the anterior portion of the upper surface of the brain, near the median line (Eulenberg and Landois). The conductors connected with these centres decussate and pass through the medulla oblongata and the spinal cord. The question arises as to whether the effects of puncture or stimulation of these parts be exciting or inhibitory; but observations regarding the mechanism of their action have not been sufficiently definite to warrant any positive conclusions on this point.

Mechanism of the Production of Animal Heat.

The definite ideas of physiologists concerning the mechanism of the production of heat by animals date from the researches of Lavoisier (1777 to 1790). As a general result of these observations, Lavoisier concluded that animal heat was produced by an internal combustion resulting in carbon dioxide and water. Even now there is little to be said beyond this, as regards the general mechanism of animal calorification, although modern investigations have brought to light many important details in the heat-producing processes.

In man and in the warm-blooded animals generally, the maintenance of the temperature of the organism at a nearly fixed standard is a necessity of life; and while heat is generated in the organism with an activity that is constantly varying, it is counterbalanced by physiological loss of heat from the cutaneous and respiratory surfaces. Variations in the activity of calorification are not to be measured by corresponding changes in the temperature of the body, but are to be estimated by calculating the quantity of heat lost. The ability of the human race to live in all climates is explained by the adaptability of man to different conditions of diet and exercise, and by the power of regulating loss of heat from the surface by appropriate clothing.

Heat is produced in the general system and not in any particular organ or in the blood as it circulates. The experiments of Matteucci, showing an elevation of temperature in a muscle excited to contraction after it had been removed from the body, and the observations of Becquerel and Breschet, showing increased development of heat by muscular contraction, are sufficient evidence of the production of heat in the muscular system; and inasmuch as the muscles constitute by far the greatest part of the weight of the body, they are a most important source of animal heat. It has been observed that the blood becomes notably warmer in passing through the abdominal viscera (Bernard). This is particularly marked in the liver, and it shows that the large and highly organized viscera are also important sources of caloric.

As far as it is possible to determine by experiment, not only is there no particular part or organ in the body endowed with the special office of calorification, but every part in which the nutritive forces are in operation produces a certain quantity of heat; and this is probably true of the blood-corpuscles and other anatomical elements of this class. The production of heat in the body is general and is one of the necessary consequences of the process of nutrition; but, with nutrition, it is subject to local variations, as is illus-

trated in the effects of operations upon the vaso-motor nerves and in the phenomena of inflammation.

Nutrition and disassimilation involve the appropriation of matters taken into the body and the production and discharge of effete substances. In its widest signification, this includes the consumption of oxygen and the elimination of carbon dioxide; and consequently, respiration may be regarded as a nutritive act. All of the nutritive processes go on together, and they all involve, in most warm-blooded animals at least, a nearly uniform temperature. During the first periods of intraüterine life, the heat derived from the mother is undoubtedly necessary to the development of tissue by a change of substance, analogous to nutrition and even superior to it in activity. During adult life, animal heat and the nutritive force are co-existent. It now becomes an important question to determine whether there be any class of nutritive matters specially concerned in calorification or any nutritive acts exclusively or specially directed to the maintenance of the normal temperature of the body.

It is evident that in normal nutrition by food, the heat of the body must be maintained by changes which take place, either directly in the blood or indirectly in the tissues, in alimentary matters, and that these changes involve oxidation to a very considerable extent. Under ordinary conditions of nutrition, it is assumed that the food furnishes all the material for maintaining the heat of the body and for the development of force in work, such as the muscular work of respiration and circulation and general muscular effort. If no food be taken for a certain time, the heat of the body must be maintained, the work must be accomplished at the expense of the substance of the body itself, and the individual loses weight. In order to maintain the equilibrium of the body, therefore, food should be taken in quantity sufficient to supply, by its changes in oxidation etc., the heat and force required. In this condition of equilibrium, the body neither gains nor loses weight. To furnish a positive scientific basis for calculations with reference to these points, physiologists have burned various articles of food in oxygen, and have estimated their heat-value in heat-units.

In 1866, Frankland made a number of calculations of the heat-units and the estimated force-value of various articles of food, which are now accepted and used by most writers upon subjects connected with the theories of animal heat and the source of muscular power. As regards the heat produced by the oxidation of these substances in the body, if it be assumed that the same quantity of heat is produced by the oxidation, under all circumstances, of a definite quantity of oxidizable matter, it is necessary simply to deduct from the heat-value of articles of food the heat-value remaining in certain parts of the food which pass out of the body in an unoxidized state. It was in this way that Frankland arrived at a determination of the heat-value of articles of food oxidized in the body.

The following selections from Frankland's table will give an idea of the heat-value of different articles of food oxidized in the body. In this table the heat-units are calculated as pound-degrees.

HEAT-VALUE OF TEN GRAINS OF THE MATERIAL OXIDIZED INTO CARBON DIOXIDE, WATER AND UREA IN THE ANIMAL BODY (FRANKLAND).

Articles of food.	Heat-units.	Articles of food.	Heat-units.
Butter	18·68	Potatoes	2·56
Beef-fat (dry)	23·33	Cabbage	1·08
Lump-sugar	8·61	Milk	1·64
Grape-sugar	8·42	Egg (boiled)	5·86
Wheat-flour	9·87	Cheese	11·20
Bread-crumb	5·52	Lean beef	3·66
Arrowroot	10·06	Ham (boiled)	4·30
Ground rice	9·52	Mackerel	4·14

In the following, selected from the table quoted by Chapman, the heat-units are calculated as kilo.-degrees C.

HEAT-VALUE OF ONE GRAMME OF THE MATERIAL OXIDIZED INTO CARBON DIOXIDE, WATER AND UREA IN THE ANIMAL BODY (FRANKLAND).

Articles of food.	Heat-units.	Articles of food.	Heat-units.
Butter	7·264	Potatoes	0·990
Beef-fat (dry)	9·069	Cabbage	0·420
Lump-sugar	3·348	Milk	0·620
Grape-sugar	3·227	Egg (boiled)	2·280
Wheat-flour	3·840	Cheese	4·360
Bread-crumb	1·450	Lean beef	1·420
Arrowroot	3·912	Ham (boiled)	1·680
Ground rice	3·760	Mackerel	1·610

The heat-value of one gramme of alcohol—taken from a table compiled by Landois—is equal to 8·958 heat-units (kilo.-degrees C.), or the heat-value of 10 grains of alcohol is equal to 23 heat-units (pound-degrees Fahr.).

As regards the processes of combustion which take place in the living organism, the oxidation of the constituents of food produces carbon dioxide and water, but it is probable that the quantity of heat produced bears a definite relation to the total consumption of oxygen, the heat, as far as this is concerned, being the same whether the oxygen unite with carbon or with hydrogen (Pflüger). This relation between the quantity of oxygen consumed and the production of heat seems to be disturbed by muscular exercise; but it has thus far been found impossible to estimate accurately the quantity of heat represented by the force expended in muscular work, circulation, respiration etc.

The heat-producing processes undoubtedly are represented mainly by the exhalation of carbon dioxide and water, and to a less degree by the discharge of urea, the quantity of heat produced by other chemical processes being comparatively small. It is also true that the carbohydrates and fats are more important factors in calorification than the albuminoids; but it seems beyond question that there must be heat evolved in the body by oxidation of nitrogenized matters. When the daily quantity of food is largely increased for the purpose of generating the immense quantity of heat required in excessively cold climates, the nitrogenized matters are taken in greater quantity, as well as the fats, although their increase is not in the same proportion. From these facts, and from other considerations that have already been fully discussed, it is evident that the physiological metamorphoses of nitrogenized matters bear a certain share in the production of animal heat. The carbohydrates and fats are not concerned in the building up of tissues and organs, except as the fats are deposited in the form of adipose tissue. Their addition to the food saves the nitrogenized tissues, which latter must be used in heat-production in starvation and in a restricted diet deficient in non-nitrogenized matters. If the non-nitrogenized constituents of food do not form tissue, are not discharged from the body, and are consumed in some of the processes of nutrition, it would seem that their change must involve the production of carbon dioxide and water and the evolution of heat.

Although it may be assumed that the non-nitrogenized constituents of food are particularly important in the production of animal heat, and that they are not concerned in the repair of tissue, it must be remembered that the animal temperature may be kept at the proper standard upon a nitrogenized diet; and it is not possible to connect calorification exclusively with the consumption of any single class of alimentary matters or with any single one of the acts of nutrition.

The exact mechanism of the oxidation-processes in the body is not understood. All physiologists, however, are agreed that the quantity of heat produced by oxidation is the same, whether the combustion be rapid or slow. The fact that fats are never discharged, but are either consumed entirely or are deposited in the body as fat, leaves their oxidation and discharge as oxidation-products the only alternative. The oxidation of albuminoids has already been considered. As regards the carbohydrates, if it can be shown that alcohol normally exists in the blood, even in very small quantity, the idea that these matters are slowly passed from the liver as sugar, into the general circulation, and are then converted into alcohol which is promptly oxidized, is worthy of serious consideration. Such a theory would explain the destination of the carbohydrates and their relations to calorification. There can be no doubt that in certain cases of fever, alcohol administered in large quantity may be oxidized and "feed" the fever, thus saving consumption of tissue.

In a series of observations made in 1879 (Flint), it seemed impossible to account for the heat actually produced in the body and expended as force in muscular work etc., by the heat-value of food and of tissue consumed. The estimates of heat-production, made by the direct method, were then adopted; but even the indirect estimates, which were much less, presented difficulty, though in a less degree. In these observations, it was shown that water was actually produced in the body in quantity over and above that contained in food and drink, during severe and prolonged muscular exertion. It was also shown that water was produced in considerable quantity during twenty-four hours of abstinence from food. It has been shown by Pettenkofer and Voit that "the elimination of water is very much increased by work, and the increase continues during the ensuing hours of sleep." As regards the oxidation of hydrogen in this formation of water, it is probable that the hydrogen of the tissues is used and that the matter thus consumed is supplied again to the tissues in order to maintain the physiological *status* of the organism. Adding the heat-value of the water thus produced to the heat-value of food, there is little difficulty in accounting for the heat and force actually produced and expended.

The demonstration that water is actually formed within the organism, under certain conditions, not only completes the oxidation-theory of the production of animal heat, but it affords an explanation of certain physiological phenomena that have been heretofore obscure. It is well known, for example, that a proper system of physical training will reduce the fat of the body to a minimum consistent with health and strength. This involves a diet containing a relatively small proportion of fat and liquids, and regular muscular exercise attended with profuse sweating. Muscular work increases the elimination of water, while it also exaggerates for the time the calorific processes. Muscular exercise undoubtedly favors the consumption of the non-nitrogenized parts of the body, and a diminution of the supply of fats, carbohydrates and water in the food prevents, to a certain extent, the new formation of fat. In excessive muscular exertion, the production of water is increased and the circulation becomes more active. The volume of blood then circulating in the skin and passing through the lungs in a given time is relatively increased, and there is an increased discharge of water from these surfaces. The same condition that produces an increased quantity of water in the body and has a tendency to exaggerate the process of calorification seems to produce also an increased evaporation from the surface, which serves to equalize the animal temperature.

Equalization of the Animal Temperature.—A study of the phenomena of calorification in the human subject has shown that under all conditions of climate the general heat of the body is equalized. There is always more or less loss of heat by evaporation from the general surface, and when the surrounding atmosphere is very cold, it becomes desirable to reduce this loss to the minimum. This is done by appropriate clothing, which must certainly be regarded as a physiological necessity. Clothing protects from excessive heat as well as from cold. Thin, porous articles moderate the heat of the sun, equalize evaporation and afford great protection in hot climates. In excessive cold, clothing moderates the loss of heat from the surface. When the body is not exposed to currents of air, garments are useful chiefly as non-conductors, imprisoning many layers of air, which are warmed by contact with the person. It is also important to protect the body from the wind, which greatly increases the loss of heat by evaporation.

When from any cause there is a tendency to undue elevation of the heat of the body, cutaneous transpiration is increased, and the temperature is kept at the proper standard. This has already been considered in treating of the action of the skin, and facts were noted showing that men can work when exposed to a heat much higher than that of the body itself. The quantity of vapor that is lost under these conditions is sometimes very large.

Tillet recorded an instance of a young girl who remained in an oven for ten minutes without inconvenience, at a temperature of 324·5° Fahr. (162·5° C.). Blagden, in his noted experiments in a heated room, made in connection with Banks, Solander, Fordyce, and others, found in one series of observations, that a temperature of 211° Fahr. (99·5° C.) could be easily borne; and at another time the heat was raised to 260° Fahr. (126·5° C.). Under these extraordinary external conditions, the body is protected from the radiated heat by clothing, the air is perfectly dry, and the animal temperature is kept down by increased evaporation from the surface.

It is a curious fact that after exposure of the body to an intense, dry heat or to a heated vapor, as in the Turkish or Russian baths, when the general temperature is somewhat raised and the surface is bathed in perspiration, a cold plunge, which checks the action of the skin almost immediately, is not injurious and is decidedly agreeable. This presents a striking contrast to the effects of sudden cold upon a system heated and exhausted by long-continued exertion. In the latter instance, when the perspiration is suddenly checked, serious disorders of nutrition, with inflammation etc., are liable to occur. The explanation of this seems to be the following: When the skin acts to keep down the temperature of the body in simple exposure to external heat, there is no modification in nutrition, and the tendency to an elevation of the animal temperature comes from causes entirely external. It is a practical observation that no ill effects are produced, under these circumstances, by suddenly changing the external conditions; but when the animal temperature is raised by a modification of the internal nutritive processes, as in prolonged muscular effort, these changes should not be suddenly arrested; and a suppression of the compensative action of the skin is liable to produce disturbances in nutrition, often resulting in inflammations.

Relations of Heat to Force.

Since the development of the theory of the conservation of forces, which had its origin in an essay published by J. R. Mayer, in 1842, physiologists have applied the laws of correlation and conservation of forces to operations involving the production of heat and the development and expenditure of force in animals. This theory, if applicable to what were formerly called vital operations, certainly affords, in its definite quantities of heat and force as expressed in heat-units and foot-pounds, a basis for calculating the absolute value of material changes in the body. Without discussing the purely physical questions involved, the laws of correlation and conservation of forces, as they are applicable to human physiology, may be briefly stated as follows:

Potential energy is something either residing in or imparted to matter, which is capable of being converted directly or indirectly into heat. The animal body, for example, is a store-house of potential energy. Its tissues may be made to unite with oxygen and heat is produced. Any body may have potential energy imparted to it. If a weight be raised to a certain height, when the force which has accomplished this work is exhausted, the potential energy imparted to the weight causes it to fall, and in this fall, heat is produced. The weight may be supported at the height to which it has been raised, for an indefinite time; but it still possesses the potential energy which has been imparted to it, and when the support is removed, this potential energy is converted into force which may be converted into heat. Potential energy may be converted directly into heat, as when a body is oxidized. It is converted indirectly into heat, when movement, falling or other force is produced, for all force may be converted into heat. This conversion into heat, directly or indirectly, affords a convenient measure of potential energy. Using the example of the change of potential energy into heat by oxidation, the energy stored up in matter is measured by estimating the heat produced by oxidation, as so many heat-units. Using the example of falling force imparted to a weight, the potential energy imparted to the body is estimated by calculating the heat produced by the body falling.

If the entire body of an animal were burned in a calorimeter, the heat produced would be an exact measure of the potential energy of the tissues, converted into heat by oxidation. If one can imagine an animal perfectly quiescent, neither losing nor gaining weight, nourished by food, expending no force in circulation and respiration, but supplied with oxygen, the potential energy of the food could be measured by the heat produced. In animal organisms, heat is produced mainly by oxidation, although other chemical processes contribute to the production of heat, to some extent. The body contains the potential energy stored up in its tissues. The oxygen taken in by respiration changes a certain part of this potential energy into heat. If food be not supplied in adequate quantity, the body loses weight by this change of tissue into certain matters, such as carbon dioxide, water and urea, which are discharged. Food supplies the waste of tissue and is the ultimate source of the potential energy of the body. If food be supplied in excess, that which is not in some form discharged from the body remains and adds to the total potential energy stored up in the organism.

Kinetic energy is mechanical force. It is the force of a falling body, or as regards animal mechanics, it is muscular force used in respiration, circulation or any kind of muscular work. In physics, kinetic energy, or force, and heat are regarded as mutually convertible. The reasoning by which this law was formulated is the following:

The force used in raising a weight to a certain height, which is imparted to the weight as potential energy, is precisely equal to the force developed by this body as it falls. If this force could be transmitted to another body of equal weight, without any expenditure of energy in friction, it would raise the second weight to an equal height. The arbitrary unit of this force is a foot-pound or a kilogrammetre, terms which have already been defined. The falling of a body of a certain weight through a definite distance produces a definite quantity of heat that itself is capable of producing force; and it is assumed that the heat produced by a falling body, if absolutely and entirely converted into force, would raise that body to the height from which it had fallen, or would exactly equal the falling force. A heat-unit is therefore said to be equal to a definite number of foot-pounds or kilogrammetres. Calculations have been made showing the conversion of foot-pounds or kilogrammetres into heat-units, but mechanical difficulties have thus far prevented the actual conversion of heat-units into their equivalents in foot-pounds or kilogrammetres. As a matter of reasoning, however, it is assumed that if a certain number of foot-pounds or kilogrammetres be equal to a certain number of heat-units, the reverse of the equation is true; but in the application of this law to animal physiology, it is always by a conversion of heat-units into foot-pounds or kilogrammetres. The experiments on which the law rests have been made by converting foot-pounds or kilogrammetres into heat-units.

In work by machinery a very large proportion of the force-value of fuel is dissipated in the form of heat. This is well illustrated by Landois. If a steam-engine burning a certain quantity of coal, but doing no work, be placed in a calorimeter, the heat produced can be measured. If, now, the engine be made to do a certain work, as in raising a weight, the heat, as measured by the calorimeter, will be less and the work done is found to be very nearly proportional to the decrease in the measured heat (Hirn). It is estimated by Landois, that of the heat produced by the body, one-fifth may be used as work. In the best steam-engine, it is possible to use only one-eighth as work, seven-eighths being dissipated as heat.

Many elaborate and careful estimates have been made of the mechanical work produced by the human body. The basis of such calculations is more or less indefinite, and the reduction of the work to foot-pounds or kilogrammetres is difficult and inexact. Even the general statement, that of the heat-units produced by the body, four-fifths remain as heat and one-fifth is converted into work, must be regarded as merely approximate.

In the animal organism, a part of the potential energy of the tissues may be converted into force by voluntary effort. In fevers, an abnormally large proportion of the potential energy of the organism is converted into heat, and it is not possible to use much of this energy as force. These and other peculiarities of living bodies, as regards the production of heat and force, are difficult of explanation. In the essential fevers, the conditions which involve the abnormal production of heat finally consume the substance of the tissues. They involve especially an increased production of carbon dioxide and urea and not to any great extent the formation of water. If heat-producing alimentary substances and alcohol can be introduced and consumed, the tissues are thereby proportionally saved from destruction and degenerations.