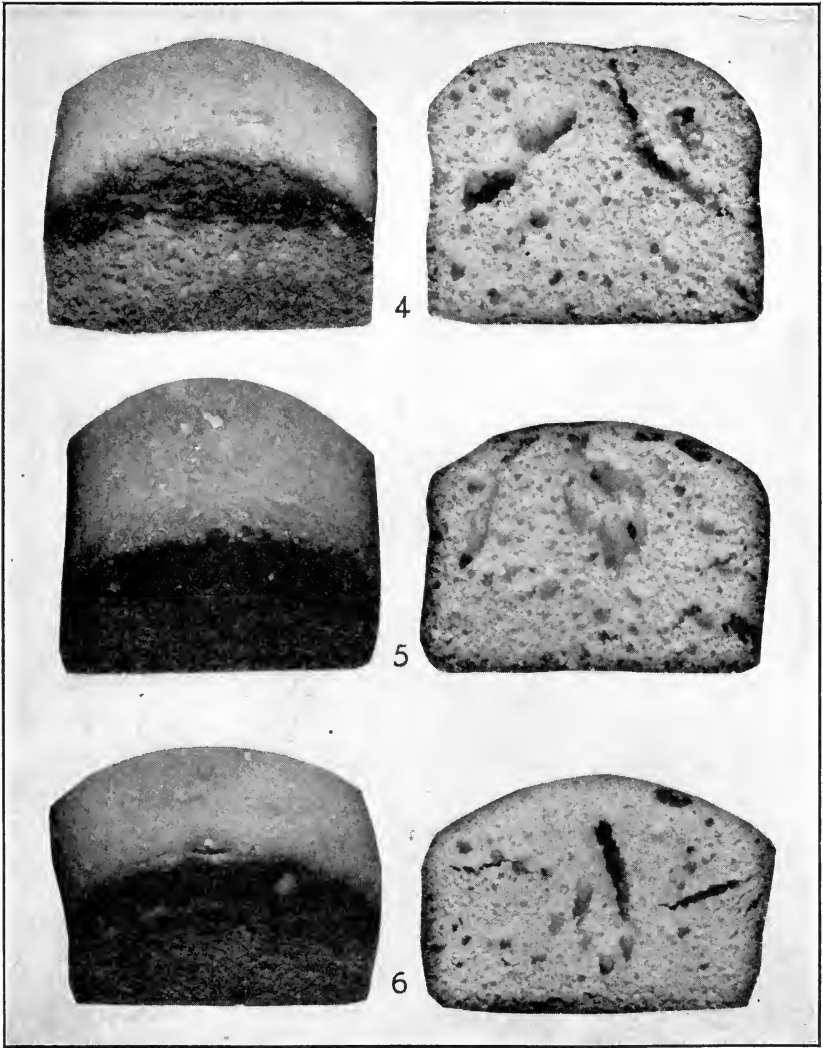


FIG. 75.

- 1. 50 strokes.
- 2. 100 strokes.
- 3. 150 strokes.

- 4. 300 strokes.
- 5. 400 strokes.
- 6. 1000 strokes.

Chocolate cake. Probably the question most often asked the author concerning chocolate cake is how to obtain a red one. The usual reply before answering the query is, "Why do you want a red chocolate cake?"

*Chocolate.* For a better understanding of the action of chocolate some knowledge of its production is necessary. Chocolate is obtained from cacao beans of the cacao tree. The term cacao is used to refer to the raw material until the press cake stage. The term cocoa refers to the powder. The beans are cut from the pods, placed in piles, and fermented. Fermentation reduces the bitterness of the chocolate. After fermentation the beans are roasted.

TABLE 58  
FORMULAS FOR PLAIN CAKE

Ingredients	Formula I		Formula II		Formula III		Formula IV	
	Meas- ure	Weight, grams	Meas- ure	Weight, grams	Meas- ure	Weight, grams	Meas- ure	Weight, grams
Butter	½ c.	112	½ c.	112	⅝ c.	140	⅜ c.	84
Sugar	1½ c.	300	1½ c.	300	1½ c.	300	1½ c.	300
Eggs	2	96	2	96	3	144	1½	72
Flour	3 c.	300	3 c.	300	3 c.	300	3 c.	300
Milk	1 c.	244	⅝ c.	204	⅝ c.	156	1⅛ c.	274
Baking powder	3 t.	8-12	3 t.	8-10	3 t.	8-10	3½ t.	10-14
Flavoring	1 t.		1 t.		1 t.		1 t.	
Salt	½ t.		½ t.		½ t.		½ t.	

After being roasted the beans are shelled and cracked. The cracked beans are called nibs. The roasting brings out the flavor, but Zenlea states that the flavor of the chocolate is dependent upon the skill used in blending, milling, and conching of the various varieties of nibs with the proper quantity of sugar and cocoa butter, milk solids, when used, and added flavors. There are approximately 30 varieties of cocoa beans commonly used and Zenlea says the nibs of these beans vary in color, chocolate character, pungency, acidity, mildness, bitterness, and creaminess. The blended nibs are ground, a temperature just above 32°C. (90°F.) being maintained during grinding, this temperature and the pressure rendering the product fluid. This chocolate liquor, which contains over 50 per cent of cocoa butter, is run into molds and cooled for chocolate, forming the bitter chocolate for household and commercial uses. In the "Service and Regulatory Announcements" of the Food and Drug Administration chocolate, plain chocolate, bitter chocolate, chocolate liquor, chocolate paste, bitter chocolate grating, all are defined as the solid or plastic mass obtained by grinding cacao nibs. Sweet chocolate, sweet chocolate coating, is chocolate mixed with sugar and/or dextrose, with or without the addition of cacao butter, spices, or



other flavoring materials. But the proportion of sugar mixed with the chocolate liquor may vary from none to about 68 per cent.

The cocoa beans before being ground vary in color from a very light brown, or nearly gray, to a deep red brown. Thus the color of the chocolate or cocoa may vary because of the different colored beans from which it is made. A higher roast also gives a darker color. Alkali-treated chocolate is also darker than natural-processed chocolate.

Though the amount of sugar added to chocolate liquor varies greatly and the blends of chocolate are unlimited, Zenlea makes the following classifications of general types: bitter-sweet, dark-sweet, medium-dark sweet, light-sweet, milk, ice cream bar, skim milk, buttermilk, malted milk, imitation, and lecithin coatings. Bywaters states that the tannin group of substances is a very important constituent of cacao matter, "for it determines to a great extent the colour and the taste of the product. Cacao catechin and cacao tannin are present in the fresh unfermented bean." The catechin gives a very bitter flavor. Adam and Jensen have both determined the amount of catechin and cacao tannin in the unfermented bean and in the manufactured chocolate and cocoa. During fermentation the cacao catechin is transformed to cacao tannin. The amount of cacao tannin found in the fully fermented beans averages 1.9 per cent.

Bywaters states that cacao tannin in the presence of oxygen is transformed into a phlobaphene, which is insoluble in water and reddish in color. The red color of cocoa is chiefly due to the presence of this phlobaphene.

To make cocoa the chocolate liquor is put in a hydraulic press and part of the cocoa butter is removed, leaving a cake containing less than one-half as much cocoa butter as the chocolate. This cake is pulverized.

*Cocoa.* Zenlea states that there are many kinds of cocoas, but depending on processing they may be separated into two main classifications: (a) natural and (b) Dutch.

Natural-process cocoas have had no alkalies or "Dutching agents" added during manufacture. Schaal states that probably about 75 per cent of the cocoas used by bakers are natural-processed cocoas. Some chocolate is also "Dutch" processed.

Dutch-process cocoas have been treated with an alkaline solution such as potassium carbonate, ammonium bicarbonate, or sodium carbonate or bicarbonate. In some instances, according to Zenlea, the cleaned nibs are actually boiled in an alkali solution as strong as 3 per cent, based on the weight of the nibs. In commercial practise 2 per cent of alkali is more commonly used. To complete the treatment, the water is evaporated and the Dutch nibs dried in a roaster. The nibs are then treated in the same manner as nibs for natural-process cocoas.

Bywaters gives the object of the Dutch process as follows: (1) To improve the flavor, (2) to improve the color, (3) to improve the solubility, and (4) to improve the digestibility. The proportion of cocoa that can be dissolved is less than 25 per cent, even after treatment. The treatment

darkens the color. Zenlea states that natural cocoas have a  $pH$  value of 5.2 to 6.0; chocolate 5.1 to 6.2; "Dutched" cocoas have a  $pH$  of 6.0 to 7.5; and chocolate a  $pH$  6.0 to 7.8. The reaction depends on the original  $pH$  of the nibs and the quantity and kind of alkali added.

Chocolate and cocoa contain some organic acids such as acetic and tartaric. The reaction of the cocoa determines the amount of soda that can be neutralized by the cocoa or chocolate in cooking. Less soda should be used with a Dutched cocoa in such products as cake and cookies in which soda is used, for the natural acidity of the cocoa has been lessened by the treatment.

Zenlea describes the following types of cocoas: (1) Semi-cocoas, not on the market in powder form, with 32 to 45 per cent fat content, and used for fine quality ice cream and icings. (2) High-quality cocoas containing 25 to 35 per cent fat. A higher fat content would prevent their preparation in powder form and a lower fat content causes loss of aromatic constituents. (3) Breakfast cocoas contain not less than 22 per cent cocoa butter. (4) Semi-dry cocoas contain 15 to 18 per cent fat and are used for malted-milk mixtures and other products in which with more fat there is difficulty in keeping the fat uniformly distributed, and with less fat the cocoa flavor is too strong. (5), (6), and (7) Dry, extra dry, and very dry cocoas contain 10 to 12, 8 to 9, and  $6\frac{1}{2}$  to  $7\frac{3}{4}$  per cent of fat, respectively. (8) Solvent extracted cocoas contain from 0.5 to 3.0 per cent fat and have practically no chocolate flavor. And (9) prepared cocoas, which are cocoa mixtures containing such materials as sugar, skim milk, and malt.

The less the fat content of the cocoa the more readily it absorbs moisture from the air and the greater its thickening power when combined with water.

Zenlea declares the ideal temperature and humidity for storing cocoa to be 60-70°F. and 50-65 relative humidity. Heat, vibration, and moisture cause cocoa to lump and lose its apparent color, which makes it more difficult to mix, though its quality may not be damaged.

*The use of chocolate and cocoa in cake.* The factors influencing the color of chocolate cake may be listed as follows. (1) Reaction. This is probably the most important factor in producing a red mahogany-colored chocolate cake, the cakes having this color usually having an alkaline reaction. Grewe states that the "color constituent of chocolate is yellow at  $pH$  5 and changes to red at  $pH$  7.5," but she does not state what this color constituent is.

Schaal states that whenever the  $pH$  of the finished cake is above 7.9, the soda taste is pronounced and objectionable. He recommends that hot water and soda should not be mixed nor the soda combined with the chocolate and hot water, for leavening gas is lost and the cake color is a too "foxy" red. The soda, he says, may be creamed with the shortening and cocoa, or it may be dissolved in the cold milk. In addition, the soda may be mixed with the flour.

Chocolate has a slight acidity which will neutralize a small amount

of soda, but many chocolate cake recipes call for an excess of soda, which gives an alkaline reaction. As the excess is increased, the soapy, bitter, alkaline flavor of the soda becomes more evident. Sweet milk and soda are likely to impart a deeper red or mahogany shade than sour milk and soda, for the acidity of the sour milk neutralizes a part or all of the alkalinity of the soda, the extent depending upon the amount of soda used. The use of soda, whether enough is used to give an alkaline reaction or not, always darkens the color; a lighter shade is obtained with baking powder. This darkening is probably due to the tannin constituents, for similar results are obtained with molasses or sorghum in gingerbread, the shade being darker with soda and lighter when baking powder is used.

(2) Time. This factor as in other reactions is also important, the length of time the batter containing soda stands before baking influencing the color obtained. It has been found that cake batter which has stood 10 to 15 minutes—some cake bakers often permit it to stand while they bake a test cake—usually gives a richer mahogany shade than a portion of the same batter baked immediately after mixing. These results have not always been consistent with different varieties of chocolate and cocoa, but are obtained in a majority of the experiments.

(3) The quantity of chocolate or cocoa used. The shade is darker with a larger quantity.

(4) The brand of chocolate or cocoa used. The reasons for variation in color with different brands of chocolate and cocoa have been indicated under their production. There is also a difference in the flavor of different brands of chocolate and cocoa.

(5) The kind of baking powder used. It was quite a surprise to find that, when butter, sugar, eggs, and chocolate have been mixed together (Experiment 85B,5), then divided, and a different baking powder used with each portion, the same shade is not obtained with all the different baking powders.

But after all is said, why try to develop the red color? The very rich mahogany red cannot be developed except with an alkaline reaction, which is obtained by using an excess of soda. It has been the experience in the author's laboratory that nearly all the students prefer the flavor of chocolate cakes that do not contain an excess of soda. An excess of soda destroys the distinctive chocolate flavor, and if a chocolate cake is eaten for real chocolate flavor, a rich brown shade will be preferred to the mahogany one.

Chocolate and cocoa contain starch. During the production of chocolate, part of the starch has been dextrinized, and this partially dextrinized starch thickens the cold cake batter, the other portion of the starch thickening when heated. For this reason the flour used in chocolate cakes must be reduced, the proportion of liquid increased, or the fat and sugar increased. The sugar needs to be increased because of the strong flavor of the chocolate. Although chocolate itself contains fat, the texture and perhaps the

flavor are improved if the chocolate cake recipe contains a rather high percentage of fat.

**White cake.** White cake usually contains a greater proportion of sugar than a plain cake. Sometimes it contains a larger proportion of fat too. Egg whites are added, but the egg yolks are omitted. In the conventional method of mixing white cake the beaten egg whites are folded into the batter after the other ingredients have been mixed.

The beaten egg white may also be folded or stirred into the fat and sugar with the flour and milk. This method, Experiment 86,6, usually produces a cake that is more tender than the cake made by the conventional method. Stirring the beaten egg white into the flour mixture is easier, and as in the plain cake seems to give as good results as folding. The texture of the white cake is usually better if the flour and liquid are added in portions and not all at one time.

**Gingerbread.** To discuss the effect of manipulation and the kind and proportion of ingredients used in gingerbread would be only to repeat what has been stated under muffins and cakes.

*Effect of alkali upon texture of gingerbread.* Soda is used with the molasses or sorghum for leavening in gingerbread. Excess soda is often used. For this reason gingerbread offers an excellent opportunity to observe the effect of an excess of alkali upon the texture and the flavor of a batter.

The gluten of bread dough becomes more elastic, more extensible and more soluble, i.e., dispersion is increased, as the acidity of the dough increases. This results in a greater volume of the bread until a degree of acidity is reached at which the gluten becomes too tender to stretch as the gas forms. At this point some of the gluten films break and the cell walls collapse. As the acidity is increased, more and more cells collapse and a bread with a thicker, coarser texture is produced.

The gluten also becomes more elastic and more extensible with alkalies. As the alkalinity is increased, the solubility or dispersion of the gluten increases more rapidly than on the acid side. Thus with an alkaline reaction the cell walls become more tender and collapse more quickly than with an acid reaction. This with the larger proportion of liquid gives the typical coarse structure of some gingerbreads and chocolate cakes.

Fortenbacher and Koch made a study of the effect on gluten of various concentrations of acids, alkalies, and salts found in baking mixtures. They found the gluten to be more soluble in alkaline solutions, for concentrations used in baking mixtures, than in acid solutions. In fact, the gluten disintegrated rapidly in alkaline solutions of increasing concentration, so that the gluten discs could be left in only for short periods or they could not be lifted to be weighed. Because of the gluten being dispersed it loses some of its elasticity. The cakes are tender owing to the dissolving of the gluten.

The gingerbread batter like all cake batters contains enough buffer substances so that with the addition of alkali it does not become as alkaline

as it otherwise would. Thus with the addition of 2 teaspoons of soda, Experiment 87,1, the batter is not as distinctly alkaline as would be expected, though the flavor is quite evident. With the large proportion of soda a hollow may form in the center of the gingerbread during baking. This is more likely to develop if the batter is allowed to stand a short time before baking. The soda causes partial dispersion of the gluten. The baking sets the crust, but the interior of the cake being baked last, the soda continues its action on the gluten during part of the baking with the result that the cake may be level across the top but have a hollow in the center. Sometimes the cake sinks across the top instead of forming the hollow in the center. With longer mixing and greater attenuation of the gluten the sinking does not occur.

The gingerbreads containing the largest proportion of soda are darker in color. This is due to several factors, i.e., the effect of the soda on the color of the flour, the decomposition of the monosaccharids of the molasses by the soda, but principally to the color produced by the tannins of the molasses in an alkaline solution. The gingerbreads with baking powder and soda are lighter in color. The flavor of the gingerbread made with baking powder and no soda is different from that of gingerbread containing soda, particularly when a strong molasses is used, probably because the soda combines with some of the ingredients of the molasses, thus producing a less strong flavor. With excess soda, its soapy, alkaline flavor is evident.

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BATTERS AND DOUGHS

I. Thin Batters

Popovers

Experiment 77.

To determine the factors that affect the texture of popovers.

Recipe:

Milk	1 cup	244 grams	Flour	1 cup	112 grams
Eggs	2	96 grams	Salt	½ teaspoon	
Fat	1 tablespoon	12 grams			

A. Batter just mixed.

Prepare ¾ of the recipe. Mix only enough to free from lumps. Bake the popovers in deep cups of the same size, shape, and material. Grease and fill the cups ⅓ full. Use 3 cups and weigh 40 grams of batter into each cup. Bake one at 180° to 190°C. (355° to 375°F.), one at 220° to 225°C. (425° to 435°F.), and the third at 240° to 250°C. (465° to 480°F.). Save the remaining batter for part B.

Temperature of baking	Volume	Appearance	Texture	
			Crust	Inside
180-190°C.				
220-225				
240-250				

B. Batter thoroughly beaten.

Beat the batter remaining from A vigorously for 3 minutes. Divide into 3 parts, using 40 grams of batter in each cup. Bake at temperatures given under A.

Temperature of baking	Volume	Appearance	Texture	
			Crust	Inside
180-190°C.				
220-225				
240-250				

C. Variations in proportions of ingredients.

Bake at the temperature found best under A and B.

1. Reduce the flour in the recipe to  $\frac{7}{8}$  cup.
2. Reduce the flour in the recipe to  $\frac{3}{4}$  cup.
3. Omit the egg in the recipe.
4. Increase the eggs in the recipe to 3.

Considering the volume, size of the cavity, the appearance, and the texture, does the beating of the batter produce a better popover? Which proportion of flour gives the best popover? Which is the best temperature for baking? Does the egg serve as a liquid or as a thickening agent? What effect does the egg have on the "lightness" of the popover? Does it serve as a leavening agent or does it hold the shape after the popover is leavened by something else? What is the means of leavening? Can the egg be omitted? Which proportion of egg is best?

Volume	Appearance	Texture	Flavor

Results and conclusions.

## Timbales

### Experiment 78.

To determine the best proportions for timbale cases or rosettes.

Prepare  $\frac{1}{4}$  of the popover recipe, using the four different proportions of flour given below. Mix the batter until free from lumps. Put the batter into custard cups just large enough to hold the timbale iron. Cook in deep fat. Heat the timbale or rosette iron with the fat. Drain the timbale iron for a short time or wipe the fat from the bottom with a paper towel before dipping into the batter. Start cooking the timbales at 175°C. Increase the



temperature of the fat and determine the temperature that gives the best timbale.

1. Use the popover recipe, Experiment 77, but reduce the flour in the recipe to  $\frac{3}{4}$  cup.
2. Reduce the flour in the popover recipe to  $\frac{7}{8}$  cup.
3. Use the proportion of flour given in the popover recipe.
4. Increase the flour in the popover recipe to  $1\frac{1}{4}$  cups.

What happens if the timbale iron is too cold? Too hot? If the drop of fat that clings to the bottom of the timbale iron is not removed? Which proportion of flour makes a timbale that is crisp, of desirable thickness to hold food, and a good shape? What is a satisfactory temperature to cook timbales? If the batter contains small lumps does this affect the texture of the timbale? Does the batter contain bubbles? Do they affect the texture?

Proportion of flour used	Cooking temperature	Appearance	Texture

Results.

### Cover Batters

#### Experiment 79.

To determine the best proportion of ingredients for a cover batter.

Prepare  $\frac{1}{4}$  of the popover recipe using the four different proportions of flour given in Experiment 78 for timbales. Use apple rings or sliced bananas. Dip them into the batter and then cook in deep fat. Which proportion of flour gives a good cover batter?

Proportion of flour used	Cooking temperature	Appearance	Texture

Results.

### Cream Puffs

#### Experiment 80.

To determine the factors that influence the texture of cream puffs.

*Recipe:*

Butter	$\frac{1}{2}$ cup	112 grams	Eggs	4	192 grams
Boiling water	1 cup	240 grams	Flour	1 cup	112 grams

### A. Temperature of baking.

Prepare  $\frac{1}{4}$  of the recipe. To the boiling water add the butter; then the flour. Stir while adding the flour and cook until the material has a tendency to form a ball and leave the sides of the pan. The paste is done when a metal spoon pressed down lightly leaves a clear, smooth print. Remove from the fire and add the beaten eggs in two portions. Beat thoroughly after adding the first half of the egg and until smooth and even in texture after the last half is added. One-fourth the recipe makes 3 fairly large puffs. Drop on baking sheets and bake at the following temperatures:  $190^{\circ}$  to  $200^{\circ}\text{C}$ . ( $375^{\circ}$  to  $390^{\circ}\text{F}$ .),  $220^{\circ}$  to  $225^{\circ}\text{C}$ . ( $425^{\circ}$  to  $435^{\circ}\text{F}$ .), and  $240^{\circ}$  to  $250^{\circ}\text{C}$ . ( $465^{\circ}$  to  $480^{\circ}\text{F}$ .). Bake until the puffs are quite firm to the touch. If any become too brown lower the temperature of the oven, or if nearly done turn off the gas and let set in the oven until firm to the touch.

The following suggestions for records of the experiments with cream puffs are given.

Temperature of baking	Volume	Appearance	Texture	Comments

### B. Variation in the amount of cooking before the eggs are added.

1. Prepare  $\frac{1}{2}$  the recipe. Cook the butter, the flour, and the water together until the emulsion begins to break and the mixture looks oily on the surface. Remove from fire. Weigh, and divide into 2 equal parts. To one part add eggs for  $\frac{1}{4}$  the recipe. Use the other part for B2. Follow directions under A for baking and cooking, or bake all the puffs at the temperature under A that gave the best product.

2. Before removing from the fire add enough boiling water to give a smooth mixture and one that does not look oily. Keep a record of the amount of water added. Remove from the stove and add eggs.

### C. Variation in extent of mixing the egg with the cooked paste.

Weigh flour, fat, and water for  $\frac{3}{4}$  the recipe and cook. After it is cooked weigh and divide into 3 equal parts. Follow directions under A for combining and the temperature of baking found best under A.

1. To part one add beaten egg for  $\frac{1}{4}$  the recipe and mix only slightly with the paste. This makes 3 puffs. Note behavior of fat in the puffs while baking.

2. To part two add beaten egg for  $\frac{1}{4}$  the recipe. Add the egg in two portions and beat thoroughly until very smooth and shiny.

3. Repeat C2 but cool the paste before adding the egg.

### D. Variations in the proportions of ingredients.

1. Omit the eggs in the recipe.

2. Reduce the number of eggs in the recipe to 3.

3. Reduce the eggs in the recipe to 3 and increase the water to  $1\frac{1}{4}$  cups.

4. Reduce the eggs in the recipe to 3 and reduce the fat to  $\frac{1}{4}$  cup.

5. Reduce the fat in the recipe to  $\frac{1}{4}$  cup.

Which is the best temperature for baking cream puffs? How much water was added in B2? What is the effect on volume of puffs of only slightly mixing

the eggs with the paste? Can the eggs be omitted? Does the emulsion hold when the eggs are reduced to 3 or does the fat ooze out of the cream puffs while they are baking in the oven? Is there a tendency for the fat to be retained better when the eggs are reduced to 3 if the water is increased? Is the texture desirable when the water is increased? Does the emulsion hold in baking when both the fat and the egg are reduced? Is a good volume attained with reduced fat and egg? If water, flour, and fat are over-cooked, how may this be remedied?

Results.

## Medium Batters

### Waffles and Griddle Cakes

#### Experiment 81.

To determine when baking powder should be added to a batter.

I. To determine the factors that affect the texture, tenderness, and flavor of waffles.

*Recipe for plain waffles:*

Milk	1 cup	244 grams
Eggs	2	96 grams
Flour	1 to 1½ cups	112 to 168 grams
Oil or melted fat	2 tablespoons	25 grams
Salt	½ teaspoon	
Baking powder	0 to 1½ teaspoons	0 to 6 grams

Sift the flour and baking powder together 2 times. Separate the yolk and white of the egg. It will be necessary to beat at least a whole white or yolk; then divide it. Mix the fat, beaten yolk, salt, and milk. Add the flour, stir only until well blended, and count the strokes used for combining. Beat the egg white until stiff and fold into the batter. Count the number of strokes used for folding the white. Use the same kind of baking powder for all the experiments until section C is reached. The amount of ingredients given under each experiment is for the full recipe.

Heat the waffle iron. Test the temperature, if the iron does not have a temperature indicator, by placing a drop of water on the iron. If the drop boils rapidly the iron is hot enough. If the drop boils so vigorously that it vaporizes very rapidly, the iron is too hot. It is better to have the waffle irons of the same make and type for some experiments so that the depth of the batter will be the same for all waffles. Put the baked waffles on cake coolers until comparisons are made. Putting the baked waffles on plates causes the under side to sweat and become soggy. To keep warm place wire cake cooler with waffle in slightly warmed oven.

A. The time of baking waffles.

1. Prepare  $\frac{3}{4}$  of the recipe. Use  $1\frac{1}{3}$  cups of flour (150 grams), and 4 grams, about 1 teaspoon of baking powder. Bake one waffle 3 minutes, one 4 minutes, and one 5 minutes. The time may need to be varied depending on the temperature maintained by the iron. Compare for crispness and tenderness.

B. Proportion of ingredients.

Prepare  $\frac{1}{4}$  of the recipe. Use time of baking found best under A for a guide. Will the thin batters under 1 and 2 require a longer time than the thick ones? Apply results with popovers and cream puffs.

1. Use 1 cup of flour and omit the baking powder.
2. Repeat 1, but add 4 grams of baking powder.
3. Repeat 1, but increase the flour to  $1\frac{1}{3}$  cups (150 grams).
4. Repeat 3, but add 4 grams of baking powder.
5. Repeat 1, but increase the flour to  $1\frac{1}{2}$  cups (168 grams), and add 1 teaspoon of baking powder (4 grams).
6. Repeat 5, but increase the baking powder to 6 grams.
7. Repeat 6, but increase the fat to  $\frac{1}{4}$  cup (50 grams).
8. Repeat 7, but add 2 tablespoons of sugar (25 grams).
9. Repeat 8, but increase the eggs to three.
10. Repeat 9, but increase the flour to  $1\frac{3}{4}$  cups and the baking powder to 8 grams.
11. Use the following: milk 1 cup, fat or oil  $\frac{1}{2}$  cup, sugar 2 tablespoons, eggs 3, flour 2 cups, salt 1 teaspoon, and baking powder 8 grams.
12. Repeat 11, but increase the baking powder to 12 grams.
13. Repeat 12, but increase the sugar to  $\frac{1}{2}$  cup (100 grams). If brown sugar is used, bake at a little lower temperature than for plain waffles. Determine the time of baking to secure a crisp waffle, suitable for serving as short cake.
14. Repeat 13, but reduce the flour to  $1\frac{7}{8}$  cups, add  $\frac{1}{8}$  cup of cocoa (28 grams), and bake with waffle iron slightly cooler than for plain waffles.

#### C. Kind and amount of baking powder.

1. Use the proportion of flour found best for a plain waffle under B. Use 4 grams of a tartrate baking powder. Standardize the time of baking the waffles under C.
2. Repeat C1, using a phosphate baking powder.
3. Repeat C1, using sulfate-phosphate powder.
4. Determine the most desirable quantity of each baking powder to use with the proportion of flour preferred.

#### D. Extent of mixing.

1. Prepare  $\frac{1}{4}$  the recipe, using the proportion of flour found best under B. Use 60 strokes for combining the flour and liquid. Add the beaten egg white, keeping a record of the number of folds used.
2. Repeat D1, but use 120 strokes for mixing the flour and liquid. Use same number of strokes for folding egg white as used under D1.

#### E. The method of mixing.

1. Prepare  $\frac{1}{4}$  the recipe. Use the method given above. Use the same proportion of flour and baking used for C and D. Use 60 strokes for mixing the flour and liquid. Keep record of number of strokes for folding the egg white. Bake all waffles under E for the same length of time.
2. Repeat E1, using the same number of strokes, but stir the egg white into the batter.
3. Repeat E1, but beat the whole egg until light and foamy. Fold into the batter, using same number of strokes as for the egg white.
4. Repeat E1, but add the fat to the batter just before adding the egg white. The total number of strokes for mixing flour and fat should be 60.

What length of time of baking gives the best waffle? Does crispness depend upon the length of time of baking or proportion of ingredients or both? Which proportion of flour do you prefer for a plain waffle? Which proportions are best for the rich waffle? Is 2 teaspoons of baking powder sufficient for the rich waffles or do they need 3? Is there any difference in the waffles made with the various types of baking powders? Should the quantity of baking powder be varied for each type of powder? What is the effect of mixing the batter too long on the texture and tenderness of the waffle? May the length of time of mixing vary with the different proportions of flour? Is the texture, tenderness, or crispness affected by time of adding the fat? The egg white? Which is preferable to use, the whole beaten egg, or the separately beaten white and yolk?

### Griddle Cakes

II. To determine the factors that affect the texture, tenderness, and flavor of griddle cakes.

#### *Recipe:*

Milk	1 cup	244 grams
Egg	1	48 grams
Fat, melted	2 tablespoons	25 grams
Flour	1 $\frac{1}{3}$ to 1 $\frac{2}{3}$ cups	150 to 186 grams
Salt	$\frac{1}{2}$ teaspoon	2 grams
Baking powder	About 1 to 2 teaspoons	4 to 8 grams

Prepare  $\frac{1}{4}$  the recipe. Use the baking powder indicated for experiments under A. Test the heat of the griddle by baking 1 tablespoon of the batter. It should be possible to bake the cake without addition of fat to griddle. The amount of ingredients is for the full recipe. Sift flour and baking powder together 2 times. Mix the well-beaten egg, milk, melted fat, and salt. Add flour and stir 50 times with a wooden spoon. Bake the whole amount as one griddle cake.

#### A. The proportion of baking powder.

1. Use 1 $\frac{1}{3}$  cups of flour and 4 grams of a tartrate baking powder.
2. Repeat A1, using 6 grams of tartrate powder.
3. Repeat A1, using 8 grams of a tartrate powder.
4. Repeat A1, using a phosphate baking powder.
5. Repeat A2, using a phosphate baking powder.
6. Repeat A3, using a phosphate baking powder.
7. Repeat A1, using sulfate-phosphate (S.-P.) baking powder.
8. Repeat A2, using S.-P. powder.
9. Repeat A3, using S.-P. powder.

#### B. The amount of mixing.

1. Repeat A1, 2 and 3 (or any third of A), but mix 120 strokes.

#### C. The proportion of flour.

1. Use 1 $\frac{1}{4}$  cups of flour and proportion of baking powder found best under A.
2. Repeat C1, using 1 $\frac{1}{3}$  cups of flour.
3. Repeat C1, using 1 $\frac{1}{2}$  cups of flour.

#### D. Substituting sour milk for sweet milk.

Repeat section C but substitute sour milk for the sweet milk and use  $\frac{1}{2}$  teaspoon soda for 4 grams of the baking powder.

Compare the griddle cakes for texture, tenderness, and lightness. Which proportion of baking powder produces the lightest product? Should the amount of baking powder be varied for the different types of baking powder? Which proportion of flour gives the best griddle cake with sweet milk? With sour milk?

When should baking powder be added to a batter? Compare the amount of baking powder needed for waffles and griddle cakes.

### Stiff Batters

#### Muffins

#### Experiment 82.

To determine the factors which affect the texture of muffins and the amount of mixing required with different types of baking powders.

##### *Recipe:*

Flour	2 cups	224 grams
Sugar	2 tablespoons	25 grams
Milk	1 cup	244 grams
Egg	1	48 grams
Fat, melted or oil	2 tablespoons	25 grams
Baking powder		12 grams
Salt	$\frac{1}{2}$ teaspoon	2 grams

##### *Directions for combining.*

Combine the milk, beaten egg, and melted fat. Since the batter is mixed very little after the dry ingredients are added, it is better to beat the egg enough so that it readily combines with the milk, or beat both egg and milk with the egg beater. Sift the baking powder with the flour twice. Mix the sugar and salt with the flour. Add the dry ingredients to the liquid, and stir. Bake the muffins in greased cups of the same size and the same material. The sides of the cups do not need greasing, but the bottoms should be well greased to facilitate removal of the muffins from the tins. Decrease the baking powder to 10 or less grams or increase to 14 or 16 grams, depending on the type of flour used and the altitude.

A. To determine the effect of the amount of mixing upon the texture and volume of muffins.

1. Prepare  $\frac{1}{2}$  the recipe. Use a tartrate baking powder. Notice the way the batter changes while mixing. Describe this change. Compare the volume of the batters for each muffin. Does the same weight of batter give the same volume after mixing different amounts?

Stir the batter. Combine with 25 strokes. For a medium-sized pan remove 60 grams of batter for one muffin. Stir the remaining batter a total of 60 strokes. Remove 60 grams for another muffin. Stir the remaining batter a total of 100 strokes. Remove 60 grams for a third muffin. Beat the remaining batter a total of 300 strokes and use 60 grams for the fourth muffin. Bake at 210°C. (410°F.).

2. Repeat A1, but use a phosphate baking powder.

3. Repeat A1, but use S.-P. powder.

Brand of baking powder used:

Amount of mixing	Appearance	Shape of top	Volume	Texture	Tenderness	Flavor

### Results.

B. To determine the effect upon the texture and the volume of muffins of adding the baking powder after the batter has been mixed.

1. Prepare  $\frac{1}{4}$  of the recipe. Reserve the baking powder to add later. Use a tartrate baking powder. Stir the batter, using 30 strokes. Sift the baking powder over the batter and stir into the batter with 15 strokes. Notice the consistency of the batter before adding the baking powder, while adding the powder, and after it has stood a few seconds. Divide into 2 muffins of 60 grams each.

2. Repeat B1, but use a phosphate baking powder.

3. Repeat B1, but use S.-P. baking powder.

What is the effect of increased mixing on the texture and the volume of muffins when the baking powder is in the mixture from the first? What amount of mixing produces the best texture in muffins? Does this vary with the different baking powders? May the baking powder be added after the batter is mixed? Is it the amount of mixing or the mixing when the baking powder is in the batter or both that has the greatest effect upon the volume and the texture of the muffins? Could the batter be beaten longer than 30 strokes before adding the baking powder and a good texture be obtained?

C. To determine the amount of mixing that gives a muffin of the best flavor, tenderness, texture, and volume.

1. Prepare  $\frac{1}{2}$  of the recipe. Use a tartrate baking powder. Stir a total of 25 strokes. Remove 60 grams of batter for one muffin. Stir the remaining batter a total of 30 strokes. Remove 60 grams of batter for a second muffin. Stir the remaining batter a total of 35 strokes. Remove 60 grams of batter for a third muffin. Stir the remaining batter a total of 40 strokes and bake 60 grams for a fourth muffin.

2. Repeat C1, but use a phosphate baking powder.

3. Repeat C1, but use S.-P. powder.

D. Varying the proportion of baking powder.

1. Repeat either or all of C1, C2, and C3 reducing the baking powder to 10 grams.

2. Repeat either or all of C1, C2, and C3 increasing the baking powder to 16 grams.

Considering tenderness, texture, volume, and flavor, which amount of mixing gives the most desirable muffin? Do 5 additional strokes in mixing produce a change in the muffins?

E. Variations in proportion of ingredients.

Use a tartrate baking powder and prepare  $\frac{1}{4}$  of the recipe. Mix with the number of strokes found best under C. Weigh 60 grams of batter into a baking cup. Beat the remaining batter 10 additional strokes. Bake 60 grams. If desired, the series may be repeated with phosphate and S.-P. powders.

1. Use the regular recipe for a control.
2. Increase the fat in the recipe to 3 tablespoons.
3. Increase the sugar in the recipe to 3 tablespoons.
4. Increase the fat to 3 tablespoons and the sugar to 3 tablespoons.
5. Increase the egg in the recipe to 2.
6. Omit the egg in the recipe.

Does variation of the proportion of the ingredients influence the amount of mixing required for the muffins? Which proportion of ingredients gives a muffin of the most desirable texture, flavor, and volume?

## Doughs

### Baking Powder Biscuits

#### Experiment 83.

To determine the factors that influence the texture of baking powder biscuits.

*Recipe:*

Flour	2 $\frac{2}{3}$ cups	300.0 grams
Fat	4 tablespoons	50.0 grams
Milk	$\frac{3}{4}$ to 1 cup	188.0 to 244 grams
Baking powder		12 grams
Salt	$\frac{1}{2}$ teaspoon	2 grams

*Directions for combining.*

Sift the baking powder with the flour. Add the fat and the salt. The fat may be combined with the flour by a fat-flour blender or by using the tips of the fingers. Portions of the fat and flour are picked up and rubbed quickly between the fingers, then dropped and other portions of the flour picked up. The lifting of the portions of the flour and fat mixture makes it more light and fluffy. Avoid mixing until a hard fat is melted and the mixture looks oily and compact. After the fat is mixed with the flour, form a cavity in the center of the flour mixture. Pour the milk in this cavity and begin to stir. The stirring may be done with a fork or a spoon. The following directions are for mixing with a three-tined fork, as the fork seems to leave the dough lighter and more fluffy than a spoon. After the milk has been mixed for the designated amount with the flour mixture, remove the ball of dough from the mixing bowl with a spatula and place it on a thin layer of flour on a bread board. Handle the dough gently and roll it without compressing it in the flour, until the sticky surface is covered. Remove to a lightly floured part of the bread board. "Lightly floured" means with a very thin layer of flour. Knead the dough gently the amount specified and place an embroidery hoop over the dough. Roll and then cut with biscuit cutters of the same size for all the experiments. The embroidery hoop is used so that the biscuit dough will be the same thickness and



the volume of the biscuits can be compared. Bake at 220° to 230°C. (425° to 455°F.). The dough, instead of being kneaded, can be lightly flattened into a square. Fold once and roll. Repeat 3 more times.

A. To determine the best proportion of liquid for the flour used in this experiment.

Brand of flour used:

The flours most often used in some sections of the United States are from soft-wheat flours. Other sections use bread flour. Since the proportion of liquid that gives the best flavor, texture, and the most tender biscuit varies with different flours it will be necessary to determine this first.

Prepare the full recipe. After the fat has been mixed with the flour divide into four portions, using 87 grams in each part.

1. To part one add 61 grams of milk. The water of the milk is equivalent to about 70 per cent of the weight of the flour. Stir 30 strokes with a three-tined fork. By this time the dough should be in a ball. Remove the dough with a spatula, roll in flour, and knead 10 times. Roll and cut.

2. Repeat 1, but to part two add 55 grams of milk, about 64 per cent of liquid.

3. Repeat 1, but to part three add 51 grams of milk, about 60 per cent.

4. Repeat 1, but to part four add 47 grams of milk, about 55 per cent of liquid.

B. To determine the amount of manipulation that gives a biscuit of the best texture and volume for a drop biscuit.

1. Prepare  $\frac{1}{3}$  of the recipe. Use a tartrate baking powder. Use the proportion of milk found best under A. Mix 20 strokes with a three-tined fork. Remove 30 grams of the dough, weighing on a piece of wax paper and then remove to the baking sheet.

2. Mix the remaining dough from 1 a total of 25 strokes. Remove 30 grams for a biscuit.

3. Mix the remaining dough from 2 a total of 30 strokes. Remove 30 grams of dough for one biscuit.

4. Mix the remaining dough from 3 a total of 35 strokes. Remove 30 grams for a fourth biscuit.

5. Mix the remaining dough from 4 a total of 100 strokes. Bake 30 grams for a fifth biscuit.

C. Repeat B, but use a phosphate baking powder.

D. Repeat B, but use S.-P. baking powder.

E. To determine the amount of manipulation to give a rolled biscuit of the best volume and texture.

a1. Prepare  $\frac{1}{2}$  of the recipe, using the proportion of milk found best under A. Mix 30 strokes with a three-tined fork. Remove to the bread board. Divide into thirds. Knead  $\frac{1}{3}$  of the dough lightly 10 times, place an embroidery hoop over the dough, roll and cut.

2. Knead  $\frac{1}{3}$  of the dough from 1, 20 times, roll and cut.

3. Knead  $\frac{1}{3}$  of the dough from 1, 30 times, roll and cut.

b1. Prepare  $\frac{1}{2}$  of the recipe, using the proportion of milk found best under A. Mix 20 strokes with a three-tined fork. Remove  $\frac{1}{3}$  of the dough and knead 10 times. Roll and cut.

2. Stir the remaining dough from 4 a total of 30 strokes. Remove  $\frac{1}{2}$  of the dough and knead 10 times. Roll and cut.

3. Stir the remaining dough from 5 a total of 40 strokes. Knead 10 times, roll and cut.

F. To determine the proportion of fat that gives a biscuit of the best flavor and texture.

1. Prepare  $\frac{1}{4}$  of the recipe. Use the proportion of milk found best under A and the amount of mixing found best under E.

2. Repeat F1, but decrease the fat to 37.5 grams for the full recipe.

3. Repeat F1, but increase the fat to 75 grams for the full recipe.

Section F can be repeated and such different kinds of fat as butter, lard, hydrogenated lard, hydrogenated cottonseed oil, and oil used.

G. To determine the best temperature for baking biscuits when different types of baking powders are used.

1. Prepare  $\frac{1}{4}$  of the recipe. Use the proportion of milk found best under A, and the amount of mixing found best under E. Use a tartrate baking powder. Divide the dough into three biscuits and bake one at  $190^{\circ}$  to  $195^{\circ}\text{C}$ . ( $375^{\circ}$  to  $385^{\circ}\text{F}$ .), one at  $220^{\circ}$  to  $225^{\circ}\text{C}$ . ( $425^{\circ}$  to  $435^{\circ}\text{F}$ .), and one at  $240^{\circ}$  to  $250^{\circ}\text{C}$ . ( $465^{\circ}$  to  $480^{\circ}\text{F}$ .).

2. Repeat G1, but use a phosphate baking powder. Do the results under C indicate that the amount of mixing should be changed for a phosphate baking powder?

3. Repeat G1, but use S.-P. powder. Should the amount of mixing be increased for this type of baking powder? See D.

Which proportion of milk gives the best volume and the best texture? Would this be the best proportion for all kinds and grades of flour? Why? Might there be slight differences in the hydration capacity of the same flour at various times of the year? Why? Should you use more or less water in biscuits to produce the same result when water is substituted for milk? Why? What amount of mixing gives the best texture with each baking powder? What is the effect of kneading upon the texture? Is it desirable? What amount of kneading and stirring gives the best texture for the flour you are using? Which proportion of fat produces the best flavor and texture? If the amount of fat in the recipe is increased, should the liquid be increased or decreased? Do you find much difference in the baking temperatures required for the different baking powders? Theoretically, which temperature should be best for each powder?

Results and conclusions.

### Suggestions for Additional Experiments for Biscuits

1. Repeat A, B, and E with a different type of flour, i.e., soft- instead of hard-wheat or *vice versa*; whole-wheat or part whole-wheat and part white flour.

2. Repeat A, B, and E with sour milk or water.

3. Use the different types of baking powders and hold biscuits in the refrigerator for several hours before baking.

4. Increase the baking powder in the recipe to 14, 16, or 18 grams. Does it improve the texture? The flavor?

## Plain Cake

## Experiment 84.

To determine the factors that affect the texture and flavor of plain cake.

*Plain cake recipe:*

Butter	½ cup	112 grams	Family flour	2¾ cups	300 grams
Sugar	1 cup	200 grams	or		
Eggs	2	96 grams	Cake flour	3 cups	300 grams
Milk	1 cup	244 grams	Baking powder		10 grams
			Salt	½ teaspoon	2 grams

Pastry or soft-wheat flour may be used instead of the all-purpose hard-wheat flour. Flavoring is added during creaming for home use, but may be omitted for experimental work. Stirring is going round and round the mixing bowl, either rapidly or slowly; beating is pulling the utensil across the contents of the mixing bowl. The directions for all the mixing are for stirring. If the class decides to beat the batter instead of stirring, this should be understood before starting the mixing so that all will use uniform methods. Bake at 185°C. (365°F.).

A. To determine the amount of mixing that gives the best texture for a plain cake with different types of baking powders.

1. Use a tartrate baking powder.

Brand of baking powder used:

Pans. Pans 5 by 2½ by 2½ inches, and 2 cups' capacity, are a good size for 1/6 of the above recipe. If larger or smaller pans are used, prepare the proportion of the recipe needed for the size of the pan. Muffin pans may be used. If they are medium size and 60 grams of batter are used for each cake, only ½ of the recipe should be prepared. Line the bottom of the pan with wax or heavy plain paper. Grease the paper on the side next to the batter. The sides of the pan do not need greasing.

Prepare the whole recipe. Sift the baking powder with the flour 2 times. It can be sifted on squares of paper or in bowls. It is preferable to have incubated the ingredients or put them in the room previous to starting work so that their temperature is about 25° to 27°C. If this is not possible, place the butter over warm, not hot, water and stir while softening it. Since the fat alone does not hold much air when stirred or creamed but does hold air after the sugar is added, some sugar should be added at the start of the creaming process. If creaming is done on a machine, add all the sugar to the fat at first, in order to standardize the procedure. Creaming is more rapid when done by hand, if the sugar is added gradually. Cream until light and fluffy. Add the well-beaten eggs and mix thoroughly. Add all the flour and all the milk to the butter mixture. Begin to stir; notice any changes that occur in the batter while stirring. Stir 50 strokes. Remove 150 grams of the batter and weigh into a cake pan. Note the position of the batter that drops from the edge of the spoon in relation to the pan in the last cakes. Do any tunnels develop at these spots in the cakes?

2. Stir the batter remaining from 1 a total of 150 strokes. Notice any changes in the batter. Use 150 grams of batter for the second cake.

3. Stir the batter remaining from 2 a total of 200 strokes. Note any changes in the batter. Use 150 grams of batter for the third cake.

4. Stir the batter remaining from 3 a total of 300 strokes. Remove 150 grams of batter for the fourth cake.

5. Stir the batter remaining from 4 a total of 400 strokes. Note any changes in the batter. Bake 150 grams of the batter.

6. Stir the batter remaining from 5 a total of 1000 strokes. Note any changes that occur in the batter. Use 150 grams of batter for a sixth cake.

The following headings are suggested for records for cakes. The shape of the top and the relative volumes may be sketched in quickly.

Total mixing	Appearance of crust	Shape of top	Volume	Texture	Tender-ness	Flavor

Results and conclusions.

B. Repeat A, using a phosphate baking powder.

Brand of baking powder used:

C. Repeat A, using S.-P. baking powder.

Brand of baking powder used:

A, B, and C. What is a desirable amount of mixing for each type of baking powder for a very plain cake? With which baking powder can the most mixing be used? With which can the least be used? Describe the way the batter changes during the mixing. Does it vary with the different baking powders? How long are the strands of batter that fall from the spoon during the different stages of mixing?

D. To determine the optimum amount of baking powder.

Prepare  $\frac{1}{6}$  or  $\frac{1}{4}$  the recipe according to the size of the baking pan used. Increase the sugar to  $1\frac{1}{2}$  cups. For  $\frac{1}{6}$  the recipe bake 150 grams of batter, for  $\frac{1}{4}$ , 235 grams. Add the flour by method *a*, *b*, or *c*, but use only one method throughout the experiment. Use 225 strokes for combining the flour and milk with the creamed mixture.

All the butter, sugar, and eggs for one section can be creamed together thoroughly and divided into 6 equal parts.

*Method a for adding flour.* (Flour first and last.)

Add approximately  $\frac{1}{3}$  of the flour and stir 50 strokes. Add  $\frac{1}{2}$  of the milk and stir 25 additional strokes or a total of 75. Add another third of the flour and stir a total of 125 strokes. Add  $\frac{1}{2}$  of the milk and stir a total of 150 strokes. Add the remainder of the flour and stir a total of 225 strokes.

*Method b for adding the flour.*

Add approximately  $\frac{1}{3}$  of the flour and  $\frac{1}{3}$  of the milk. Stir 75 strokes. Add another  $\frac{1}{3}$  of the flour and  $\frac{1}{3}$  of the milk and stir a total of 150 strokes. Add rest of flour and milk and stir a total of 225 strokes.

*Method c for adding flour.* (Milk first and last.)

Add  $\frac{2}{3}$  of the milk to the creamed mixture and stir 5 strokes. Add all the

flour and stir a total of 175 strokes. Add the remainder of the milk and stir a total of 225 strokes.

a. Use a tartrate baking powder.

1. Use 6 grams of baking powder for the full recipe.

2. Use 8 grams of baking powder for the full recipe.

3. Use 10 grams of baking powder for the full recipe.

4. Use 12 grams of baking powder for the full recipe.

5. Use 14 grams of baking powder for the full recipe.

6. Use 16 grams of baking powder for the full recipe.

b. Repeat section D,a, using a phosphate baking powder.

c. Repeat section D,a, using an S.-P. baking powder.

Which amount of powder produces the best-textured cake with a tartrate, phosphate, and S.-P. baking powder respectively? Do all members of the class agree on which amount is preferable? Might the optimum amount vary with the maker's technic? With other factors? Enumerate. What is the effect on volume, texture, velvetiness, and crumbliness of cake of a small amount of powder? Of the large amounts? Which amounts of baking powder yield cakes that stale rapidly?

E. To determine the effect of varying the temperature of baking and the method of combining ingredients for a plain cake.

Prepare  $\frac{1}{4}$  or the proportion of recipe desired. Increase the sugar to  $1\frac{1}{2}$  cups. Use 225 strokes for combining the flour and milk with the creamed mixture. For  $\frac{1}{4}$  the recipe, 235 grams of batter should be weighed into the baking pan; for  $\frac{1}{6}$  use 150 grams. Use the proportion of baking powder found best under D, but use the same kind of powder for all of section E.

1. Conventional method. Cream enough butter, sugar, and eggs for 3 cakes. Add the sugar gradually to the butter, and cream thoroughly. Add the beaten egg and mix until light and fluffy. Divide into 3 equal parts. If using  $\frac{1}{4}$  the recipe, weigh out 124 grams for each cake unless a smaller amount is necessary to divide the creamed mixture evenly.

1a. To part 1 of the creamed mixture add the flour by method *a* given under D.

1b. To the second part add the flour by method *b* under D.

1c. To the third part add the flour by method *c* under D.

2. Muffin method. Sift the baking powder and the flour together 2 times. Use melted butter. Beat the egg. Combine the liquid ingredients. Add dry ingredients to the liquid ones and mix 225 strokes.

3. Separating the yolk and white of the egg. Prepare  $\frac{3}{4}$  or proportion of recipe desired. Separate the white and yolk of the egg. Cream the butter and sugar thoroughly. Add the yolks to the creamed butter and mix until light and spongy. Sift the baking powder and flour together 2 times. Add the flour and milk according to method *c* under section D, but stir only a total of 160 strokes after adding the flour and 195 after adding the last of the milk. Add the beaten egg white and fold 30 strokes with a spatula or stir with the spoon. Divide into three cakes, using equal weights of batter for each cake. Bake one at  $185^{\circ}\text{C}$ . ( $365^{\circ}\text{F}$ .), the second at a lower temperature, and the third at a higher temperature.

4. Cake-mixer method. Cream butter, sugar, and egg for 3 cakes. Have the

butter room temperature or about 25°C. Add the sugar and well-beaten egg, and cream until very light and spongy. Sift the flour and baking powder together 2 times. Divide the creamed mixture into three equal parts.

4*a*. To part 1 of the creamed mixture add the flour by method *a* under section D.

4*b*. To part 2 add the flour by method *b* under section D.

4*c*. To part 3 add the flour by method *c* under section D.

5. Emulsion method. Beat the egg slightly. Melt the butter carefully so that it does not reach a high temperature. Add a few drops of the melted butter to the egg and beat with an egg beater. After the emulsion is started add more butter. The butter is added to the egg in the same manner as in making mayonnaise. After the butter is added to the egg add the sugar gradually. Sift the baking powder and flour together 2 times. Add the flour and milk by method *a*, *b*, or *c* under section D.

6. Conventional-sponge. Prepare  $\frac{1}{4}$  or proportion of recipe desired. Cream  $\frac{1}{2}$  of the sugar and fat thoroughly. Add a tablespoon of flour, with which the baking powder has been sifted 2 times, and fold 20 times. Add  $\frac{1}{2}$  of the remaining flour and  $\frac{1}{2}$  of the milk and stir 75 additional strokes or a total of 95. Repeat, adding the rest of the flour and milk. Total strokes 170. Beat the egg, adding the remaining sugar gradually, until mixture is very light and looks like sponge cake batter. Combine quickly with the cake batter using 55 strokes, making a total of 225 strokes after starting to add the flour.

7. Repeat E6 using melted butter or oil, or both. In addition a soft lard may be used. For fats other than butter increase the salt to 4 grams.

8. When an oil or soft fat is used, a much better texture is obtained if the egg goes into the cake batter late in the mixing process, for less fat is emulsified as an oil-in-water emulsion. Increase the salt to 4 grams for fats other than butter. Some other methods that may be tried are:

*a*. Combine by any method desired but add the thoroughly beaten whole egg last.

*b*. Combine the egg with the milk.

Which method of mixing gives the best cake? Is one method of adding the flour preferable to another? Which method of adding the flour is quickest and easiest? Should cakes made with different fats always be combined by the conventional method or can different methods be used to advantage for some fats and oils? Is there any advantage in separating the yolk and white of the egg in a plain cake?

F. To determine the effect of varying the proportion of the ingredients in the plain cake recipe upon texture, volume, and flavor.

Prepare the full recipe unless otherwise indicated. Cream by the method decided upon by the class. Follow directions under A. Use a tartrate baking powder and divide the batter into six cakes of 150 grams each. Notice any changes occurring in the batter during mixing.

1. Increase the eggs in the recipe to 4. Prepare  $\frac{1}{2}$  the recipe, using a total of 100, 150, and 200 strokes respectively for the three cakes.

2. Repeat F1, but separate the yolk and white of the egg. Add the beaten white with the flour and milk.

3. Increase the sugar in the recipe to  $1\frac{1}{2}$  cups.

4. Increase the sugar in the recipe to 2 cups. Stir the left-over batter from the sixth cake a total of 1500 strokes and bake 150 grams for a seventh cake.

5. Increase the fat in the recipe to  $\frac{3}{4}$  cup. Prepare  $\frac{1}{2}$  the recipe using a total of 100, 150, and 200 strokes for the three cakes.

6. Increase the sugar in the recipe to  $1\frac{1}{2}$  cups, the fat to  $\frac{3}{4}$  cup, and the eggs to 3. A seventh cake may be baked from the batter left over after weighing the sixth cake. It should be stirred 1500 strokes.

7. Increase the flour in the recipe to  $3\frac{1}{2}$  cups. Prepare  $\frac{1}{2}$  the recipe using a total of 100, 150, and 200 strokes for the three cakes.

Characteristic appearance of crust	Shape of top and edges	Volume	Texture	Tender-ness	Flavor

Results and conclusions.

Give characteristic differences in the appearance of the crust for each series as the mixing is increased. The characteristic differences in crust when the proportion of different ingredients are changed. Compare the texture of each series. Of the different series. What is the effect on the volume of increasing the different ingredients? Which amount of mixing gives a cake of the best texture in each series? Do the cakes with the best texture usually have the best flavor? The increase of which ingredients increases tenderness, volume, velvetiness, toughness, and breadiness of the cake?

G. To determine the effect on the texture, volume, and flavor of plain cake of varying the ingredients used.

Prepare  $\frac{1}{6}$  of the recipe. Use the proportion of ingredients found best under F and the type of baking powder desired. Combine by whatever method the class decides to use and mix with the number of strokes that will give the best texture for the brand of baking powder used. Use 150 grams of batter for each cake.

1. Liquid.

Use, (a) milk; (b) water; (c) orange juice; (d) pineapple juice; (e) sour cream; and (f) sour milk. What other changes will need to be made for (e) and (f)?

2. Sugar.

Use different kinds of granulated sugar obtainable, such as (a) fine granulated, berry, and transformed; (b) powdered sugar; and (c) brown sugar. Always substitute sugar by weight.

3. Fat.

Double the salt for all fats other than butter. Use, (a) butter; (b) different types of lard, i.e., grainy and smooth, and prime-steam and open-kettle rendered; (c) oil; (d) Crisco; (e) Spry; and (f) any other fat commonly used in your locality.

4. Flour.

Use, (a) a hard-wheat all-purpose flour; (b) a soft-wheat all-purpose; and (c) a specially prepared cake flour.

## Chocolate Cake

## Experiment 85.

A. To determine the amount of mixing to give the best texture and the best method of mixing for a rich chocolate cake.

*Recipe:\**

Butter	1¼ cups	280 grams	Baking powder	16 grams
Sugar	2¼ cups	450 grams	Vanilla	1 teaspoon
Eggs	4	192 grams	Salt	2 grams
Chocolate	4 squares	113 grams		
Cake flour	3 cups	300 grams		
Milk	1 cup	244 grams		

Sift the flour and baking powder together 2 times for all the following experiments.

1. Mix by any of the methods given below, but it will be necessary to add all the flour and milk at one time. The full recipe will make 10 cakes of 150 grams each, so that portions of the batter may be removed after stirring 50, 100, 150, 200, 250, 300, 350, 400, 500, and 1000 strokes. For high altitudes the proportion of fat, sugar, and baking powder may need to be reduced.

2. Conventional method. Prepare ¼ of the recipe. Cream the butter, flavoring, salt, and sugar until very light and spongy. Add the beaten egg and mix until very fluffy. Melt the chocolate carefully over warm water. Do not let it get too hot, as it should not melt the butter. Add to the butter mixture and stir thoroughly. For adding the flour and milk follow directions under Experiment 84D, method a, b, or c, but mix a total of 350 strokes or the number found best under 85,1. For a loaf cake a pan with a top 8 by 4, bottom 7¼ by 3¼, and a depth 2¾ inches, of 5 cups' capacity will be needed for ¼ of the recipe. For a layer cake a pan 7 by 7 and 2⅛ inches deep will be satisfactory. Bake at 195° to 200°C. (about 385° to 400°F.).

3. Muffin method. Put the softened butter, the melted chocolate, the sugar, flavoring, and beaten egg in the mixing bowl. Add the flour and milk and stir 500 times. If the other ingredients are too cold the melted chocolate will not blend and may be in flakes in the mixture. On the other hand, if the butter and melted chocolate are very warm they raise the temperature of the other ingredients, the gluten develops rapidly and the cake is more rubbery and tough.

4. Cake-mixer method. Combine the butter softened sufficiently to cream, the sugar, and the beaten egg. Mix thoroughly until light and spongy. Add the melted chocolate; see 85,2, for directions for melting the chocolate. Add the flour and milk to the batter according to directions given under 85,2.

5. Use the conventional-sponge method. See Experiment 84, E6.

B. Temperature of baking.

Prepare the full recipe, using the method of mixing decided upon. Divide into 6 cakes using 235 grams in each cake. Bake 1 cake at 165°C., 1 at 175°C., 1 at 185°C., 1 at 195°C., 1 at 205°C., and 1 at 215°C.

C. To determine the effect of varying the ingredients upon the color of the cake.

\* This recipe was developed by Betty Ingersol Aitken.



1. Use different brands of chocolate.
2. Use  $\frac{1}{2}$  teaspoon of soda and reduce the baking powder to 3 teaspoons.
3. Use thick sour milk. Add  $\frac{1}{2}$  teaspoon of soda, reduce the baking powder to 3 teaspoons and the flour to 286 grams for the full recipe.
4. Use brown sugar.
5. Mix enough of the following for  $\frac{1}{2}$  the recipe: butter, sugar, egg, chocolate, flavoring, and salt. After they are thoroughly mixed, weigh and divide into three parts. Use for a, b, and c.
  - a. In part one use a tartrate baking powder. The quantity of flour, baking powder, and milk will be for  $\frac{1}{6}$  of the recipe. Add flour and milk by method found best under A.
  - b. In part two use a phosphate baking powder.
  - c. In part three use S.-P. baking powder.

D. Substituting cocoa for chocolate.

Substitute 63 grams of cocoa for the chocolate. Also use larger and smaller quantities to determine the optimum quantity.

Compare the appearance, shape of top, volume, and texture of the cakes made by the different methods. Is there any difference in tenderness? Is the texture of a rich chocolate cake better, if the butter and sugar are thoroughly creamed? Which method requires the shortest time for mixing? Did the ingredients of your cake have a high or a low temperature while mixing? Is the flavor improved by adding soda? Do different brands of chocolate produce the same color? The same flavor? What is the effect of different types of baking powder on the color of the cake?

### Red Devil's Food

#### Recipe:

Butter	$\frac{1}{2}$ cup	112 grams
Sugar	2 cups	400 grams
Eggs	2	96 grams
Flour	2 cups	200 grams
Thick sour milk	$\frac{3}{8}$ cup	162 grams
Baking powder	$1\frac{1}{2}$ teaspoons	
Vanilla	1 teaspoon	
Chocolate	3 squares	84 grams
Boiling water	$\frac{1}{2}$ cup	
Soda	1 teaspoon	
Salt	$\frac{1}{4}$ teaspoon	

Mix the first seven ingredients by the conventional method. Cut the chocolate into small pieces. Add the boiling water to the chocolate. Cool before adding to the cake batter.

A. The proportion of soda to give the best flavor.

1. Prepare  $\frac{1}{4}$  of the above recipe.

2. Repeat 1, but reduce the soda to  $\frac{3}{4}$  teaspoon for the full recipe.

3. Repeat 1, but increase the soda to  $1\frac{1}{4}$  teaspoons for the full recipe.

B. To determine the effect of different brands of chocolate.

1. Try as many different brands of chocolate as you can secure.

C. To determine the effect of varying ingredients upon color of cake.

1. Substitute sweet milk for the sour. How much soda should be used? How much baking powder?

2. Use brown sugar.

With which proportion of soda is the real chocolate flavor retained best? Is the color the same with the different proportions of soda? What must the reaction be to give a deep red color to chocolate cake? With what reaction is the best flavor obtained?

### White Cake

#### Experiment 86.

To determine the effect of mixing by different methods on the volume, texture, and tenderness of white cake.

*Recipe:*

Butter	$\frac{3}{4}$ cup	168 grams	Flavoring	1 teaspoon
Sugar	2 cups	400 grams	Baking powder	3 teaspoons
Cake flour	3 cups	300 grams	Salt	$\frac{1}{2}$ teaspoon
Milk	1 cup	244 grams		
Egg whites	6	180 grams		

1. Conventional method. Prepare  $\frac{1}{6}$  of the recipe. The amount of mixing to give the best texture varies with the kind of flour used and may need to be determined. The butter is creamed, and the sugar added gradually to it. Add the salt and the flavoring. Sift the baking powder and the flour together several times. Add approximately  $\frac{1}{3}$  of the flour and  $\frac{1}{3}$  of the milk. Stir 100 strokes. Add a second portion of flour and milk, stirring a total of 200 strokes. Add the remainder of the flour and milk, stirring a total of 350 strokes. The egg whites are beaten until they flow slowly when the bowl is partially inverted. They are then added to the cake mixture and folded in with 50 folds, using a spatula. Weigh 200 grams of batter into a pan of  $2\frac{1}{2}$  cups' capacity. Bake at  $185^{\circ}\text{C}$ . ( $365^{\circ}\text{F}$ .).

2. Repeat 1, but fold the egg whites 100 times.

3. Repeat 1, but stir instead of folding the egg whites into the batter.

4. Partially cream the butter. Then add the sugar and unbeaten egg white. Beat until light and creamy. It is not necessary to cream the butter by this method, but the creaming lightens the color of the butter and thus a whiter cake is obtained. If the butter is not creamed the only difference is in the color, provided the sugar, butter, and egg white are thoroughly creamed. Add the salt, flavoring, flour, and milk according to directions given under 86,1, mixing a total of 400 strokes.

5. Thoroughly cream the butter, sugar, salt, and flavoring. Sift the flour and baking powder together several times. Add approximately  $\frac{1}{3}$  of the flour,  $\frac{1}{3}$  of the milk, and  $\frac{1}{3}$  of the beaten egg white. Stir 100 strokes. Add another  $\frac{1}{3}$  of the flour, milk, and the beaten egg white. Stir a total of 200 strokes. Add the remainder of the flour, milk, and egg white. Stir a total of 400 strokes.

Compare the appearance of the crust, the volume, the texture, the tenderness, and the flavor of the cakes. Which method gives the greatest volume? The most tender cake? What is the effect of folding the egg white too long? Which method is the easiest to prepare?

Appearance of crust	Shape of top	Volume	Texture	Tender-ness	Flavor	Color

Results and conclusions.

### Suggestions for Additional Experiments with White Cakes

1. Vary the proportion of ingredients, and determine the amount of mixing required to give the best texture.
2. Add all the flour and milk at one time, instead of in several portions.
3. Add the flour and milk in several portions, but alternately.
4. Test the creaming ability of different fats, and determine how much the baking powder can be reduced, when creaming is very thorough.
5. Determine the optimum baking temperature.

### Gingerbread

#### Experiment 87.

To determine the effect of using baking powder or soda and sour milk for leavening in gingerbread.

#### Recipe:

Molasses	1 cup	328 grams
Sour milk	$\frac{1}{2}$ cup	122 grams
Fat	$\frac{1}{4}$ cup	50 grams
Egg	1	48 grams
Flour	2 cups	224 grams
Ginger	$1\frac{1}{2}$ teaspoons	
Salt	$\frac{1}{2}$ teaspoon	

A. Prepare  $\frac{1}{4}$  of the recipe. Use 100 strokes for combining each cake unless otherwise stated. Weigh 180 grams of batter for each cake. Bake at  $185^{\circ}\text{C}$ . ( $365^{\circ}\text{F}$ .).

1. Use 2 teaspoons of soda.
2. Repeat 1, but use 200 strokes in combining.
3. Repeat 1, but let stand 15 to 20 minutes before baking.
4. Use  $\frac{3}{4}$  teaspoon of soda.
5. Use  $\frac{3}{4}$  teaspoon of soda plus 1 teaspoon of baking powder.
6. Use 3 teaspoons of baking powder.
7. Use 3 teaspoons of baking powder and substitute sweet milk for the sour milk.

Appearance of crust	Shape of top	Color of crumb	Texture	Tender-ness	Flavor

B. Repeat A, substituting sorghum for the molasses.

What is the effect of soda upon the color of gingerbread? Does the baking powder affect the color? What is the effect of soda upon the gluten and the resulting texture of the gingerbread in 3 when the batter stands before baking? Why does it show more decidedly in the center and not so much at the edge of the cake? Would a less amount of mixing produce a better gingerbread?

Conclusions.

### Cookies

#### Experiment 88.

To determine the proportion of ingredients for drop and roll cookies.

A. Drop cookies.

*Recipe:*

Butter	$\frac{1}{2}$ cup	112 grams
Sugar	$1\frac{1}{2}$ cups	300 grams
Milk	1 cup	244 grams
Eggs	2	96 grams
Flour	$3\frac{3}{4}$ cups	384 grams
Baking powder	4 teaspoons	
Flavoring	1 teaspoon	

Prepare  $\frac{1}{4}$  of the recipe. The size of the drop cookies should be the same in all the experiments. As the liquid is reduced in the following experiments the flour must be reduced. Flour should be added in each to have the consistency of the batter the same as that in 1. Keep a record of the flour added for each experiment. As the flour is reduced, the amount of baking powder should be reduced. Use 1 teaspoon of baking powder for each cup of flour and sift with the flour. Wrap a portion of the cookies in wax paper and put away in a covered container to determine the comparative keeping quality of the different cookies.

1. Prepare recipe as given.
2. Reduce the milk in the recipe to  $\frac{1}{2}$  cup.
3. Reduce the milk in the recipe to  $\frac{1}{4}$  cup.
4. Omit the liquid in the recipe.
5. Omit the liquid in the recipe and reduce the eggs to 1.

Amount of flour added for full recipe	Richness	Crispness	Flavor	Texture	Keeping quality

## Results.

## B. Roll cookies.

*Recipe:*

Butter	1 cup	224 grams	Baking powder	4 teaspoons
Sugar	2 cups	400 grams	Flavoring	1 teaspoon
Milk	1 cup	244 grams	or spices	$\frac{1}{2}$ teaspoon
Eggs	2	96 grams		
Flour	4 cups	448 grams		

Prepare  $\frac{1}{6}$  of the recipe. The amount of mixing should be the same for all the experiments. The dough rolls better if it is chilled first. The cookies should be the same size and the dough the same thickness. As the liquid is reduced the amount of flour will need to be reduced. Keep a record of the flour used. Use 1 teaspoon of baking powder for each cup of flour, sifting it with the flour.

Wrap some of the cookies in oil paper and store in a covered container to compare the keeping quality with that of the drop cookies. Store 2 weeks or longer.

1. Prepare the recipe as given. Try 150 strokes for mixing. If more mixing is necessary keep a record of the amount used. If more flour is needed keep a record of the amount added.

2. Reduce the milk in the recipe to  $\frac{1}{2}$  cup. Mix with the same number of strokes used under B1.

3. Reduce the milk in the recipe to  $\frac{1}{4}$  cup. Mix with the same number of strokes used under B1.

4. Omit the milk in the recipe. Mix with the same number of strokes used under B1.

5. Omit the milk. Reduce the eggs to 1. Mix with the same number of strokes used under B1.

6. Omit the milk. Reduce the eggs to  $\frac{1}{2}$  for the whole recipe. Mix with the same number of strokes used under B1.

7. Omit the milk. Increase the eggs to 3. Mix with the same number of strokes used under B1.

How much flour is added in each instance? Would increased mixing when the milk is reduced improve the texture?

Flour added for whole recipe	Appearance	Texture	Crispness	Flavor	Keeping quality

## Results.

C. The series under B may be repeated and less flour added to make drop cookies to compare with A.

Which proportions give a crisp cooky? A soft one? Which cookies keep better, the roll or drop ones? Could the amount of mixing be increased and improve the texture for either series?

## CHAPTER XIII

### FATS AND OILS

The principal uses of fats and oils in cookery are as follows: (1) to give richness and flavor, as the addition of fat to vegetables, and in mayonnaise and French dressings; (2) for sautéing and for cooking foods in deep fat; (3) for shortening, as in biscuits, muffins, cakes, and pastries. For the first use, flavor is important and may be the deciding factor, unless cost needs to be considered. Examples of this are butter or bacon fat for vegetables in preference to lard or Crisco, and olive oil for salad dressings in preference to other oils. This is a matter of personal choice. For the latter two uses, not only the flavor but also the chemical and physical characteristics may to some extent be deciding factors as to the preferable fat to use.

True fats and oils are composed of hydrogen, carbon, and oxygen, though certain fat derivatives, the lipins, contain either nitrogen or nitrogen and phosphorus.

**Properties of fats and oils.** One characteristic of fats and oils that may be an advantage or disadvantage in food preparation is that they are excellent solvents for many aromatic compounds. They are solvents for odors of onions, fish, perfumes, and many of the aromatic flavors used for seasoning food. Onions, celery, parsley, etc., may be cooked in fat, and this fat stored in the refrigerator to use in seasoning sauces, meats, etc. This can save many preparations of small amounts of onion or other vegetables used for seasoning. Perhaps the enhanced flavor when fat is added to the fruit filling of pies is partially due to the fat retaining more of the aromatic flavor of the fruit as well as to the enriching of the filling. Because the fat is a good solvent for vanilla and other flavor, it is often advised that it be added to the fat during creaming in mixing cake.

The fats, the fatty acids, and the soaps formed from the fatty acids and alkalies all lower the surface tension of water.

Fats and oils are only sparingly soluble in alcohol, but are readily soluble in ether, chloroform, carbon tetrachloride, etc. Fats and oils are insoluble in water. They have a greasy feel and produce characteristic transparent spots on paper.

**Specific gravity of fats and oils.** All the naturally occurring fats and oils have a specific gravity of less than 1.0. The term specific gravity is used to denote the ratio between the weight of a substance and the weight of an equal volume of water. Usually the weights are compared at the same temperature. Thus if the specific gravity of an oil is given as 0.919

at 25°/25°C. it means that the weight of the oil at 25° is compared with the weight of an equal volume of water at 25°C. Fats and oils are lighter than water, and if they are poured into water they float on its surface. Cream has a higher fat content than milk and is lighter than the milk. The average specific gravity of some edible fats and oils is given below.

Butter	not less than 0.905 at 40°/40°C.
Cottonseed oil	about 0.917–0.918 at 25°/25°.
Corn oil	about 0.919–0.921 at 25°/25°.
Lard	about 0.931–0.932 at 15°/15°.
Olive oil	about 0.916–0.918.

**Distinction between fats and oils.** One distinction between fats and oils is that at ordinary temperatures, 18° to 24°C., the fats are solid and the oils are liquid. Chemically the fats contain higher percentages of the saturated glycerides than the oils, and the oils contain more of the unsaturated glycerides than the fats.

**Glycerides.** Fats and oils are esters of glycerol and fatty acids, and thus are often spoken of as glycerides. Glycerol is a trihydric or triatomic alcohol and as such combines with three fatty acids to form a molecule of fat or oil. Of the three fatty acids which combine with glycerol to form the molecule of fat or oil, all may be the same acid. If, for example, the three are stearic acid, the name of the glyceride is tristearin. Two of the acids may be the same and the third different. If the molecule contains two stearic and one palmitic acid, it is known as distearo-palmitin. Each of the three may be a different acid. This gives many possible combinations in fats and oils.

The approximate percentage of the unsaturated glycerides in some of the fats and oils used in cooking is given in Table 59.

TABLE 59

THE APPROXIMATE PERCENTAGE OF UNSATURATED GLYCERIDES FOUND IN SOME FATS AND OILS

Kind of fat	Unsaturated glycerides	Investigator
	Percentage	
Coconut oil	6 to 8	Lewkowitsch
Butter	40	Lewkowitsch
Lard	60 to 65	Lewkowitsch
Chicken fat <sup>1</sup>	77	Kerr
Cottonseed oil	75	Jamieson and Baugham
Peanut oil		
From Spanish-type peanuts	75	Jamieson and Baugham
From Virginia-type peanuts	79	Jamieson and Baugham
Corn oil	85	Jamieson and Baugham

<sup>1</sup> Personal communication from R. H. Kerr, Bureau of Animal Industry.

Since the above figures are approximate, it follows that individual samples of each oil or fat vary slightly, some having a higher and some a lower percentage of unsaturated glycerides. Lard obtained from leaf fat has a lower percentage of unsaturated glycerides than that obtained from the back fat of the same animal. In addition, the composition of such fats as butter, lard, tallow, and chicken fat may be influenced by the diet. Pork fed soybeans or peanuts in sufficient quantity produces the so-called "soft pork," because the body fat contains a higher percentage of unsaturated glycerides, hence is softer at room and refrigerator temperatures.

**Melting point of fats.** Because of the mixture of glycerides the melting points of fats are not constant but vary. The melting points of fats are not only affected by the percentage of their component unsaturated fatty acids but also by the length of the saturated acid chains. The shorter saturated fatty acids have lower melting points than the longer ones, and, in general, the fats composed of glycerides containing a high percentage of the higher or longer chained saturated fatty acids have the highest melting points; those with a high percentage of the shorter saturated fatty acids have intermediate melting points; and those with a high percentage of unsaturated acids have the lowest melting point. As the percentage of the shorter fatty acids or the unsaturated fatty acids is increased the melting point of the fat is lowered. Butter produced in summer has a lower melting point than butter produced in the winter months because the percentage of unsaturated fatty acids is higher in the summer. The oils have a higher percentage of oleic acid and consequently have a low melting point. Hard fats like mutton tallow contain high percentages of palmitic and stearic acids and little oleic and have a high melting point. Soft fats like lard contain more oleic acid than tallow but not so much as the oils.

**Congealing point.** The solidifying point of a glyceride or a mixture of glycerides is lower than the melting point, the difference in the two often being great. For example, Bloor cites the melting point of a sample of tristearin as  $71.5^{\circ}\text{C}$ ., whereas the solidifying point was  $52.5^{\circ}\text{C}$ . A sample of butter melted at  $34.5^{\circ}$  but congealed at  $22.7^{\circ}\text{C}$ . This wide spread in melting and congealing points has some advantages and some disadvantages. When melted fats are added to a batter or other product they do not solidify as rapidly as they would if the melting and congealing points were the same. On the other hand, butter once melted requires a lower temperature to congeal.

**Iodine number (or value).** The iodine number is defined as the number of grams of iodine absorbed by 100 grams of fat or other substance. The iodine is absorbed by the unsaturated carbons or at the double bonds. The class to which an oil belongs is indicated by its iodine number. The non-drying oils, such as peanut and coconut, have iodine values less than 100. Cacao butter and the fats such as lard, beef, and mutton tallows, and butter also, have iodine values below 100. The semi-drying oils, which include corn, cottonseed, sesame, wheat, oat, rice, rye, Brazilnut, raisin seed, peach, cherry, and apricot kernels, and many others, have iodine



values between 100 and 130. Drying oils, which include linseed and soybean, have iodine values above 130.

**Acid value.** Acid value is defined as the number of milligrams of KOH required to neutralize the free fatty acids in one gram of substance. It is a measure of the quantity of free fatty acids or those not combined in glycerides and is usually reported as "free fatty acids as oleic."

**Refractive index.** The refractive index is the degree of deflection caused in a ray of light in passing from one transparent medium to another. For some fats the iodine value may be calculated with a fair degree of accuracy from the refractive index. Since the determination can be made rapidly, the refractive index is used to determine the extent of hydrogenation during the hydrogenation process.

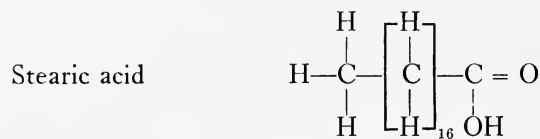
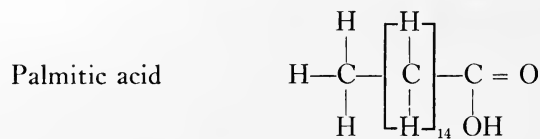
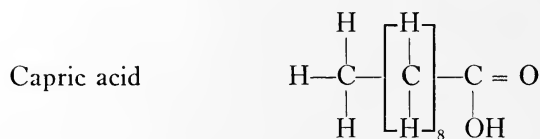
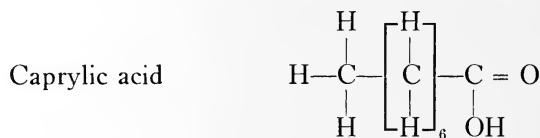
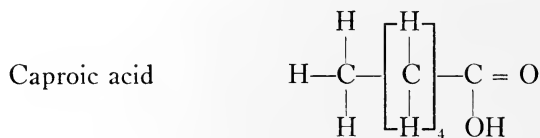
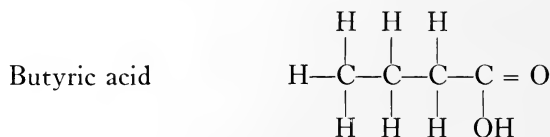
**Peroxide value.** The peroxide value is the amount of peroxide present per 1000 grams of fat. It is expressed as milli-equivalents or as milli-moles, 1 milli-mole equaling 2 milli-equivalents. The peroxide is determined in accelerated tests to learn the relative induction periods or relative keeping quality of fats. King, Roschem, and Irwin describe the principle of this test as follows: By aerating a sample of fat in a test tube held at constant temperature in a bath, the aging of the fat is greatly accelerated. They state that the temperature at which the fat is held, the surface exposed, the amount of oxygen available, the amount of agitation, and the presence or absence of light, all have a bearing on the peroxide value. When these conditions are controlled, an accelerated test may be completed in a short time. The aging of the fat under these conditions is as rapid in a few hours as in a few weeks or months when stored at lower temperatures with exclusion of light and air.

**Hydrogenation.** Hydrogenation is the process by which hydrogen is added to the unsaturated carbon bonds of oils, thus forming hard fats. By using a metal catalyst, such as iron, copper, nickel, or platinum, at an elevated temperature in the presence of an atmosphere of hydrogen the oils take up hydrogen at their unsaturated bonds, becoming plastic, or hard, brittle fats, depending upon the completeness of hydrogenation. Crisco and Snowdrift, hydrogenated fats in common use in food preparation, are not completely hydrogenated. They contain about 25 per cent of the saturated fatty acids. If they were completely hydrogenated the product would be too hard to use in food preparation. In addition to oils or mixtures of oils some soft lards are also hydrogenated for edible purposes.

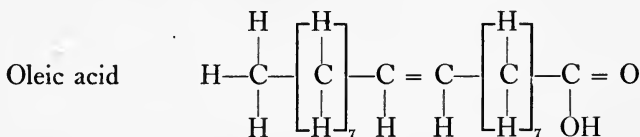
**Texture and consistency of fats.** The texture or consistency of a fat, and hence its properties in baked products, is not only influenced by its component glycerides, but also by the rate of cooling and mechanical agitation. For example, if a sample of lard is divided into two parts, and one portion is cooled slowly, i.e., kept in a warm room or an incubator just below the congealing point of the fat, the glycerides with high melting points tend to crystallize and separate from those with low melting points. As a result the crystallized glycerides form granular spots surrounded by oil. If the second portion of lard is chilled rapidly, there are fewer granules

and the fat is not so grainy. If in addition to rapid chilling, the fat is also stirred while it is being cooled it becomes very smooth. If the temperature to which it is cooled is several degrees below its melting point the fat may become waxy and so firm that it is rather difficult to cream at ordinary temperatures. The oil does not separate from the smooth fat as the fat becomes soft. It is for this reason that only smooth lard or fat is sold in paper cartons. Grainy lard may be purchased but comes in metal containers. The commercial smooth lards are not cooled sufficiently to become waxy.

**Fatty acids commonly found in foods.** The fatty acids commonly found combined with the glycerol in food and cooking fats are palmitic, stearic, and oleic. Chemically the fatty acids of the acetic acid series have the general formula  $C_nH_{2n}O_2$ . The most important of this series in foods are the palmitic and stearic, though butyric and caproic, with small amounts of caprylic and capric, form about 7 per cent of the glycerides of butter.



Of the fatty acid series with the general formula  $C_nH_{2n-2}O_2$  oleic acid is the most important in food fats. The acids of this series contain one double bond in the chain and are unsaturated.



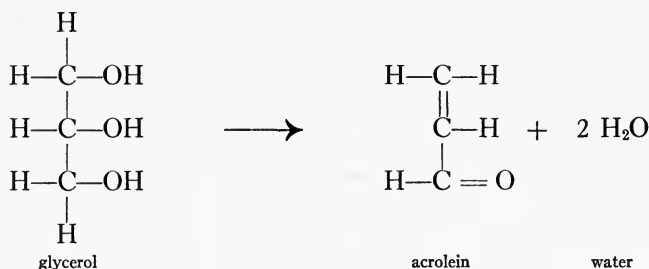
Linolic acid belongs to the fatty acid series with the general formula  $C_nH_{2n-4}O_2$ . Linolic and linolenic acids are very important because they are necessary for proper functioning of the body, and the animal body does not have the ability to synthesize the unsaturated fatty acids. Linolic acid contains two double bonds.

Linolenic acid belongs to the series  $C_nH_{2n-6}O_2$  and contains three double bonds.

When oils or fats are hydrogenated, it is generally agreed that the more highly unsaturated acids are the first to become saturated.

Though present in only small amounts both linolic and linolenic acids may influence the properties of foods. Their effect, or the effect of their oxidation products, on gluten quality has been considered. The glycerides with more than one double bond also oxidize readily. The shortening power of a fat or oil because of the number of double bonds it contains is still to be discussed.

**Glycerol.** Glycerol or glycerin and fatty acids are formed by hydrolysis of the fats by enzymes during digestion or by saponification, i.e., hydrolysis by alkalies. Glycerine has the ability to retain moisture to a high degree, being more hygroscopic than the levulose compounds. It has long been used by many European bakers to retain the moisture in cakes, cookies, etc.



**Heat decomposition products of glycerol.** Some free and uncombined fatty acids and glycerol are usually found with the fats. When heated to a high enough temperature the glycerol decomposes, losing two molecules of water and forming acrolein. Acrolein is an aldehyde that has a sharp odor and is irritating to mucous membranes of the nose and throat and to the eyes. The odor and irritation are familiar to all who have had experience with "burning fats."

**Free fatty acids.** The amount of free fatty acids found in some fats and oils is greater than in others. As previously stated, upon hydrolysis, which may be brought about by enzymes, the lipases, or by boiling with alkali, fats and oils split into glycerol and fatty acids. In cooking materials in fat, particularly foods with considerable water content, the percentage of free fatty acids is increased. During heating in the presence of moisture some hydrolysis occurs, yielding glycerol and free fatty acids.

### The Smoking Temperatures of Fats

When fats or oils are heated to a high temperature decomposition occurs and finally a point is reached at which visible fumes are given off. This point is called the smoking temperature. Some fats decompose at lower temperatures than others; those that smoke at low temperatures are not pleasant to use because of the odor and irritating effect of the fumes. The decomposition also gives an unpleasant and disagreeable flavor to the food. Therefore, it is preferable to use fats with high smoking temperatures for sautéing and deep fat frying.

Blunt and Feeny investigated the smoking temperatures of edible fats. They found the smoking temperatures of various fats when tested in a small evaporating dish having a diameter of about  $3\frac{3}{4}$  inches to be as follows:

TABLE 60

THE SMOKING TEMPERATURES OF SOME EDIBLE FATS (*Blunt and Feeny*)

Kind of fat	Smoking temperature, °C.	Free acid as oleic, per cent
Cottonseed oil (Wesson).....	233	0.07
Snowdrift.....	232	0.06
Crisco.....	231	0.13
Leaf lard.....	221	0.15
Butter fat.....	208	0.28
Leaf lard heated 5 hours.....	207	0.34
Bulk lard.....	194	0.51
A much-used lard.....	190	0.61
Olive oil.....	175	0.92
Peanut oil, I.....	162	1.10
Peanut oil, II.....	149	1.64
Coconut oil.....	138	1.90

The following factors cause variations in the smoking temperatures of fats and oils: (1) the amount of free fatty acids present, (2) the surface exposed, and (3) the presence of foreign particles.

**Free fatty acids and smoking temperature.** Blunt and Feeney have determined the amount of free fatty acids in the fats they used and report as shown in Table 60 that the fats with the highest percentage of free fatty acids have the lowest smoking points, from which they decide that the smoking temperature of the fat is closely dependent upon its acidity. To confirm this they removed the free fatty acid from some of the olive oil and found its smoking point to be 234°C. and its free acid, as oleic, 0.03 per cent. To some of the cottonseed oil, oleic acid in different proportions was added, its smoking temperature being lowered with the increased oleic acid content.

**Surface exposed.** They report that the smoking temperature for a particular fat is lowered when the surface exposed is increased. Thus the wider the diameter of the cooking utensil used, the more the smoking temperature is lowered. They advise using a vessel with as small a diameter as is convenient for deep fat frying.

**Foreign particles.** They have found that another factor that lowers the smoking temperature is the presence of finely divided foreign particles in the fat. Flour and small particles of other materials accumulate in a fat used for cooking purposes. Hence, a much-used fat has a lower smoking temperature than the original fat.

**Smoking temperature and fat absorption.** The cooperators in fat investigations at Iowa State College found that absorption of fat by doughnuts is influenced to a greater degree by the smoking point of the fat than by any other chemical or physical factors investigated. Fat absorption was greater the lower the smoking point of the fat or oil.

### Rancidity

Fats are added directly to many products such as crackers, cookies, and cake because of their shortening power; they are added to other products in the form of such ingredients as nut meats, coconut, fatty seeds, milk, and cheese. Prevention of rancidity may become a problem in such baked goods as crackers, cookies, and fruit cake which may be stored for longer or shorter periods; in the cereal industry; in the confectionery industry; in dairy products; in the fat and oil industry; in salad dressings; and in storage of meats, particularly cured meats such as bacon and ham, and in stored frozen fresh meats. Meat, the fat of which contains more unsaturated glycerides, is subject to the development of rancidity more rapidly than fat containing greater percentages of saturated glycerides. Thus frozen poultry and pork present more problems when stored for long periods than beef and mutton.

**Types of fat spoilage.** The chemical change that needs to occur in a fat before taint is detectable organoleptically is very small. Davies states that butyric and capric acids are detectable by smell and taste in concentrations of less than 80 parts per million parts of fat. Changes in fats can be

detected by smell and taste before they can be detected by chemical tests. An isolated fat possessing excellent keeping qualities may show deterioration rapidly after it is combined with other ingredients, and *vice versa*; but, in general, the fresher the fat and the better its keeping quality, the better the keeping quality of the product with which it is combined.

Different types of spoilage may occur in fats. Davies says "mustiness" is due to microorganic breakdown of higher fatty acids and is accelerated by moisture. Mustiness is common in cereal products, particularly maize. Davies states it is accompanied by an increase in acidity of water extracts, matting of the product because of mold growth, and local spontaneous heating. It is prevented by keeping the humidity sufficiently low.

"Fishiness," according to Davies, is due to the production of trimethylamine in the presence of catalysts from lecithin, before the auto-oxidation of the fat proper. Fishiness occurs most commonly in butter. The presence or absence of other products can alter the fishy odor.

The term rancidity is used by the homemaker to designate the development of any disagreeable odor and flavor in fats and oils. But in the fat and oil industry the term is often restricted to the oxidative changes in fats and oils. Different investigators classify the disagreeable odors and flavors according to their production in different ways. Davies gives three types of rancidity as follows: (1) acid, (2) oxidative, and (3) ketonic. Triebold's classification is (1) hydrolytic, (2) oxidative, and (3) ketonic.

**Hydrolytic rancidity.** Hydrolytic or the acid rancidity of Davies is brought about by the action of lipase enzymes which by hydrolysis split the fat into glycerol and fatty acids. Davies adds that free fatty acids may also be liberated by a relatively high hydrogen-ion concentration in contact with the fat. Lipases are associated with fats in their natural state, i.e., nuts, seeds, milk, and fat of meat. Since lipase enzymes are destroyed by heat, this type of rancidity is encountered in products which are not heated to a high enough temperature to destroy the enzyme. The flavors developed by lipase action depend upon the composition of the fat. Thus flavors caused by butyric acid will be found only in products containing butter fat. Davies states that lipase activity in itself is of no great economic importance, except in the fats rich in the lower fatty acids, but secondary reactions associated with oleic acid introduce another aspect. The free fatty acids act as catalysts for oxidative changes. Greenbank says that lard with a low free fatty acid content keeps well, even when stored for long periods, and butter from sweet cream does not become rancid as rapidly as butter from sour cream. The better-keeping quality of the sweet-cream butter is attributed to its lower free fatty acid content.

**Chemical and physical changes in fats with development of oxidative rancidity.** Among the changes which occur when a fat or oil becomes rancid are the following: the iodine value decreases, whereas the specific gravity, acid value, and peroxide value increase. Coe states that numerous investigations have shown that when an oil or fat is protected

from light by means of a green wrapper or container it may have a peroxide value equal to or even greater than an unprotected fat that has become rancid and still be organoleptically free from rancidity. From this Coe concludes that the reaction that gives rise to the rancid taste and odor has no connection with formation of peroxides.

**Oxidative rancidity.** Oxidative rancidity occurs through the taking up of oxygen at the double bonds of the unsaturated glycerides. Many oxidative decomposition products may be formed, though Kerr states the exact nature of these changes is not always clear. These products include aldehydes, ketones, fatty acids of lower molecular weight, hydroxy acids, oxy acids, and gases. Andrews has reported that among the gaseous decomposition products of rancid fats are carbon dioxide, carbon monoxide, hydrogen, nitrogen, oxygen, and other gases. Triebold gives a good summary of the products formed in development of rancidity.

*Induction period.* There is a period before the uptake of oxygen by a fat becomes appreciable which is known as the induction period. During this period the fat is still fresh and "sweet." The induction period varies for different fats and oils and for different samples of the same fat or oil. But oxidation products act as catalysts so that oxygen uptake receives increased momentum as these products are formed. Reports in the literature indicate that the first compounds formed in oxidation of unsaturated fatty acids are not oxides or peroxides. These compounds have never been isolated and have been given the name "mloxides." Exclusion of air or oxygen from a fat may retard but not inhibit its oxidation. It has been suggested that the source of this oxygen is oxygen in loose combination with the fat. It is sometimes suggested that loosely bound oxygen is the source of oxygen for the mloxides.

*Prooxidants and antioxidants.* A prooxidant accelerates but an antioxidant retards oxidation of a fat. Because of the economical importance of prevention of rancidity many investigations have been conducted to find physiologically harmless antioxidants. The literature on rancidity is voluminous and many contradictions occur, particularly in regard to the activity of different substances as accelerators or retarders of oxidation. The contradictions can be attributed to the lack of suitable tests for minute quantities of some substances, the different conditions under which the tests are made, and the differences in degree of purity or refinement of the fats and oils. Fats and oils always contain at least traces of different substances in varying proportions, some of which can act as prooxidants and others as antioxidants. Patents have been granted for the use of many substances as antioxidants.

*Metals.* Traces of certain metals (King, Roschem, and Irwin) may act as catalysts, copper in particular being an active prooxidant. Tin had the least effect of any metals used in the experiments, although the authors state the results were not conclusive in that tests were not made under many

conditions. The effect of metals is important, for in the manufacture, refining, and storage of fats they come in contact with metals.

*Lecithin.* Lecithin, found in egg yolk, soybeans, and other substances added to baked products, has been reported to be a powerful antioxidant and inactive. Olcott and Mattill say that commercial "lecithin," which is not a pure lecithin, has antioxidant action on refined cottonseed oil, little effect on lard, and none at all on lard-cod liver oil mixtures. They attribute the antioxidant properties to the cephalin found in the commercial lecithin. It is well known that egg yolk has antioxidant properties in cookies, cakes, and similar products in which both egg yolk and fat are used.

*Cereals.* Soybean flour (Musher) is said to be strongly antioxidant. Oat, corn, barley, or other cereal may be employed but oat flour is preferable because of its bland flavor. Wheat flour is a weak retarder of oxidation and oat flour is not as strong an antioxidant as soybean flour.

*Effect of inert gases and humidity.* Triebold and Bailey found that crackers as well as fats stored in an atmosphere of  $\text{CO}_2$  were as rancid as control samples stored in air. Other investigators have also reported the ineffectiveness of  $\text{CO}_2$  in retarding the development of rancidity. However, storage in an atmosphere of nitrogen or hydrogen retards the development of rancidity.

Triebold and Bailey also found that zero-per cent relative humidity favors, but some humidity retards, oxidative rancidity. However, humidity as high as 50 to 75 per cent produces mustiness. The 5- to 6-per cent moisture content of crackers aids in keeping the crackers fresh. They also found that in general the keeping quality of crackers was related to the length of the induction period of the shortenings used in them, but several outstanding exceptions to this relationship were noted, so that the keeping quality was more closely related to the induction period of the crackers themselves.

*Antioxidants for fats in contact with water.* Lea was interested in finding antioxidants for bacon fat. He investigated the effect of different substances on fat in contact with a brine pickle. His results follow. Oxidation of lard in a glass vessel in contact with water is much more rapid at an alkaline than at an acid  $\text{pH}$ . It is suggested that this is due to dissolution of copper from the glass. At a  $\text{pH}$  below 5, nitrate is a powerful accelerator. Copper and iron in aqueous solution accelerate the oxidation of lard, copper being approximately 20 times as active as iron. Copper was active in as low concentrations as 0.01 p.p.m. Aliphatic polyhydroxy-compounds such as glycerol and the sugars are weak antioxidants. Aliphatic hydroxy-acids, e.g., lactic and glycollic, the ethanalamines and maleic acid are moderate, and polybasic hydroxy-acids, e.g., tartaric and citric, are powerful antioxidants. Aliphatic amino-acids, e.g., glycine, aspartic and glutamic acids, and asparagine are all powerful antioxidants. Protein has considerable antioxidant activity and may be partly responsible for the stabilization of



crude natural oils and fats. The prooxidant effect of copper at low concentrations (up to approximately 1 p.p.m.) is completely inhibited by protein and other antioxidants. At higher concentrations of the metal, even 4 per cent of protein fails to prevent a powerful acceleration of oxidation. Orthophosphoric acid is a fairly good, and pyrophosphoric a very good, antioxidant. Phosphorous acid is also effective. These water-soluble antioxidants still retard oxidation when the water content is as low as 0.25 per cent. They are active at pH 7, certainly in more acid and probably in more alkaline solutions.

*Volatilization of rancid products.* Roschem and Newton found that samples of rancid lard blown with steam at 100°C. were odorless, bland-tasting, and entirely palatable, i.e., the products causing the rancid flavor and odor were volatile. Furthermore these volatile substances had no accelerating effect in oxidation of lard. This was interpreted to mean that the accelerating effect is due to a substance or substances of heavy molecular weight not volatile, with steam distillation at 200°C. and 3 to 5 mm. mercury pressure.

*Protective action of green light.* Coe and Le Clerc compared the inhibiting effect of excluding all light, using only green light of 490 to 580 m $\mu$  wave length or 4900 to 5800 Ångström units, with the effect of several antioxidants, including maleic acid and pyrogallol, upon oxidation of fats. They report that oils or fats stored at low temperatures and with all light excluded remained fresh longer than if treated with antioxidant or packaged in green wrappers and exposed to light at room temperature. Packaging in green glass or opaque wrappers was more effective in keeping fat fresh than the addition of the antioxidants. Green glass or opaque wrappers which exclude all light except the aforementioned wave lengths are suitable for packaging nuts, potato chips, or food products for display purposes.

**Ketonic rancidity.** Davies states this type of fat spoilage is caused by molds which attack the short-chained saturated fatty acids, the decomposition products producing disagreeable flavors. Since butter and coconut oil are the principal fats which contain short-chained acids in the glycerides, most ketonic rancidity is confined to these fats.

**Effect of light, heat, and air.** It has been known for years that exposure of fats to light, heat, and air is deleterious to keeping the fat fresh. Greenbank investigated the relative effect of each of these factors. He concludes that in the presence of air, light is the most powerful accelerator, and moisture and heat follow in the order given. "This conclusion holds only for lower temperatures." A vacuum may retard oxidation but not prevent it.

Triebold and Bailey found that all hydrogenated shortening samples stored in unopened containers showed induction periods of approximately the same length. Samples from containers once opened and then restored

had shorter induction periods. A lard sample stored in the laboratory for a year with air excluded appeared in as good condition at the end as at the start of the experiment. They emphasize the practical importance of preventing undue exposure of shortenings to air and decreasing the surface area of the fat exposed to air.

**Home storage of fats and oils.** All the work on development of rancidity in fats and oils indicates that the fat should be stored so that light is excluded, at a low temperature, and with as little exposure to air as possible. For farm storage of lard, when 5, 10, or more gallons are stored in one container, the light should be excluded and Triebold and Bailey's results suggest a tall narrow container, rather than a wide flat one, for the former exposes a smaller surface of the fat to the air. When lard is removed from these containers it is preferable to remove a level layer rather than to dig out the center portion.

### Changes in Fats during Cooking Processes

Masters and Smith have investigated the character of the changes in fat during cooking. They state that the changes occurring in the fat in cooked pastry are slight, unless the pastry is very thin or over-cooked.

Woodruff and Blunt have reported the changes in fats absorbed by potato chips and a dough mixture. They state that the iodine number is lowered, and the percentage of free fatty acids increased. These changes are not great, but the fat absorbed by the food undergoes greater changes than the fat in which the food is cooked. Long cooking or use of the fat increases the amount of decomposition of the fat. The higher the temperature to which the fat is heated, the greater the decomposition products formed. Thus during cooking the fat should not be heated higher than the temperature needed for cooking the food.

Morgan and Cozens found that fats used for frying a standard dough showed consistent decreases in iodine number, lowering of the melting point and increases in acidity and refractive index. They state that in general the increase in acidity is greater in those fats showing the larger amounts of absorption.

King *et al.* used 9 fats, including 3 kettle-rendered lards from animals fed on rations consisting largely of (1) peanut, (2) corn, and (3) brewer's rice, a standard prime steam lard, a hydrogenated lard, a hydrogenated cottonseed oil, and three highly refined oils from corn, cottonseed, and peanuts, respectively, for studying frying of potato chips. The fat absorbed by the chips was about the same for all the fats used. Chemical tests showed deterioration of all fats. After 10 fryings the fitness of the fats, particularly the lards on account of their high peroxide value, for further use was questionable. They found no relation between chemical changes and the flavor of the chips. The percentage of free fatty acids in the fat

extracted from the chips was greater than in the frying fat. Based largely upon desirability of flavor the palatability tests indicated oils were preferable to lards for frying potato chips, those fried in peanut oil ranking highest with cottonseed oil second. Of the lards, the hydrogenated and that from animals whose rations consisted largely of peanuts were considered best. Potato chips fried in oils and in most cases those stored in the refrigerator kept fresh longest.

### The Amount of Fat Absorbed by Fried Foods

The chief factors governing the amount of fat which will be absorbed by a food during frying are (1) the time of cooking, (2) the temperature of the cooking fat, (3) the total surface area of the food, and (4) the composition and nature of the food.

**Time of cooking.** In general, it can be stated that the longer the food is cooked the greater the fat absorption. There will be some exceptions to this. For instance, with some foods cooked at high temperatures, coagulated material or a hardened crust may prevent greater fat absorption with longer cooking. Other foods which contain a high percentage of fat like breaded pork chops may lose fat during cooking. This is also true of fried chicken, if the chicken has a high fat content.

**Temperature of cooking fat.** Usually there is less fat absorption at higher cooking temperatures. This is probably due to the quick formation of a crust or coagulated material at the high temperature. However, slight differences in cooking temperature, 30° to 40°C., cause little variation in fat absorption. Ordinarily food is cooked at moderate temperatures to thoroughly cook the food without excessive browning.

**Surface area.** The larger the surface for a given weight of material the greater the area over which fat may be absorbed. Cracks caused by handling or expansion in cooking, rolling thin rather than thick, roughened surfaces, due to little mixing or other causes, stretching and pulling the material out of shape in handling, all increase the surface area and thus tend to increase the fat absorption.

**The composition and nature of the food.** Some foods by their nature tend to absorb more or less fat than others. For example, fried eggs may absorb less fat than some foods. This is due to the smooth surface and to the coagulation of the egg proteins, which tends to prevent fat absorption. Large amounts of flour on the surface of chops may tend to increase the fat absorption, owing to the absorption of fat by the flour. Variations in composition of the food and variations in the proportion of ingredients used in foods cause wide variations in the amount of fat absorbed. A food like doughnuts, containing sugar, fat, liquid, eggs, flour, and baking powder, may show wide variations in the amount of fat absorbed, even when the length of time of cooking and the amount of surface area are kept as

standardized as possible. Variations in the extent of mixing foods like doughnuts produce variations in the amount of fat absorbed during cooking because the characteristics of the dough are altered by mechanical treatment.

### The Amount of Fat Absorbed by Doughnuts Reported by Different Investigators

**Fat absorption in doughnuts by McKee.** McKee has determined the amount of fat absorbed in frying doughnuts. The doughnuts were made under standard conditions and fried for 5 minutes at 200°C. The standard recipe averaged 34.7 per cent fat absorbed. When the fat was doubled and quadrupled in the doughnut recipe the fat absorption was increased to 43.4 and 47.8 per cent, respectively; sugar doubled caused an increase to 44.3 per cent. But when the sugar was quadrupled the doughnut disintegrated during cooking, absorbing large quantities of fat.

**Fat absorption in doughnuts. From various sources.** Morgan and Cozens have determined the amount of fat absorbed in frying doughnuts. Their dough contained less egg and more flour than the dough used by McKee. Their doughnuts were larger than McKee's, which gave a relatively larger surface for a given weight of dough for the McKee doughnut. They cooked their doughnuts for 3 minutes at 205° to 210°C., which resulted in an average fat absorption of 17.4 per cent. The time of cooking, the temperature of the cooking fat, and the proportion of ingredients in the recipes used by McKee and Morgan-Cozens were not the same; hence the fat absorption differed.

The cooperators in lard investigations at Iowa State College Experiment Station determined the amount of fat absorbed by doughnuts and the changes in the fats caused by cooking doughnuts in each fat, the period of heating each fat being kept constant at 10¼ hours. These studies were continued over a period of 3 years, the same operator, Jensen, making and frying all the doughnuts, so that a highly specialized technic was developed. Standardized conditions of mixing, which included incubation of all materials at a definite temperature before mixing and mixing with a Kitchen-Aid, were maintained. Six mixes or batches of dough were required for the doughnuts fried in each fat. The term "firsts" was applied to doughnuts cut after the first rolling of the dough. The scraps were then collected and rerolled. The doughnuts from this lot were designated as "rerolls." Again the scraps were collected and rerolled, the doughnuts from this lot designated as "re-rerolls." The following results are from tests during the third year only.

A total of 12 fats were used, of which 2 were open-kettle rendered lards, 5 were prime-steam rendered lards, 1 hydrogenated lard, 1 hydrogenated cottonseed oil, and 1 corn oil.

Number of "firsts" cooked in each fat	12	dozen
Number of "rerolls" cooked in each fat	6	dozen
Number of "re-rerolls" cooked in each fat	2½	dozen
Average fat absorption from all fats for "firsts"	28.6	per cent
Average fat absorption from all fats for "rerolls"	22.3	per cent
Average fat absorption from all fats for "re-rerolls"	18.5	per cent

The analysis of variance indicated exceedingly high uniformity among rollings, i.e., "firsts" always absorbed the most fat, etc., but great variation among different mixes or batches so that the variation from mix to mix was used as the experimental error. The variation of amount of fat absorbed by the different fats was also highly significant. Further analysis of the data showed a significant negative correlation between the smoking point of the fat and the amount of fat absorbed by the doughnuts, which indicated that the lower the smoking point the greater the amount of fat absorbed by the doughnuts. The iodine value, the percentage of free fatty acids, and the refractive index had no effect on the amount of fat absorbed. However, a highly significant negative correlation was found between the free fatty acids content and the smoking point of the fat which agrees with former findings of Blunt and Feeney and Morgan and Cozens.

Denton and co-workers have also published results for fat absorption in doughnuts and other foods. Their conclusions are similar to those of the investigators mentioned above and to the following class results, so will not be given in detail.

### Factors Affecting the Amount of Fat Absorbed During Cooking and the Texture of the Doughnuts

The factors that affect the amount of fat absorbed by doughnuts may be outlined as follows. Other factors than those listed may also affect the amount of fat absorbed: (1) surface area, (2) the temperature of the ingredients when mixed, (3) the extent of mixing, (4) the kind and brand of flour used, (5) the amount of flour, (6) the cooking temperature and the length of time of cooking, (7) letting the dough stand before frying, and (8) variation in the proportion of ingredients used in the recipe. All the above factors either directly or indirectly affect the texture and also the tenderness of the doughnuts.

**Surface area.** Other things being equal, the greater the surface area the greater the fat absorption. The total surface area of doughnuts may be increased by stretching the dough in handling and by cracks on the surface of the dough. The thicker the doughnut is rolled, the smaller the total surface area in proportion to the weight of the doughnut. The thickness of the dough in all the following experiments is ¼ inch. This is controlled by rolling the dough between cleats tacked to a bread board.

**Temperature of ingredients when mixed.** The results in Table 61 show that the temperature of the ingredients when mixed has a decided

effect upon the amount of fat absorbed during cooking. The tenderness of the doughnuts was as marked as the fat absorption, for all the doughnuts of series II were tougher than those of series I. The dough made from the materials that had been incubated at 40°C. developed very rapidly, becoming quite elastic and rubbery in a short time. The dough stretched yet was so tenacious that it was difficult to divide it. It had a tendency to draw up and shrink after rolling. With this temperature even 60 strokes was too long to mix the dough to secure tender doughnuts. The best temperature of the ingredients to secure doughnuts of desirable texture and tenderness is about 22° to 27°C. (72° to 80°F.).

TABLE 61

VARIATION IN FAT ABSORPTION DUE TO DIFFERENCE IN TEMPERATURE OF THE INGREDIENTS OF THE DOUGH WHEN MIXED, SIX DOUGHNUTS IN EACH LOT. COOKED 3 MINUTES AT 175° TO 180°C.

Experiment 94	Number strokes for mixing	Temperature of ingredients when first mixed	Weight of uncooked doughnuts, grams	Weight of cooked doughnuts, grams	Fat absorbed	
					Grams	Per cent
I, 1 2 3 4	60	22°C.	140.6	181.1	60.5	33.4
	80		143.5	179.5	55.5	30.9
	100		144.0	175.0	47.0	26.8
	120		141.0	169.9	47.0	27.8
II, 1 2 3 4	60	40°C.	146.6	158.6	28.0	17.6
	80		145.8	154.8	26.0	16.7
	100		153.7	161.7	24.5	15.1
	120		150.4	159.4	24.5	15.3

A word of explanation is necessary regarding the percentage of fat absorbed. As given in the tables it is only approximate. Doughnuts both lose and gain weight during cooking. Moisture is lost and fat is absorbed. The only accurate way to obtain the percentage of fat absorbed in doughnuts is to run an analysis on the ingredients used, i.e., to determine the amount of fat in the dough and in the cooked doughnuts. This requires too long for regular class work. Denton has suggested that the percentage of fat be calculated on the weight of the cooked doughnuts, and this has been followed in determining the percentage of fat given in the tables. The uncooked weight of the doughnuts is also given.

**Extent of mixing.** Both the manner of mixing the ingredients and the length of time of mixing the dough influence the texture obtained in doughnuts. Doughnuts, like cakes, seem to have a finer, more even texture

if the eggs are thoroughly creamed with the fat and sugar. Adding the flour and milk in different portions may also affect the texture. Too little mixing after the flour and liquid are added gives a coarse, harder, rather crystalline texture, for the ingredients are not thoroughly blended. With over-mixing the doughnuts are tougher and more compact. The temperature of the ingredients affects the amount of mixing required to obtain a tender doughnut. As the temperature increases less mixing is required; at too low a temperature, the fat does not blend with the other ingredients. The length of time of mixing the dough also affects the amount of fat absorbed by doughnuts. In general, the longer the dough is mixed the more the gluten is developed unless mixing is extremely long. The development of the gluten by mixing forms thin filaments of gluten throughout the dough that probably tend to prevent fat absorption. The longer mixing produces a more uniformly mixed dough, which has a smoother crust. The smoother crust has less surface for fat absorption than a dough with a rougher surface.

**Kind and brand of flour used.** The amount of fat absorbed by doughnuts varies with the kind or brand of flour used, if other conditions are standardized. In general, the strong flours show greater decrease in fat absorption with longer mixing. The soft-wheat flours tend to increase the fat absorption. The amount of flour, that is of bread or soft-wheat flour, to give a soft tender doughnut also varies. This is apart from varying the proportion of flour.

**The amount of flour.** As the amount of flour in the recipe is increased the amount of fat absorbed by the doughnuts is decreased. This is shown in Table 62.

TABLE 62

EFFECT OF AMOUNT OF FLOUR IN THE RECIPE UPON FAT ABSORPTION IN DOUGHNUTS (*Average 13 tests*)

Experiment 94A. Amount flour, cups	Number of strokes used for mixing	Weight of uncooked dough- nuts, grams	Weight of cooked dough- nuts, grams	Fat absorption	
				Grams	Per cent
4 $\frac{3}{4}$ .....	80	142.6	192.3	72.5	37.4
5.....	80	140.6	182.4	60.9	33.6
5 $\frac{1}{4}$ .....	80	143.2	182.5	59.0	32.5
5 $\frac{1}{2}$ .....	80	149.0	182.8	51.3	28.2

**The cooking temperature and the length of time of cooking.** In general, the longer the time of cooking the greater the fat absorption. Table 63 shows rather typical results.

TABLE 63

EFFECT OF THE COOKING TEMPERATURE AND THE LENGTH OF TIME OF COOKING UPON FAT ABSORPTION IN DOUGHNUTS. DOUGH MIXED 80 STROKES WITH WOODEN SPOON. SIX DOUGHNUTS IN EACH LOT

Experi- ment 94C	Time of cooking, minutes	Temp. of cooking fat, °C.	Weight of uncooked dough- nuts, grams	Weight of cooked dough- nuts, grams	Fat absorbed	
					Grams	Per cent
1	2	155-160	184.0	219.0	44	20.1
2	3	155-160	168.0	194.0	49	25.2
3	4	155-160	170.0	201.0	53	26.4
4	2	175-180	168.0	190.0	44	23.2
5	3	175-180	168.5	193.5	47	24.3
6	4	175-180	169.0	196.0	51	26.0
7	2	195-200	176.5	195.5	38	19.4
8	3	195-200	179.5	197.5	39	19.7
9	4	195-200	165.5	181.5	42	23.1

The results in Table 63 show less fat absorption at the higher temperatures. Sometimes the differences are not so great. Extreme temperatures were used in these doughnut experiments. In ordinary cooking as low a temperature as 155°C. would not be used, for the doughnuts would require too long a time to brown. Nor would the high temperature be used, for the doughnuts become too brown in a very short time. The doughnuts cooked for 2 minutes are not so brown as those cooked 4 minutes. Those cooked at 155° to 160° are very pale in color; those at 195° to 200°, except the ones cooked 2 minutes, are too dark in color. Usually the preferable color is obtained by cooking at 175° to 180° for 3 or 4 minutes. The doughnuts cooked at the highest temperature usually have a smaller volume than those cooked at 175° to 180°, probably because the crust hardens quickly at the higher temperature and thus prevents expansion. This would be one factor that causes decreased fat absorption at 195° to 200°, as the doughnuts would have less surface area.

**Letting the dough stand before frying.** If the dough is allowed to stand a short time before frying the amount of fat absorbed while cooking is usually lessened, but sometimes just the opposite happens, and a larger quantity of fat is absorbed. The volume of the cooked doughnuts is usually greater after the dough is allowed to stand a short time. This would tend to cause greater fat absorption on account of greater surface area.



**Effect of variation of proportion of ingredients in the recipe.**  
 If different doughnut recipes are compared, the proportion of ingredients

TABLE 64

EFFECT UPON FAT ABSORPTION OF INCREASING THE SUGAR IN THE RECIPE FROM 1 TO 1½ CUPS. COOKED 3 MINUTES AT 175° TO 180°C.

	Number of strokes used for mixing	Weight of uncooked doughnuts, grams	Weight of cooked doughnuts, grams	Fat absorption	
				Grams	Per cent
1	140	146.6	185.3	68	36.7
	160	146.1	186.7	65	34.8
	180	148.7	178.9	52	29.1
	200	154.0	175.6	42	23.9

will be found to vary somewhat. One recipe may contain a larger proportion of sugar, another of fat. This variation of proportion of ingredients will influence the percentage of fat absorbed.

*Sugar.* When the sugar in the regular recipe is increased from 1 to 1½ cups the dough is quite sticky and difficult to handle. The dough appears as if it contained a thick sirup. The fat absorbed during cooking is decidedly increased. If the dough is mixed longer it becomes less sticky and the gluten better developed, and fat absorption is decreased. The result upon the texture is similar to that obtained when sugar is increased in cake. The dough requires more mixing than the regular recipe to obtain good doughnuts. The best texture is usually obtained with 180 to 200 strokes.

*Fat.* When the fat in the recipe is increased the fat absorbed during cooking is increased. When the fat in the recipe is increased, the extent of mixing does not affect the fat absorption so much, i.e., fat absorption does not decrease so rapidly with longer mixing as in the regular recipe. There is also the possibility of variation of amount of fat absorbed, when different kinds of fats, such as butter, Crisco, or lard, are used in the dough. When flour is increased, which the homemaker tends to do because increased fat gives a softer dough, the fat absorption is not always increased by doubling the fat in the recipe.

*Eggs.* When the number of eggs in the recipe given in the outline is increased from 2 to 3, with no other change, the dough is softer and more sticky, because of the moisture content of the egg. This tends to cause increased fat absorption. The coagulation of the increased egg in the crust tends to decrease the fat absorption. The final result is the sum

of these antagonistic effects. Sometimes one factor and sometimes the other predominates. In making doughnuts the tendency would be to add more flour to roll the dough more readily, and this would decrease the fat absorption. Other factors in addition to the two mentioned above will also affect the amount of fat absorbed. These include surface area and the extent of mixing. The volume of the doughnuts with increased egg may be larger than the volume of those in the regular recipe, giving a greater surface area for absorption of fat. Doughnuts made with increased egg may contain tunnels, and there is a tendency for them to be tough.

### The Shortening Power of Fats and Oils

Shortening power has been defined and tested in various ways. The ordinary household way is to test the product by feel either by breaking or by crushing. Davis has defined shortening as follows: "That material has the greatest shortening power, which when baked in a dough under standard conditions gives to the product a minimum crushing or a minimum breaking strength." Shortening power or the ability of fats and oils to make a product more tender so that it breaks or crushes more readily is due to several factors. These factors for discussion may be classified as follows: (1) differences in structure of the dough, (2) differences in adsorption of different fats and oils at interfaces and orientation, and (3) the surface area covered by the fat or oil. The author is aware that this classification is somewhat superficial, for plasticity, the melting point of the fats used, and other factors might be listed. But differences in plasticity of the fats used will influence the structure of the dough and thus may be considered under the classification given.

**Differences in structure of the dough.** In the chapter on batters and doughs it was found that differences in structure of batters and doughs were due to several causes, i.e., the method of mixing or combining of ingredients, the temperature of the ingredients when mixed, the extent of mixing, the plasticity of the fat used, the ingredients used, and the proportions of these ingredients. It is rather difficult to exactly duplicate the structure of a dough, but it is particularly difficult when the material is thin like pastry. The fat or oil is seldom distributed evenly throughout the dough. This gives structural weakness in certain areas. For this reason breaking tests of individual pastries may vary considerably.

**Theory concerning differences of shortening power of different fats and oils.** The theory for differences in shortening power of different fats and oils is based upon the concepts of differences in cohesion, adhesion, adsorption at interfaces, and orientation of molecules. These are in turn based on the concept of polarity. Polar groups or polar molecules, owing to an electric charge, are very reactive and strongly attracted to each other. Some substances like fatty acids have polar groups, while a portion of the molecule is non-polar. This theory for the shorten-

ing power of fats and oils has been developed from the work of Langmuir, Harkins, and their co-workers, upon cohesion, adhesion, interfacial tension, and molecular attraction, between water and organic liquids.

Langmuir has reported: "When a small quantity of an oil, such as olive oil, is placed upon a large clean surface of water, the oil spreads rapidly upon the water surface until a definite area has been covered, and then the oil shows little or no tendency to spread further." The following is a brief summary of his article. Some portions of the molecule have greater affinity for water than other parts. In determining the cause of this spreading of the oil upon the water he found that the film was one molecule thick. If the cause of spreading is an attraction between the oil and water this attraction may be the molecule as a whole or certain portions of the molecule may have greater attraction than other parts for the water. If the whole molecule is attracted there would be solubility of oil in water. If a portion of the oil molecule is attracted by the water while another portion is more attracted by the oil molecules we have a ready explanation of the spreading of the oil on the water.

If oleic acid is considered, as an example, the carboxyl group has a strong affinity for water, and when placed on water this group is probably absorbed in it. The hydrocarbon chain of oleic acid has no attraction for water but it is attracted by other hydrocarbon chains. From this, one can picture the hydrocarbon chains as standing in the air side by side and the carboxyl group dissolved in the water. Since the hydrocarbon chains have an attraction for each other when the amount of oleic acid upon the surface of the water is small, there is a tendency for it to remain in a globule. This attraction of parts of the molecule for each other is in the nature of a chemical force. With very small amounts of oleic acid the hydrocarbon chain may lie along the surface of the water. With enough for a layer the chains may stand upright.

The hydrocarbon chain of oleic acid is not a saturated one. It contains a double bond. With a limited amount of oil on the surface of the water the double bond as well as the carboxyl group may be drawn down onto the surface of the water. In this way it covers a larger surface area of the water.

**Unsaturated fatty acids cover a larger surface area than saturated ones.** Langmuir has measured the length of the molecules and the area of the water covered by them. He reports that the area covered by the three saturated acids, palmitic, stearic, and creotic, is practically the same, yet the number of carbons in palmitic is 16 and in creotic 26, the latter having the longer molecule. The glyceride tristearin covers an area three times that of one molecule of stearic acid. From this it is seen that the area covered is the same whether as an acid or as an ester of a glyceride. In measuring the height above the surface of the water he found it to be the same as the length of the hydrocarbon chains, showing that they are packed vertically side by side. The results are probably best told in his

words. "The unsaturated fatty acids all cover much greater areas per molecule than the saturated. The double bond in oleic acid is thus apparently drawn down onto the water surface. It is interesting to note, however, that linoleic acid with its two double bonds, does not cover any greater area per molecule than oleic acid. It may be that the double bonds attract one another to some extent in place of the water. Linolenic acid, however, with three double bonds, covers a considerably greater area than oleic or linoleic. As the number of double bonds increases, the energy consumed in compressing the film decreases, probably because the carboxyl groups tend to be attracted by the double bonds in adjacent molecules and are thus more easily separated from the water surface."

Polar groups of molecules and water are attracted to each other. Harkins and co-workers have reported that, if an organic liquid contains polar groups in its molecules, these groups turn towards the water, and the amount of work required to separate it from the surface of the water is greater than when the polar groups are absent. These polar groups are substances containing oxygen, nitrogen, sulfur, iodine, bromine, chlorine, or double or triple bonds.

In a later paper Harkins and Cheng have reported that a paraffin with a triple bond increases the adhesional work very decidedly; they state: "This and other studies in this paper should prove of value in study of lubrication and other adhesional phenomena."

Wilson and Barnard have reported that a good lubricant is one that has the property of "oiliness." They define oiliness as "The property by virtue of which one fluid gives lower coefficients of friction (generally at slow speeds or high loads) than another fluid of the same viscosity."

**Orientation in lubricants.** Wilson and Barnard, with other investigators, find the "animal and vegetable oils to be superior in oiliness to straight mineral oils." They conclude that the property of oiliness is due to selective adsorption of parts of the oil by the metal surface so that they adhere closely and are not squeezed out from between the metals, or in other words the polar groups of the animal and vegetable oils are attracted by the polar metal, and the fat or oil is less readily squeezed out from between the metal surfaces than oils or fats containing no polar groups. Thus they make better lubricants.

**Theory of shortening power applied to cookery.** If the results of Langmuir and Harkins can be applied to lubricants they should be equally applicable to the use of fats and oils in cookery. The glycerol part of the fat is attracted by water. If it adheres closely to the water, one can conceive that the water might cement the flour particles less firmly together. Fats and oils with double bonds in their fatty acid chains, or those containing unsaturated glycerides, can be spread over a greater surface area than the saturated fats and would thus adhere to a larger water surface, or compete with the gluten for the water. Also, since the double bond of the fat adheres closely to the metal surface, it may be that it will

adhere to the amino groups of the flour proteins, as well as to the water. This would make it more difficult to squeeze out from between the flour particles. Fats and oils containing unsaturated glycerides would have more shortening power because they cover a greater surface area per molecule and because they adhere more firmly to the water surface. If this is true, the fats and oils having the highest percentage of unsaturated acids and covering the greatest surface area should give the tenderest baked products. However, the area covered by a given amount of fat or oil in a dough or batter may vary. A sphere gives the least surface area for a definite weight or volume of a substance. If the oil or fat is emulsified and distributed in the batter in small spheres the total area covered may be less than if the same weight were distributed in very thin films or sheets. Even in oil-in-water emulsions the surface area covered for a definite weight of oil will vary with the degree of dispersion of the oil, for the greater the dispersion the greater the surface area covered.

**The surface area covered determines the shortening power of a fat or oil in baked products.** The degree of shortening produced by a fat or oil in a given product depends primarily upon the surface area of the flour particles covered by the fat or oil. To a lesser degree shortening power may also depend upon the extent of separation of the egg and milk proteins and the sugar from the flour particles by the fat. The fats and oils are insoluble in the other ingredients of baked products. Thus they may to a greater or less degree mechanically separate the ingredients of the batter but they never entirely lose their identity or change their characteristics. If flour and water are mixed together and baked, the resulting product is very hard, firm, and tough. When the water is added to the flour the protein particles become hydrated and form a continuous phase, somewhat similar to a gel, throughout the mass. When coagulated by heat they form a cement-like structure throughout the dough. If fat or oil is mixed with the flour particles, and water is then added, the fat coats a portion of the flour particles and forms layers, sheets, or films between them, giving the baked product tenderness. The factors that affect the area of the flour covered are (1) manipulation, (2) temperature, (3) the ingredients used and their concentration, (4) the consistency of the fat or oil when added and its degree of unsaturation, and (5) the concentration of the fat.

*Manipulation.* The manipulative factors include creaming, the thoroughness with which the fat is mixed with the flour, and the manner of rolling, kneading, etc. In products containing sugar, if the fat and sugar are creamed so that air is incorporated, the product may be shorter or more tender. This will depend somewhat on the proportion of fat and sugar, and whether the maximum amount of air is incorporated. With certain proportions of fat to sugar more air can be incorporated. The increased shortness of the product may be attributed to the increased porosity. But creamed fat is also more plastic and thus more easily blended with flour. In addition the

sugar crystals absorb fat which may aid in distributing fat in a batter but will probably reduce the area of the flour covered by the fat and thus tend to reduce the shortening power of the fat. This may at least partially explain why wafers, made by adding sugar to a standard pastry dough, are shorter with creamed fats, and least short with oils, the order of shortening power being nearly reversed from the order in pastry.

In pastry the fat is mixed with the flour before the water is added. If this mixing is extensive so that the flour particles are well coated with the fat or oil, the product is shorter than when made from the same fat only slightly mixed with the flour. In the last instance the distribution of the fat increases and in the first decreases the heterogeneity of the final product. An oil or melted fat coats the flour particles more thoroughly with short mixing than a plastic fat. Noble *et al.* found flour added to the board when the dough was rolled lessened the shortening value of a modified shortbread.

*Temperature.* Temperature affects the plasticity of a fat and the mobility of a melted fat or of an oil. At lower temperatures the plasticity of fats such as butter is not great. They spread less readily and the area of flour and other particles covered is less with the same extent of mixing than at higher temperatures. But at higher temperatures the surface area covered by a melted fat may decrease because of the increased tendency to form an oil-in-water emulsion, particularly in thin batters. In addition, at temperatures at which the fat is melted or very soft the gluten absorbs water rapidly and becomes developed rapidly. This development of the gluten may offset increased shortening power owing to the soft fat coating a greater flour surface.

*The ingredients and their concentration.* When the proportion of water in the product is rather high, as in griddle cakes, waffles, and muffins, or in the so-called "pour" batters, the consistency of the batter permits the fat to form spheres easily because the batter is not stiff enough to deform the spheres entirely. Melted fat or oil is generally used in the "pour" batters. In addition the lecithio-protein of the egg yolk used in these products has strong emulsifying properties and increases the tendency to disperse the melted fat or oil as an oil-in-water emulsion. Observations have shown that the major portion of the fat, unless the fat solidifies and with the exception of fat adsorbed by the sugar crystals, is distributed as an oil-in-water emulsion in thin batters.

In biscuits and pastry, in which the proportion of water is relatively smaller, and because the method of adding the fat to the flour is different from that in the "pour" batters, the major portion of the fat is adsorbed by or coats the flour particles. In cake a plastic fat like butter, when creamed with the sugar, always produces a more tender product than when the butter is melted. And, in general, all plastic fats produce more tender cakes than oils or melted fats.

*Consistency of fat and degree of saturation.* Both these factors have been

considered. Obviously unsaturated glycerides have an opportunity to cover a greater surface area of the flour particles in biscuits and pastry because there are no emulsifying agents such as egg to tend to prevent their spreading.

*Concentration of fat.* Other things being standardized, the surface area covered is greater as the concentration of the fat or oil is increased.

Shortening power of a fat or oil varies in different products. Because of differences in methods of combining, in the concentration and kinds of ingredients, in concentration of the fat, in temperature of the fat, and in manipulative factors the shortening power of the same fat may vary in relation to that of other fats in different products. For example, butter generally produces tougher pastry than any of the plastic fats or the oils commonly used in food preparation, but butter generally produces more tender cakes than oils. The more tests one makes to determine the shortening power of fats and oils, the more one hesitates to make dogmatic statements about the comparative shortening powers of various fats. However, in considering the comparative shortening power of fats and oils, the results published in the literature are usually based on the performance of the fat in pastry only.

### Summary of Experimental Work by Different Investigators on Shortening Power of Fats and Oils

A machine to test the shortening power of cooked foods needs to be very sensitive. Davis has devised such a machine, called a shortometer. From tests upon cookies he reports lard to be the best shortening agent. He gives no explanation of the results obtained.

Platt and Fleming have stained fats and oils with Sudan III, a red dye soluble in fats but not soluble in water, and examined the baked products and the batter, in this case cookies, under the microscope. They find the fat to be in thin layers between the starch granules when the material is mounted dry. In some instances the fat completely surrounds the starch granules; in others the granules touch with no fat layer between them. These layers of fat, which physically separate different parts of the dough and prevent them from coming together in a solid mass, vary in thickness in different sections of the dough. To have the best shortening effect a fat must adhere to the flour particles and not be squeezed out by pressure. They give the following order for the shortening power of different fats, lard having the greatest shortening power.

- Lard
- Lard compound
- Cottonseed oil
- Butter
- Coconut oil
- Vaseline
- Purified petroleum oils, as Nujol

For these differences in shortening power, Platt and Fleming have suggested that the following factors have minor or major effect: viscosity, surface tension of oil, the melting point of the fat, and orientation of the molecule due to double bonds of the fatty acid chains of the glycerides. The following is a short summary of their article.

Viscosity gives a fat the power of spreading easily in the dough; a more viscous fat will run out of the dough less readily in baking, but it is of relatively little importance in shortening power, as shown by the fact that some of the petroleum products were as viscid as lard but gave less shortening power.

A melting point close to that of lard seems desirable, yet this factor alone is not a satisfactory explanation in all cases, as coconut oils may be prepared having the same melting point as butter but less shortening power.

Plasticity gives a fat the ability to spread easily, which is beneficial; but the fact that the oils having no plasticity give greater shortening power than butter shows that plasticity is only one of the important factors.

Owing to orientation of molecules, fats containing unsaturated glycerides cover a greater surface area than those with saturated glycerides. The shortening power of fats tested, with the exception of lard and lard compound, was in the same order as the percentage of unsaturated glycerides contained by the fats.

The author has found that an oil is partially or wholly emulsified as an oil-in-water emulsion in uncooked cake batter. However, the cake batter contained milk and egg, whereas the cooky batter of Platt and Fleming did not contain milk. In cake batters an unmelted fat is distributed in sheets, layers, or films of different thicknesses between the starch granules, and around the air bubbles and sugar crystals. Whether the oil remains emulsified during baking of a cake batter might have some effect on the finished product, but the distribution of the oil or fat when the batter or dough is being mixed undoubtedly affects the tenderness, for this is the period when the gluten is being developed.

Sudan III was first used in oils and fats. In trying to take photomicrographs it was found that the Sudan III dye was not always deep enough in value to give a clear picture. Dr. Benbrook and Miss Sloss of the Veterinary Department suggested using Scarlet R or Scharlach R, which stained the fat or oil a deeper color than Sudan III. It was a surprise to find that Scarlet R aided in locating some distributions not found with Sudan III. Often the dyed fat can be seen through the microscope when the color is not intense enough to show clearly in a photomicrograph.

Fisher found lard to have the greatest shortening power of the plastic fats tested in pastry. Using 41 and 44 per cent of fat (based on weight of the flour) she found the shortening value of 5 lards, 2 hydrogenated cottonseed oils, 1 hydrogenated lard, an animal stearin, and 1 all-vegetable oil compound as determined by breaking strength with the Bailey Shortom-



eter approximately paralleled their congealing points, those fats having the lowest congealing point having the greatest shortening power.

Noble, McLaughlin, and Halliday investigated several factors influencing the apparent shortening value of a fat, using a modified shortbread (sugar added to a pastry formula). They found that creaming the fat and sugar to a maximum volume produced wafers with smaller breaking strength, as determined by a Bailey Shortometer, than when the same fat was creamed to a minimum volume. Also after adding the flour and liquid to the creamed mass, thorough mixing so that no spots of creamed fat and sugar showed produced markedly more tender wafers than when the dough was incompletely mixed. If no flour was sprinkled on the board for rolling, wafers markedly more tender resulted than when the minimum amount of flour to prevent sticking was used. Beating the extra flour into the dough gave a more tender product than using it in rolling but a less tender one than omitting it entirely.

**Shortening experiments with pastry.** Denton and Lowe have determined the shortening power of different fats in pastry. "Pastry was chosen for the baked product in their experiments, as it is commonly used, contains a large proportion of fat and is made with a small number of ingredients. In addition to fat it contains water, flour, and salt." The pastry was mixed in a KitchenAid and the materials were incubated before mixing, so that the temperature of the ingredients when mixed was 80°F.

Denton and Lowe used the shortometer as designed by Davis for the shortening tests. Weight is applied at the upper end of a vertical rod. At the lower end of the rod a bar is attached which rests across the material to be broken. The crushing strength was determined by substituting for the bar a rod which punctured a hole in the pastry. Sometimes the weight rested an appreciable length of time on the pastry before breaking or crushing occurred. Thus they found in the breaking and crushing tests that the rate at which the load is applied and the time through which the load acts are both factors in determining the breaking and the crushing strength of pastry, which is quite fragile. In order to obtain a more uniform rate of loading than with shot they used mercury, run from a burette into a receptacle resting on a cap at the top of the shortometer. Thus the weight or load for crushing the pastry gradually increased.

Denton and Lowe found that in general the fats and the oils having the highest percentage of unsaturated glycerides gave the shortest pastries. They found an exception in butter, which gave less shortening power than coconut oil, although moisture-free butter, with only the butter fat used, drained free of curd, produced a very tender pastry. Here the heating of the butter fat to render it moisture free may have affected its shortening power.

From data, Table 65, it can be seen that the order for different fats in the table varies in some cases according to whether the crushing or the breaking average is taken. Therefore, the results should be taken in groups

TABLE 65\*

BREAKING AND CRUSHING STRENGTH OF DIFFERENT PASTRIES MADE UNDER STANDARDIZED CONDITIONS. (EACH FIGURE AN AVERAGE OF 48 TESTS.) TEMPERATURE OF INGREDIENTS WHEN MIXED 80°F. (*Denton and Lowe*)

Kind of fat	Melting point, °C.	Grams to break	Grams to crush
Puff pastry shortening.....	61.0	612	1380
Nutmargarine.....	28.4	644	1096
Puff pastry shortening (moisture free).....		592	1000
Butter, sample I.....	34.7	530	902
Butter, sample II.....		525	802
Petrolatum.....		402	680
Mineral oil, purified.....		418	635
Nutmargarine (moisture free).....		340	554
Coconut oil.....		333	588
Commercial coconut fat.....	19.5	334	537
Lard, all leaf, sample II†.....	44.6	350	532
Lard, all leaf, sample I.....		344	477
Lard, largely leaf, sample I.....	40.6	327	487
Lard, largely leaf, sample III.....		276	527
Hydrogenated cottonseed oil.....		317	506
Lard, bulk.....	45.4	316	466
Cottonseed oil, emulsion made of oil and water.....		266	528
Lard, second grade.....	41.4	261	398
Butter, moisture-free, curd removed.....		268	387
Cottonseed oil.....		249	399
Corn oil.....		240	399
Chicken oil or fat.....		233	375

\*Published by courtesy of Dr. Louise Stanley, Chief, Bureau of Home Economics. Experimental work on pastry done at the Bureau of Home Economics, Washington, D. C.

†Average of 96 tests.

rather than individual experiments. The oils, corn, cottonseed, and chicken gave the most tender pastries. The pastries next in order were obtained with second-grade lard, bulk lard, or when a temporary emulsion was made by shaking the oil and the water and then adding this emulsion quickly to the flour. The latter is a method often suggested in recipes, as it tends to produce a flakier and less crumbly pastry than when the oil is first mixed with the flour and the water added last.

**Puff pastry shortening.** The puff pastry shortening is a product containing about 30 to 45 per cent of oleostearin and from 45 to 60 per cent of cottonseed or other vegetable oil. It is prepared by mixing the ingre-

dients and heating to a common melting point, mixing, chilling in water, and working. The finished product has 7 to 10 per cent of moisture. It is very waxy, and is easily rolled in thin layers for use in puff pastry, for which it produces excellent results, but it is poor for ordinary pastry.

**Butter and margarine.** Butter and margarine gave a very hard pastry. The emulsified fats, such as butter, margarine, and puff pastry shortening, gave harder pastries than their moisture-free products. To render the butter and margarine moisture free, they were heated at 75°C.

**Class results.** Class results are in agreement with results by the shortometer. There is enough difference in the shortening power of different fats, so that pastries in which butter, lard, hydrogenated fats and oils, and oil have been used can be placed in order of tenderness by breaking with the fingers, if the pastry has been made under standardized conditions. Butter gives the hardest and toughest, and oil may give the most tender. The lards usually give more tender pastry than the hydrogenated fats or hydrogenated oils. Observing housekeepers often state that they obtain shorter pastry from second-grade lard, although the odor and flavor may not be so good as the first-grade lard. Second-grade lards contain a higher percentage of the unsaturated glycerides. Two types of pastry are obtained with oil. If the pastry is crumbly, the oil yields the most tender pastry of the series. However, if it is flaky, the pastry may be about as tough and hard as that with butter or like the lard. These two types are probably due to the temperature of the ingredients when mixed, the thoroughness with which the oil is mixed with the flour before the water is added, the extent of mixing the water with the flour, and the proportion of water. Longer mixing after the water is added seems to increase the flakiness of the pastry made with oil. For several quarters the class has had only flaky pastry with oil, the pastry being mixed 40 to 50 strokes with a three-tined fork.

Increasing the fat results in a more tender pastry. Increasing the water in a given recipe decreases the tenderness of pastry. If both fat and water are increased, the result depends upon the proportion of each used; but unless the increase in fat is very small, the resulting pastry is more tender, the fat having a greater effect than the water. The gluten of pastry flour cannot be developed to the extent that gluten of bread flour can; thus pastry flour gives a more tender pastry than bread flour if the conditions under which the pastries are made are standardized.

**Effect of extent of mixing on shortness of pastry.** The extent of mixing after the water is added affects the shortness of pastry. It is rather interesting that, although longer mixing, a great deal of handling, and rerolling tend to increase the toughness of pastry, mixing the water and flour with a fork or a utensil which cuts through the dough instead of packing it, as in Experiment 95B, for 40 to 50 strokes, usually gives a more tender pastry than mixing 20 to 30 strokes. But handling the pastry after it is mixed, i.e., kneading and rerolling, increases its toughness,

though very careful rerolling may increase the flakiness without materially increasing its toughness.

**Flakiness.** Flakiness is considered a desirable quality in pastry. Melted fats and the oils usually give a more crumbly and a less flaky crust, although a flaky crust is often obtained with oil or melted fat. Bread flour tends to give a more flaky crust than soft-wheat flour. The temperature of the ingredients may affect the flakiness. With the harder fats there is a greater tendency for the fat to stay in layers, as flakiness depends upon the layers of fat and flour being separated by steam and probably to a lesser extent by air in the baking. The proportion of water to fat has some effect. When the proportion of water to fat exceeds or falls below a certain ratio, the pastry is less flaky. The extent of mixing the fat with the flour, as well as the method of combining the water, by mixing or by cutting the water into the fat and flour, may also influence the flakiness of the pastry. The method of handling the dough may have some effect. Rerolling and careful handling may increase flakiness and also toughness. The flakiness of pastry is also increased by rolling with thin layers of fat between layers of the dough.

**Soaking of crust in baking pies.** Excessive soaking of the crust during and after baking occurs most frequently with fruit pies, as cherry, blackberry, blueberry, and loganberry, and custard pies. Many suggestions to prevent soaking have been offered and these have been collected in Experiment 98. Tests, using pastry made in one batch and rolling all to the same thickness, have shown that partially baking the under crust before adding the filling only increases the soaking. Brushing the under crust with butter or fat aids to a certain extent, but for cooked or canned fruit thickening the juice before adding the filling to the pastry is the most effective means of preventing soaking. If fresh cherries or berries are used, then mixing flour or cornstarch with the sugar is as good as cooking the fruit first before adding it to the pie. The only advantage of cooking and thickening fresh fruit before adding the hot filling to the pastry is that it shortens the cooking time in the oven.

The best way to prevent soaking of the crust in custard pie has been mentioned in the chapter on eggs, that is, cooking the filling and pastry separately. If this is not desirable, scalding the milk before adding it to the eggs and using 3 eggs to a pint of milk help the custard to set more rapidly.

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## FATS AND OILS

### Experiment 89.

To determine the smoking temperatures of different fats.

Use, preferably, evaporating dishes or small sauce pans of the same size. Have the fat come to within 1 inch of the top of the dish. Heat the fat slowly. When you see the first puff of smoke, record the temperature of the fat. Cool and take the smoking temperature a second time. Compare the smoking temperature of olive oil, cottonseed oil, peanut oil, corn oil, fresh hydrogenated fat, lard, used lard, and used hydrogenated fat.

Kind of fat	Smoking temperature

**Experiment 90.**

To determine the factors which may cause variations in the smoking temperature of the same fat.

1. Take the temperature of used hydrogenated fat or used lard in a large kettle. Compare with the smoking temperature of used hydrogenated fat or used lard in the small dish under Experiment 89.

2. Take the smoking temperature of hydrogenated fat to which 1 tablespoon of flour has been added. Compare with the smoking temperature of hydrogenated fat under Experiment 89.

Smoking temperature
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**Experiment 91.**

Household tests for determining the temperature of fats.

Find the temperature of a fat when a cube of dry bread browns in 60 seconds; in 40 seconds; in 20 seconds.

Make the first test when the fat is at 170°C. (340°F.). Which temperature is said to be used for cooking raw foods? For browning cooked foods?

Seconds	Temperature

**Experiment 92.**

To determine the temperature at which foods actually cook.

Use potatoes sliced and cut into strips, and croquettes. When the fat has reached the temperature which has been decided as best for cooking raw foods under Experiment 91, immerse the food in the fat. Watch the temperature of the fat as the food cooks. Note also the time required to brown the food. Do you think as a result of this experiment that heating a fat to its smoking temperature always gives a desirable temperature for cooking foods?

Kind of food	Temperature of fat	Temperature of fat during cooking	Length of time to cook	Fat absorbed	
				Grams	Per cent

**Experiment 93.**

To determine the tendency of fats to retain the flavor of food that has been cooked in the fat.

Use hydrogenated fat, cottonseed oil, lard, or other fat or oil. Cook fish or onions in the fats, then potato cut in strips. Cook croquettes also. Do the potato and croquettes taste of fish or onions?

### Doughnuts

#### Experiment 94.

To determine the factors which influence the tenderness, the texture, and the amount of fat absorbed in doughnuts.

*Recipe:*

Flour	5¼ cups	588 grams or use the amount found best under A	
Baking powder		2 tablespoons	21 grams
Salt		1 teaspoon	4 grams
Sugar		1 cup	200 grams
Fat		2 tablespoons	25 grams
Eggs		2	96 grams
Milk		1 cup	244 grams
Nutmeg		⅛ teaspoon	
Cinnamon		⅛ teaspoon	

It is more convenient to work in groups of five or six girls for the doughnut experiments. It will take two girls to fry the doughnuts; one to watch the temperature, one to time, to put the doughnuts in, turn, and take them out of the fat. Or a third girl may time the cooking. One girl should do all the mixing, doing it in the same way each time and with the number of strokes designated under each experiment. Another girl should do all the rolling and cutting, handling each batch in the same way and trying not to stretch or pull the cut dough out of shape. Other girls may weigh the materials. The eggs should be beaten together for all the experiments to be done by the group in one period. It is best not to use the results of the first mixing for comparisons but to use them for obtaining technic in handling the dough in mixing, cutting, and cooking.

*Directions for mixing.*

Remove the flour for rolling before the baking powder is added to it. Sift the flour and baking powder together 2 times. Combine the thoroughly beaten eggs, sugar, salt, and softened or melted fat, mixing until very light and fluffy. Use the same kind and size of bowl for mixing the materials for each experiment. Add the milk and flour to the other ingredients and mix the designated amount.

Roll the dough between boards ¼ or ⅜ inch in thickness, tacked to a bread board, so that all the doughnuts will be the same thickness. Each group should use cutters that have the same diameter. If the dough is divided into 2 parts and each half rolled in part of the flour and shaped into a long roll before placing between the boards it facilitates ease of handling. There should be 3 doughnuts from each part of the dough and 6 for each experiment.

In cooking, the doughnuts should be turned when half of the time allowed for cooking is gone. When the time is up, lift each doughnut quickly from the fat onto a skewer held over the kettle so that the fat will drain back into the kettle. The doughnuts should be turned and taken out in the same order they are put into the fat.





## C. Temperature and time of cooking.

Prepare  $\frac{1}{4}$  of the recipe. Use the proportion of flour found best under A, and mix with the number of strokes found best under B.

1. Cook 2 minutes at 155° to 160°C. (310° to 320°F.).
2. Repeat C1, but cook 3 minutes.
3. Repeat C1, but cook 4 minutes.
4. Repeat C1, but cook 2 minutes at 175° to 180°C. (345° to 355°F.).
5. Repeat C1, but cook 3 minutes at 175° to 180°C.
6. Repeat C1, but cook 4 minutes at 175° to 180°C.
7. Repeat C1, but cook 2 minutes at 195° to 200°C. (380° to 390°F.).
8. Repeat C1, but cook 3 minutes at 195° to 200°C.
9. Repeat C1, but cook 4 minutes at 195° to 200°C.

D. To determine the effect of letting the dough stand a short time before cooking upon fat absorption.

1. Prepare all the recipe. Reserve 4 tablespoons of flour for rolling. Use the proportion of flour found best under A and the number of strokes for mixing found best under B. Use the time and temperature of cooking found best under C. Use approximately  $\frac{1}{4}$  of the dough and cook the doughnuts as soon as possible after mixing and rolling.

2. Use approximately  $\frac{1}{4}$  of the dough and let the doughnuts stand  $\frac{1}{2}$  hour or longer after rolling and cutting before they are cooked. Use the remaining dough for the following experiments.

3. Let approximately  $\frac{1}{4}$  of the dough from D1 stand for  $\frac{1}{2}$  hour or longer; then roll, cut, and cook the doughnuts.

4. Let  $\frac{1}{4}$  of the dough from D1 stand  $\frac{1}{2}$  hour or longer. After the dough has stood, mix with 10 additional strokes before rolling.

If desired,  $1\frac{1}{4}$  times the recipe may be mixed and one part of the dough chilled  $\frac{1}{2}$  hour or longer before rolling.

E. To determine the effect upon the texture and fat absorption of increasing the proportion of sugar.

1. Prepare the full recipe, using the proportion of flour found best under A. Reserve 4 tablespoons of flour for rolling. Increase the sugar to  $1\frac{1}{2}$  cups (300 grams). Mix 140 strokes with a wooden spoon and remove approximately  $\frac{1}{4}$  of the dough (about 300 grams). Roll according to directions. Cook 6 doughnuts at 175° to 180°C. for 3 minutes or at the temperature and time found desirable under C.

2. Mix the remaining dough from E1 a total of 160 strokes and remove approximately 300 grams. Follow directions under E1.

3. Mix the remaining dough from E2 a total of 180 strokes and remove approximately 300 grams. Follow directions under E1.

4. Mix the remaining dough from E3 a total of 200 strokes. Follow directions under E1.

F. To determine the effect upon the texture and fat absorption of increasing the fat in the recipe.

1. Increase the fat in the recipe to 4 tablespoons. Prepare  $\frac{1}{2}$  the recipe, reserving 2 tablespoons of flour for rolling. Use the proportion of flour found best under A. Mix 80 strokes with a wooden spoon and remove approximately  $\frac{1}{2}$  of the dough (about 280 grams). Follow directions under E1.

2. Mix the remaining dough from F1 a total of 100 strokes. Follow directions under E1.

G. To determine the effect upon the texture and the fat absorption of increasing the egg in the recipe.

Increase the eggs in the recipe to 3. Repeat directions for F.

H. To determine the effect upon the texture and fat absorption of adding the flour and milk in portions.

Prepare  $\frac{1}{4}$  of the recipe. Use the proportion of flour found best under A and the number of strokes found best for mixing under B. Follow directions for cooking used for B. Compare with doughnuts from B. Add approximately  $\frac{1}{3}$  of the flour and  $\frac{1}{3}$  of the milk to the egg-sugar mixture. Stir approximately  $\frac{1}{3}$  of the total number of strokes to be used for mixing. Add the second  $\frac{1}{3}$  of the milk and flour, stirring  $\frac{1}{3}$  of the total number of strokes. Add the remainder of the flour and milk and stir the number of strokes needed to make the total desired.

If the flour and milk are to be stirred a total of 80 strokes, the first  $\frac{1}{3}$  may be stirred 25 strokes, the second  $\frac{1}{3}$  25 strokes, and the remainder of the flour 30 strokes to make a total of 80 strokes.

What is the effect of increased mixing of the dough upon fat absorption in doughnuts? Does the dough become more or less sticky with longer mixing? Which amount of mixing gives the best flavor and the best texture? The least fat absorption? What is the effect of length of time of cooking upon fat absorption of doughnuts? The effect of temperature of cooking? Compare the dough that has stood with the dough that did not stand, in respect to the ease of rolling and the consistency. Does chilling increase the ease of rolling? What is the effect upon the texture and the fat absorption of standing before cooking?

What is the effect of increasing the sugar in the recipe upon fat absorption? Upon texture? Does increase of sugar in the recipe require longer mixing of the dough? Is there any relation between the texture of the doughnuts with increased sugar and the texture of cakes when the proportion of sugar is increased? What is the effect of increasing the proportion of egg upon the texture of the doughnuts? Upon fat absorption? Of increasing the fat? Adding the flour in portions instead of all at once? Which doughnuts have the best texture? The best flavor?

Write a summary of the factors that affect the fat absorption in frying doughnuts. Compare your results with those published in the literature, and with previous classes.

Suggestions for additional experiments with doughnuts.

1. Vary the method of mixing.
2. Vary the kind of fat used and its temperature when added to the doughnuts.
3. Determine the amount of mixing that is desirable with each type of baking powder.
4. Turn the doughnuts several times during cooking.

### Pastry

#### Experiment 95.

To determine the factors that influence the quality of pastry.

*Recipe:*

Flour, all-purpose	1 cup	112 grams
Fat	$\frac{1}{3}$ cup	66 grams
Salt	$\frac{1}{2}$ teaspoon	2 grams-
Water		

*Directions for mixing:*

The flour may be either a hard- or soft-wheat all-purpose one. If a soft-wheat flour is used, it is probably preferable to reduce the proportion of fat to  $\frac{1}{4}$  cup (50 grams).

Place the weighed flour and the salt in a bowl, add the fat, and cut into the flour with a fat cutter. The fat may be worked into the flour by rubbing between the tips of the fingers. The fat should be mixed with the flour until the mixture resembles coarse corn meal. The number of strokes required to cut the fat into the flour will vary, the hard, cold fats requiring far more strokes than the softened fats or the oil. A record may be kept of the number of strokes required for comparison of ease of mixing. In mixing the fat with the finger tips, work quickly so as not to melt the fat. Compare your fat and flour mixture with your neighbors' to see if they are about the same consistency. Add the water in such a manner that it is distributed rather evenly over the flour mixture. Cut the water into the fat and flour, or stir with a two-tined fork.

The pastry rolls better if allowed to stand about 5 minutes after mixing. Then work into a ball, using 8 motions of the hand to get the material together. In rolling the pastry some can be rolled without adding flour to the board, but do not use more than 1 teaspoon of flour for each pastry. The pastry may be rolled between boards  $\frac{1}{8}$  to  $\frac{3}{16}$  inch in thickness, which are tacked to the bread board. Strips of wax paper just wide enough to fit between the cleats may be used for rolling and handling the pastry. One piece of paper is placed between the cleats. The dough to be rolled is placed on this paper and a second sheet of paper is placed over the dough. After rolling the top paper is removed. The dough is lifted on the lower sheet of paper and is placed on the baking sheet or tin by inverting the paper, pressing lightly, and then removing the paper. If the dough is rolled in long strips, it should be shaped into a long strip before rolling. For the pastries in which the proportion of ingredients is changed until they will not roll easily, the pastry can be partially rolled, then placed in the pan and patted quickly to the same thickness as the rolled pastry. If the pastries are not the same thickness they bake differently and require different lengths of time for baking.

Bake in pans of the same size, shape, and material. Bake at 220° to 225°C. (425° to 435°F.), until a light golden brown.

A. To determine the proportion of water to give a desirable pastry with the brand of flour used.

1. Use 24 grams or cc. of water for the full recipe. Mix 40 strokes with a two- or three-tined fork.

2. Repeat A1, but use 30 grams or cc. of water for the full recipe.

3. Repeat A1, but use 36 grams or cc. of water for the full recipe.

4. Repeat A1, but use 42 grams or cc. of water for the full recipe.

B. To determine the extent of mixing required to give a desirable pastry.

1. Prepare the full recipe, using lard or other fat. Cut the fat into the flour as outlined in the directions. Use the proportion of water found best under A and mix 20 strokes with a two- or three-tined fork. Remove approximately  $\frac{1}{4}$  of the dough (about 44 grams). Roll and bake.

2. Mix the remainder of the dough from B1, a total of 30 strokes. Remove about 44 grams of the dough and bake.

3. Mix the remainder of the dough from B2, a total of 40 strokes. Remove about 44 grams of the dough and bake.

4. Mix the remainder of the dough from B3, a total of 50 strokes. Roll and bake.

C. To determine the effect on shortness of the pastry of using different kinds of fat.

1. Use an all-purpose flour and butter. Repeat directions under B. Use the proportion of water found best under A.

2. Repeat C1, but use a hydrogenated cottonseed oil.

3. Repeat C1, but use lard.

4. Repeat C1, but use oil.

5. Repeat C1, but use a hydrogenated lard.

The following headings are suggested for pastry records.

Number of strokes		Appearance	Flakiness	Tenderness	Flavor
For cutting fat	For mixing water				

D. To determine the effect of type of flour.

If a hard-wheat flour has been used, substitute a soft-wheat flour or *vice versa*. Repeat B using any fat desired.

What is the effect of increased mixing upon the tenderness of pastry? Upon its flakiness? Which amount of mixing results in the best pastry? What is the effect of substituting soft-wheat for hard-wheat flour? Can the fat be reduced when pastry flour is used? Can the pastry-flour pastries be mixed longer than bread-flour ones? Which pastries roll easiest? Which are difficult to handle? Which fat gives the shortest pastry? Which the toughest? Which fat produces the most flaky pastry? Which the least flaky?

E. To determine the effect of varying the proportion of ingredients.

1. Increase the fat to 100 grams or  $\frac{1}{2}$  cup and the water to 6 grams more for the full recipe than that found best under A. Use bread flour and butter. Mix the water with the fat and flour with the number of strokes found best under B.

2. Repeat E1, but use hydrogenated cottonseed oil.

3. Repeat E1, but use lard.

4. Repeat E1, but use oil.

5. Repeat E1, but use hydrogenated lard.

F. Decrease the fat in the full recipe to 50 grams or  $\frac{1}{4}$  cup. Use all-purpose flour and any fat desired. Use the proportion of water found best under A. Mix with the number of strokes found best under B.

### Experiment 96.

To determine the effect of the temperature of the ingredients when mixed upon the texture and tenderness of pastry.

1. Use all-purpose flour and lard. Use the proportion of water found best under 95A, and mix with the number of strokes found best under 95B. Use ice water and chilled fat.

2. Prepare twice the quantity used in the other experiments. Repeat 1, but have the water boiling. Add the fat and stir until the fat is melted. Then add the flour and salt and mix with the number of strokes found best under 95B. Divide in two portions. Roll and bake one part. Use the other portion for 3.

3. Chill the dough remaining from 2 before rolling.

4. Repeat 1, but melt the fat before cutting into the flour.

Which gives the flakiest pastry? Is the pastry made with hot water difficult to roll unless chilled? What is the effect of melting the fat upon the texture of the pastry?

### Experiment 97.

To determine the effect of mixing by different methods and continued rolling upon pastry.

1. Repeat Experiment 96,1, but prepare twice the quantity used in the other experiments. Roll and bake half the dough. Use the other portion for 2.

2. Reroll the dough remaining from 97,1, four or five times and bake. Compare with 97,1, for flakiness and tenderness.

3. Use all-purpose flour and lard. Use the proportion of water found best under 95A. Put all the ingredients in the mixing bowl together. Then cut with knives until the dough is the consistency to roll. Compare with other methods of mixing.

4. Use all-purpose flour and lard. Mix the fat very thoroughly with the flour. Use the proportion of water found best under 95A. Add the water and mix with the number of strokes found best under 95B.

5. Repeat 97,4, but cut the fat into the flour with only a few strokes, leaving the fat and flour coarsely flaked.

6. Decrease the fat in the full recipe to 40 grams. Use all-purpose flour and the proportion of water found best under 95A. Mix with the number of strokes found best under 95B. After rolling the dough add 5 grams of fat in small flakes over half the rolled dough. Fold the dough and reroll. Add 5 more grams of fat and reroll. Bake.

What is the effect of rolling the dough several times upon the tenderness of the pastry? Its flakiness? Can a good pastry be obtained by combining all the ingredients at one time? Does adding a portion of the fat while rolling increase the flakiness of the pastry? Its tenderness?

### Suggested Additional Experiments

1. Use other fats in addition to the ones given in the outline.

2. Reduce the proportion of the fats and the oil, and find the amount equivalent to 50 grams of butter, as far as can be determined from breaking the pastries with the fingers.

3. Make a temporary emulsion of the oil and water. Then add quickly to the flour and mix.

4. Spiced pastry. Add  $\frac{1}{2}$  teaspoon of a spice mixture to the pastry recipe, Experiment 95. It may be any mixture of spices desired or the following:  $\frac{1}{3}$  teaspoon cinnamon,  $\frac{1}{6}$  teaspoon nutmeg,  $\frac{1}{4}$  teaspoon allspice, and  $\frac{1}{4}$  teaspoon cloves.

**Experiment 98.**

To determine the best method of preventing juicy fruit soaking the crust in pies.

Make enough pastry at one time for all the tests. It can be made on a KitchenAid or mixed by hand. It is preferable, if possible, to roll all the pastry the same thickness. A large rolling pin may be made or a rod used to roll the pastry the same thickness. The cleats between which the dough is rolled should be placed wide enough apart on the bread board so that when rolled the dough is large enough for the pans used. See directions under Experiment 95. Bake at 220° to 225°C. (425° to 435°F.). The temperature may be lowered if necessary for the last part of the baking. One-half tablespoon of butter for each cup of fruit improves the flavor.

Use an upper and a lower crust in baking the pies. Use a fruit that is juicy. Sweeten the fruit in one large container. Then divide into equal portions for each pie.

1. Use the sweetened juicy fruit for a control.
2. Brush the top of the under crust with melted butter. Then add the sweetened fruit.
3. Brush the top of the under crust with egg white. Add the sweetened fruit.
4. Partially bake the under crust. Then add the fruit and upper crust. Bake.
5. Drain the juice off the fruit and thicken with cornstarch. Use 1 tablespoon of cornstarch for every cup of juice from very sour fruit with thin juice; but use a smaller proportion of cornstarch for fruit juice that is not very tart. Boil the juice and cornstarch. Remove from the fire and add the fruit. Add to the rolled dough while the fruit is still warm. Bake. Is the baking time of the pie shortened when the fruit is added to the dough while warm?
6. Sprinkle the top of the lower crust with flour. Add fruit.
7. Mix the cornstarch or flour with the sugar. Add to the fruit. Use the same proportion of cornstarch as given under 5.
8. Repeat 1, but bake the pie at a much lower temperature than that used for the other pies.

If desired, the series may be repeated using fresh fruit.

Keep portions of each pie until the next day to compare the amount of soaking on standing. The addition of a small amount of butter and salt to the fruit in each pie will improve the flavor.

Appearance	Sogginess of crust		Flavor
	At first	On standing	

Results and conclusions.





## INDEX

- Absorption at interfaces, 14  
Acid, cooking of meat, 223  
Acidity, juices for jelly, 162  
Acids,  
    acetic, 107  
    in jelly, 161  
    citric, 107, 108, 109, 162, 166  
    coagulation of proteins, 18  
    combination with,  
        gelatin, 179, 181  
        metals of utensils, 110  
        proteins, 12  
        vegetables, 107-108  
    curdling of milk, 12, 304  
    dispersion by, 5  
    fruit, 108-109  
    fruit juice, 161  
    jelly, effect of, 160-163  
    malic, 107, 108, 109, 169  
    oxalic, 107, 108, 109, 169  
    plant, 106-110  
        non-volatile, 107  
        volatile, 107  
    starch and, 411  
    tartaric, 107-109, 156, 161, 162, 164,  
        169, 185  
    vegetable, 107  
Acrolein, 547  
Adhesion, 18  
Adipose tissue, 200  
Adsorption, 16  
Albumin,  
    egg, 330, 333, 334  
    milk, 298  
Alkalies,  
    adding to milk, 307-308  
    combination with,  
        gelatin, 181, 184  
        proteins, 11  
        vegetables, 112, 116, 129  
    dispersion by, 5  
    jelly, effect of, 156  
    proteins, coagulation, 18  
Amino acids,  
    and dextrose, 309  
Ammonia, baking, 448  
Amorphous sugar, 39, 54  
Amphoteric colloids, 11  
Angel cake, see Cake, angel  
Anthocyanins, 116-121  
    and metals, 120  
    reactions of, 116  
Apples, cooking of, 132  
Aromatic compounds, 129  
Bacon, 212, 229, 264  
Bacteria,  
    cheese, 312  
    meat, 213, 217  
    milk, 304  
    pickles, 130-131  
Baking powder, 450-456, 460  
    brown spots from, 455  
    cakes, 481, 504-506, 515  
        optimum amount, 504-506  
        temperature for baking, 474  
    carbon dioxide from, 450  
        lost from batters, 453  
    fineness of division, 455  
    ideal, 450  
    muffins, 470-471  
    phosphate, 451  
        reactions, 451  
    sulfate-phosphate, 452  
        reactions, 452  
    tartrate, 451  
        reactions, 451  
    temperature for reaction, 452  
    types of, 450-456  
    weight, 1 t., 505  
Batters and doughs,  
    electrolytes in, 457  
    experiments for, 519-541  
    ingredients of, 459-461  
    mechanical treatment, 457  
    methods of mixing, 457  
    mixing,  
        effect on flavor, 459  
        effect on texture, 456  
        optimum amount, 458  
    structure of, 456-460  
        affected by,  
            electrolytes, 457  
            extent of, 459  
            mechanical treatment, 457  
            method of mixing, 458

- Batters and doughs—(*Continued*)  
 structure of—(*Continued*)  
 affected by—(*Continued*)  
 proportion ingredients, 457  
 temperature of, 458  
 temperature ingredients, 458
- Beans, dried, 135-141  
 Lima, 141  
 mineral content of water, 136, 141  
 navy, 136-140  
 pectic substances of, 138  
 pinto, 141  
 soda and, 139, 141  
 soy, 141
- Beaten biscuits, 472
- Beef,  
 classes, 194  
 connective tissue, 202, 204, 205  
 cooking of, 254-257  
 dried, 212  
 grades, 196  
 less tender cuts, 260-261  
 ribs, 226, 254-257
- Beet sugar in jelly, 169
- Beets, 116, 120
- Biscuit, 471-473  
 beaten, 472  
 experiments for, 528-530  
 method of mixing, 472
- Bisque, 96
- Boiling point,  
 elevation of, 47  
 ionized substances upon, 48  
 lowering of, 47  
 solutions, 48  
 sucrose, 49
- Boundary phenomena, 13
- Bran, 398
- Bread,  
 baking of,  
 temperature, 435  
 time, 435  
 experiments for, 443-446  
 fermentation, 425, 431-436  
 action of enzymes, 425, 431  
 dispersion of gluten, 432  
 imbibition during, 432  
 length of, 433  
 reaction, 432  
 treatment during, 429-436  
 flavor due to, 435  
 improvers, 432  
 manipulation of dough, 429-430  
 mechanical treatment, 429-430  
 extensibility, 429
- Bread—(*Continued*)  
 methods of mixing, 428-444  
 sponge process, 428  
 straight-dough process, 428  
 microorganisms in, 431  
 mixing of ingredients, 425-429, 444  
 pans for, 434  
 greasing of, 430  
 preparation of materials, 425, 444  
 proportion of ingredients, 425-428  
 rosy, 438  
 soft-wheat flour in, 435  
 amount of ingredients, 436  
 staling of, 436-438  
 temperature for enzymes, 424
- Brittles, 68
- Broilers, 245, 246
- Bromelin, 124, 308
- Butter, 295-297, 542, 543, 544, 570, 571  
 churning of, 297  
 creaming of, 296  
 fatty acids of, 295  
 flavor of, 295  
 in cake, 479-484  
 in pastry, 570, 571
- Butter fat,  
 size of globules, 297  
 test for, 297
- Butterscotch filling for pies, 337
- Cabbage,  
 cooking time, 127  
 experiments for, 147  
 red, 119  
 sulfur compounds, 128
- Cake, chocolate, 511-516  
 baking, 477  
 experiments for, 536-538  
 reddish color of, 515
- Cake, plain, 479-510  
 experiments for, 531-535  
 extent of mixing, 498  
 appearance, 498  
 crust, 498  
 texture, 499  
 volume, 498  
 formulas for, 507  
 methods of mixing,  
 cake mixer, 485  
 conventional, 482  
 conventional-sponge, 488  
 emulsion, 488  
 muffin, 485  
 optimum mixing for, 502  
 staling of, 503

- Cake—(*Continued*)  
 tunnels of, 499  
 varying ingredients in,  
   baking powder, 504  
   egg, 506  
   fat, 507  
   sugar, 506  
 Cake, sponge, 372  
   experiments for, 390  
 Cake, white, 516  
   experiments for, 538  
 Cake formulas, balancing of, 507  
 Cakes,  
   baking, 474-479  
   cooling of, 478  
   creaming fat for, 479-485  
   emulsions in, 496  
   ingredients used in,  
     baking powder, 481  
     eggs, 481  
     fat, 479  
     flour, 479  
     sugar, 481  
   temperature of baking, 474-478  
     of ingredients, 492  
     of removing from pan, 478  
 Calcium chloride,  
   freezing solutions, 84  
 Calcium phosphate,  
   added to flour, 401  
 Calcium salts,  
   beans, 136  
   flour, 400-401  
   gelatin, 188  
   jelly, 163  
   milk, 294, 295  
   pickles, 131  
   tea, 123  
   vegetables, 104  
 Candy,  
   brittles, 68  
   caramels, 67  
   cold water test, 54  
   fondant, 56  
   fudge, 66  
   making and crystallization, 54  
   stages cookery for, 55  
   taffy, 68  
 Cane sugar in jelly, 169  
 Canned fruits,  
   violet colorations in, 119  
 Capillary chemistry, 13  
 Capillary-active substances, 13  
 Capillary-inactive, 13  
 Capons, 245, 246  
 Caramels, 67  
   experiments for, 76  
   stages cookery for, 55  
 Carbohydrates,  
   classification, 31  
   structure, 32-33  
 Carbon dioxide,  
   from baking powder, 450  
   lost from batters, 453  
 Carotene, 114, 294, 397  
 Carotinoid pigments, 114  
   flour, 397  
   milk, 294  
 Casein, 12, 297  
   coagulation of,  
     acid, 304  
     alcohol, 301  
     heat, 305  
     mechanism of, 301  
     rennin, 301  
   isoelectric point, 297  
 Cellulose, 33, 129-132  
   acid upon, 129  
   alkali, 129  
   calcium, 130  
 Cerelese, 44  
 Cheese, 310-315  
   Cheddar in cans, 313  
   classification, 310, 311  
   composition, 311  
   definition, 310  
   experiments for, 320-322  
   in cooked products, 314  
   loaf, 314  
   making of, 312  
   processed, 313  
   soufflé, 315  
   spreads, 314  
 Chlorophyll, 110-114  
   composition of, 111  
   heat upon, 112  
   magnesium of, 114  
   reactions of, 112  
   solubility, 110  
 Chocolate, 512-515  
   acidity of, 514  
   in cake, 514  
   manufacture of, 512  
 Chocolate creams,  
   hydrolysis in, 37  
 Chops, 228  
 Citric acid, see acids

- Coagulation of proteins,  
see proteins
- Cocoa, 513-514  
Dutch process, 513  
in fudge, 66
- Cohesion, 18
- Collagen,  
hydrolysis of, 179  
in meat, 203
- Colloid chemistry,  
Bancroft's definition of, 2  
relation to cookery, 1
- Colloidal particles,  
charge on, 9
- Colloidal solutions,  
characteristics of, 3  
size of particles, 2
- Colloids,  
amphoteric, 11  
classification, 6  
denaturing, 11  
hydrophilic, 8  
hydrophobic, 8  
irreversible, 6  
peptization of, 21  
properties of, 6  
protective, 12  
reversible, 6
- Commercial pectin, 159
- Connective tissue,  
chicken, 204  
composition of, 202  
of beef, 204, 205  
pork, 205  
tough cuts, 205  
white, 202, 203  
yellow, 202, 203
- Cookies,  
experiments for, 540-541
- Copper,  
and egg albumin, 350  
in gelatin, 188  
in milk, 294
- Corn,  
loss of sugar from, 128
- Corn, canned,  
ferrous sulfide, 128
- Corn oil, 570
- Corn sirup,  
composition, 55  
in caramels, 67  
soda to neutralize, 449  
source of, 34  
with sucrose sirups, 55-56
- Cornstarch,  
added to flour, 479  
gelatinization temperature, 410  
pastes, 409
- Cottage cheese, 311, 319
- Cottonseed oil, 548  
pastry, 570, 571
- Cover batters, 461  
experiments for, 521
- Crab-apples, 153, 174
- Cranberries, 157, 165
- Cream, 296  
whipping of, 298-299
- Creaming fats, 479-485
- Cream puffs, 461-463  
as emulsions, 286  
experiments for, 521-523
- Cream of tartar,  
in angel cake, 348, 372  
with soda, 449
- Cryohydric point, 87
- Crystallization, 49-54  
agitation in, 51  
and candy making, 54  
effect of impurities, 51  
formation of nuclei, 50  
rate of, 50  
seeding, 50  
sugar manufacture, 52
- Cucumber pickles, 130-131
- Currant juices, 167
- Custards, 337, 343-346  
absorption of heat, 344  
baked, 343  
coagulation of, 333-337, 343-347  
distilled water, 334  
experiments for, 378-381  
optimum temperature for, 345  
pie, 345  
salts upon, 334-335  
soft, 343
- Denaturation,  
changes during, 18-19  
heat, 19  
interfacial, 19
- Dextrin, 33, 55, 56, 66
- Dextrose,  
alkalies upon, 37  
in fondant, 64  
in jelly, 169  
melting point, 39  
solubility, 44  
sources, 34

- Dextrose—(Continued)  
 structure, 31-33  
 sweetness, 34-35
- Disaccharids, 31-33
- Dispersion of substances, 4, 5, 6
- Dough, 417-424  
 added substances, 423-424  
 baking powder in, 424  
 eggs in, 423  
 enzyme action, 431  
 hydration capacity, 419  
 quality, 418  
 structure, 422  
 sugar in, 424  
 temperature for, 423
- Doughnuts,  
 experiments for, 576-579  
 factors affecting fat absorption,  
 amount of eggs, 561  
 fat, 561  
 flour, 559  
 sugar, 561  
 cooking temperature, 559  
 extent of mixing, 558  
 kind of flour, 559  
 letting dough stand, 560  
 smoking temperature of fat, 549  
 surface area, 557  
 temperature,  
 cooking fat, 560  
 ingredients, 557  
 fat absorption, 556
- Edible meat,  
 percentage of, 242-244, 245
- Egg albumin,  
 combination with metals, 350
- Egg beaters, 349  
 rotary, 350  
 whisk, 350
- Egg proteins,  
 albumin, 330  
 coagulation,  
 factors affecting, 333-337  
 acids, 336  
 alkalies, 336  
 concentration of proteins, 334  
 pH, 335  
 salts, 334  
 sugar, 337  
 temperature, 333  
 time, 333  
 denaturation, 332  
 globulin, 330  
 isoelectric point, 331
- Egg proteins—(Continued)  
 ovovitellin, 330  
 peptization, 332  
 properties of, 330
- Eggs,  
 color of shell, 325  
 composition, 325  
 cooked in shell, 340-341  
 deterioration,  
 changes in, 330  
 factors causing, 329-330  
 alkaline hydrolysis, 329  
 chemical, 330  
 enzymes, 329  
 storage, 328  
 dried, 328  
 ferrous sulfide, 342-343  
 frozen, 328  
 hydrogen sulfide, 342  
 in angel cakes, 355-372  
 in cakes, 481  
 in custards, 343-346  
 in omelets, 352-355  
 oil-dipping, 329  
 pigments, 325  
 poached, 341  
 preservation, 328  
 quality,  
 factors affecting, 327  
 tests for, 326-327  
 reactions, 326  
 salts, 334-335  
 uses of, 330
- Egg white,  
 coagulation of,  
 by beating, 350  
 temperature of, 333  
 deterioration, 329  
 foaming of, 346-349  
 acids and stability, 348  
 season, 349  
 temperature, 348  
 in fondant, 64  
 pH, 326  
 whipping of, 346-351  
 salt, effect on, 347  
 stage of stiffness, 346  
 thick, 350, 356  
 thin, 350, 356
- Egg yolk,  
 change in pH, 326  
 coagulation of, 333  
 color of, 325  
 deterioration, 329-330  
 lecithio-protein, 278

Egg yolk—(*Continued*)

- in mayonnaise, 278, 284
- standing up quality, 327

## Elastin, 203

## Electrolytes,

- effect on colloids, 9, 10

## Emulsification, theories, 267-269

## Emulsifiers, 266

- efficiency of, 272

## Emulsifying properties,

- mustard, 276-277
- oils, 277

## Emulsions,

- agitation, 274
- classes, 267
- factors in formation, 279

fats in, 271-272

foams and, 275

French, 273

illustrations, 282-283

in cakes, 287

in cream puffs, 286

making of, 274

mayonnaise, 275-286

- methods of mixing, 279

- oils in, 277

- peptization in, 275

- stabilized by,

- colloids, 273

- electric charge, 273

- powders, 273

types of, 269

- found in foods, 286

- means of determining, 270

- reversal of, 270

whipped cream, 298-300

## Emulsoids, 6

## Energy, 25-26

## English walnuts, tannins, 123

## Enzymes,

- amylolytic,

- flour, 397, 431

- meat, 217

- milk, 294

- coagulation by, 301-304

- discoloration in food, 125

- dispersion by, 6, 217, 294

- invertase, 37

- lipolytic,

- flour, 399

- meat, 217

- milk, 294

- oxidizing, 124

Enzymes—(*Continued*)

- proteolytic,

- bromelin, 124, 308

- flour, 398, 412, 413, 418, 431, 432

- meat, 209, 212, 217

- milk, 294

- papain, 124, 222

- sugar hydrolysis by, 37

## Experiments,

- bacon, 264

- batters and doughs, 519-541

- biscuits, 528-530

- bread, 443-446

- cabbage, 147

- cake,

- angel, 386-389

- chocolate, 536-638

- plain, 531-535

- sponge, 390

- white, 538

- caramels, 76

- cheese, 319-332

- cooked salad dressing, 382

- cookies, 540

- cover batters, 521

- cream puffs, 521-523

- custards, 378-381

- doughnuts, 576-579

- eggs, 376-390

- emulsions, 289-292

- fats and oils, 574-583

- fondant, 77-79

- freezing, 98-102

- fruits, 150-151

- fudge, 79-81

- gelatin, 188-193

- gingerbread, 539

- griddle cakes, 525

- Hollandaise sauce, 383

- ice cream, 98-100

- ices, 101

- jelly, 174-177

- meat, 253-265

- beef roasts, 254-257

- broth, 261

- ground beef, 261

- in water, 260

- lamb roasts, 257, 258

- less tender cuts, beef, 260

- pork roasts, 257-258

- steaks, 258

- Swiss steaks, 260

- veal roasts, 257, 258

- meringues, 385-386

## Experiments—(Continued)

- milk, 317-319
  - muffins, 526-528
  - omelets, 383-385
  - pastry, 579-583
  - popovers, 519-520
  - sherbets, 101
  - strawberries, 150
  - sugar, 70-82
    - solubility, 70
  - taffy, 75
  - timbales, 520
  - vegetables, 144-149
  - waffles, 523
- Fasciculi, 198, 199
- Fat,
- and toughness of meat, 208
  - in cakes, 479-481, 492-498, 507
    - chocolate, 515-516
  - in doughs, 423
  - in emulsions, 271-272
  - in meat, 200-202
  - in pastry, 567-572
- Fats,
- acid value, 545
  - amount absorbed by foods, 555
  - changes during cooking, 554
  - congealing point, 543
  - fatty acids of, 546
  - free fatty acids, 545, 548
  - glycerides, 543
    - unsaturated, 543
  - glycerol, 547
  - hydrogenation of, 545
  - iodine number, 543
  - melting point, 544
  - orientation of, 564
  - properties of, 542
  - rancidity,
    - antioxidants, 551, 552
    - cereals and, 551
    - effect air, light, and heat, 553
    - green light, 553
    - inert gases and, 552
    - metals and, 551
    - prooxidants, 551
  - rancid products,
    - volatilization of, 553
  - refractive index, 545
  - shortening power of, 565
  - smoking point, 548
  - specific gravity, 542
  - texture and consistency, 545

- Fatty acids,
  - area covered by,
    - saturated, 563
    - unsaturated, 563
  - free, 548
  - in flour, 399-400
  - in milk, 295
- Fermentation of bread, 425, 431-436, 445
- Ferrous sulfide,
  - canned corn, 128
  - cheese, 313
  - eggs, 342
  - omelets, 353
  - peas, 128
- Fish, 206
- Flavones, 114-116, 372, 397
- Flavonols, 114
- Flavor, 128
- Flours,

  - aging of, 412
  - ash content, 400-402
  - bleaching of, 396
  - cellulose, 398
  - clear, 395
  - color of, 397
  - composition of, 396
  - definition of, 394
  - effect overgrinding, 411
  - enzymes of, 397, 413, 431
  - fat of, 399-400
  - fatty acids of, 399
    - free, 399, 413
  - gluten, 415-424
  - hydration capacity, 419
  - hygroscopic property, 399
  - lecithio-protein of, 415
  - milling process, 391-394
  - patent, 395
  - pigments of, 397
    - carotene, 397
    - flavones, 397
  - proteins,
    - gliadin, 415
    - gluten, 415
    - glutenin, 415
    - salts and extraction of, 413
    - status of, 414
  - salts of, 400-402
  - starch, 402-411
  - straight, 395
  - sugars, 402

## Flours—(Continued)

- types of,
  - hard-wheat, 395
  - all-purpose, 395
  - bread, 395
  - soft-wheat,
    - all-purpose, 395
    - cake, 396
    - cracker, 396
    - pastry, 396
  - rye, 396
- Fluidity, 23
- Foams,
  - cream, whipped, 298-300
  - egg white, 346-351
  - formation of, 14
  - gelatin, 187
- Fondant, 56-66
  - addition of dextrose, 64
  - cream of tartar, 65
  - egg white, 64
  - levulose, 64
  - color, 65
  - concentration of sirup, 57
  - cooking of, 56
  - experiments for, 77-79
  - growth of crystals in, 64
  - honey, 66
  - illustrations, 58-63
  - invert sugar in, 65
  - ripening of, 66
  - size of crystals in, 65
- Formulas,
  - for angel cakes, 360
  - cakes, 512
- Free surface energy, 14
- Freezers, ice cream, 86
  - packing of, 88
- Freezing,
  - cryohydric point, 87
  - experiments for, 98-102
  - mixtures, 85
  - point, 83
    - effect ionized substances, 84
    - lowering of, 84
- Frozen meat,
  - cooking of, 224-225
- Fruits,
  - acids in, 108
  - and milk, 308
  - browning of, 124, 125
  - color changes of, 116-119
  - cooking with sugar, 131-133
  - sugar and firmness of, 131-133
  - violet colorations in canned, 119

## Fryers, 245, 246

Fudge, 66, 79

## Gelatin,

- addition of acids, 179, 181, 184
    - alkalies, 181, 184
    - cream, 187
    - egg white, 187
  - agitation of, 187
  - collagen and, 178
  - experiments for, 188-193
  - foam formation, 187
  - gelation,
    - concentration for, 182
    - temperature for, 183
    - time for, 182
  - hydration of, 180
  - hydrogen-ion concentration, 184
  - in emulsions, 273
  - in ice cream, 95
  - initial pH, 184
  - isoelectric point, 181
  - manufacture of, 178
  - market types, 179
  - opacity in, 186
  - precipitated by tannins, 122
  - properties of, 180
  - salts and gelation, 185
  - seeding of, 183
  - solution of, 180
  - sources of, 178
  - stiffening power, 181
  - sugar in, 185
  - swelling of, 180-181
  - uses in foods, 178
  - viscosity and solutions, 182
- Gels,
- definition of, 6
  - effect of acids, alkalies, 7, 8
  - starch, 407
  - swelling of, 7
- Gingerbread, 516
  - experiments for, 539
- Gliadin, 415
- Globulin,
- flour, 413
  - meat, 211
- Glue, 178
- Gluten,
- coagulation of, heat, 416
  - dough, 417-424
  - effect of adding substances, 423
  - hydration capacity, 419
  - quality, 416-417
- Glutenin, 415



- Glutathione, 126  
 Glycerol, 547  
   heat decomposition of, 547  
 Gooseberry juice, 156, 165, 167, 170  
 Griddle cakes, 463  
   experiments for, 525  
  
 Ham,  
   cooked in milk, 307, 318  
   cooking of, 229, 263-264  
   curing, 212  
 Heat,  
   coagulation by, see proteins,  
   dispersion by, 4  
 Hemoglobin, 209  
   muscle, 209  
 Hens, 245, 246  
 Hollandaise sauce, 383  
 Homogenization, 5  
   of milk, 298  
 Homologous series, 14  
 Honey, 34  
   in fondant, 66  
   soda to neutralize, 449  
 Hydrogenation, 545  
 Hydrogen-ion concentration, 26  
   in jelly, 160  
 Hydrophilic colloids, 8  
   effect electrolytes on, 10  
 Hydrophobic colloids, 8  
   effect electrolytes on, 9  
 Hydrogen sulfide, 126-128, 342, 353  
 Hysteresis, 2  
  
 Ice cream,  
   acidity, 90  
   adding chocolate, 91  
   adding fruit, 91  
   aging of mix, 94  
   body and texture, 91  
   classification of, 96  
   composition of, 89  
   experiments for, 98-100  
   flavor of, 89  
   flavoring in, 90  
   freezing, 92  
   gelatin in, 95  
   homogenization for, 94  
   overrun in, 92  
   pasteurization of mix, 94  
   sandy, 90  
   serum solids not fat, 90  
   sugar in, 90, 95  
   texture, 91  
   viscosity, 94  
  
 Ice cream freezers, 86  
 Ice-cream improvers, 95  
 Ices, 95, 101  
 Illustrations,  
   angel cakes,  
     varying,  
       beating egg white, 369  
       folding flour, 368  
       folding sugar, 364  
       increasing sugar, 371  
   cakes,  
     bowls for folding, 362  
     varying,  
       amount flour and mixing, 510-511  
       amount sugar and mixing, 508-  
       509  
       creaming, 489  
       kind baking powder,  
       phosphate, 496  
       sulfate-phosphate, 500  
       tartarate, 494  
   cake photomicrographs,  
     fat creamed with sugar, 483, 486,  
     487  
     fat distribution in cake batter; 486,  
     487, 490  
     fat distribution in cake crumb, 490,  
     491  
   eggs,  
     fresh and deteriorated, 323  
     structure, 325  
     structure white, 324  
   emulsions with egg white foam, 272  
   jelly,  
     dextrose, 170  
     yield, 166, 167  
   mayonnaise,  
     size fat globules, 282-283  
   meat,  
     diagram, 234  
     grades, stamping of, 195  
     muscle fibers, 199, 201, 207  
     roast beef, pan, and thermometer,  
     225  
     skewers, 230  
   muffins, 466, 467, 468, 469, 470  
   starch granules, 403  
   sugar crystals in divinity, 62-63  
   sugar crystals in fondant, 58-61  
 Interfacial tension,  
   liquids/liquids, 15  
   liquids/solids, 17  
 Intermicellar, 3  
 Inversion of sucrose, 36-37  
 Invertase, 37

- Iron,  
 and egg albumin, 350  
 eggs, 342  
 and flavones, 115  
 loss from vegetables, 105  
 meat, 223  
 milk, 294  
 tea, 123
- Isoelectric point, 11  
 egg proteins, 331  
 flour proteins, 415  
 gelatin, 181  
 milk proteins, 297  
 muscle proteins, 211  
 proteins, 11
- Jelly,  
 acid, rôle of, 160-163  
 acidity, reporting of, 162  
 acids in juices, 161  
 beet sugar in, 169  
 cane sugar in, 169  
 concentration pectin, 156  
 cooked fruit for, 154  
 definition of, 172  
 dextrose in, 169  
 experiments for, 174-177  
 extractions for, 156  
 fruits used for, 153, 156  
 hydrogen-ion concentration, 160  
 inversion of sucrose, 168  
   rate of, 168  
 levulose in, 170  
 maltose in, 170  
 mold, 171  
 pectin, rôle of, 156-160  
 salts, rôle of, 163-164, 171  
 starch removal from juice, 156  
 storage of, 171  
 sugar,  
   concentration for, 165  
   rôle of, 164-170  
   when to add, 164  
   without, 164  
   and yield, 165  
 syneresis, 170  
 tartaric acid. removal, 156  
 temperatures sirup, 171  
 test, 171  
 theory for formation, 152  
 yield, 165
- Lactalbumin, 298  
 Lactoglobulin, 298
- Lactose, 33, 295, 309, 310  
 caramelization of, 310  
 hydrolysis of, 35  
 solubility, 43  
 sweetness, 35
- Lamb,  
 cooking of, 227  
   preparation for, 257  
 grades, 196
- Lard,  
 for doughnuts, 556  
 for potato chips, 454  
 in cake, 489, 493  
 in pastry, 567, 568, 570, 571  
 rancidity, 553  
 seasoning, 542  
 texture, 545
- Leavening agents,  
 baking ammonia, 448  
 baking powders, 450-456  
 soda, 447  
 steam, 447
- Lecithio-protein,  
 egg yolk, 278  
 flour, 415
- Legumes, dried,  
 cooking of, 135-141  
 salts, effect on cooking, 136, 139
- Lemon juice,  
 and condensed milk, 310  
 eggs, 354  
 gelatin, 184
- Leucosin, 413
- Levulose,  
 acids on, 35  
 alkalis, 38  
 in fondant, 64  
 in jelly, 170  
 melting point, 39  
 solubility, 45  
 sources, 34  
 sweetness, 35
- Liquids,  
 boiling point, 46  
 interfacial tension of, 15  
 surface tension, 14
- Magnesium salts,  
 beans, 136  
 flour, 400, 401  
 milk, 294, 295  
 tea, 123  
 vegetables, 104

- Maltose,  
 in jelly, 170  
 hydrolysis of, 35  
 melting point, 39  
 solubility, 43  
 sources, 34  
 structure, 32-33  
 sweetness, 35
- Margarine, 571
- Mayonnaise,  
 air film on oil, 276  
 breaking of, 284  
 concentration of oil in, 285  
 definition of, 275  
 emulsifiers, 271  
 emulsifying properties,  
 egg yolk, 278  
 mustard, 276  
 oils, 277  
 experiments for, 289-291  
 factors in making, 279-284  
 adding to emulsion, 284  
 agitation, 279  
 ingredients used, 281-285  
 methods of mixing, 277-278, 279-281  
 temperature, 284  
 peptization in forming, 275  
 reforming, 285
- Meat,  
 adipose tissue, 200  
 binding water, 220  
 carbohydrates of, 210  
 changes,  
 bacterial, 213, 217  
 chemical, 218  
 storage, 217-218  
 classes, 194  
 percentage, 196  
 cold storage, 212  
 collagen, 203  
 color changes, 220  
 composition, 202-207, 207-211  
 connective tissue, 199, 202-206  
 kinds, 202  
 cooking losses, 240-242  
 factors affecting, 238-240  
 cooking of,  
 acid added, 223  
 changes in, 218-223  
 color changes, 220  
 cured meat, 228  
 formation gelatin, 219  
 frozen meat, 224-225  
 inner temperature rise, 237  
 less tender cuts, 205, 226, 260
- Meat—(Continued)  
 cooking of—(Continued)  
 methods, 226-230  
 constant, 231  
 dry heat, 226  
 moist heat, 226  
 pressure cooker, 230  
 searing, 231  
 use of skewers, 230  
 pans for, 229  
 preparation for, 254  
 temperatures, 231-232  
 use of skewers, 231  
 curing, 212  
 definition, 198  
 edible portion, 242-243  
 cost of, 242, 244  
 percentage, 242, 244  
 elastin, 203  
 enzymes, 209, 217-218  
 fasciculi, 198-199  
 fat, 200-202  
 size of cells, 202  
 federal inspection, 197-198  
 freezing, 212, 224  
 defrosting, 224  
 grades, 196  
 distribution, 196  
 packers, 197  
 U. S., 196  
 grading, 194-197  
 basis for, 194  
 incipient putrefaction, 217  
 inspection, 197  
 juiciness of, 219-220  
 muscles, 198-211  
 classes, 199  
 fibers, 198, 201, 206-211  
 pH, 220  
 pigments, 209  
 proteins, 210  
 structure, 198  
 pigments, 209  
 ripening on, 210  
 post-mortem changes, 211-218  
 preservation of, 212  
 proteins, 210-211  
 records for, 226  
 rigor mortis, 211, 214-215  
 ripened, 215-217  
 rise of inner temperature, 287-288  
 salt added, 225  
 salts of, 209  
 searing of, 231  
 shearing tests, 208, 221-222

- Meat—(*Continued*)  
 stage of cookery,  
   medium, 232  
   rare, 232  
   well-done, 233  
 steaks, 227  
 storage, 212-214  
   changes in, 217  
 tenderness, 208, 220-223  
   increasing, 222-223  
   methods of estimating, 220-222  
 thermometers for, 233  
 time of cooking, 233-237  
 time per pound, 235  
 toughness, 200, 207-208
- Meringues,  
 experiments for, 385-386  
 hard, 352  
 soft, 351
- Metals and  
 egg, 350  
 fruit acids, 109-110
- Micelles, 3
- Milk,  
 boiling, 308  
 bread, use in, 426  
 carotene, 294  
 clotting by fruits, 308  
 coagulation,  
   by acid, 304  
   by alcohol, 301  
   by heat, 305  
   by meat cooked in, 307  
   by rennin, 301  
   by vegetables, 307  
 composition, 293  
 constituents, 293-298  
 cooking meat in, 302, 318  
 cooking vegetables in, 307  
 enzymes of, 294  
 experiments for, 317-319  
 fat, 295-297  
 fatty acids of, 295  
 fermentation of, 304  
 heating on acidity, 301  
   endothermic, 306  
 homogenization, 298  
 lactose, 295  
 pigments of, 294  
 proteins of, 297-298  
   isoelectric point, 297  
 reaction, 300  
 rennin, 301-305  
 salts of, 294  
 sour, 304, 448
- Milk—(*Continued*)  
 sour—(*Continued*)  
   neutralization by soda, 448  
   sugar reactions with, 309-310  
   uses, 293  
   vitamins, 294
- Molasses, 15, 67, 75, 449  
 soda to neutralize, 449
- Molecules,  
 orientation of, 17
- Monosaccharids, 31-33
- Mousse, 88, 96
- Muffins, 465-471  
 baking of, 471  
   standing before, 471  
 baking powder, 470  
 experiments for, 526-528  
 illustrations, 466-470  
 mixing, extent of, 465-470  
 tunnels of, 465  
 varying ingredients, 470
- Muscle,  
 carbohydrates of, 210  
 classes, 199  
   cross striated, 199  
   smooth, 199  
 fat in, 200-202, 210  
 nitrogenous extractives, 210
- Muscle fibers,  
 constituents of, 208-211  
 effect exercise on, 199, 206, 208  
 maturity on, 206, 208  
 proteins of, 210, 211
- Muscle pigments, 209
- Muscle proteins, 210-211
- Mustard, 126  
 in emulsions, 273, 276-277, 281
- Myogen, 211
- Myosin, 211
- Myrosin, 126
- Non-polar groups, 17
- Nitrogenous extractives, 210
- Oils, 543, 566, 567  
 in cakes, 488-489, 490, 491, 567  
 in emulsions, 271  
 hydrogenation of, 545  
 iodine number, 544  
 in pastry, 569, 570, 571  
 properties of, 542  
 rancidity, 549  
 refractive index, 545  
 smoking temperature, 548

- Omelets,  
 addition of liquid, 354  
 experiments for, 383-385  
 ferrous sulfide, 353  
 method of mixing, 352  
 temperature for cooking, 355
- Onions, 122, 128  
 for flavor, 127, 542
- Orientation,  
 fats, 564  
 molecules, 17
- Osmotic pressure, 44
- Ovovitellin, 330
- Oxyhemoglobin, 209
- Pans,  
 for bread, 434  
 for cakes, 473  
 for meat, 229
- Papain, 124, 222
- Parfait, 96
- Pasteurization, 94, 303
- Pastry,  
 experiments for, 579-583  
 extent of mixing, 571  
 flakiness, 572  
 shortening experiments, 569-571
- Peas,  
 loss of sugar, 128
- Peas, canned,  
 ferrous sulfide, 128
- Pectic acid, 153, 154, 155
- Pectic substances, 153-156  
 constitution, 155  
 function of, 153  
 in beans, 138
- Pectin, 153  
 alcohol test for, 157  
 commercial forms, 159  
 concentration of, 156  
 from different sources, 157  
 high temperature on, 158  
 in fruit pulp, 156  
 uses for, 159  
 viscosity test, 158
- Peptization, 16, 21-22  
 means of, 21  
 proteins, 21-22
- Peroxidases, 124
- Persimmons, 122
- pH, term, 26-28
- Phosphates,  
 flour, 400-401, 405  
 meat, 223
- Phosphates—(*Continued*)  
 milk, 295  
 vegetables, 104
- Pickles, 130-131  
 crisping of, 131
- Pie,  
 butterscotch filling, 337  
 custard, 345  
 soaking of crust, 572
- Pie fillings, 337
- Pigments,  
 anthocyanins, 116  
 carotinoids, 114, 397  
 chlorophyll, 110  
 flavones, 114, 397  
 in egg yolk, 325  
 in flour, 397  
 in milk, 294  
 in muscle, 209  
 in plants, 110-121
- Pineapple, 118, 126
- Plant acids, 106-109
- Plasticity, 23, 25
- pOH, term, 27
- Polar groups, 17, 562
- Polysaccharids, 31-33
- Popovers, 460  
 experiments for, 519
- Pork,  
 binding water, 249  
 connective tissue, 205  
 cooking of, 227  
 preparation for, 227, 258  
 grades, 196
- Potassium,  
 flour, 400-401  
 vegetables, 104
- Potatoes,  
 chips, 134-135, 554-555  
 flavones, 115  
 French fries, 135  
 quality, 133  
 starch, 134  
 storage temperature, 134  
 sugar in, 135  
 test for, 135
- Poultry,  
 cooking of, 244-249  
 basting, 249  
 interior temperature for, 248  
 losses, 245, 246  
 pans for, 247  
 roasting, 245-247  
 temperature, 246-247  
 time, 249

- Poultry—(*Continued*)  
 edible meat,  
   cost, 242, 246  
   percentage, 245, 246  
 fat distribution, 250-251  
 turkey, 248-249  
 Preserves, 132, 133  
 Proteins,  
   coagulation of, 18  
     changes during, 18-19  
     factors affecting, 20  
     heat, 19  
     interfacial, 20  
     mechanical means, 18  
     SH groups in, 19  
     S-S groups in, 19  
   combination with acids, 12  
   combination with alkalis, 12  
   denaturation, 18-20  
   egg, 330-337  
   flour, 413-417  
   isoelectric point, 11  
   meat, 210-211  
   milk, 297-298  
   peptization of, 21-22  
   stoichiometrical combination, 12  
   surface concentration, 15  
 Protopectin, 153, 154  
 Puff pastry shortening, 570  
 Punch, color of, 117  
 Rancidity,  
   antioxidants, 551, 552  
   cereals and, 551  
   effect air, light, and heat, 553  
   green light, 553  
   inert gases and, 552  
   metals and, 551  
   prooxidants, 551  
   volatilization of products, 553  
 Rennin,  
   coagulation of milk, 301-305  
 Reversible colloids, 6  
 Rice, flavones of, 115  
 Rigor mortis, 214-215  
 Ripening of meat, 215-217  
 Roasters, young, 245, 246  
 Roasts, see meats  
 Salad dressing, cooked, 338-340  
   experiments for, 382  
   French dressing, 273, 291  
   mayonnaise, 275-286  
 Salsify, 123  
 Searing, 231  
 Seeding, 50  
 Sherbets, 95, 96, 101  
 Shortening,  
   in bread, 427, 436  
   definition of, 562  
   factors affecting, 562-567  
 Smoking temperatures fats, 548  
 Soda,  
   as leavening, 447  
   curdling of milk and, 307  
   to neutralize,  
     corn sirup, 449  
     honey, 449  
     molasses, 449  
     sour milk, 448  
   with legumes, 139-141  
   with vegetables, 112, 113  
 Sodium chloride,  
   beans, 136  
   distilled water custards, 334  
   flour, 400  
   freezing mixtures, 85  
   jelly, 163  
   meat, 209, 212  
   milk, 294  
 Sols, 6  
 Solubility,  
   temperature and, 40  
 Solute, 39  
   fineness of division, 40  
 Solutions, 39-49  
   boiling point, 46-49  
   characteristics of, 3  
   colloidal, 2, 3  
   heat of, 49  
   properties of, 44  
   saturated, 41  
   supersaturated, 41  
   surface tension of, 14  
   true, 2, 3  
   vapor tension, 45  
 Sorghum, 15  
 Soups,  
   meat, 261  
   tomato, 308, 317  
 Soybeans, 141  
 Specific gravity,  
   cake batters, 357  
   egg white foams, 347  
   fats, 542  
 Sponge cake, 372  
   experiments for, 390  
 Staling,  
   bread, 436-438  
   cake, 503

- Starch,  
 acid and, 411  
 alpha-amylase, 402  
 apple juice and, 156  
 beta-amylase, 402  
 chain length, 404  
 combined with,  
   fatty acids, 406  
   phosphoric acid, 405  
   protein, 404  
   silicic acid, 404  
 constitution, 404-406  
 gelatinization,  
   factors affecting  
     combinations, 408  
     granule size, 407, 408  
     kind of starch, 407, 408  
     temperature, 407, 408  
     time granule is wetted, 407  
 gels, 405  
 granules,  
   size and shape, 402-404  
 hydrolysis, 37, 411  
 nitrogen, 405  
 paste,  
   in emulsions, 273, 286  
   viscosity of, 409-411  
     acid, 411  
     chain length, 410  
     degree grinding, 410  
     kind of starch, 409  
     proportion of,  
       alpha and beta, 410  
       phosphoric acid, 409  
     stiffness, 409  
     temperature, 409  
     sugar, 411  
 phosphorus, 404, 405  
 solubility, 404  
 soluble, commercial, 411  
 sources, 402  
 uses, 402  
 Steaks, 227, 258  
 Steam, 447  
 Stews, 261  
 Stoichiometrical combinations, 12  
 Strawberries, 132-133  
   experiments for, 150-151  
 Sucrose,  
   acids, 35  
   alkalies, 37  
   crystallization of, 49-54  
   hydrolysis, 35  
   inversion of, 36  
   melting point, 39  
 Sucrose—(Continued)  
   solubility, 42-44  
   sources, 34  
   sweetness, 35  
 Sucrose solutions,  
   boiling point of, 49  
   corn sirup added, 55  
   stages of cookery for, 55, 56  
 Sugars,  
   amorphous, 54  
   cooking fruits in, 119  
   crystallization, 49-54  
   effect of acids, 35  
     alkalies, 37  
   gelatin and, 185  
   grades, 52-54  
   granulated, 52  
   hydrolysis, 35-37  
   jelly and, 169-170  
   melting points, 39  
   moisture absorbing power, 38  
   powdered, 53  
   potatoes and, 135  
     test for, 135  
   reactions with proteins, 67, 309-310  
   solubility, 41-44  
   sources, 34  
   starch pastes and, 411  
   stored vegetables, 128  
   structure, 31-33  
   sweetness, relative, 34-35  
   tannins in, 122  
   transformed, 53  
 Sulfur,  
   in denaturation, 19  
 Sulfur compounds, 126-128  
 Surface films, 15  
 Surface skins, 17  
 Surface tension, 13-15  
   alcohol, 14  
   interfacial, 15  
   solutions, 14  
   water, 14  
 Suspensions, 2, 3  
   characteristics, 2, 3  
 Suspensoids, 6  
 Syneresis, 8, 170  
 Taffy, 68  
   experiments for, 75  
 Tannins, 121-123  
   astringent quality, 122  
   cherry juice and, 123  
   chocolate and, 513  
   discolorations due to, 122-123

Tannins—(*Continued*)

reactions of, 121  
tea, 123

Tartaric acid, see acids

Tea, 123

Thermometers, meat, 233

Timbales, 461

experiments for, 520

Tin salts, 110

and discolorations, 119

Tomato soup, 308, 317

Tomatoes,

acid in, 108

acidity of, 308

gelatin and, 184

pigment in, 114

Traube's rule, 14

Trichinosis, 197-198

processing and, 198

refrigeration and, 198

Tunnels,

in cakes, 499

in muffins, 464

Turkey,

roasting of, 248-249

temperature for, 248, 249

time, 249

Vapor, 46

saturated, 46

Vapor tension, 44, 45

soluble upon, 45

Veal,

cooking of, 227, 258

grades, 196

Vegetables,

cooked in milk, 307

cooking of,

green, 112-114

red, 119

yellow, 114

Vegetables—(*Continued*)

cooking losses, 103-106

iron, 105

nitrogen, 103

salts, 104

methods of cooking, 106

salts of, 104

sulfur compounds of, 127

Viscosity, 23-24

lyophilic systems, 24

Vitamins, 104, 294

Waffles, 464

experiments for, 523-525

Watermelon, 130, 131

Walnuts, tannins in, 122

Water,

boiling point, 46

bound and free water, 22-23

freezing point of, 83

hard, 137

loss from eggs, 330

softened, 138

Wheat,

classes of, 394

White cake, 516

experiments for, 538

Xanthophyll, 114

of eggs, 325

plants, 114

Yeast,

amount for bread, 425, 431, 436

fermentation, 431

strains, 431

Zinc,

in milk, 294

utensils, 110

Zymase, 431













