black introduced into the intestinal canal of animals, showed that although the intestinal mucous membrane became of a deep black, this could easily be removed by a stream of water and no carbonaceous particles could be discovered in the mesenteric veins, the lacteals or the mesenteric glands. When the carbon is used in the form of lamp-black, the particles are very minute and rounded, and they do not present the sharp points and edges which sometimes enable the grains of pulverized charcoal to penetrate the vessels mechanically.

Variations and Modifications of Absorption.

Very little is known concerning the variations in lacteal or lymphatic absorption; but in absorption by blood-vessels, important modifications occur, due, on the one hand, to different conditions of the fluids to be absorbed, and on the other, to differences in the constitution of the blood and in the conditions of the vessels.

The different conditions of the fluids to be absorbed apparently do not always have the same influence in physiological absorption as in endosmotic experiments made out of the body. Saccharine solutions of different densities confined in distinct portions of the intestinal canal of a living animal do not present any marked variations in the rapidity of their absorption, and they are taken up by the blood, even when their density is greater than that of the blood-plasma. Solutions of potassium nitrate and of sodium sulphate, of greater density than the serum, which would, therefore, attract the endosmotic current in an endosmometer, are readily taken up by the blood-vessels in a living animal. Indeed, nearly all soluble substances, whatever be the density of their solutions, may be taken up by the various absorbing surfaces during life. The curare poison and most of the venoms are remarkable exceptions to this rule. In a series of experiments upon the absorption of curare, Bernard has shown that this poison, which is absorbed so readily from wounds or when injected under the skin, generally produces no effect when introduced into the stomach, the small intestine or the urinary bladder. This result, however, is not invariable, for poisonous effects are produced when curare is introduced into the stomach of a fasting animal. This peculiarity in the absorption of many of the animal poisons has long been observed; and it is well known that the flesh of animals poisoned with curare may be eaten with impunity. It is curious, however, to see an animal carrying in the stomach without danger a fluid which would produce death if introduced under the skin; and the explanation of this is not readily apparent. The poison is not neutralized by the digestive fluids, for curare digested for a long time in gastric juice, or taken from the stomach of a dog, is found to possess all its toxic properties. This may be shown by poisoning a pigeon with curare drawn by a fistula from the stomach of a living dog (Bernard). If the absorption of this poison be recognized simply by its effects upon the system, it must be assumed that during digestion, it can not be absorbed by the mucous membrane of the stomach and small intestine, notwithstanding its solubility.

It has been shown that liquids which immediately disorganize the tissues, such as concentrated nitric or sulphuric acid, can not be absorbed. Another important peculiarity in absorption is that solutions which readily coagulate the albumen of the circulating fluids are absorbed very slowly (Miahle). This is explained by the supposition that there is a coagulation of the albuminous fluids with which the absorbing membrane is permeated, which interferes with the passage of liquids. These substances are nevertheless taken up by the blood-vessels, though rather slowly.

Influence of the Condition of the Blood and of the Vessels on Absorption.—After loss of blood or deterioration of the nutritive fluid from prolonged abstinence, absorption generally takes place with great activity. This is well known, both as regards the entrance of water and alimentary substances and the absorption of medicines. It was at one time quite a common practice to bleed before administering certain remedies, in order to produce their more speedy action upon the system.

The rapidity of the circulation has an important influence in facilitating absorption, and this process is generally active in proportion to the vascularity of different parts. During intestinal absorption, the increase in the activity of the circulation in the mucous membrane is very marked and undoubtedly has an influence upon the rapidity with which the products of digestion are taken up by the blood.

Influence of the Nervous System on Absorption.—It is certain that absorption, especially in the stomach, is subject to certain variations, which can hardly be dependent upon anything but nervous action. Water and other liquids, which usually are readily absorbed from the stomach, are sometimes retained for a time, and are afterward rejected in nearly the condition in which they were taken. It is probable, however, that the most important influences thus exerted by the nervous system are effected through the circulation. The experiments of Bernard and others upon the vaso-motor nerves, by the action of which the supply of blood in different parts is regulated, point out a line of experimentation which would probably throw much light upon some of the important variations in absorption. When it is remembered that the small arteries may become so contracted under the influence of the vaso-motor nerves that their caliber is almost obliterated, of course retarding in a corresponding degree the capillary and venous circulation in the parts, and again, that the same vessels may be so dilated as to admit to a particular part many times more blood than it ordinarily receives, it becomes apparent that absorption may be profoundly affected through this system of nerves. It has been ascertained that while a section of some of the nerves distributed to the alimentary canal will slightly retard the absorption of the poisonous substances, the process is never entirely arrested.

Imbibition and Endosmosis.

If liquids pass through the substance of an animal membrane, it is evident that the membrane itself must be capable of taking up a certain portion by imbibition; and this must be considered as the starting-point in absorption.

Imbibition is, indeed, a property common to all animal tissues. It is a well known fact, however, that the tissues do not imbibe all solutions with the same degree of activity. Distilled water is the liquid which is always taken up in greatest quantity, and saline solutions enter the substance of the tissues in an inverse ratio to their density. This is also the fact with regard to mixtures of alcohol and water, imbibition always being in an inverse proportion to the quantity of alcohol present in the liquid. Among the other conditions which have a marked influence upon imbibition, is temperature. It is a familiar fact that dried animal membranes may be more rapidly softened in warm than in cold water; and with regard to the imbibition of liquids by sand, the researches of Matteucci and Cima have shown a considerable increase at a moderately elevated temperature. While nearly all the structures of the body, after desiccation, will imbibe liquids, the membranes through which the processes of absorption are most active are, as a rule, most easily permeated; and the character of the liquid, the temperature etc., have a great influence upon the activity of this process. For example, all liquids which have a tendency to harden the tissues, such as saline solutions, alcohol etc., pass through with much less rapidity than pure water.

Mechanism of the Passage of Liquids through Membranes.—The passage of liquids through membranes is called osmosis. In the case of two liquids passing in opposite directions, the stronger current is called endosmotic and the weaker current is called exosmotic. In the passage of liquids into the vessels, in physiological absorption, the process is generally called endosmosis. The attention of physiologists was first directed to these phenomena by the researches of Dutrochet, published in 1826.

It is now definitely ascertained that the following conditions are necessary for the operation of endosmosis and exosmosis:

1. That both liquids be capable of "wetting" the interposed membrane, or in other words, that the membrane be capable of imbibing both liquids. If but one of the liquids can wet the membrane, the current takes place in only one direction.

2. That the liquids be miscible with each other and be differently constituted. Although it is found that the currents are most active when the liquids are of different densities, this condition is not indispensable; for currents will take place between solutions of different substances, such as salt, sugar or albumen, when they have precisely the same density.

The physiological applications of the laws of endosmosis can now be more fully appreciated, as it is evident that the above conditions are fulfilled whenever absorption takes place, with the single exception of the absorption of fats, which has been specially considered. For example, all substances are dissolved or liquefied before they are absorbed, and in this condition, they are capable of "wetting" the walls of the blood-vessels. All the liquids absorbed are capable, also, of mixing with the plasma of the blood. What makes this application still more complete, is the behavior of albumin in endosmotic experiments. In physiological absorption, there is always a great predominance of the endosmotic current, and there is very little transudation,

or exosmosis, of the albuminoid constituents of the blood. On the other hand, there is a constant absorption of peptones, which are destined to be converted into the albuminoid constituents of the blood.

Recognizing the fact that albumin is capable of inducing a more powerful endosmotic current than almost any other liquid, it has been shown that it never itself passes through membranes in the exosmotic current, but that albuminoids, after transformation by digestion into peptones, or albumin mixed with gastric juice, pass through animal membranes with great facility. The experiments by which these facts are demonstrated are of the highest physiological importance. On removing part of the shell of an egg, so as to expose its membranes, and immersing it in pure water, the passage of water into the egg is rendered evident by the projection of the distended membranes; but although the surrounding liquid becomes alkaline and the appropriate tests reveal the presence of some of the inorganic constituents of the egg, the presence of albumin can not be detected. When the contents of the egg are replaced by the serum of the blood, the same result follows. "After six or eight hours of immersion, the serum had yielded to the water in the vessel all its saline elements, chlorides, sulphates, phosphates, which were easily recognized by their peculiar reactions, but not a trace of albumin" (Dutrochet).

A very simple apparatus for illustrating endosmotic action can be constructed in the following way: Remove carefully a circular portion, about an inch (25·4 mm.) in diameter, of the shell from one end of an egg, which may be done without injuring the membranes, by cracking the shell into small pieces, which are picked off with forceps. A small, glass tube is then introduced through an opening in the shell and membranes of the other end of the egg, and is secured in a vertical position by wax or plaster of Paris, the tube penetrating the yelk. The egg is then placed in a wine-glass partly filled with water. In the course of a few minutes the water will have penetrated the exposed membrane, and the yelk will rise in the tube.

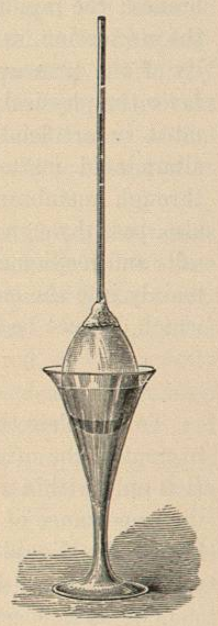

FIG. 97.—*Egg prepared so as to illustrate endosmotic action.*

The force with which liquids pass through membranes, called endosmotic or osmotic force, is to a great degree dependent upon the influence of the membranes themselves. This influence is always purely physical, in experiments made out of the body; and physiological absorption can be explained, to a certain extent, by the same laws. It must be remembered, however, that the properties of organic structures, which are manifested only in living bodies, are capable of modifying these physical phenomena in a remarkable degree. For example, all living tissues are capable of selecting and appropriating from the nutritive fluids the materials necessary for their regeneration; and the secreting structures of glands also select from the blood certain constituents which are used in the formation of their secretions. These phenomena and their modifications through the nervous system can not be fully explained. This is true, also, of many of the phenomena of absorption and their modifications, which are probably dependent upon the same kind of action.

It is not necessary to assume the existence of infinitely small openings in homogeneous membranes through which osmotic currents can be made to take place, in order to explain the mechanism of these currents. In the case of two liquids capable of diffusing with each other and separated by an animal membrane, the mechanism of the endosmotic and exosmotic currents is very simple. In the first place, the membrane imbibes both the liquids, but one is always taken up in greater quantity than the other. If water and a solution of common salt be employed, the surface of the membrane exposed to the water will imbibe more than the surface exposed to the saline solution; but both liquids will meet in its substance. The first step, therefore, in the production of the currents is imbibition. Once in contact with each other, the liquids diffuse, the water passing to the saline solution, and *vice versâ*. This takes place by precisely the same mechanism as that of the passage of liquids through porous *septa*.

In no experiments performed out of the body, can the conditions favorable to the passage of liquids through membranes in accordance with purely physical laws be realized as they exist in the living organism. The great extent of the absorbing surfaces; the delicacy and permeability of the membranes; the rapidity with which substances are carried on by the torrent of the circulation, as soon as they pass through these membranes; the uniformity of the pressure, notwithstanding the penetration of liquids; all these favor the physical phenomena of absorption in a way which can not be imitated in artificially constructed apparatus. Within the blood-vessels, the albuminoid matters exist in a form which does not permit them to pass through membranes, while the peptones are highly osmotic. The sugars, also, pass through the walls of the vessels with facility, as well as various salts and medicinal substances in solution. The fats, as has been stated, pass mainly into the lacteals, by a process which has already been described and which can not be fully explained by the laws of endosmosis.

Lymph and Chyle.

To complete the history of physiological absorption, it will be necessary to treat of the origin, composition and properties of the lymph and chyle. It is only within a few years that physiologists have been able to appreciate the importance of the lymph, for the experiments indicating the great quantity of this liquid which is continually passing into the blood are of comparatively recent date.

The first successful experiments in which the lymph and chyle were obtained in quantity were made by Colin. This observer, in operating upon large animals, particularly the ruminants, experienced no great difficulty in isolating the thoracic duct near its junction with the subclavian vein and introducing a metallic tube of sufficient size to allow the free discharge of fluid. These experiments, made upon horses and the larger ruminants, were

the first to give any clear idea of the quantity of liquids—lymph and chyle—which pass through the thoracic duct. In an observation upon a cow of medium size, he succeeded in collecting, in the course of twelve hours, 105·3 lbs. (47,963 grammes); and he stated that a very much greater quantity can be obtained by operating upon ruminants of larger size.

According to the estimates of Dalton, deduced from his own observations upon dogs and the experiments of Colin upon horses, the total quantity of lymph and chyle produced in the twenty-four hours in a man weighing one hundred and forty-three pounds (65 kilos.) is about 6·6 pounds (3,000 grammes). And again, reasoning from experiments made upon dogs thirteen hours after feeding, when the fluid which passes up the thoracic duct may be assumed to be pure, unmixed lymph, the total quantity of lymph alone, produced in the twenty-four hours by a man of ordinary weight, would be about 4·4 pounds (2,000 grammes). These estimates can be accepted only as approximate, and they do not indicate the entire quantity of lymph actually contained in the organism.

There are no very satisfactory recent researches with regard to the physiological variations in the quantity of lymph. Collard de Martigny found the lymphatics always distended with fluid in dogs killed after two days of total deprivation of food. This condition continued during the first week of starvation; but after that time, the quantity in the vessels gradually diminished, and a few hours before death, the lymphatics and the thoracic duct were nearly empty. In comparing the quantity of fluid in the lymphatics of the neck, during digestion and absorption, with the quantity which they contained soon after digestion was completed, the same observer found that while digestion and absorption were going on actively, the vessels of the neck contained scarcely any fluid; but the quantity gradually increased after these processes were completed.

Properties and Composition of Lymph.—Lymph taken from the vessels in various parts of the system, or the fluid which is discharged from the thoracic duct during the intervals of digestion, is either perfectly transparent and colorless or of a slightly yellowish or greenish hue. When allowed to stand for a short time, it becomes faintly tinged with red, and frequently it has a pale rose-color when first discharged. Microscopical examination shows that this reddish color is dependent upon the presence of a few red blood-corpuscles, which are entangled in the clot as the lymph coagulates, thus accounting for the deepening of the color when the fluid has been allowed to stand.

Lymph has no decided or characteristic odor. It is very slightly saline in taste, being almost insipid. Its specific gravity is much lower than that of the blood. Magendie found the specific gravity in the dog to be about 1022. According to Robin, the specific gravity of the defibrinated serum of lymph is 1009. In analyses by Dähnhardt, of the lymph taken from dilated vessels in the leg, in the human subject, the specific gravity was 1007.

A few minutes after discharge from the vessels, both the lymph and chyle undergo coagulation. This process, as regards the chemical changes involved, is identical with the coagulation of the blood, in which the leucocytes play an important part. According to Colin, the fluid collected from the thoracic duct in the large ruminants coagulates at the end of five, ten or twelve minutes, and sets into a mass having exactly the form of the vessel in which it is contained. The clot is tolerably consistent, but there is never any spontaneous separation of serum (Colin). This may be the fact with regard to the lymph and the chyle of the large ruminants, but in the observations of Dalton, who operated upon dogs and goats, after a few hours' exposure, the clot contracted to about half its original size, precisely like coagulated blood, expressing a considerable quantity of serum. In one instance, in the dog, the volume of serum, after twenty-four hours of repose, was about twice that of the contracted clot.

Although many analyses have been made of lymph from the human subject, the conditions under which the fluid has been obtained render it probable that in the majority of instances it was not entirely normal. It will be necessary, therefore, to compare these analyses with observations made upon the lymph of the inferior animals; as in the latter, this fluid has been collected under conditions which leave no doubt as to its normal character. In the experiments of Colin especially, the fluids taken from the thoracic duct during the intervals of digestion undoubtedly represented the normal, mixed lymph collected from nearly all parts of the body; and the operative procedure in the large ruminants is so simple as to produce little if any general disturbance. The following is an analysis by Lassaigne of specimens of lymph collected by Colin from the thoracic duct of a cow, under the most favorable conditions:

COMPOSITION OF LYMPH FROM A COW.

Water	964·0
Fibrin	0·9
Albumin	28·0
Fatty matter	0·4
Sodium chloride	5·0
Sodium carbonate, sodium phosphate and sodium sulphate	1·2
Calcium phosphate	0·5
	1,000·0

The proportions given in the table are by no means invariable, the differences in coagulability indicating differences in the proportion of fibrin-factors, and the degree of lactescence showing great variations in the quantity of fatty matters. The table may be taken, however, as an approximation of the average composition of the lymph of these animals, during the intervals of digestion.

The analysis of human lymph which seems to be the most reliable, and in which the fluid was apparently pure and normal, is that of Gubler and Quevenne. The lymph in this case was collected by Desjardins from a female who suffered from a varicose dilatation of the lymphatic vessels in the anterior and superior portion of the left thigh. These vessels occasionally ruptured, and the lymph could then be obtained in considerable quantity.

When an opening existed, the discharge of fluid could be arrested at will by flexing the trunk upon the thigh. Gubler and Quevenne made analyses of two different specimens of the fluid, with the following results:

COMPOSITION OF HUMAN LYMPH.

	First analysis.	Second analysis.
Water	939·87	934·77
Fibrin	0·56	0·63
Caseous matter (with earthy phosphates and traces of iron)	42·75	42·80
Fatty matter (in the second analysis, fusible at 102·3° Fahr., or 39° C)	3·82	9·20
Hydro-alcoholic extract (containing sugar, and leaving, after incineration, sodium chloride, with sodium phosphate and sodium carbonate)	13·00	12·60
	1,000·00	1,000·00

The above analyses show a much larger proportion of solid constituents than was found by Lassaigne in the lymph of the cow. This excess is pretty uniformly distributed throughout all the constituents, with the exception of the fatty matters and fibrin; the former existing largely in excess in the human lymph, especially in the second analysis, while the latter is smaller in quantity than in the lymph of the cow. It is evident, however, from a comparison of the two analyses by Gubler and Quevenne, that the composition of the lymph, even when it is unmixed with chyle, is subject to great variations. The caseous matter given by Gubler and Quevenne is probably equivalent to the albuminous matter mentioned by other chemists.

The distinctive characters of the different constituents of the lymph do not demand extended consideration, inasmuch as most of them have already been treated of in connection with the blood. In comparing, however, the composition of the lymph with that of the blood, the great excess of solid constituents in the latter fluid is at once apparent.

In nearly all analyses the organic nitrogenized constituents have been found to be very much less in the lymph than in the blood. This is generally most marked with regard to the fibrin-factors; but as before stated, the proportion of all these substances is quite variable. On account of this deficiency, lymph is much inferior to the blood in coagulability, and the coagulum, when it is formed, is soft and friable. There does not appear, however, to be any actual difference between the coagulating constituents of the lymph and of the blood.

Fatty matters have generally been found to be more abundant in the lymph than in the blood; but their proportion is even more variable than that of the albuminoid constituents.

Very little remains to be said concerning the ordinary inorganic constituents of the lymph. The analyses of Dähnhardt have shown that nearly if not all of the inorganic matters which have been demonstrated in the blood are contained in the lymph; and a small proportion of iron is given in the analyses by Gubler and Quevenne.

These facts indicate a remarkable correspondence in composition between the lymph and the blood. All of the constituents of the blood, except the red corpuscles, exist in the lymph, the only difference being in their relative proportions.

In addition to the constituents of the lymph ordinarily given, the presence of glucose, and more lately, the existence of a certain proportion of urea, have been demonstrated in this fluid. It has not been ascertained how the sugar contained in the lymph takes its origin.

The presence of urea in considerable quantity in both the chyle and the lymph has been determined by Wurtz; and it is thought by Bernard that the lymph is the principal fluid, if not the only one, by which this excrementitious substance is taken up from the tissues. Although urea always exists in the blood, its quantity is less than in the lymph.

According to Ludwig and Hammersten, the lymph of the dog contains about forty parts per hundred in volume of carbon dioxide, of which seventeen parts may be extracted by the air-pump and twenty-three parts, by acids. In addition, the lymph contains a trace of oxygen and one or two parts of nitrogen.

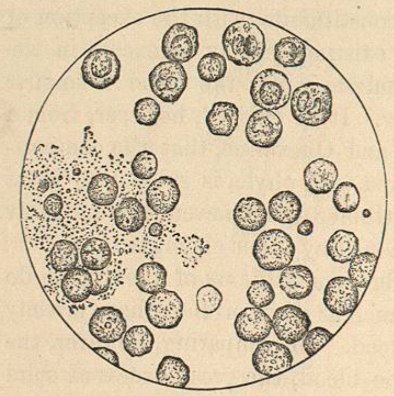

FIG. 98.—*Chyle taken from the lacteals and thoracic duct of a criminal executed during digestion* (Funke).
This figure shows the leucocytes and excessively fine granules of fatty emulsion.

Corpuscular Elements of the Lymph.—In every part of the lymphatic system, in addition to a few very minute fatty granules, there are found certain corpuscular elements known as lymph-corpuscles. These exist, not only in the clear lymph, but in the opaque fluid contained in the lacteals during absorption. They are now regarded as identical with the white blood-corpuscles, or leucocytes. Eight thousand two hundred leucocytes have been counted in 0·061 cubic inch (1 c. c.) of lymph from a dog (Ritter).

The leucocytes found in the lymph and chyle are rather less uniform in size and general appearance than the white corpuscles of the blood. Their average diameter is about $\frac{1}{2500}$ of an inch (10 μ.); but some are larger, and others are as small as $\frac{1}{5000}$ of an inch (5 μ.). Some of these corpuscles are quite clear and transparent, presenting but few granulations and an indistinct nuclear appearance in their centre; but others are granular and quite opaque. They present the same adhesive character in the lymph as in the blood, and frequently they are found collected in masses in different parts of the lymphatic system. In all other regards, these bodies present the same characters as the leucocytes of the blood, and they need not, therefore, be farther described.

In addition to the ordinary leucocytes and a certain number of fatty granules, a few small, clear globules or granules, about $\frac{1}{7500}$ of an inch (3·3 μ.) in diameter, called sometimes globulins, are almost constantly present in the lymph. These are insoluble in ether and acetic acid but are dissolved by ammonia. They were regarded by Robin as a variety of leucocytes and described by him as free nuclei.

Origin and Uses of the Lymph.—There can hardly be any doubt concerning the source of most of the liquid portions of the lymph, for they can be derived only from the blood. Although the exact relations between the smallest lymphatics and the blood-vessels have not been made out in all parts of the system, there is manifestly no anatomical reason why the water, mixed with albuminoid matters and holding salts in solution, should not pass from the blood into the lymphatics; and this is rendered nearly certain by the fact that the lymphatics surround many of the blood-vessels. In comparing the composition of the lymph with that of the plasma of the blood, it is seen that the constituents of these fluids are nearly if not quite identical; the only variations being in their relative proportions. This is another argument in favor of the passage of most of the constituents of the blood into the lymph.

One of the most important physiological facts in the chemical history of the lymph is the constant existence of a considerable proportion of urea. This can not be derived from the blood, for its proportion is greater in the lymph, notwithstanding the fact that this fluid is being constantly discharged into the blood-vessels. The urea which exists in the lymph is derived from the tissues; it is discharged then into the blood, and is constantly being removed from this fluid by the kidneys.

The positive facts upon which to base any precise ideas with regard to the general office of the lymph are not very many. From the composition of this fluid, its mode of circulation, and the fact that it is being constantly discharged into the blood, it would not seem to have an important use in the active processes of nutrition. The experiments of Collard de Martigny sustain this view, inasmuch as the quantity and the proportion of solid constituents of the lymph were rather increased than diminished in animals that had been deprived of food and drink for several days; while it is well known that starvation always impoverishes the blood from the first. On the other hand, urea, one of the most important of the products of disassimilation, is undoubtedly taken up by the lymph and conveyed in this fluid to the blood. It remains for future investigations to determine whether other excrementitious matters may not be taken up from the tissues in the same way—a question of importance in its relations to the mechanism of excretion.

What is positively known with regard to the uses of the lymph may be summed up in a very few words: A great part of its constituents is evidently derived from the blood, and the relations of these to nutrition are not understood. The same may be said of sugar, which is a constant constituent of the lymph. Urea and perhaps other excrementitious matters are taken up from the tissues by the lymph, and are discharged into the blood, to be removed from the system by the appropriate organs.

Properties and Composition of Chyle.—During the intervals of digestion, the intestinal lymphatics and the thoracic duct carry ordinary lymph; but