Guides for Science Teaching.

No. XIV.

HINTS FOR TEACHERS OF PHYSIOLOGY.

Bowditch

BOSTON:
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BY

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PREFACE.

THE rudiments of PHYSIOLOGY are taught in most of our Grammar Schools; but the exercise too frequently consists simply in the recitation of statements from a text-book, and the pupil at the end of the course scarcely suspects that the science he has been studying is one which is based as firmly upon observation and experiment as either physics or chemistry.

In the following pages an attempt has been made to show how a teacher may supplement his text-book instruction by means of simple observations and experiments on living bodies or on organic material, thus imparting to his pupils a knowledge of the foundation on which Physiology rests, and at the same time bringing the impressions made on the senses to aid the memory in retaining the facts communicated in a purely didactic way. It need scarcely be said that the production of a complete treatise on Physiology has not been attempted, since those subjects only have been selected for discussion which are capable of easy experimental illustration.

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HARVARD MEDICAL SCHOOL,
BOSTON, *January*, 1889.

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Hints for Teachers of Physiology.

INTRODUCTION.

WITHOUT seeking to present a perfectly accurate definition of the words "life," "vital," etc., the teacher may begin his instruction by explaining that physiology treats of the phenomena of living bodies, and by asking the members of the class how it is possible to distinguish a living body from one which is not living. Some pupil will doubtless suggest that the power of locomotion distinguishes animate from inanimate objects; and the teacher can then explain that this distinction holds good in most instances, but that those pupils who have lived at the sea-shore will doubtless be able to suggest exceptions to the rule, — *e. g.*, mussel-shells, polyps, etc.

Another pupil will very likely suggest that living animals are warm. Here the teacher may mention frogs, snakes, fishes, etc., as apparent exceptions to the rule, and explain that the vital phenomena of cold-blooded animals differ in degree only, and not in kind, from those of warm-blooded animals. The pupils may then be asked to mention some inanimate body which moves and is warm. A locomotive will probably be suggested. It is thus evident that a living body cannot be defined as a warm body which moves, for this definition includes a locomotive. The comparison of a living body to a steam-engine is, however, a very useful one, for the class may next be asked to point out the source of heat and motion in the steam-engine. The conception of the expanding steam and the burning fuel, if not already familiar, may then be explained, and the question what will happen to the engine when the supply of fuel is exhausted, will elicit the answer that the engine will stop and grow cold. The necessity for a periodical supply of fuel to a locomotive may then be shown to be strictly analogous to the necessity for food in the living animal, death by starvation, with loss of heat and power of motion, in the case of the animal corresponding to the stoppage and cooling of the engine when fuel is not supplied.

The class may next be asked to point out a resemblance between the materials used for fuel and those used for food. Some pupil familiar with wood-burning locomotives will doubtless suggest that the materials are in both cases of *vegetable* origin. An opportunity will here be given to the teacher to explain that coal-burning locomotives do not furnish an exception to this statement, since coal must be regarded as fossil wood grown upon the surface of the earth in former geological periods.

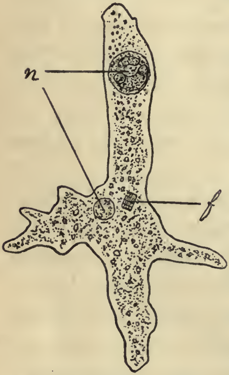
The fact that certain animals (including man) live wholly or in part upon the flesh of other animals, may also be shown to be consistent with the statement that food is of vegetable origin, since the animals thus used as food have built up their bodies by the use of vegetable nutriments; and the carnivorous animals, living upon the flesh of the herbivora, thus derive their food indirectly instead of directly from the vegetable kingdom.

It may next be pointed out that whether an organic substance undergoes rapid combustion, as in a locomotive, or a slow chemical change, known as retrograde metamorphosis, or catabolism, in the animal body, the final products — namely, carbon-dioxide, water, and ammonia — are the same in both cases, and that consequently the amount of energy liberated in the form of heat and mechanical work must also be the same. The extent to which this branch of the subject may be profitably pursued will depend upon the proficiency of the pupils in chemistry and physics. A class of students who have mastered the rudiments of these sciences will readily understand that we have here a most interesting example of that great law, the distinct formulation of which is the greatest triumph of modern science — namely, the law of the conservation and correlation of forces; and that all the energy manifested in the animal body as heat and mechanical work is derived (like nearly all the forms of force with which we are familiar on the surface of the earth) from the radiant energy of the sun.

Since the taking in of a regular supply of food is necessary to enable us to manifest those forms of energy which distinguish living bodies, a natural method of studying physiology is to trace the successive steps by which food is taken into the body, the changes which it undergoes while there, and the manifestations of force to which its transformation gives rise. It must of course be borne in mind that organic substances, in order by their decomposition to liberate their potential energy in any of the forms of force which characterize the living animal body, must be brought into intimate contact with the tissues in which the force is manifested. Hence when we speak of "taking food into the body" to supply its need of organic material, we do not mean simply that food is to be swallowed; for substances contained in the stomach or in any part of the alimentary canal are, strictly speaking, no more "in the body" than when they are held in the hand; they are simply in contact with an internal surface.

An interesting digression into the domain of zoölogy may here be made if time will allow, and it may be shown that an alimentary canal, with its orifices of entrance and exit, is by no means universal in the animal kingdom. Beginning with the amœba, it may be shown that animals exist with bodies consisting of a simple mass of undifferentiated protoplasm (see Fig. 1); that these animals absorb their food at all points of the surface of their body; and that the various functions which in higher animals are assigned to special organs are in the amœba performed indifferently by every part of its protoplasmic mass. As an example of an animal somewhat higher in the scale of creation, the hydroid polyp

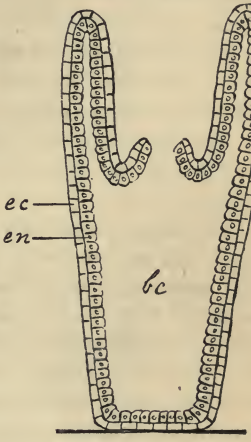
FIG. 1. — AMŒBA (after Sedgwick).



n, Nucleus.
f, A microscopic plant which has been eaten.

(represented diagrammatically in Fig. 2) may be selected. Here we find a body of a definite shape, namely, that of a deep cup, forming a cavity for the reception of food. This cavity has of course but one opening, and the articles of food, after remaining there for a certain length of time, and parting with their nutritious constituents, are rejected by the same opening through which they entered. As we ascend in the animal series, the differentiation of function becomes more and more complete, the alimentary tract becomes a long convoluted tube opening externally at both ends, while special organs known as glands pour into it fluids destined to exert a solvent action upon the food which has been swallowed, and thus enable it to penetrate the living membrane of the intestines. At the same time the development of the blood-vessels affords a ready means for the conveyance of the absorbed nutriments to the organs in which they are to be decomposed. The circulating blood in the higher animals, besides conveying organic materials for decomposition in the force-producing organs, absorbs oxygen from the air

FIG. 2. — HYDRA.



e c. Ectoderm.
e n. Entoderm.
b c. Body cavity.

in the lungs and conveys it to all the tissues of the body, thus providing for the complete oxidation of the organic materials and the liberation of their potential energy. The products of this decomposition are likewise conveyed by the circulating blood to the organs destined to remove them from the body; and in addition to these important functions the circulatory system serves to distribute and regulate the heat of the body (being comparable in this respect to the hot-water or steam pipes used to heat buildings).

It will thus be seen that a study of the way in which organic substances enter, pass through, and leave the body, with a consideration of the various functions associated with these processes, will cover the whole subject of physiology as far as it relates to the life of the individual. Taking up the various problems of physiology somewhat in the order indicated by the above scheme, an attempt will now be made to show how a large number of them may be illustrated by observations and experiments requiring no apparatus that cannot be readily obtained by Grammar-School teachers.

MASTICATION.

The first process to which food is subjected on its entrance into the alimentary canal is mastication, and the teacher may begin the study of this subject by asking the pupils to mention those articles of food which require the most, and those which require the least, amount of chewing. The question is best investigated by observations on animals, which as a rule have a much less varied diet than man.

If none of the pupils have any observations to report, they may be requested to give a piece of meat to a dog and a handful of hay or oats to a horse, to notice the different ways in which the two animals dispose of their food, and to report the result at the next lesson. The quick, snapping movement with which the dog seizes the meat, and the rapidity with which he swallows it, almost as soon as it is in the mouth, show clearly how very imperfectly the function of mastication is performed by carnivorous animals ; while the slow lateral movement of the jaw and the prolonged grinding process to which the horse subjects his food indicate the much greater relative importance which this function possesses in the herbivora.

Can we generalize from this observation and say that vegetable food always requires more mastication than animal? When vegetable food is used in its natural state, this is generally the case ; for the nutriments in vegetables are commonly contained in a more or less indigestible envelope of cellulose or woody fibre, which must be removed by mechanical means in order to make the nutriments accessible to the digestive fluids of the animal. This envelope may be very delicate, as, for instance, in the green sprouts of asparagus, harder and more brittle, as in the bran of wheat, or may constitute a dense mass of woody tissue, as in the shell of the cocoanut. To illustrate this portion of the subject, the pupils may be requested to bring specimens of vegetable nutriments enclosed in their natural cellulose envelopes. The collection of nuts, seeds, and grains of all sorts which may thus be formed, will serve well to show how important it is for herbivorous animals to possess effective organs of mastication.

It must not be supposed, however, that vegetable food, as used by man, necessarily requires a greater amount of mastication than animal food. In fact, the reverse is often true, as in the case of an oatmeal porridge and a beef-steak. Numerous instances of this sort may be elicited by questions judiciously directed to the pupils, and the class may, by the same method, be brought to the conclusion that it is the millstone and the oven which do for mankind much of the work accomplished by the molar teeth of the herbivora.

In this connection it is well to point out that among civilized nations teeth seem to be gradually becoming superfluous organs. In the evolution of the human race the teeth have long since ceased to be necessary as weapons of offence and defence, and the progress of the art of cooking is gradually rendering them equally unimportant as organs of mastication. Since by a law of evolution superfluous organs tend to be imperfectly developed, and ultimately to disappear, it is perhaps reasonable to conclude that the dental caries which is so prevalent in all civilized communities is a necessary result of the relatively unimportant function which the teeth are called upon to perform.

In order still further to illustrate the difference between the carnivora and the herbivora with regard to the function of mastication, the teacher will do well to obtain the skull of a cat or dog to illustrate the carnivorous, and that of a sheep or goat to illustrate the herbivorous jaw. The older boys in a Grammar School will generally gladly undertake to secure the necessary specimens, the preparation of which may be best effected by removing the skin and so much of the flesh as can easily be cut off with a knife, and then allowing the skull to soak in water till the soft parts are so far decomposed that they may be readily washed from the bones. This result will usually be accomplished in five or six weeks in summer. If the work is done in winter, the jar containing the specimens should be kept in a warm place. The soft parts having been thus removed by maceration, the skull after being well washed should be bleached by exposure to the sun and air for two or three weeks. It is to be observed that skulls of adult animals must be used for this purpose, since those of young animals are apt to fall to pieces on maceration.

On the skulls thus obtained the following points are to be observed: The articulation of the lower jaw to the skull is, in the carnivora, a perfect hinge-joint, permitting a free up and down, but no lateral motion; while in the herbivora the articulation is much looser, thus permitting a free lateral movement to the lower jaw. Corresponding to this difference in the movement of the jaw, we find in the carnivora the canine teeth well developed, and adapted for seizing and holding the prey, while the molar teeth, having sharp edges and closing past each other like the blades of a pair of scissors, are fitted simply for cutting the food into pieces small enough to be swallowed. In the herbivora, on the contrary, the canine teeth are rudimentary or wholly wanting, while the molars have rough and flattened surfaces, showing by their transverse groovings the direction of the movement which has been impressed upon them by the grinding motion of the lower jaw. While demonstrating the sheep's jaw, the teacher may request the pupils to point out a structural reason why a ruminant animal cannot chew the cud on both sides at the same time.

Another type of skull, of which the rat or the squirrel may furnish an illustration, is that of the rodent family. Here the lower jaw articulates into a longitudinal groove in the base of the skull, and has consequently a free movement forward and backward, which is well adapted to bring the large incisor teeth into contact with each other in the act of gnawing. These teeth, which in the skulls previously examined are small or wholly absent, as in the upper jaw of most ruminants, are in rodents of enormous size, and differ from ordinary teeth in the following respects:—

1. The milk-teeth, when present, are shed before the animal is born, — an arrangement the importance of which is readily appreciated when we consider the results which must follow from an animal's being deprived during his lifetime of the use of organs so important as the incisor teeth of a rodent.

2. These teeth continue to grow as long as the animal lives, and are only prevented from becoming too long by being continually worn away in the act of gnawing. If by any accident one of the incisor teeth is broken, the opposite tooth, having nothing to oppose it, continues to grow, and if an upper tooth, may even curve round and penetrate the skull of the animal through the roof of the mouth.

3. The enamel of these teeth, instead of surrounding the whole tooth in the usual way, is found only on the front surface. Hence in the act of gnawing, the softer dentine at the back is worn away faster than the hard enamel on the front, and the tooth thus always preserves the sharp, chisel-like edge which is so important for its efficiency.

The molar teeth of rodents have rough, flattened crowns ; but they differ from those of the sheep in being grooved in a longitudinal direction corresponding to the above-mentioned motion of the jaw, and in the fact that the teeth on both sides can be brought into use at the same time.

The pupils may now be asked to compare their own jaws and teeth with those of the animals they have been studying. They will notice, in the first place, that all the movements of the animal jaws — namely, the up-and-down, the longitudinal, and the lateral movements — can be executed by the human jaw ; and in the second place, that the different sorts of teeth — namely, the incisors, the canines, and the molars — are all present, and about equally well developed. They will thus be led to the conclusion that man is adapted by the character of his dentition for a mixed and varied diet, and is not fitted to subsist exclusively upon any one sort of food.

STRUCTURE OF THE TEETH.

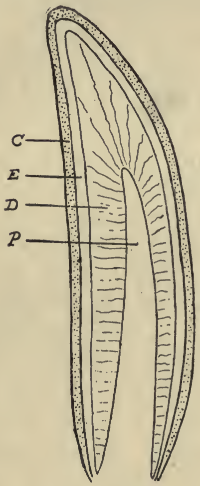
Attention has already been called to the rough and flattened crowns of the molar teeth in the herbivora ; and the pupils may now be asked to suggest a reason why these surfaces always remain rough, and do not become smoothed and polished by the grinding process to which they are subjected. If no answer be forthcoming, it may be mentioned that a mill-stone and an emery-wheel likewise remain always rough, grinding and polishing other things, but never becoming smooth themselves; and it may be shown that wherever a rough grinding surface is desired, the object is attained (by Nature and mankind alike) by the use of a composite material, consisting of hard and soft substances mingled together. When such a material is subjected to friction, the softer substances are worn away faster than the harder, leaving the latter projecting above the former, thus producing and maintaining a rough surface. Thus the so-called "mill-stone grit," from which mill-stones are made, is a species of conglomerate rock consisting of fragments of hard stone imbedded in a softer matrix.

The way in which a similar result is accomplished in the teeth by the use of materials of different density may best be understood by a study of the teeth of the horse. These may be readily obtained in large numbers from those whose duty it is to dispose of the animals constantly dying in large cities. Each horse's skull will furnish twenty-four molar and twelve incisor teeth.

Into the structure of teeth three different substances enter. Immediately surrounding the pulp-cavity, which contains the nerves and blood-vessels of the tooth, is a mass of dentine, resembling ivory in its composition, and forming the bulk of the tooth; over this is a layer of a very hard substance, known as enamel; and outside of all is a layer of cement, — a substance identical with ordinary bone. The enamel is thus imbedded between two substances, both of which are much softer than itself.

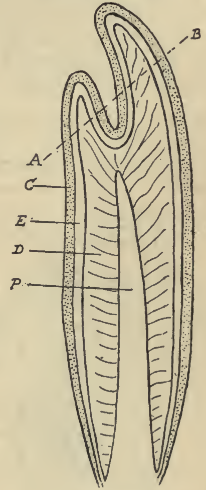
Fig. 3, which may be regarded as representing a section through a typical tooth, shows the relation of

FIG. 3.—TYPICAL TOOTH.



C, Cement.
E, Enamel.
D, Dentine.
P, Pulp-cavity.

FIG. 4.—TOOTH DEPRESSED AT APEX.

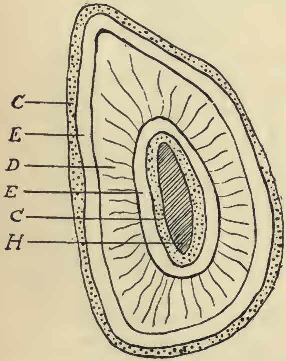


C, Cement.
E, Enamel.
D, Dentine.
P, Pulp-cavity.

these layers to each other. These layers, however, are not all equally well developed in all teeth. In the human teeth, for instance, the enamel reaches only a short distance below the neck of the tooth, and the cement a short distance above this point; so that these two layers barely overlap each other.

If we now suppose a depression to be formed in the apex of the typical tooth, as above represented, an appearance such as is shown in Fig. 4 is produced. If the crown of a tooth thus formed is subjected to friction, it is evident that, as it wears away, materials of different density will be brought to the surface. If the tooth is worn away as far as the line A B, the crown will be seen to be composed of concentric layers arranged round a central cavity, as shown in Fig. 5. This figure represents the appearance of the crown of an incisor tooth of an adult horse, which is formed precisely in the manner here described. The two rings of enamel, being harder than the adjacent cement and dentine, will always remain projecting above the general level, and thus afford a rough grinding surface. An examination of a horse's incisor teeth will generally show that the outer layer of cement is present only at a few points on the surface of the tooth, this relatively soft material having been worn away from the sides as well as from the crown of the tooth.

Fig. 5. — Crown of Incisor Tooth of Horse.

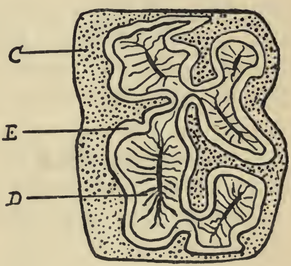


C, Cement.
E, Enamel.
D, Dentine.
H, Central cavity, or pit.

It is evident that as the tooth continues to be worn away, the central pit, or depression, will in time be ground out and disappear. It is, in fact, the disappearance of this pit or depression from the incisor teeth of a horse which enables the dealer to determine the age of an animal by examining its mouth. The central incisors of the lower jaw lose their pit at six, those next to them at seven, and the outer incisors at eight years of age. A valuable practical lesson in quite a different field may thus be taught incidentally to instruction in physiology.

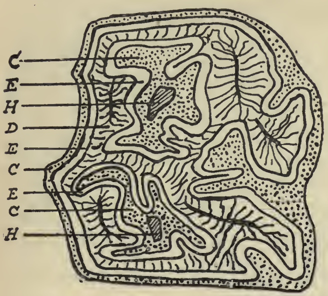
The arrangement of the materials composing the tooth in concentric rings, as in the incisors of the horse, does not produce that intimate mingling of hard and soft substances which is essential in a good grinding surface. We accordingly find that in the horse's molar teeth a much greater complication of structure is observed. This is effected either by a lateral infolding of the layers of dentine, enamel, and cement, as in the lower molars (see Fig. 6), or by a combination of this lateral infolding with the production of two irregular pits or depressions at the apex, as in the upper molars (see Fig. 7). A still more complicated intermingling

FIG. 6. — CROWN OF LOWER MOLAR TOOTH OF HORSE



C, Cement.
E, Enamel.
D, Dentine.

Fig. 7. — Crown of Upper Molar Tooth of Horse.



C, Cement.
E, Enamel.
D, Dentine.
H, Central cavity, or pit.

of the materials composing the tooth may be seen in the molars of the elephant and other large herbivorous mammals, the result being in all cases the production of a surface which retains its rough grinding character as long as the animal lives.

To demonstrate still more clearly the relation of the various materials entering into the structure of teeth, the older pupils may be encouraged to prepare sections of the teeth of horses and other animals. These may be made by sawing the tooth in various directions, and polishing the cut surfaces with a file or a grindstone. A fine, well-tempered saw is needed to cut through the enamel. If such an instrument be not at hand, a tooth may often be split by a blow of a hammer.

Before leaving the subject of mastication it will be well to ask the pupils to observe whether any other movements except those of the jaws are concerned in this process. A little careful experimenting will show them that the muscles of the tongue and cheeks serve to keep the food in position between the teeth while it is subjected to the grinding action of the molars.

The importance of the saliva in favoring the movements of mastication may be illustrated by the experiment of wiping the inside of the mouth perfectly dry with a towel or handkerchief; when it will be found almost impossible to move the jaws until the saliva is again secreted in sufficient quantity to moisten the surfaces of the tongue, cheeks, and gums.

INSALIVATION.

The action of the saliva upon the food is both mechanical and chemical. The former consists in moistening the food so that it may be swallowed, and in bringing into solution those substances which are soluble in neutral or slightly alkaline fluids.

The importance of moisture as an aid in deglutition may be illustrated by requesting some of the pupils to swallow some dry powdery substance, — *e. g.*, a mouthful of pulverized cracker. This will be found to be impossible until saliva enough has been secreted to moisten the entire mass.

The importance of the saliva as a solvent may be shown by wiping the upper surface of the tongue quite dry with a napkin, and then placing a small quantity of powdered sugar upon it. The sugar will be found to be as destitute of taste as so much sand; whereas in its ordinary moist condition the tongue perceives the taste of sweet substances very distinctly. This experiment also illustrates the fact that the terminations of the nerves of taste can be affected only by substances brought in contact with them in the liquid state.

The chemical function of the saliva consists in changing the starch of the food into grape-sugar. This property it possesses in common with many other animal fluids; and it is not probably so important a function as the above-mentioned mechanical ones. It may be illustrated by holding a small quantity of boiled dilute starch paste in the mouth. After a few minutes the substance, which is at first perfectly insipid, becomes decidedly sweetish, owing to the conversion of starch into sugar. By prolonging the experiment a sour taste is sometimes developed, in consequence of a further change of the sugar into lactic acid.

In connection with the fact above alluded to, that herbivorous animals can chew only on one side at a time, it is interesting to notice that during mastication the parotid gland in these animals is active only on the side on which the food is actually being chewed, and that the secretion of the gland entering the mouth by the side of the upper molar teeth is in the best possible position for being thoroughly incorporated with the food as it undergoes mastication.

DEGLUTITION.

Much can be learned of the mechanism of deglutition by observing the process in one's own person. The pupils may be asked to swallow a small piece of bread, and to notice how the morsel to be swallowed is, after being masticated and coated with saliva, carried backward by the tongue, grasped by the muscles forming the pillars of the fauces, and finally carried downward to the stomach by the contracting muscles of the mouth and pharynx, aided by the movements of the œsophagus. They may also be asked to observe that the first portion of this complicated movement is voluntary, and the last part involuntary; since the morsel of food passes out of the control of the will when it enters the pharynx, and continues its course to the stomach not only without any voluntary effort, but with little or no consciousness of the movement.

The pupils may then be requested to place the hand upon the front of the neck just over the larynx, and to notice how that organ is drawn up towards the mouth during deglutition. The teacher may then explain the anatomical connection between the larynx and the muscles of the floor of the mouth, in consequence of which the latter, in contracting to press the food into the œsophagus, necessarily raise the larynx. It may next be pointed out that most of the muscles concerned in this movement arise from the lower jaw. Hence these muscles can act effectively only when the lower jaw is raised and fixed. To illustrate this point, the pupils may be asked to observe how difficult the movement of swallowing becomes when the mouth is open.

The latter portion of the movement of deglutition has been spoken of as involuntary. It may more properly be described as a reflex movement; *i. e*, a movement brought about, not by an impulse coming from the centres of volition in the brain, but by a stimulus applied at the termination of some sensitive nerve. The pressure of the morsel of food upon the sensitive mucous membrane at the back of the mouth is the stimulus which calls forth the movements of swallowing; and a proof of this statement is afforded by the fact that it is impossible by any effort of the will to make these movements unless there is something in the mouth to be swallowed. The pupils may readily convince themselves of this by swallowing three or four times in rapid succession. After they have thus emptied the mouth of any saliva which it may contain, it will be found impossible to repeat the movement until the salivary glands shall have again secreted fluid in an amount sufficient to serve as a stimulus to the nerves presiding over the motions of deglutition.

DIGESTION.

Digestion, as it takes place in the stomach and intestine, may be described as a process by which solid articles of food are dissolved, and substances already in solution are rendered more diffusible, the various nutritious materials being thus prepared for absorption.

To illustrate the process of gastric digestion, the following simple experiment may be performed. Make a solution of weak hydrochloric acid by adding one part of the strong acid to 125 parts of water. Procure from an apothecary a few grains of pepsin. Fill four small (one or two ounce) bottles with the following fluids: —

1. Water.	3. Water + pepsin.
2. Weak HCl.	4. Weak HCl + pepsin.

The pepsin need not be added in any special proportion; as much as can be taken up on the point of a penknife will answer the purpose.

The best substance for testing the activity of a digestive fluid is blood fibrin, which can be obtained at an abattoir by stirring freshly drawn blood. The fibrous material which collects after a few minutes round the stirring rods is to be washed thoroughly with water and preserved in glycerine. If fibrin is not readily obtainable, a delicate form of albuminoid material, suitable for digestive experiments, may be prepared by dropping the white of an egg into slightly acidulated boiling water and stirring it as it falls. A small quantity of the light, flaky, coagulated albumen which is thus formed is to be placed in each of the four bottles, which are then to be kept for an hour or two in a situation where the temperature is, as nearly as possible, that of the human body. An examination of the bottles will then show that the contents of Nos. 1 and 3 are unchanged; in No. 2 the fibrin is swollen but undissolved, or (if egg has been used) the albumen is rendered somewhat translucent; while in No. 4 the materials are more or less completely dissolved.

This shows that for prompt and complete digestion *both acid and pepsin* are necessary.

ABSORPTION.

The various physical processes by which the products of digestion are transferred from the intestinal canal to the circulating blood may be illustrated by simple experiments; but it should be pointed out to the pupils that although osmosis, diffusion, etc., doubtless play an important part in the absorption of digested material, yet these processes, occurring in connection with the living tissues of the body, present themselves under quite a different form from that with which the physicist is familiar in his laboratory experiments.

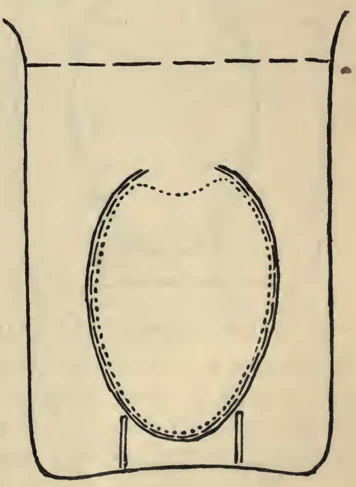
Imbibition is commonly spoken of as of two sorts; namely, capillary, and molecular imbibition; though in some cases it is not easy to decide to which class a given phenomenon belongs. Imbibition by capillarity may be illustrated by placing a few pieces of glass tubing of different sizes in a glass of water, and noting the greater height to which the water rises in the smaller tubes. A strip of filter paper suspended so that one end dips into a one or two per cent solution of aniline blue, illustrates the same phenomenon by the rise of the colored fluid through the pores of the paper. A thin strip of plaster of Paris (cut from a sheet made by allowing the plaster to set between two plates of glass held about one eighth of an inch apart) may also be used for this purpose; and in this case it will be noticed that the plaster imbibes the water more readily than the aniline, — showing that, even in perfect solutions, there may be a difference in the rate of imbibition, dependent upon the varying size of the molecules.

Molecular imbibition may be illustrated by comparing the size and appearance of a piece of dried glue with those of a similar piece which has been soaked for half an hour in cold water. Here the fluid has not entered into open spaces in the solid body, as in capillary imbibition, but the fluid molecules have penetrated between the molecules of the solid body and produced a different condition of molecular aggregation.

Imbibition in the human body may be best illustrated by placing an impermeable covering on a portion of the skin; *e. g.*, a rubber cot on one of the fingers. The insensible perspiration will thus be prevented from evaporating, and the epidermis, imbibing the moisture, will become thick, soft, and whitish. A similar condition of the epidermis may be observed after the hands have been kept a long time in warm water; *e.g.*, in washing clothes.

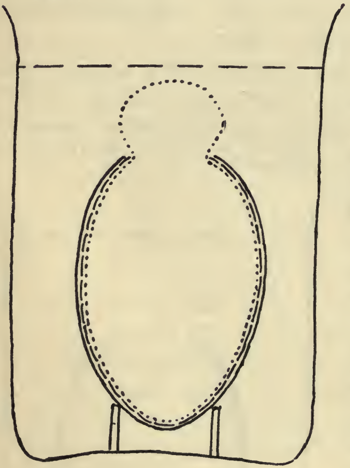
Osmosis may be well illustrated by a simple experiment with an egg. A hole about half an inch in diameter is made in the large end of an egg by breaking through the shell and cutting the outer shell-membrane (it is well to make the hole in the shell a little larger than that in the membrane); the air-space between the inner and outer shell-membranes is thus opened. The egg is then immersed in a glass of water, as shown in Fig. 8. It may be kept in a vertical position by supporting it upon a napkin-ring or upon a ring made by bending a narrow strip of sheet-lead

FIG. 8. — EGG, WITH AIR-SPACE OPENED, AND IMMERSED IN WATER, TO ILLUSTRATE OSMOSIS.



into a circle. The albumen of the egg is thus separated from the water merely by the inner shell-membrane, and through this membrane osmosis takes place very readily, the water passing towards the albumen much more freely than the albumen towards the water. As a result, the membrane becomes more and more distended, bulges out through the hole in the shell, as shown in Fig. 9, and finally bursts.

FIG. 9. — EGG, SHOWING INNER SHELL-MEMBRANE DISTENDED BY ENDOSMOSIS OF WATER.



Whether the materials contained in the intestinal canal are absorbed by these physical processes, or by more mysterious methods associated with vital changes in the intestinal epithelium, the final result is the transference of the nutriments of the food into the circulating blood.

BLOOD.

Important points in the physiology of the blood may be illustrated by a few drops which may be drawn from the finger by the prick of a needle.

If the teacher is in possession of a microscope, the pupils may be asked to observe that the blood consists of a fluid, called the plasma, and of small semi-solid amber-colored bodies, called red blood globules, or blood-disks, suspended in the fluid together with a few pale granular bodies known as white blood globules, or leucocytes. The varying size and shape of the red blood globules in different animals may be illustrated by means of models, which the older boys in the class may be asked to construct. The bi-concave disks which characterize nearly all the mammalia may be readily made by any boy who has access to a turning-lathe. The oval globules which are found in the camel tribe, in birds, and in cold-blooded animals may be carved out of wood or modelled in clay.

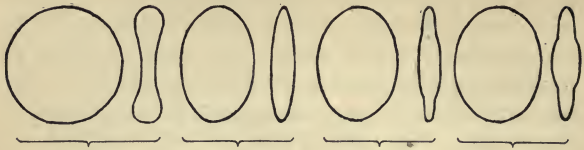
The following table gives the diameters in micro-millimeters[1] of the globules of a sufficient number of animals to illustrate this subject.

Circular.		Oval.	Long diam.	Short diam.
Elephant	9.4 μ			
Man	7.7 "	Llama	8.0 μ	4.0 μ
Dog	7.3 "	Pigeon	14.7 "	6.5 "
Rat	6.4 "	Tench	12.8 "	10.2 "
Horse	5.7 "	Frog	22.3 "	15.7 "
Sheep	5.0 "	Triton	29.3 "	19.5 "
Goat	4.1 "	Proteus	58.2 "	33.7 "
Musk deer	2.5 "			

The models will be found to be of convenient dimensions if made five thousand times as large as the originals. The following figures show the sectional outlines of the various globules, and will serve as guides in making the models.

[1] Micro-millimeter = 0.001 millimeter.
" " = 0.00004 inch.

Fig. 10. — Outlines of Blood-globules.



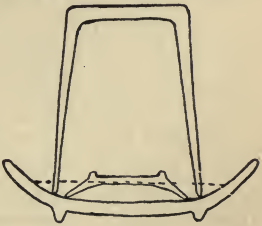
Mammals, exc. Camel Family. Camel Family and Birds. Reptiles. Fishes.

In this connection it is well to point out that the greater size of the globules of the cold-blooded animals is associated with a correspondingly smaller number of these structures; so that there is no great difference in the total volume of the globules, the more active metabolism of the warm-blooded animals being connected with a finer subdivision of the red-globule material as solutions and chemical re-actions are favored by pulverizing the reagents.

The coagulation of the blood may be studied by making two little pools of blood (drawn from the finger by the prick of a needle), of four or five drops each, on the bottom of a saucer. Stir one of the pools with a needle. The blood will be observed to assume a brighter red color, owing to the more complete oxidation of the hæmoglobin, and in a short time a very small quantity of a stringy material will be found adhering to the point of the needle. The fibrin thus obtained may be washed in a few drops of water, and some of its properties — *e. g.*, its elasticity and its power of swelling in weak acids — may be demonstrated.

The other pool of blood, left to itself, will in a few minutes assume a gelatinous consistency. The clot thus formed will subsequently contract, squeezing out a small quantity of serum. In order that the blood may not dry up during this process, the experiment should be performed in a moist chamber. This may be readily provided by collecting the blood upon the bottom of an "individual butter" plate inverted in a saucer of water and covered with an inverted glass tumbler. (See Fig. 11.)

FIG. 11. — MOIST CHAMBER.



The association of the coloring matter of the blood with the globules may be illustrated by preparing two little pools of blood as before, and mixing one of them with twice the quantity of water, and the other with twice the quantity of a strong solution of salt. In the first case the coloring matter will diffuse from the globules into the water, causing the liquid to assume a "laky" color, and to appear very dark by reflected light. In the other case the globules will shrink under the influence of the strong salt solution, and owing to their greater density the color of the fluid will be brighter than before. The influence of salt to retard or prevent coagulation may also be observed in this experiment.

HEART.

The mechanism of the heart and the action of its various valves can be demonstrated to a class of pupils by dissecting in their presence the heart of an ox, which can be obtained from any provision-dealer.[1] A transverse section of the heart just below the auriculo-ventricular valves shows the right ventricle as a split in the walls of the left, and a vertical section through the left ventricle shows how the ventricular walls grow thinner from the base to the apex of the heart.

The pupils may then be taught to apply their ears to each other's chests in the region of the heart, and to describe the sounds which they hear. A simple stethoscope for ausculting one's own heart may be made by attaching a piece of rubber tube about eighteen inches long to a small glass funnel.

The impulse of the heart between the fifth and sixth ribs on the left side may be felt by each pupil on his own person; and if the fingers of the other hand are applied at the same time to the radial or the posterior tibial artery, the interval of time between the heart-impulse and the pulse-beat will give an idea of the rate at which the pulse-wave traverses the arterial system. And in this connection it will be well to remind the pupils that the rapidity of the pulse-wave has no relation whatever to the rate of the arterial blood-flow. The effect of muscular exertion in quickening the heart-beat may be illustrated by requesting a pupil to count the pulse-beats before and after running up and down stairs.

[1] The large blood-vessels are generally cut off by the butcher too close to the heart for the convenience of the teacher who wishes to demonstrate the anatomy of the organ. It is well, therefore, to request the dealer to procure a heart with a good "pipe" on it.

CIRCULATION.

Many of the phenomena of the circulation may be illustrated by means of a common syringe bulb to which a short piece of rubber tube is attached for suction, and a long piece (from six to twelve feet) for the delivery of water. This long tube should be compressed at the end, or, still better, fitted with a piece of glass tubing drawn out to a fine point, so as to represent the resistance offered by the small arteries and capillaries to the flow of the blood. It should then be spread out upon a table in such a way as to avoid sharp bends and kinks, and the water should be forced through it by slow rhythmical compressions of the bulb. It will be observed that though the water is thrown into the rubber tube in an intermittent manner by the successive compressions of the bulb, it issues from the contracted orifice in a steady flow, thus illustrating the manner in which the uniform flow of blood in the capillaries is maintained, although the blood is thrown rhythmically into the elastic arteries by the successive contractions of the heart. That an elastic tube and an obstacle at the end of it are both necessary for the production of this uniformity of movement, may be shown by removing the finely drawn glass tube from the end of the rubber tube, which will greatly reduce the resistance to the flow of the water ; or by substituting for the rubber tube a series of glass tubes united by short pieces of rubber, which will greatly diminish the elasticity of the tube through which the water is delivered, without affecting the obstacle. In both these cases it will be found that the water will flow from the tube in intermittent jets corresponding to the compressions of the bulb. A little judicious questioning will probably elicit from the older pupils the observation that the same principle is illustrated by a fire-engine. Here the elastic air in the air-chamber of the engine plays the part of the elastic walls of the arteries in producing a uniformity of flow through the tubes beyond.

The passage of the analogue of the pulse-wave through the long rubber tube may be studied by placing upon it at different points levers weighted so as slightly to compress the tube (rulers with paper-weights resting upon them answer very well for this purpose). The successive movements of these levers as the wave passes under them give a very good idea of the rate at which the wave traverses the tube. If the tube is bent so that the orifice is near the bulb, the interval of time between the movements of the levers at these points may be estimated with considerable accuracy, and an approximate quantitative determination of the wave-rate be thus made.

The movements of the artery in the human body as the pulse-wave passes through it may be shown to consist in a sudden dilatation, followed by a slow contraction, interrupted by one or more secondary dilatations. In the absence of a sphygmograph, this demonstration may be best made by pressing a small piece of looking-glass, about one centimeter square, upon the wrist over the radial artery in such a way that with each pulse-beat the mirror may be slightly tilted, as shown in Fig. 12. If the wrist be now held in such a position that sunlight will fall upon the mirror, a spot

FIG. 12. — PULSE STUDIED BY MIRROR ON RADIAL ARTERY.

of light will be reflected to the opposite side of the room, and by its motion upon the wall will show that the expansion of the artery is a sudden movement, while the subsequent contraction is slow and interrupted.

The circulation of blood in the capillaries can be best shown under the microscope in the web of the frog's foot or in the tail of the tadpole in the manner described in all elementary text-books of physiology; but in the absence of facilities for this demonstration the pupils may be reminded that the pinkish hue of the skin in health is due to the circulation of blood in the cutaneous capillaries, and may be asked to observe how the blood may be driven out of the capillaries by a slight pressure applied to the skin, thus producing a pale spot which only slowly recovers its natural color as the capillaries gradually refill themselves.

The circulation of blood in the veins may be studied in the superficial veins of the skin. The pupils may be asked to notice how the veins of the hand and arm, for instance, fill and empty themselves according as the limb is dependent or raised above the head.

By stroking these veins in the direction opposite to that of the flow of the blood, the valves may be distended, and their situation thus revealed. By making a powerful expiratory effort with closed glottis the venous blood may be prevented from entering the thorax, as is shown by the purple color of the face and the distended condition of the veins of the neck. A sudden inspiration relieves this condition immediately, by drawing the blood into the thorax. This alternate congestion and depletion of the venous system may also be observed in the faces of crying children and of persons who are heartily laughing, since in both of these conditions a series of forcible expiratory efforts with narrowed glottis alternates with a prolonged inspiration. A string or a rubber band drawn moderately tightly round the finger will cause the part to become distended with blood, since the veins carrying the blood away are more readily compressed than the arteries which convey it into the finger.

MOTION.

The structure of striped muscular fibre, the most important tissue in which the potential energy of the food appears as motion, can be satisfactorily demonstrated only by a microscope of tolerably high power.

The occurrence of cadaveric rigidity (caused by the coagulation of myosin in the muscles, as fibrin produces a similar phenomenon in the blood) may be demonstrated upon the body of any small warm-blooded animal — *e. g.*, a mouse — a few hours after death. It should be pointed out that the *rigor mortis* tends to fix the muscles in any position in which they happen to be at the moment of death, that it may be broken up by passive movements of the limbs, and that, when thus broken up, it does not tend to return.

The various bones of the body form a system of levers which are moved upon each other by the muscles. The different sorts of levers should be described, and the pupils, after they have acquired a general knowledge of the anatomy of the muscles, should be asked to point out movements in their own bodies which illustrate the three different kinds of levers.

The bones which are thus moved may next be studied, and will be found to illustrate various principles of mechanics. Thus, the hollow cylinders constituting the shafts of the long bones have precisely the structure which gives the greatest strength with the minimum of material, as is illustrated in the construction of tubular bridges, etc. A section through the spongy tissue which constitutes the heads of the long bones and the bodies of the vertebræ shows an arrangement of the trabeculæ which adapts the bones to sustaining the pressure to which they are subjected by the weight of the body. Many of the long bones of birds, instead of containing marrow, as is the case with mammalian bones, are filled with air, which communicates with the air in the lungs, thus securing greater lightness.

The pupils may be encouraged to prepare specimens of bones illustrating these points. The ordinary joints of meat after they have been used upon the table will supply the necessary bones, and the sections may be made with a meat-saw or even with an ordinary hand-saw. A section through the head of a femur obtained from an ordinary leg of mutton will exhibit the arrangement of the trabeculæ above described, and the wing-bones of chickens and turkeys will show by their air-cavities their special adaptation to purposes of flight.

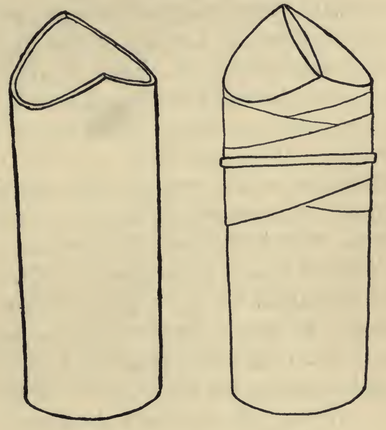
LOCOMOTION.

The oscillations of the body in walking which cause the height to be always less than when the individual is standing still, may be illustrated by causing one of the pupils to walk under a horizontal rod placed at such a height that it just touches the head when he is standing erect. It will be observed that in walking the maximum height is attained when the body is supported on one foot, and the minimum when both feet are on the ground.

VOICE.

A very good illustration of the action of the vocal bands in the production of the voice may be given by means of a piece of bamboo or any hollow wooden tube, and a strip of rubber, about an inch or an inch and a half wide, cut from pure sheet rubber such as is used by dentists for rubber dams. One end of the tube is to be cut sloping in two directions, as shown in Fig. 13 *a*, and the strip of sheet rubber is then to be wrapped round the tube as shown in Fig. 13 *b*, so as to leave a narrow slit terminating at the upper corners of the tube. By blowing into the other end of the tube the edges of the rubber bands will be set in vibration, and by touching the vibrating membrane at different points so as to check its movements it may be

FIG. 13. — ARTIFICIAL GLOTTIS.



a b

shown that the pitch of the note emitted depends upon the length and breadth of the vibrating portion of the vocal bands.

The upward movement of the larynx corresponding to the pitch of the note produced may be demonstrated by placing the finger over the larynx and singing notes of successively higher pitch. That low notes in the larynx excite vibrations of the air in the lungs (chest-tones) may be shown by the thrill communicated to the hand placed over the upper part of the thorax when a low note is sung. High notes, on the other hand, excite vibrations in the air-cavities of the head, though this cannot be so easily demonstrated.

SPEECH.

That articulate speech is produced by modifications of the air as it passes the mouth, and not by the action of the vocal bands, may be shown by the fact that whispered speech, in which the larynx is held open and the vocal bands do not vibrate, is just as complete and comprehensible as loud speech.

The production of the various vowel-sounds by the combination of tones resulting from the resonance of the air in the mouth may be illustrated by means of a piano. Let the cover of the piano be raised and the loud pedal depressed so as to allow all the wires to vibrate freely. If then a vowel-sound be sung with a loud voice close to the instrument, it will be found that, when the voice ceases, the piano will continue not only to resound with the note on which the vowel was sung, but will return to the ear the particular vowel-sound which had been uttered. The particular notes which by their combination give the different vowels cannot be determined without delicate acoustic apparatus; but it may be readily shown that the fundamental notes of the vowels vary in pitch. For this purpose it is only necessary to whisper the vowels in the following order, — *u, o, a, e, i,* giving to each its Continental, and not its English, sound.[1] It will be noticed that the pitch of

[1] The vowel-sounds of the following words may be taken as a guide for the sounds indicated, — *rule, pole, far, fate, meet.*

the whispered sound rises in the order in which the vowels are uttered. This variation of pitch is not noticed when the vowels are sung or spoken with a loud voice, for the strong vibrations of the vocal bands overpower the feeble resonance-sounds of the air in the mouth.

The pupils may be requested to observe and describe the position of the various parts of the mouth while the different vowel-sounds are uttered. It will readily be seen that if, while the air is escaping from the lungs, the mouth be opened widely so as to afford no obstacle to its passage, the sound uttered will be that of *a* in *far*. If the lips be now gradually brought together so as to narrow the opening of the mouth, the sound will change first to that of *o* in *so*, and then to that of *u* in *rule*. If, while the lips are kept open, the tongue is gradually raised so as to narrow the back part of the mouth, the sound will change first to that of *a* in *fate* (Continental *e*), and then to that of *e* in *me* (Continental *i*). That these vowel-sounds are really produced by the varying vibration of the air in the mouth as it assumes these different shapes, may be shown by bringing the mouth into the proper shape for uttering a given vowel-sound, — *e. g.*, *a* or *o* — without allowing any air to pass through it from the lungs, and then causing the air in the mouth to vibrate by sounding a jews-harp in front of it. As the shape of the mouth is altered, it will be found that the sound of the jews-harp changes its character, and approaches that of the vowel for which the mouth is adjusted.

The production of the various consonant-sounds (*i. e.*, labials, linguals, palatals, etc.) may be made an excellent object-lesson by requiring the pupils to describe the parts of the mouth employed in producing the different consonants, to point out the difference between explosives and aspirates, and to observe the effect upon a consonant-sound of allowing the vocal cords to vibrate while the sound is uttered. The difficulty of distinguishing such words as *pit* and *bid* from each other when both are whispered may be used to illustrate this last point.

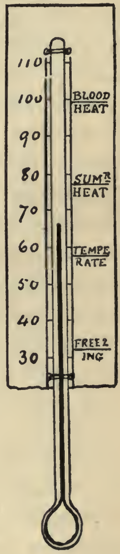
ANIMAL HEAT.

A temperature nearly constant, and usually higher than that of the surrounding air, characterizes warm-blooded animals. To measure this temperature it is of course necessary to place the thermometer in such a position that its bulb will be in contact on all sides with the warm body. This is best effected by placing the bulb in the mouth.

A substitute for a clinical thermometer may be readily improvised by withdrawing an ordinary chamber thermometer from its tin case and cutting off the lower part of the scale so that the bulb may project freely, as shown in Fig. 14. With an instrument thus arranged, the pupils may take their own and each other's temperature; and it will be found that whatever may be the season of the year or the temperature of the room, the thermometer in the mouth will record about 99° F. Care must, of course, be taken to keep the thermometer in the mouth till it ceases to rise, and to read it while it is still in position.

At this point a discussion of the physical principles upon which the construction of thermometers depends, and of the differences between the Fahrenheit and the Centigrade scales, may, if time permits, be profitably introduced.

FIG. 14. — IMPROVISED CLINICAL THERMOMETER.



It may be next pointed out that the constancy of the temperature shows that the body must lose heat as fast as it produces it; and the pupils may be asked to describe the conditions under which their bodies part with heat most rapidly. If suggestions on this point be not forthcoming, they may be asked how they can cool a piece of pudding that is too hot to eat. The cooling effect of spreading the pudding upon a plate may then be explained as due to an increase in the exposed surface of the hot substance relatively to its bulk, thus giving a better opportunity for heat to be lost by radiation and conduction; and it may be pointed out that the greater part (60–70 per cent) of the heat produced in the body is radiated and conducted away, just as it is from any other hot body in cool surroundings, — those portions of the body cooling off most rapidly which present the greatest extent of surface in proportion to their bulk. The testimony of the pupils as to the effect of cold weather upon their noses, ears, and other projecting portions of their body will serve to illustrate this point.

The cooling of the body by the evaporation of moisture from the surface of the skin and lungs may be illustrated by pouring a little alcohol or ether on the hands of the pupils and asking them to note the sensation of coolness produced by waving the hands in the air, so as to favor the evaporation of the liquid. The explanation of the phenomenon in accordance with the molecular theory of matter may be given to students sufficiently advanced to comprehend it. The fact that water is continually leaving the body in the form of vapor by the lungs and skin may be illustrated by showing the cloud of condensed moisture produced upon a cold polished surface (*e. g.*, a mirror, or a piece of polished silver) by breathing upon it, or by holding the hand near to it. One or two of the pupils may also be requested to wear upon one of their fingers during the night a cot of rubber or oiled silk. The insensible perspiration being thus prevented from evaporating will, as already pointed out in another connection, soak into and soften the epidermis, imparting to it an appearance similar to that seen on the skin of persons (*e. g.*, laundresses) who keep their hands constantly immersed in warm water. A good illustration of the importance of this method of cooling the body is furnished by our experience in dog-day weather, when, the air being loaded with moisture, the perspiration cannot readily evaporate, and a much greater degree of discomfort is produced than in dry weather with the thermometer equally high.

A further illustration of this subject is to be found in the importance attached to the occurrence of perspiration in the course of a fever, — the evaporation of the moisture thus poured out upon the skin tending to lower the abnormally elevated temperature of the body.

The observation of dogs in summer will serve to illustrate another way in which the body loses heat. These animals perspire very little, and in hot weather they seek by rapid respiratory movements to bring a large amount of air into contact with the respiratory tract, in order to lower the temperature of the body by raising that of the inspired air, as well as to afford an increased opportunity for the evaporation of moisture.

REGULATION OF TEMPERATURE.

As the temperature of a house in winter may be raised by increasing the amount of fuel consumed in it or by putting on double windows, and lowered by diminishing the fires or by opening the windows, so the temperature of the body may be regulated by changes in the amount of heat-production or of heat-loss. Moreover, these changes are effected either by voluntary, though generally instinctive, actions of the individual, or by involuntary modifications of vital processes. The heat-regulating processes may thus be divided into four categories; and it will be a useful exercise to require the pupils to enumerate as many as possible of these processes, indicating the category to which they belong. The following table will serve as a guide: —

CHANGES ARE PRODUCED

In Heat Production,	In Heat Loss,
Voluntarily,	
(1) By eating more or less food;	(1) By wearing thick or thin clothing;
(2) By making more or less muscular effort.	(2) By varying the position of the body;
	(3) By the use of baths, fans, hot and cold beverages, etc.
Involuntarily,	
(3) By varying metabolism, dependent, within certain limits, upon external temperature.	(4) By changes in the size of the cutaneous blood-vessels;
	(5) By varying activity of the sweat-glands;
	(6) By changes in the respiratory activity.

RESPIRATION.

The essential portion of the respiratory act being the gas exchange between the blood and the surrounding medium, it is evident that in large animals, whose surface is small relatively to their bulk, an organ with a very large free surface must be provided to facilitate this exchange. This may be accomplished either by vascular projections from the surface of the body, as in the finger-like gills of the water-breathing animals, or by the folding in of the external surface of the body to form more or less complicated cavities surrounded by blood-vessels, as in the lungs of air-breathing animals. The pupils may be asked to suggest reasons why gills would not serve for aerial and lungs for aquatic respiration. The older pupils may be encouraged to make preparations of the lungs of various animals, which will illustrate the different degrees of complication which the organ presents. This may be accomplished by dissecting out the lungs, tying a tube into the trachea, blowing up the organ, and hanging it up to dry. If the lungs are slightly injured by dissection, so that they are not perfectly air-tight, they will collapse after being blown up before they have time to dry. In this case it is best to connect the trachea with a rubber tube attached to a rubber bag filled with air. A small weight placed upon this bag will keep the lungs distended while they are drying, in spite of any small leakage that may occur. By this method the lungs of the frog, the snake, the turtle, the rat (or any other small mammal), may be prepared, and will illustrate the various degrees of pulmonary structural complication.

The way in which the respiratory movements in the higher animals cause the air to enter the lungs may be illustrated by a simple form of apparatus (represented in Fig. 15), which can be constructed as follows: —

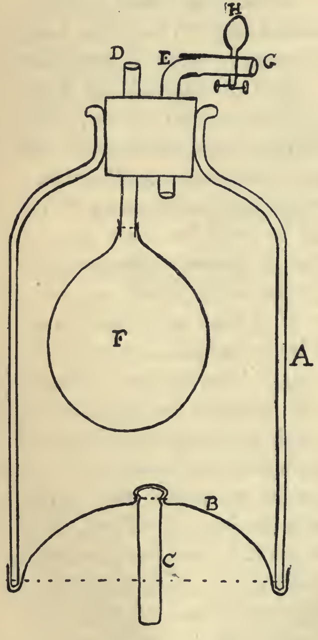
1. Cut off the bottom of a four or eight ounce bottle, A, by any of the methods described in works on the manipulation of glass; *e. g.*, by wrapping a thread soaked in alcohol round the bottle at the point where it is to be cut off, setting fire to it, and dashing cold water upon it as soon as the alcohol is burned out.

2. Smooth the cut edges of the bottle with a file, and close the lower end with a sheet of rubber, B, in the middle of which a short stick, C, has been fastened for convenience in taking hold of it. This attachment can be made by cutting a groove round the stick near one end, and then stretching and tying the rubber over it.

3. Place in the neck of the bottle a doubly perforated cork into which two short pieces of glass tube, D and E, are fitted.

4. To the inner end of one of these tubes, D, attach a small rubber bulb, F, of the kind used for children's toy balloons; and to the outer end of the other tube fit a piece of rubber tubing, G, provided with a pinch cork, H, or other convenient method of closing it.

FIG. 15. — MODEL TO ILLUSTRATE RESPIRATORY MOVEMENTS.



5. Partially exhaust the air from the bottle by sucking through the tube G. This will cause the rubber diaphragm to arch upward, as represented in the figure, and the bulb F to be expanded by the air entering through the tube D. Close the pinch-cork H, to maintain the partial vacuum in the bottle, and the apparatus is ready for use.

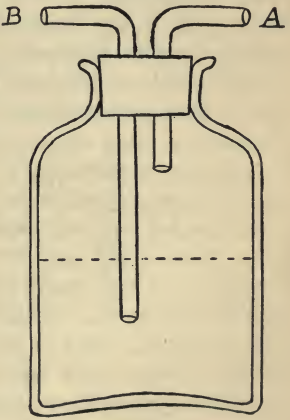
By drawing down the stick C, the diaphragm may be caused to descend, — thus further rarefying the air in A, and producing a further expansion of the bulb F, in the same way that the inspiratory movements of the thorax cause an expansion of the lungs.

The pupils may be taught to observe in themselves and each other the movements connected with diaphragmatic and with thoracic respiration, the protrusion of the abdominal walls indicating the descent of the diaphragm, and the spreading of the thoracic walls the contraction of the intercostal muscles.

The daily excretion of carbonic acid removes from the body of the average man about 8.7 ounces of carbon. This amount of charcoal weighed out and exhibited to the pupils will convey a clear idea of the activity of the pulmonary gas-exchange.

The excretion of carbonic acid may also be illustrated by a bottle containing lime-water and fitted with cork and tubes, as shown in Fig. 16. If the air of the room is drawn through the bottle by sucking through the tube A, the lime-water remains clear; but if air from the lungs is forced through the bottle by blowing through the tube B, the lime-water at once becomes turbid by the formation of calcium carbonate. In ordinary air analysis the amount of CO_2, as determined in this way, is taken as the measure of the pollution of the air by the pulmonary excretions. This is done, not because the amount of

FIG. 16. — LIME-WATER BOTTLE TO SHOW CO_2 EXCRETION BY LUNGS.



CO_2 usually found in the air of crowded rooms is in itself injurious, but because it is associated with really deleterious volatile excretions from the body which do not admit of ready quantitative determination. Of course if in the room where the air is collected for analysis there are sources of CO_2 other than the human lungs (*e.g.*, gas-flames or substances undergoing fermentation), the CO_2 determination loses its value as a measure of the unfitness of air for respiration.

VISION.

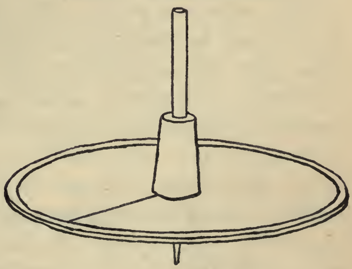
The formation of an inverted image on the retina of the eye by the refracting media in front may be illustrated by a common hand-lens throwing the image of a window on to a sheet of paper. The cheap lenses sold in toy-shops as burning-glasses are very suitable for this purpose.

The existence of the "blind spot" in the retina may be readily demonstrated to the pupils by requesting them to close one eye and to look steadily at one of two spots drawn upon the blackboard at a convenient distance apart in a horizontal direction, at the same time keeping the attention fixed upon the other spot. If the right eye is closed and the left eye directed to the right-hand spot, the left-hand spot will disappear when the individual is standing at a distance from the board equal to about three or four times the distance between the spots. At greater or less distances the spot will be visible. The experiment may be varied by keeping the distance from the board fixed, and altering the distance between the spots.

COLOR.

The subject of complementary colors, and the effect of mixing colors, may be conveniently illustrated by teetotums made by thrusting a small stick through a large button-mould, as shown in Fig. 17. A cork sliding upon the stick serves to confine one or more perforated disks of colored paper upon the upper surface of the button-mould. These disks should have a cut running in a radial direction, so that they may be made to overlap each other to any desired extent when placed upon the teetotum. Spinning the teetotum will now cause the colors to be mixed upon the retina. If, for instance, a blue and a yellow disk are placed upon the teetotum in such a way that each occupies about half the surface, the mixing of these colors by the rapid movement of the teetotum will produce the effect of white light, since blue and yellow are complementary colors. In a similar way, if a white and a colored disk are placed together on the teetotum, the various degrees of saturation of colored light may be studied by varying the relative amounts of each disk exposed to view. Thus the various shades of pink may be produced by mixing

FIG. 17. — COLOR TEETOTUM.



red and white light in different proportions, straw color by mixing yellow and white, etc.

The experiment with blue and yellow paper will doubtless suggest to the mind of some pupil familiar with painting, the question why blue and yellow thus mixed produce white instead of green, as when mixed on the painter's palate. To explain this point the pupils may be requested to look through a piece of blue glass and a piece of yellow glass placed so as to overlap each other. It will be seen that the light coming through both glasses has a green color.

In accordance with the Young-Helmholtz theory of color, these phenomena are explained as follows: The retina contains elements specially adapted to be stimulated by rays of light of the three primary colors, red, green, and violet. The sensation of white light is produced by the simultaneous stimulation of all three sets of elements, while that of yellow light is due to the stimulation of the red and green perceiving elements, and that of blue light to the stimulation of the green and violet perceiving elements. Hence, when blue light and yellow light fall together upon the retina, as in the experiment with the teetotum, all three sets of retinal elements are stimulated, and the sensation of white light results.

On the other hand, blue and yellow glass owe their respective colors to the fact that the former absorbs the red rays and transmits the violet and green rays to the eye, thus producing the sensation of blue; while the latter absorbs the violet rays and transmits the green and yellow rays, thus producing the sensation of yellow. The green rays therefore are the only rays that can get through both sorts of glass. Hence the sensation of green light is produced when white light is transmitted through both blue and yellow glass before it falls upon the retina. The mixing of colors upon the retina by the rapid revolution of the teetotum may be described as a process of *addition;* while in the experiment with colored glasses a successive *subtraction* of the different colored constituents of white light occurs. The mixing of colored pigments resembles the latter process, since their color depends upon their power to absorb rays of certain colors, and reflect back others to the eye.

FATIGUE OF THE RETINA.

When light falls steadily upon the retina, the eye becomes fatigued, like any other organ subjected to constant stimulation. Hence a white surface appears gradually less and less brilliant the longer it is looked at. This may be readily shown by placing a small black card on a sheet of white paper and looking at it steadily for about a minute. Then withdraw the card, but keep the eyes fixed upon the part of the white paper previously covered by it. A bright spot of the size and shape of the black card will appear upon the paper. This depends upon the fact that while looking at the black card the side portions of the retina, upon which the image of the white paper fell, gradually became fatigued; while the central portion covered by the image of the black card remained unstimulated. Hence when the card was withdrawn, the light from the white paper below it fell upon a fresh portion of the retina and produced a more intense sensation than that falling upon the lateral portions, which were fatigued by previous stimulation.

The experiment may be varied by substituting for the black card cards of various colors. The spot appearing on the white paper after the colored card is withdrawn will now have a color complementary to that of the card used; *e. g.*, a yellow spot will appear on the removal of a blue card, etc. This is due to the fact that the light coming from the blue card has fatigued the eye for light of that particular color. Hence when white light is subsequently thrown upon the same portion of the retina, the blue-producing components of white light find the retinal elements less sensitive to their action, while the yellow-producing components act with their full effect. Hence the white light coming from the portion of the paper previously covered by the blue card will appear of a yellowish color. Effects thus produced are known as negative after-images.

HEARING.

The difference between an *irregular* succession of sonorous impulses, producing a noise, and a *regular* succession of such impulses, producing a musical tone, can be well illustrated by shaking a small wooden or paper box containing buttons, tacks, or any other small, hard objects, and by setting in vibration a tightly stretched cord, or a needle held firmly by pincers at one end.

That sounds are transmitted through solid bodies and through the bones of the head better than through the air, can be readily shown by scratching lightly with a pin on one end of a long stick, and allowing a pupil to hold the other end between his front teeth. It will be found that the sound is heard much more intensely when the stick is held in this way than when it is simply held in the hand. It will also be observed that while the stick is held in the teeth the intensity of the sound is increased by closing the external ears, — apparently because the sound-waves passing out through the external meatus are reflected back upon the membrana tympani.

The principle of *resonance* — *i. e.*, the power possessed by feeble undulations of setting in motion solid bodies having corresponding periods of vibration — may be illustrated by balancing a heavy stick (*e. g.*, a short broomstick) over the back of a chair or some other convenient support, and bringing near to one end of it a piece of sealing-wax which has been rubbed on the sleeve of the coat. If the sealing-wax be brought alternately above and below the end of the stick at intervals corresponding to its natural periods of vibration, it will be found that the feeble force of electrical attraction will reinforce the vibrations of the stick so as finally to throw it from its support. In a similar way the feeble sonorous undulations of the air are supposed to set in vibration the solid structures of the internal ear, and thus to stimulate the terminations of the auditory nerve, which are there distributed.

The fact that our knowledge of the direction from which sound proceeds depends upon unequal impressions produced upon the two ears, may be shown by blindfolding a pupil and producing in various positions around the head a short, sharp sound; *e. g.*, by striking together two coins. If the pupil is asked to tell the direction from which the sound seems to come, he will probably indicate quite correctly the positions on one side or the other of the head, but will not readily distinguish the different positions lying in a plane passing through the median line of the head perpendicularly to a line joining the ears; for a sound proceeding from any point in this plane affects the two ears equally.