a time will come when some of the organs necessary to life will be unable to perform their office. When this occurs, there is death from old age, or physiological dissolution. This may be a gradual failure of the general process of nutrition or it may occur in some one organ or system that is essential to life.

## Animal Heat and Force.

The processes of nutrition in animals are always attended with the development and maintenance of a bodily temperature that is more or less independent of external conditions. This is true in the lowest as well as the highest animal organizations; and analogous phenomena have been observed in plants. In cold-blooded animals, nutrition may be suspended by a diminished external temperature, and certain of the functions become temporarily arrested, to be resumed when the animal is exposed to a greater heat. This is true, to some extent, in certain warm-blooded animals that periodically pass into a condition of stupor, called hibernation; but in man and most of the warm-blooded animals, the general temperature of the body can undergo but slight variations. The animal heat is nearly the same in cold and in hot climates; and if from any cause the body become incapable of keeping up its temperature when exposed to cold, or of moderating it when exposed to heat, death is the inevitable result.

*Estimated Quantity of Heat produced by the Body.*—In order to express quantities of heat, it is necessary to fix upon some definite quantity to be taken as a heat-unit. In what is to follow, a heat-unit is to be understood as the heat required to raise the temperature of one pound of water 1° Fahr. (pound-degree Fahr.).

It has been calculated that one heat-unit is equal to the force expended in raising one pound 772 feet or 772 pounds one foot (Joule). This force is called a foot-pound. The equivalent of heat in force has been calculated by estimating the heat produced by a certain weight falling through a certain distance, assuming the falling force to be precisely equal to the force which has been used in raising the weight; but physicists have not actually succeeded in so completely converting heat into force as to raise one pound 772 feet or 772 pounds one foot, by the expenditure of one heat-unit.

The heat-unit and its equivalent in force are, of course, differently expressed according to the metric system. When heat-units or foot-pounds are given in the text, the equivalents, according to the metric system, are given in parantheses. These equivalents are as follows:

A heat-unit, according to the metric system, or the heat required to raise the temperature of one kilo. of water one degree C., will be designated as a kilo.-degree C.

One pound-degree = 0·252 kilo.-degree C. One kilo.-degree C. = 3·96 (nearly 4) pound-degrees. A kilogrammetre represents the force required to raise a weight of one kilogramme one metre. One foot-pound = 0·138 kilogrammetre. One kilogrammetre = 7·24 foot-pounds. One pound-degree = 772 foot-pounds. One pound-degree = 106·6 kilogrammetres. One kilo.-degree C. = 422·25 kilogrammetres. One kilo.-degree C. = 3,057 foot-pounds.



Two methods have been employed in arriving at estimates of the actual quantity of heat produced by the body in a definite time:

1. The direct method consists in placing an animal in a calorimeter and measuring the heat produced, making all necessary corrections. This has been repeatedly done, but the results obtained have been very variable and not entirely satisfactory.

The observations of Senator (1872) seemed to fulfill the necessary experimental conditions; and as an average of five observations made on dogs at rest and fasting, he found a production of about 4·21 heat-units per hour per pound weight of the body (2·34 kilo.-degree C. per kilo.).

J. C. Draper (1872) estimated the heat-production in his own person by immersing the body in water. In this observation, many errors must have escaped correction; but the results agreed remarkably with those obtained by Senator. Deducting 1° Fahr. of heat lost by the body, as shown by a reduction in the general temperature, and imparted to the water—a correction not made by Draper—about 4 heat-units were produced per hour per pound weight of the body (2·22 kilo.-degrees C. per kilo.). According to the estimate of Draper, a man weighing 140 pounds (63·5 kilos.) would produce 13,440 heat-units (3·383 kilo.-degrees C.) in twenty-four hours of repose. This would be equal to 10,375,680 foot-pounds, or about 1,430,000 kilogrammetres.

An important element of inaccuracy in all direct observations and one, indeed, which it seems impossible to correct absolutely, is due to the great variations in heat-production with digestion, conditions of muscular repose or exercise, external temperature etc. Another source of error is the difficulty in estimating the heat lost by the body and not actually produced during the time of the observation. These possible inaccuracies are so important and so evident, that the results of direct observations have not been generally accepted by physiologists.

2. The indirect method consists in estimating the heat represented by oxidation, calculated from the quantity of oxygen consumed in the various processes which result in the production and discharge of carbon dioxide, water, urea etc. These estimates have been compared with the calculated heat-value of the food consumed, and the results very nearly correspond.

According to the estimates of Helmholtz, Ranke and others, by the indirect method, the heat-production is equal to about 2·5 heat-units per hour per pound weight of the body (1·39 kilo.-degree C. per kilo.) In a man weighing 180·4 pounds (82 kilos.) the heat-production in twenty-four hours (Helmholtz) was 10,818 heat-units (2,732 kilo.-degrees C.). According to this estimate, a man weighing 140 pounds (63·5 kilos.) would produce 8,400 heat-units (2,118 kilo.-degrees C.) in twenty-four hours. This would be equal to 6,484,800 foot pounds, or about 894,500 kilogrammetres.

Comparing the results of direct observations, showing a production of about four heat-units per pound per hour (2·22 kilo.-degrees C. per kilo.),

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with those obtained by the indirect methods, 2·5 heat-units per pound per hour (1·39 kilo.-degree C. per kilo.), it is seen that the indirect estimates give about 37½ per cent. less heat produced than is given by direct estimates. It is on account of this great difference, that writers are at a loss to give definite estimates of the actual quantity of heat produced by the body.

A study of this subject and of the details of observations both direct and indirect has made it evident that the experimental difficulties to be overcome and the unavoidable elements of inaccuracy are greater in the direct than in the indirect method. In comparing the estimates of heat actually produced with the heat value of food—which, of course, is the ultimate source of heat and force in the body—the correspondence is much closer if the indirect estimates be adopted. It therefore seems more in accordance with ascertained facts to adopt the indirect estimates, although this can not be done without reserve. The heat produced, then, is probably equal to about 2·5 heat-units (pound-degrees) per hour per pound weight of the body (nearly 1·4 kilo.-degree C. per kilo.) This is equal to about 8,400 heat-units, or about 2,120 kilo.-degrees C., in twenty-four hours; which is equal to about 6,500,000 foot-pounds, or about 900,000 kilogrammetres.

The normal variations in the production of heat are not absolutely and definitely represented by variations in the actual temperature of the body and by the consumption of oxygen. Muscular work may increase the production of heat 60 per cent. (Hirn) while it increases the consumption of oxygen about 4½ times, a large part of the oxidation being expended in the form of work. The production of heat is diminished in fasting animals (dogs) by nearly 45 per cent. (Senator), after deprivation of food for two days. In old age and in infancy, there is less heat produced than in adult life. The production of heat is less in females than in males and is less during the night than during the day. These points will be touched upon again in connection with the normal variations in the temperature of the body.

*Limits of Variation in the Normal Temperature in Man.*—One of the most common methods of taking the general temperature has been to introduce a registering thermometer into the axilla, reading off the degrees after the mercury has become absolutely stationary. Nearly all observations made in this way agree with the results obtained by Gavarret, who estimated that the temperature in the axilla, in a perfectly healthy adult man, in a temperate climate, ranges between 97·7° and 99·5° Fahr. (36·5° and 37·5° C.). Davy, from a large number of observations upon the temperature under the tongue, fixed the standard, in a temperate climate, at 98° Fahr. (36·67° C.) The axilla and the tongue, however, being more or less exposed to external influences, do not exactly represent the general heat of the organism; but these are the situations, particularly the axilla, in which the temperature is most frequently taken in pathological examinations. As a standard for comparison, it may be assumed that the most common temperature in these situations is 98° Fahr. (36·67° C.) subject to variations, within the limits of health of about 0·5° Fahr. (0·27° C.) below and 1·5° (0·82° Fahr. C.) above.

*Variations with External Temperature.*—The general temperature of the



body varies, though within very restricted limits, with extreme changes in climate. The results obtained by Davy, in a large number of observations in temperate and hot climates, show an elevation in the tropics of 0·5° to 3° Fahr. (0·27° to 1·65° C.). It is well known, also, that the human body, the surface being properly protected, is capable of enduring for some minutes a heat greater than that of boiling water. Under these conditions, the animal temperature is raised but slightly, as compared with the intense heat of the surrounding atmosphere. In the observations by Dobson, the temperature was raised to 99·5° Fahr. (37·5° C.) in one instance, 101·5° Fahr. (38·6° C.) in another, and 102° Fahr. (38·9° C.) in a third, when the body was exposed to a heat of more than 212° Fahr. (100° C.). Delaroche and Berger, however, found that the temperature in the mouth could be increased by 3° to 9° Fahr. (1·65° to 5·05° C.) after sixteen minutes of exposure to intense heat. This was for the external parts only; and it is not probable that the temperature of the internal organs ever undergoes such wide variations.

It is difficult to estimate the temperature in persons exposed to intense cold, as in Arctic explorations, because care is always taken to protect the surface of the body as completely as possible; but experiments have shown that the animal heat may be considerably reduced, as a temporary condition, without producing death. In the latter part of the last century, Currie caused the temperature in a man to fall 15° Fahr. (8·25° C.) by immersion in a cold bath; but he could not bring it below 83° Fahr. (28·33° C.) This extreme depression, however, lasted only two or three minutes, and the temperature afterward returned to within a few degrees of the normal standard. The results of experiments show that while the normal variations in the temperature in the human subject, even when exposed to great climatic changes, are very slight, generally not more than two degrees Fahr. (1·1° C.), the body may be exposed for a time to excessive heat or cold, and the extreme limits, consistent with the preservation of life, may be reached. As far as has been ascertained by direct experiment, these limits are about 83° and 107° Fahr. (28·33° and 41·67° C.).

*Variations in Different Parts of the Body.*—The blood becomes slightly lowered in its temperature in passing through the general capillary circulation, but the difference is ordinarily not more than a fraction of a degree. This fact is not opposed to the proposition that animal heat is produced in greatest part in the general capillary system, as one of the results of nutritive action; for the blood circulates with such rapidity that the heat acquired in the capillaries of the internal organs, where little or none is lost, is but slightly diminished before the fluid passes into the arteries, even in circulating through the lungs; and cutaneous evaporation simply moderates the heat acquired in the tissues and keeps it at the proper standard.

Bernard ascertained that the blood is usually 0·36° to 1·8° Fahr. (0·2° to 1° C.) warmer in the hepatic veins than in the aorta. The temperature in the hepatic veins is 0·18° to 1·44° Fahr. (0·1° to 0·8° C.) higher than in the portal veins. These results show that the blood coming from the liver is warmer than in any other part of the body. In a series of experiments by

Breschet and Becquerel, who were among the first to employ thermo-electric apparatus in the study of animal heat, it was found that the cellular tissue was 2·5° to 3·3° Fahr. (1·37° to 1·8° C.) cooler than the muscles. As regards the temperature of the blood in the two sides of the heart, experiments upon the lower animals have been somewhat contradictory; but there is no positive evidence of any considerable change in the temperature of the blood in passing through the lungs in the human subject. In the lower animals, there probably exist no constant differences in temperature in the two sides of the heart. When the loss of heat by the general surface is active, as in animals with a slight covering of hair, the blood generally is cooler in the right cavities; but in animals with a thick covering, that probably lose considerable heat by the pulmonary surface, the blood is cooler in the left side of the heart.

*Variations at Different Periods of Life.*—The most important variations in the temperature of the body at different periods of life are observed in infants just after birth. The body of the infant and of young mammalia removed from the mother presents a diminution in temperature of 1° to 4° Fahr. (0·55° to 2·2° C.). In infancy the ability to resist cold is less than in later years; but after a few days the temperature of the child nearly reaches the standard in the adult, and the variations produced by external conditions are not so great.

W. F. Edwards found that in certain animals, particularly dogs and cats, that are born with the eyes closed and in which the foramen ovale remains open for a few days, the temperature rapidly diminished when they were removed from the body of the mother, and that they then become reduced to a condition approximating that of cold-blooded animals; but after about fifteen days, this change in temperature could not be effected. In dogs just born, the temperature fell, after three or four hours' separation from the mother, to a point but a few degrees above that of the surrounding atmosphere. The views advanced by Edwards are illustrated in instances of premature birth, when the animal heat is much more variable than in infants at term, and in cases of persistence of the foramen ovale.

In adult life there does not appear to be any marked and constant variation in the normal temperature; but in old age, while the actual temperature of the body is not notably reduced, the power of resisting refrigerating influences is diminished very considerably. There are no observations showing any constant differences in the temperature of the body in the sexes; and it may be assumed that in the female the animal heat is modified by the same influences and in the same way as in the male.

*Variations in the Heat of the Body at different Times of the Day etc.*—Although the limits of variation in the animal temperature are not very wide, certain fluctuations are observed, depending upon muscular repose or activity, digestion, sleep etc. It has been ascertained that there are two well marked periods in the day when the heat is at its maximum. These are at eleven A. M. and four P. M.; and while all observations agree upon this point, the observations of Lichtenfels and Fröhlich have shown that these periods are



well marked, even when no food is taken. Bärensprung and Ladame have observed that the fall in temperature during the night takes place sleeping or waking; and that when sleep is taken during the day, it does not disturb the period of the maximum, which occurs at about four P. M. According to these experiments, at eleven in the morning, the animal heat is at one of its periods of maximum; it gradually diminishes for two or three hours and is raised again to the maximum at about four in the afternoon, when it again undergoes diminution until the next morning. The variations amount to between 1° and 2·16° Fahr. (0·55° and 1·19° C.). The minimum is always during the night.

The influence of defective nutrition or of inanition upon the heat of the body is very marked. In pigeons the extreme variation in temperature during the day, under normal conditions, was found by Chossat to be 1·3° Fahr. (0·7° C.). During the progress of inanition this variation was increased to 5·9° Fahr. (3·25° C.). with a slight diminution in the absolute temperature, and the periods of minimum temperature were unusually prolonged. Immediately preceding death from starvation, the diminution in temperature became very rapid, the rate being 7° to 11° Fahr. (3·85° to 6° C.) per hour. Death usually occurred when the diminution had amounted to about 30° Fahr. (16·5° C.).

When the surrounding conditions call for the development of an unusual quantity of heat, the diet is always modified, both as regards the quantity and kind of food; but when food is taken in sufficient quantity and is of a kind capable of maintaining proper nutrition, its composition does not affect the general temperature. The temperature of the body, indeed, seems to be uniform in the same climate, even in persons living upon entirely different kinds of food (Davy). Nevertheless, the conditions of external temperature have a remarkable influence upon the diet. It is well known that in the heat of summer, the quantity of meats and fat taken is relatively small, and of the succulent, fresh vegetables and fruits, large, as compared with the diet in the winter; but although the proportion of carbohydrates in many of the fresh vegetables used during a short season of the year is not great, these articles are also deficient in nitrogenized matters. During the winter the ordinary diet, composed of meat, fat, bread, potatoes etc., contains a large proportion of nitrogenized substances as well as a considerable proportion of carbohydrates; and in the summer the proportion of both of these varieties of food is reduced, the more succulent articles taking their place. This is farther illustrated by a comparison of the diet in the torrid or temperate and in the frigid zones. It is stated that the daily ration of the Esquimaux is twelve to fifteen pounds (5·433 to 6·804 kilos.) of meat, about one-third of which is fat. Hayes noted that with a temperature of − 60° to − 70° Fahr. (about − 51° to − 57° C.), there was a continual craving for a strong, animal diet, particularly fatty substances.

The influence of alcoholic beverages upon the animal temperature has been studied chiefly with reference to the question of their use in enabling the system to resist excessive cold. The universal testimony of scientific

Arctic explorers is that the use of alcohol does not enable men to endure a very low temperature for any considerable length of time.

As a rule, when the respiratory activity is physiologically increased—as it is by exercise, bodily or mental, ingestion of food or diminished external temperature—the generation of heat in the body is correspondingly raised; and on the other hand, it is diminished by conditions which physiologically decrease the absorption of oxygen and the exhalation of carbon dioxide. The relations of animal heat to the general process of nutrition are most intimate. Any condition that increases the activity of nutrition and of disassimilation, or even any thing that increases disassimilation alone, will increase the production of heat. The reverse of this proposition is equally true.

Notwithstanding the fact that there is a certain correspondence between the activity of the respiratory processes and the production of heat, this is far from being absolute. It has been shown by Senator that digestion increases heat-production rather more than it increases the exhalation of carbon dioxide. Muscular exertion has been found to increase the quantity of oxygen consumed in very much greater proportion than it increased the heat-production (Hirn). Even adding to the heat produced, the work, reduced to heat-units, the heat-production was about doubled, while the quantity of oxygen consumed was increased about four and a half times.

*Influence of Exercise etc., upon the Heat of the Body.*—The most complete repose of the muscular system is observed during sleep, when hardly any of the muscles are brought into action, except those concerned in tranquil respiration. There is always a notable diminution in the general temperature at this time. In the variations in the heat of the body, the minimum is always during the night; and this is not entirely dependent upon sleep, for a depression in temperature is always observed at that time, even when sleep is avoided. It is a matter of common observation, that one of the most efficient means of resisting the depressing influence of cold is to constantly exercise the muscles; and it is well known that after long exposure to intense cold, the tendency to sleep, which becomes almost irresistible, if yielded to, is followed by a very rapid loss of heat and almost certain death. Muscular exercise increases the production of heat; but the variations in the actual temperature of the body in man, although distinct, are seldom very considerable, for the reason that muscular exertion is generally attended with increased action of the skin, which keeps the heat of the body within restricted limits. In very violent muscular exertion, as in fast running, the increased production of heat may be so rapid that it can not be entirely compensated by evaporation from the skin, and the temperature may rise to 104° Fahr. (40° C.). In about an hour and a half the temperature falls to the normal standard (Billroth, quoted by Landois).

The elevation in temperature that attends muscular action is produced directly in the substance of the muscle (Becquerel and Breschet). Introducing a thermo-electric needle into the biceps of a man who used the arm in sawing wood for five minutes, these physiologists noted an elevation of temperature of nearly two degrees Fahr. (1° C.). The production of heat in the muscular tissue has been observed in experiments with portions of muscle from the frog. Not only was there an absorption of oxygen and exhalation of carbon dioxide after the muscle had been removed from the body of the animal, but an elevation in temperature of about one degree Fahr. (0·55° C.) was noted following contractions artificially excited (Matteucci). Observations upon the influence of mental exertion on the temperature of the body have not been so many, but they are, apparently, no less exact in their results. Davy observed a slight but constant elevation during "excited and sustained attention." Lombard noted an elevation of temperature in the head during mental exertion of various kinds, but it was slight, the highest rise not exceeding 0·05° Fahr. (0·027° C.). According to Burdach, the temperature of the body is increased by the emotions of hope, joy, anger and all exciting passions, while it is diminished by fear, fright and mental distress.



It is evident that if animal heat be one of the necessary, attendant phenomena of nutrition, it must be greatly influenced by conditions of the circulation. It has been a question, indeed, whether the modifications in temperature, produced by operating upon the vaso-motor nerves, be not due entirely to changes in the supply of blood. It is certain that whatever determines an increased supply of blood to any part raises the temperature; and whenever the quantity of blood in any organ or part is considerably diminished, the temperature is reduced. This fact is constantly illustrated in operations for the deligation of large arteries. It is well known that after tying a large vessel, the utmost care is necessary to keep up the temperature of the part to which its branches are distributed, until the anastomosing vessels become enlarged sufficiently to supply the quantity of blood necessary for healthy nutrition.

*Influence of the Nervous System upon the Production of Animal Heat (Heat-Centres).*—The local influences of the vaso-motor nerves upon calorification operate mainly if not entirely through changes in the nutrition of parts, produced by variations in blood-supply. These influences will be fully considered in connection with the physiology of the nervous system.

The general temperature of the body may be modified through the nervous system by reflex action, and this implies the existence of nerve-centres, or of a nerve-centre, capable of influencing the general process of calorification. Experiments have been made, chiefly on parts of the encephalon, with the view of determining the existence and location of heat-centres. In a recent publication by Ott (1887), four heat-centres are recognized, irritation of which by puncture increases the temperature of the body in rabbits by several degrees (4° to 6° Fahr., or 2·2° to 3·3° C.). These four centres are as follows: 1, in front of and beneath the corpus striatum (Ott); 2, the median portion of the corpora striata and the subjacent parts (Aronsohn and Sachs); 3, between the corpus striatum and the optic thalamus (Ott); 4, the anterior inner end of the optic thalamus (Ott). Puncture of these parts is followed by rise in temperature, which continues for a variable time, two to four days. A similar centre has been described as existing in the dog, in the cortex of