ENZYMES, which are within the food material itself and necessary to life processes, continue their chemical activity after harvesting or storage and produce decomposition. Thus micro-organisms, described in the previous article, are not the only cause of food spoilage. Here is a brief account of this enzyme activity and the methods used to prevent or minimize it.

Because agricultural production is seasonal while food consumption is steady, the storage of food in some edible form has always been one of mankind's greatest problems. Practically all natural foodstuffs except ripe seeds undergo decay unless measures are taken to prevent it. Dried fruits, pickles, preserves, cheese, and fermented drinks probably all have their origin in attempts at food preservation. Today there is an increasing tendency, due to the possibilities of cold storage, to keep foods in their natural state as long as possible. Cold storage in itself merely delays the natural processes of decay, although when the temperature is extremely low the rate of destruction is very slow. Frozen meat, if it were kept cold enough, would probably last a great many years without "going bad." Defects such as poor flavor and appearance and loss of moisture are about the worst that might be expected. It has been reported that the flesh of prehistoric animals found frozen in the Arctic was eaten by dogs without any apparent ill effect.

There are two agencies that cause decay in natural—that is, unprocessed—foods: (1) Micro-organisms, which come from contamination, and (2) enzymes, which already exist in the living tissue. The number of micro-organisms can be greatly reduced by keeping things clean, but under no circumstances is it possible to get rid of the enzymes, because they were a part of the material while it was alive. Enzymes are curious special proteins built up by the plant for the purpose of accelerating the chemical reactions that must go on if the tissue is to live. After the death of the tissue many such

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substances continue to function, and they cause the disintegration known as autolysis when enzymes only are present, and as decay when both enzymes and micro-organisms are present.

If food could be stored for a very much longer period than is possible today, it would be an advantage to everybody. There do not seem to be any insuperable difficulties in the way of finding out how this can be done. Predictions are always hazardous, but it is perhaps not too rash to predict that the differences between large and small crop yields will some day be smoothed out more completely than can be done now by long-time storage.

**STORAGE OF LIVE FOOD MATERIAL**

Foods are stored either alive or dead. Fruit, for example, is usually stored in the living state, whereas meat is invariably stored as dead material. It is obvious that dead material may be frozen without necessarily injuring it, whereas live material cannot usually be frozen without killing it. Therefore different considerations underlie the best methods of preserving these two groups.

**FRUIT**

Fruit meant for storage is usually picked green and ripens during the storage period. Fruit should not be frozen nor should it be chilled too close to the freezing point. The optimum temperature for its storage varies with different fruits, but it is usually a few degrees above freezing.

The changes that fruit undergoes during live storage have been worked out very well for apples (624). It has been found that fruit respires—that is, it takes in oxygen and gives off carbon dioxide. The production of carbon dioxide is easily measured and serves as an indicator of the vital processes taking place. As an apple ripens the amount of carbon dioxide given off increases, some of the starch changes to sugar, and some of the sugar forms carbon dioxide. At the moment of ripeness the apple gives off carbon dioxide at the highest rate; this rate then gradually decreases during a long period while the fruit grows old. The life processes as indicated by the evolution of carbon dioxide slow down in intensity and the amount of sugar present is lessened because there is no more starch to replenish it. The apple finally dies, at which time there is a short burst of biological activity followed by a fall to zero. The dead fruit then decays. The presence of molds and bacteria, of course, hastens this process, but even without them the enzymes within the cells carry on the disintegration.

Respiration is the most striking chemical process that goes on in stored fruit. Since respiration is a process of oxidation, the ripening of fruit requires a supply of oxygen. Oxidation is also observed on the exposed surfaces when some kinds of fruit are cut open. The well-known darkening of apples, pears, and the other fruits is due to this reaction. The darkening is caused by the activity of an enzyme either of the peroxidase type or of the phenol oxidase type, the difference between which is that the latter can use the oxygen of the air but the former can use only the hydrogen peroxide that is produced by the fruit during respiration. From present knowledge it seems probable

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2 Italics numbers in parentheses refer to Literature Cited, p. 1075.
that the respiration of the whole fruit, bound up as it is with the process of ripening, depends on oxidizing enzymes in which the protein of the enzyme is combined with a metal such as iron or copper.

The final result of the chemical reactions which constitute tissue oxidation, or respiration, is the same as though the food substances used (sugars in this case) were burnt. It is therefore obvious that respiration produces heat. The heat of respiration can amount to a great deal in a cargo of fruit. It is known that the rate of respiration is greatly diminished at low temperatures. Consequently, the lower the temperature, the less respiration takes place in the fruit and the less heating occurs in storage. A small increase in temperature may entail a large increase in respiration, with the result that a refrigerating machine capable of maintaining the fruit at a low temperature already reached becomes overloaded when it is necessary to cool the fruit down to that temperature. Figures showing the amount of heat evolved by respiration at different temperatures are given in table 1 (980). In other words, the higher the temperature, the greater the heat produced by the cargo; and the greater the heat produced the higher the temperature goes, because beyond a certain point the cooling machinery is unable to take the heat away fast enough. Once started, this vicious circle ends in the complete spoilage of the fruit. For this reason the best method of shipping fruit is to precool it before it is stored in the car or hold, thus avoiding the danger of overheating the refrigerating machinery.

Table 1.—Heat evolved in a ton of fruit per day at several temperature levels

<table>
<thead>
<tr>
<th>Temperature (°F.)</th>
<th>Apples</th>
<th>Pears</th>
<th>Cantaloupes</th>
<th>Temperature (°F.)</th>
<th>Apples</th>
<th>Pears</th>
<th>Cantaloupes</th>
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<tbody>
<tr>
<td></td>
<td>British thermal units</td>
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<td>British thermal units</td>
<td>British thermal units</td>
</tr>
<tr>
<td>32</td>
<td>1,100-1,760</td>
<td>660-880</td>
<td>213</td>
<td>60</td>
<td>4,400-6,600</td>
<td>8,800-13,200</td>
<td>3,938</td>
</tr>
<tr>
<td>40</td>
<td>1,100-1,760</td>
<td>660-880</td>
<td>506</td>
<td>85</td>
<td>4,400-6,600</td>
<td>6,600-15,500</td>
<td>5,938</td>
</tr>
</tbody>
</table>

There is another way of slowing down respiration and thereby lengthening the time required for ripening. It does not take the place of cooling but augments its effect. The process is based on the principle of storing fruit in the presence of carbon dioxide. Since carbon dioxide is a product of respiration, it is reasonable to suppose that a high concentration of the gas on the outside of the fruit might prevent more of the same gas from forming on the inside. Apples stored in air containing about 10 percent of carbon dioxide actually respire and ripen very slowly, and the length of time that they may be stored without damage is said to be at least twice the ordinary period (685).

Carbon dioxide is not the only gas given off by ripening apples, which in this respect are probably typical of most fruit. At least, two other volatile substances are produced, one of which is ethylene. The effect of ethylene on green fruit is to speed up the ripening process very markedly, so that an accumulation of ethylene in a storage space would defeat the purpose of the storage—the retardation of ripening. It is thus evident that there is need for ventilation in storage. The disadvantage of ventilation, however, is that the fruit now loses water by evaporation and may become dried out and
unsightly. To prevent this, the humidity of the air is generally controlled and made as high as is possible without furthering the growth of molds. A relative humidity of about 75 or 80 percent is usually employed.

**GRAIN**

Ripe grain, though alive, is dormant. The germ continues to respire slowly, but the remainder of the seed behaves like dead material. On long-continued storage the proteins of soybeans and of corn have been observed to become partly denatured. This change may cause the loss of a certain amount of food value (592). It has been found that such changes in grain take place more slowly at low temperatures.

Flour is no longer living matter, but it is still capable of undergoing oxidative changes. There is always a large quantity of air in flour, which assures a supply of oxygen. The alterations that occur in white flour while in storage appear at first to improve its bread-making properties. White flour is therefore "aged" as a rule. The oxidation is said to cause, among other things, the partial inactivation of a protein-digesting enzyme that tends to make the dough sticky (59). The effect is probably similar to that of certain oxidative bleaching agents, to which improvement in baking quality is often ascribed.

**STORAGE OF DEAD FOOD MATERIAL**

**MEAT**

Meat is the best example of material stored in a nonliving state. No respiration takes place as with living material, but enzymes cause other changes. A loss of water is always to be feared in any material stored below freezing. Ordinary cloth wrappers usually suffice to decrease evaporation in stored meat. In a process recently developed a whole side of meat or a large fowl is encased in a tight-fitting rubber bag. Since meat is kept at temperatures at which biological activity is very low, the importance of ventilation is not great.

Stored meat is subject to all the natural processes of decomposition, and these are ordinarily held in check only by low temperature. Carbon dioxide, however, is an aid to preservation of meat as well as of fruit. The color unfortunately suffers, but the process is useful when meat must be shipped a long way, as from Australia (811). The effect of the gas is evidently to inhibit the growth of micro-organisms, but in view of the results with other products it probably inhibits enzymes as well.

When the micro-organisms are left out of the picture, meat, like all dead tissue, autolyses—at ordinary temperatures, rather rapidly. The most prominent feature of the autolysis of meat is the decomposition of the protein.

Chemically, autolysis and digestion are not dissimilar, though of course in stored meat autolysis should not proceed far enough to make the similarity apparent. Autolysis is caused by a different set of catalysts, for the enzymes inherent in meat are not the same as those of the digestive tract. The Department of Agriculture has studied the changes that occur in stored beef (518). In particular, there is a liberation of ammonia and the production of other break-down products from protein, apparently peptides and peptones. There is also a separation of phosphate from organic compounds originally occurring in the
tissue. Not only is the protein broken down during autolysis, but the fat also undergoes some decomposition, becoming more acid and sometimes rancid also. There may be no connection between these two results, but both indicate that the fat has been broken down.

EGGS

Though eggs are dead material they cannot be frozen in the shell because freezing causes the shell to burst. A storage temperature slightly above freezing is therefore necessary. Broken-out eggs may of course be frozen.

It is not often realized how rapidly an egg deteriorates just after it is laid. The nest is usually warm and not a good place for storage. The sooner the egg can be brought to a low temperature the better, and a few hours' difference may make possible many weeks more of commercial storage.

Eggs give off carbon dioxide, though they absorb little or no oxygen. This is not respiration but a form of decomposition. As with meat, however, this decomposition is inhibited by the presence of carbon dioxide outside the egg in the storage room. The result is of course an accumulation of carbon dioxide in the egg, where it inhibits the reaction by which more would be formed. The same result could be obtained by plugging up the pores of the shell and preventing the escape of the carbon dioxide formed within the egg. A coating of thick mineral oil tends to do this. According to a process tried out by the Department of Agriculture (1115) the eggs are dipped in oil, then the air is pumped out of them by a vacuum pump, and finally the oil is pushed into the pores of the shell by releasing the vacuum. Such eggs have been found by the candling test to grade higher after storage than untreated eggs. Just how far candling or any other method may be taken as a test of the flavor of an egg is at present hard to say. Candling probably does give some indication of flavor, but it does not seem to be very direct.

The loss of moisture by eggs in storage is serious for it causes them to lose grade. Since candling grades are based to a large extent on the size of the air cell, the prevention of evaporation is important. In order to reduce the loss of water very high humidities are often used. This is safe only if everything is clean and the ventilation is good; otherwise mold growth is favored too much. Oiling the eggs also helps to minimize evaporation of the water.

VEGETABLES

Vegetables stored in a frozen state may be considered as dead material, since no respiration takes place in them. Because of the enzymic changes to which they are subject, however, vegetables are frequently pasteurized before freezing—a process known as "blanching." This brief heating destroys some of the enzymes and prevents any rapid action in the frozen material. Enough activity remains, however, to require low storage temperatures for good results. The chemical changes in frozen vegetables are as yet little understood. Curious off flavors sometimes arise, such as the haylike flavor that occasionally develops in frozen black raspberries. To prevent loss of water in fruits and vegetables stored below freezing, waxed-paper wrappings are used to decrease evaporation.