CHEMISTRY

OF

FOOD AND NUTRITION

THE MACMILLAN COMPANY
NEW YORK · BOSTON · CHICAGO
SAN FRANCISCO

MACMILLAN & CO., LIMITED
LONDON · BOMBAY · CALCUTTA
MELBOURNE

THE MACMILLAN CO. OF CANADA, LTD.
TORONTO

CHEMISTRY

OF

FOOD AND NUTRITION

BY

HENRY C. SHERMAN, PH.D.

PROFESSOR IN COLUMBIA UNIVERSITY

New York
THE MACMILLAN COMPANY
1912

Set up and electrotyped. Published February, 1911. Reprinted October, 1911; March, October, 1912.

Norwood Press
J. S. Cushing Co. — Berwick & Smith Co.
Norwood, Mass., U.S.A.

PREFACE

THE purpose of this volume is to present the principles of the chemistry of food and nutrition with special reference to the food requirements of man and the considerations which should underlie our judgment of the nutritive values of food. The food is here considered chiefly in its nutritive relations. It is hoped that the more detailed description of individual foods and the chemical and legal control of the food industry may be treated in a companion volume later.

The present work is the outgrowth of several years' experience in teaching the subject to collegiate and technical students who have represented a considerable diversity of previous training and points of view, and, while published primarily to meet the needs of the author's classes, it is hoped that it may also be of service to students and teachers elsewhere and to general readers whose main interests may lie in other fields, but who appreciate the importance of food and nutrition as factors in hygiene and preventive medicine.

While neither the size nor the purpose of this book would permit an historical or technically critical treatment, a limited number of historical investigations and controverted views have been mentioned in order to give an idea of the nature and validity of the evidence on which our present beliefs are based, and in some cases to put the reader on his guard against theories which, while now outgrown, are still sometimes encountered.

The author desires to express his indebtedness to the former students and other friends who have aided him with helpful suggestions, and specifically to Miss M. Helen Keith and Miss Mildred D. Schlesinger for assistance in the revision of manuscript and proof.

CONTENTS

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

APPENDIX

CHEMISTRY

OF

FOOD AND NUTRITION

CHEMISTRY OF FOOD AND NUTRITION

INTRODUCTION

The activities on which the life of the body depends involve a continuous expenditure of energy and a constant breaking down of body constituents. The energy expended leaves the body chiefly as heat; the material expenditures of the body are shown in the various end-products eliminated through the lungs, skin, kidneys, and intestines. We may consider all those substances which supply the body either with matter needed for its substance or with energy for its activities as collectively constituting its food, and any individual compound which thus nourishes the body may be considered a nutrient or a foodstuff. The energy expended by the body is derived from the burning of organic materials, chiefly carbohydrates, fats, and proteins. The material expended includes compounds of carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, and iron. These expenditures are unavoidable. They may be reduced, but can never be stopped; neither by resting the body as completely as possible, nor by stopping the intake of food.

The nutrition of the body includes all those processes which have to do with the upbuilding and repairing of the tissues and supplying them with fuel for their work. Lusk defines nutrition as: The sum of the processes concerned in the growth, maintenance, and repair of the living body as a whole, or of its constituent organs.

Most of the nutrient material contained in food requires more or less change to bring it into the exact forms most useful in nutrition. These changes as a rule take place in the digestive tract and together constitute the process of digestion.

The changes which take place in the foodstuffs, after they have been absorbed from the digestive tract, are included under the general term "metabolism." Although the chemical changes and the energy transformations are of course inseparable, it has become customary to speak of the metabolism of matter and the metabolism of energy, and to regard the extent of the metabolism of any material substance as measured by the amount of its end-products eliminated, and the extent of the energy metabolism as measured by the amount of heat, or of heat and external muscular work, which the body gives off.

The metabolism of matter and the metabolism of energy are normally supported by the food; but if no food is taken, they continue at the expense of the body substance. The expenditure of energy can never cease in the living body because it includes the work involved in carrying on the internal processes which are essential to life itself; and the expenditure of matter cannot cease because the energy for this necessary work is obtained by the breaking down of the organic compounds of the food or of the body substance into simpler compounds, many of which are of no further use to the body and must be eliminated. When the food supplies sufficient energy, the body substance is protected; when the food is insufficient, body substance is burned as fuel, and the waste of the materials which make up the body tissues is increased. In order, then, to consider intelligently the nutritive requirements of the body as regards the substances of which it is composed, it is necessary first to know whether the fuel requirements (the requirements of the energy metabolism) have been fully met.

The plan of the present work is (1) to describe briefly the principal foodstuffs and the agencies and processes through which they become available for the uses of the body; (2) to follow their functions in the tissues and their fate in metabolism; (3) to determine the food requirements of the body under different conditions; (4) to ascertain the functions of the individual chemical elements in nutrition and the quantities in which they should be supplied by the food; (5) to consider the criteria by which we should judge the nutritive value and economy of articles of food. This order of study has been found advantageous both from the standpoint of food chemistry and of application to the practical problems of human nutrition.

CHAPTER I

THE ORGANIC FOODSTUFFS

CARBOHYDRATES

THE carbohydrates include the simple sugars and all those more complex substances (such as dextrin, starch, etc.) which by hydrolysis can be resolved into simple sugars. Of the constituents of an ordinary mixed diet the carbohydrates are usually the most abundant and the most economical. They are also the first of the three great groups of foodstuffs to be formed by synthesis from simple inorganic substances in plants.

The chlorophyll cells of the leaves of green plants utilize the energy of the sun's rays to bring about reactions between carbon dioxide and water, with the liberation of oxygen and the formation of an organic compound. There is still some doubt as to the exact mechanism of the process, but the volume of oxygen liberated is equal to the volume of carbon dioxide which disappears, and whatever the intermediate products, there is normally an early production of carbohydrate. If the intermediate stages be omitted, the net result may be represented schematically as follows: —

$$6\ CO_2 + 6\ H_2O = C_6H_{12}O_6 + 6\ O_2.$$

There is much evidence that formaldehyde is an intermediate product, and according to the recent work of Usher and Priestley,[1] hydrogen peroxide is also produced. Such a reaction might be represented by the equation: —

$$CO_2 + 3\ H_2O = CH_2O + 2\ H_2O_2.$$

Under the influence of the chlorophyll cell the hydrogen peroxide is rapidly decomposed into water and oxygen, and the formaldehyde built up into carbohydrate. Glucose and other sugars belonging to the simplest group of carbohydrates are in composition direct polymers of formaldehyde and are classified as hexoses, pentoses, etc., according to the number of carbon atoms in the molecule.

Two pentoses, xylose and arabinose, have been obtained from both animal and vegetable sources and are of considerable biological interest; but by far the most important and best-known carbohydrates are the hexoses and their anhydrides.

The nine carbohydrates of most importance in human food and nutrition may be grouped as follows: —

Monosaccharides — simple sugars, those which cannot be split by hydrolysis into sugars of lower molecular weight: —

Glucose
Fructose
Galactose

---

[1] *Proc. Royal Society* (B), 77, 369; 78, 318 (1906).

Disaccharides — sugars each of which can be split by hydrolysis to yield two molecules of monosaccharide: —

Sucrose
Lactose
Maltose

Polysaccharides[1] — anhydrides of unknown molecular weight, each molecule yielding an undetermined number of molecules of monosaccharide when completely hydrolyzed: —

Starch
Dextrin
Glycogen

MONOSACCHARIDES

The monosaccharides are all soluble, crystallizable, diffusible substances, unaffected by digestive enzymes, and if not attacked by bacteria in the digestive tract, they are absorbed and enter the blood current unchanged. All of those here considered have the formula $C_6H_{12}O_6$, are susceptible to alcoholic fermentation, and are utilized for the production of glycogen in the animal body and the maintenance of the normal glucose content of the blood. A few of the leading facts regarding the occurrence in food and the nutritive relations of the individual monosaccharides are given below.

Glucose (*d.* glucose, dextrose, grape sugar, starch sugar,

---

[1] Some writers use the term "polysaccharides" to include all carbohydrates other than monosaccharides.

diabetic sugar) is widely distributed in nature, occurring in the blood of all animals in small quantity (usually about 0.1 per cent), and more abundantly in fruits and plant juices, where it is usually associated with levulose and sucrose. It is especially abundant in grapes, of which it often constitutes 20 per cent or more of the weight of the fresh fruit and considerably more than half of the solid matter. Sweet corn, onions, and unripe potatoes are among the common vegetables containing considerable amounts of glucose.

Glucose is also obtained from many other carbohydrates by hydrolysis either by acids or by enzymes, and thus becomes the principal form in which the carbohydrate of the food enters into the animal economy. In the healthy animal body the glucose of the blood is constantly being burned and replaced. In diabetes the body loses to a greater or less degree the power to burn glucose, which then accumulates in excessive amount in the blood, from which it escapes through the kidneys. A temporary and usually unimportant loss of glucose in the urine may occur as the result of feeding large quantities at a time. This condition is known as alimentary glycosuria. Ordinarily any surplus of glucose absorbed from the digestive tract is converted into glycogen in the liver.

Fructose (*d.* fructose, fruit sugar, levulose) occurs with more or less glucose in plant juices, in fruits, and especially in honey, of which it constitutes about one half the solid matter. It results in equal quantity with glucose from the hydrolysis of cane sugar and in smaller proportion from some other less common sugars. There also occurs in a few food plants (*e.g.* in the bulb of the Jerusalem artichoke) a polysaccharide — inulin — which on hydrolysis yields fructose only; but this appears not to be attacked by the ordinary digestive enzymes and so probably does not supply fructose to the body. Fructose may occur in normal blood, but probably only in insignificant amounts. It serves, like glucose, for the production of glycogen; and the fructose which enters the body either through being eaten as such or as the result of the digestion of cane sugar is mainly changed to glycogen on reaching the liver, so that it does not enter largely into the blood of the general circulation. Recently it has been found that glucose and fructose are partially convertible, either one into the other, by proper treatment with very dilute alkalies. It is not surprising, therefore, that fructose should be converted in the liver into glycogen which on hydrolysis yields glucose.

Galactose is not found free in nature, but results from the hydrolysis of milk sugar, either by acids or by digestive enzymes, and appears to have the same power as glucose and fructose to promote the formation of glycogen in the animal body. Anhydrides of galactose known as galactans occur quite widely distributed in plant products. The galactans of certain legumes studied by Schulze and Castro were found to be readily digested, while certain other galactans are not.

DISACCHARIDES

The three disaccharides here considered are hexo-bioses of the formula $C_{12}H_{22}O_{11}$, and are crystallizable and diffusible. Sucrose crystallizes anhydrous; maltose and lactose, each with one molecule of water, which can be removed by drying at temperatures of 100° and 130° respectively. They are soluble in water (lactose much less readily than sucrose and maltose), and much more sparingly soluble in alcohol. These disaccharides are important constituents of food and are changed to monosaccharides during the process of digestion.

Sucrose (saccharose, cane sugar) is widely distributed in the vegetable kingdom, being found in considerable quantity, generally mixed with glucose and fructose, in the fruits and juices of many plants. The commercially important sources of sucrose are the sugar beet, the sugar and sorghum canes, the sugar palm, and the sugar maple; but many of the common fruits and vegetables contain notable amounts, *e.g.* sucrose is said to constitute at least half the solid matter of pineapples and of some roots such as carrots. A molecule of sucrose yields on hydrolysis one molecule each of glucose and fructose. These sugars all rotate the plane of vibration of polarized light, sucrose and glucose to the right (+), and fructose to the left (−). The terms "dextrose" and "levulose," synonyms for glucose and fructose respectively, arose from this behavior of the sugars in rotating the plane of polarized light to the right and left. Since at ordinary temperatures the fructose rotates more strongly to the left than the glucose does to the right, the result of the hydrolysis is to change the sign of rotation from + to −. For this reason the hydrolysis of cane sugar is often called "inversion," and the resulting mixture of equal parts glucose and fructose is known as "invert sugar."

Sucrose is very easily hydrolyzed either by acid or by the *sucrase* ("invertase" or "inverting" enzyme) of yeast or of intestinal juice. So far as known neither the saliva nor the gastric juice contains any enzyme capable of hydrolyzing cane sugar, and the slight amount of hydrolysis which takes place in the stomach is believed to be due simply to the presence of hydrochloric acid. Under normal conditions the sucrose of the food passes mainly into the intestine unchanged and is there split by the sucrase of the intestinal juice, and the resulting glucose and fructose are absorbed into the portal blood.

When large amounts of sucrose are fed, some absorption takes place in the stomach; but the unchanged sucrose thus absorbed appears to be largely, if not wholly, lost through the kidneys, as it is when injected directly into the blood current. Sugar eaten in considerable quantities at a time is apt to undergo lactic acid fermentation in the stomach. According to Herter, sucrose and glucose are more liable to such fermentation than lactose. In cases where fermentation does not occur and the sucrose itself has no irritating effect, it may be especially useful as a rapidly available foodstuff. It is not known whether sucrose has any advantage over maltose and lactose in this respect.

Lactose (milk sugar) occurs in the milk of all mammals, constituting usually from 4 to 7 per cent of the fresh secretion. At the time of parturition, or if the milk is not withdrawn from the udder, some lactose may occur in the urine. If in such a case the mammary glands are removed, the percentage of glucose in the blood increases, and glucose (but no lactose) may appear in the urine. These observations indicate that lactose is formed in the mammary gland and probably from the glucose brought by the blood (Abderhalden).

When hydrolyzed either by heating with acids or by the *lactase* of the intestinal juice, each molecule of lactose yields one molecule of glucose and one of galactose. In normal digestion probably none of the lactose eaten is absorbed as such, for lactose injected into the blood is eliminated quickly and almost completely through the kidneys, whereas large amounts of lactose can be taken by the mouth without any such loss.

Maltose (malt sugar) is formed from starch by the action of diastatic enzymes (amylases) and is therefore an important constituent of germinating cereals, malt, and malt products. It is also formed as an intermediate product when starch is hydrolyzed by boiling with dilute mineral acids, as in the manufacture of commercial glucose.

In animal digestion maltose is formed by the action of the ptyalin of the saliva or the amylopsin of the pancreatic juice upon starch or dextrin. The maltose-splitting enzyme of the intestinal juice readily hydrolyzes maltose to glucose. Maltose is also readily and completely hydrolyzed by boiling with dilute mineral acids.

While it is probable that little if any maltose is absorbed as such from the digestive tract under ordinary conditions, it is possible that such absorption may occur and that maltose as such may play a part in the normal carbohydrate metabolism; for when injected into the blood it appears to be utilized to better advantage than either sucrose or lactose, and it may be obtained from glycogen by the action of diastatic enzymes in much the same way as from starch and dextrin (Abderhalden).

POLYSACCHARIDES

The polysaccharides are all uncrystallizable, non-diffusible, and insoluble in alcohol. Some dissolve in water, some swell and become gelatinous, some are unchanged. The members of greatest importance in nutrition are starch and glycogen, the typical reserve carbohydrates of plants and animals respectively.

Starch, $(C_6H_{10}O_5)_x$, is the form in which most plants store the greater part of their carbohydrates, and is of great importance as a constituent of many food materials and as the source of dextrin, maltose, commercial glucose, and many fermentation products. Starch is found stored in the seeds, roots, tubers, bulbs, and sometimes in the stems and leaves, of plants. It constitutes one half to three fourths of the solid matter of the ordinary cereal grains and at least three fourths of the solids of mature potatoes. Unchanged starch occurs in distinct granules, and those formed in different plants vary in size and structure, so that in most cases the source of a starch which has not been altered by heat, reagents, or ferments can be determined by microscopical examination. Starch granules are scarcely affected by cold water; on warming they absorb water and swell. Finally the starch passes into a condition of colloidal solution or semisolution, "starch paste." A more perfect solution is readily obtained by the use of water containing a small amount of caustic alkali. The best-known reaction of starch is the formation of an intense blue compound with iodine in the cold. The granular forms of the starches produced in different plants are often characteristic.

When treated with hydrochloric acid (usually 7 to 10 per cent) in the cold or with very moderate warming, more or less hydration occurs with the production of "soluble starch." Starch on hydrolysis gives first mixtures of dextrin and maltose, and finally glucose only as an end-product. The most satisfactory hydrolysis of starch to glucose is accomplished by boiling or heating in a boiling water bath with hydrochloric acid of a concentration of about 2.5 per cent. When brought in contact with saliva, starch is hydrolyzed by the ptyalin with the formation of dextrin and maltose. A similar hydrolysis is effected by amylopsin, the starch-splitting enzyme of the pancreatic juice.

Dextrins, $(C_6H_{10}O_5)_x$ or $(C_6H_{10}O_5)_x \cdot H_2O$, are formed from starch by the action of enzymes, acids, or heat. Small amounts of dextrin are found in normal, and larger amounts in germinating, cereals. Malt diastase acting upon starch in fairly concentrated solution yields usually about one part of dextrin to four of maltose. During acid hydrolysis, dextrin is formed as an intermediate product between soluble starch and maltose. Commercial dextrin, the principal constituent of "British gum," is obtained by heating starch, either alone or with a small amount of dilute acid.

The splitting of dextrin has already been mentioned in connection with that of starch, both ptyalin and amylopsin forming dextrin as an intermediate product and acting upon it with the production of maltose. Complete hydrolysis of dextrin yields glucose as the sole product.

Glycogen, $(C_6H_{10}O_5)_x$, plays much the same rôle in animals which starch plays in plants, and is sometimes called "animal starch." Glycogen also takes the place of starch as reserve carbohydrate in fungi and other forms of plant life not provided with the chlorophyll apparatus. It is a white, amorphous powder, odorless and tasteless, which swells up and apparently dissolves in cold water to a colloidal opalescent solution which is not cleared by repeated filtration, but loses its opalescence on addition of a very small amount of potassium hydroxide or acetic acid. Water solutions of glycogen treated with iodine react yellow-brown, red-brown, or deep red. Acid hydrolysis yields glucose only as end-product.

Glycogen occurs in the lower as well as the higher animals, and in all parts of the body, but is especially abundant in the liver, where it is found deposited in the cell substance but not in the nucleus. The amount of glycogen in the liver depends to a great extent upon the condition of nutrition of the animal. In the average of seven experiments by Schöndorff in which dogs were fed for the production of as much glycogen as possible, 38 per cent of that found was in the liver, 44 per cent in the muscles, 9 per cent in the bones, and the remaining 9 per cent in the other tissues and the fluid of the body. But the distribution of glycogen in the body as shown by these experiments was quite variable, even among animals of the same species which had been fed in the same way; while it is well known that some species store glycogen in their muscles to a greater extent than others, attempts even having been made to distinguish between horseflesh and beef by the difference in their glycogen content.

The storage of glycogen in the body is promoted by rest as well as by liberal feeding, and stored glycogen is used up rapidly during active muscular work.

FATS

Fats are glycerol esters of fatty acids, and since glycerol is a triatomic alcohol and the fatty acids are monatomic, a normal glyceride is a triglyceride and on hydrolysis yields three molecules of fatty acid and one molecule of glycerol. Thus, for example: —

$$\underset{\substack{\text{Stearin}\\\text{(glyceryl tristearate)}}}{C_3H_5(C_{18}H_{35}O_2)_3} + 3\ H_2O = \underset{\text{Glycerol}}{C_3H_5(OH)_3} + \underset{\text{Stearic acid}}{3\ C_{18}H_{36}O_2}.$$

When the splitting of the fat is brought about by means of an alkali instead of water, the corresponding products are glycerol and three molecules of the alkali salt of the fatty acid. Alkali salts of the fatty acids being commonly known as soaps, this reaction is usually called saponification of the fat.

The fats are therefore a definite group of chemical compounds, and the term applies equally to the solid and the liquid members of this group. As a matter of convenience, however, the liquid fats are often called "fatty oils." The fatty oils are also sometimes called fixed oils, since a spot made by dropping a fatty oil on paper cannot be removed by drying (as can a volatile oil), nor by washing with water (as can glycerin). All of the fats are practically insoluble in water, and all except those of the castor oil group are sparingly soluble in cold alcohol, but dissolve readily in petroleum ether and mix in all proportions with light petroleum oils. All of the fats are readily soluble in ether, carbon bisulphide, chloroform, carbon tetrachloride, and benzene. All natural fats contain small amounts of free fatty acid and of other substances aside from the glycerides of which they are principally composed. The actual glycerides of any common natural fat, with the exception of butter, would, if obtained absolutely pure, be colorless, tasteless, and odorless. The colors, tastes, and odors of fats are therefore ordinarily due to substances present in small amount which might be removed by refining processes.

All of the quantitative differences among the fats are to be accounted for by the kinds and the amounts of the fatty acids which enter into the composition of the glycerides. The greater number of the fatty acids belong to a few homologous series. The series to which stearic acid belongs may be represented by the general formula $C_nH_{2n}O_2$, and is made up of homologues of acetic acid. The principal members of physiological importance are as follows: —

ACIDS OF THE SERIES $C_nH_{2n}O_2$

Butyric acid ($C_4H_8O_2$) occurs as glyceride to the extent of about 5 to 6 per cent in butter and in very small quantities in a few others fats.

Caproic acid ($C_6H_{12}O_2$) is obtained from goat and cow butter and cocoanut fat.

Caprylic acid ($C_8H_{16}O_2$) is obtained from cocoanut oil, butter, and human fat.

Capric acid ($C_{10}H_{20}O_2$) is obtained from cocoanut oil, butter, and the fat of the spice bush.

Lauric acid ($C_{12}H_{24}O_2$) occurs abundantly as glyceride in the fat of the seeds of the spice bush, and in smaller proportions in butter, cocoanut fat, palm oil, and some other vegetable oils.

Myristic acid ($C_{14}H_{28}O_2$) is obtained from nutmeg butter, cocoanut oil, butter, lard, and many other fats, as well as from spermaceti and wool wax.

Palmitic acid ($C_{16}H_{32}O_2$) occurs abundantly in a great variety of fats, both animal and vegetable, including many fatty oils, and also in several waxes, including spermaceti and beeswax.

Stearic acid ($C_{18}H_{36}O_2$) is found in most fats, occurring most abundantly in the solid fats and especially in those having high melting points.

Butyric acid is a mobile liquid, mixing in all proportions with water, alcohol, and ether, boiling without decomposition, and readily volatile with steam. With increasing molecular weight the acids of this series regularly show increasing boiling or melting points, decreasing solubility, and loss of volatility with steam. Stearic acid is a crystalline solid, insoluble in water and only moderately soluble in alcohol and ether.

ACIDS OF THE SERIES $C_nH_{2n-2}O_2$

These are unsaturated compounds. Each molecule contains one ethylene linkage or double bond, and can take up by addition two atoms of halogen to form a saturated compound.[1] These unsaturated acids have, as a rule, much lower melting points than the saturated acids containing the same number of carbon atoms. The glycerides show correspondingly lower melting points than those of the saturated fatty acids and are therefore found more largely in the soft fats and the fatty oils.

Phycetoleic acid ($C_{16}H_{30}O_2$) is obtained from seal oil and sperm oil; an isomeric acid, hypogæic, occurs in peanut oil.

Oleic acid ($C_{18}H_{34}O_2$) occurs as glyceride in nearly all fats and fatty oils and is much the most important member of the series. Many of the typical oils of both animal and vegetable origin, such as lard oil and olive oil, consist mainly of olein.

Erucic acid ($C_{22}H_{42}O_2$) is obtained from rape seed and mustard seed oils, and is not found in animal fats except when oils which contain this acid have been fed to the animal.

The gradual change in physical properties with increasing molecular weight which is noticeable in the stearic acid series, is not apparent in this series, probably because the known acids of the series differ as regards the position of the double bond and are therefore not strictly homologous.

---

[1] The relative number of double bonds is measured analytically by determining the percentage of iodine which the fat or fatty acid will absorb. Thus pure oleic acid (mol. wt. 282) absorbs 2 atoms of iodine, giving an "iodine number" of 90; pure linoleic acid would absorb 4 atoms of iodine to the molecule, giving an "iodine number" about twice as great.

OTHER UNSATURATED FATTY ACIDS

Acids of the series $C_nH_{2n-4}O_2$, $C_nH_{2n-6}O_2$ and $C_nH_{2n-8}O_2$ have been found to occur as glycerides in some of the fats. Linoleic acid, $C_{18}H_{32}O_2$, and linolenic acid, $C_{18}H_{30}O_2$, are the best known of these acids. They are found abundantly in linseed oil and in others of the so-called "drying oils," which on account of the affinity for oxygen of their highly unsaturated glycerides oxidize to solids on exposure to the air. Fatty acids having the same number of double bonds but not the same property of oxidizing to hard, solid films are found in fatty oils of animal origin, especially those obtained from marine animals and from fishes. Since the acids of this series have still lower melting points than the corresponding acids of the oleic series, and since the physical properties of the glycerides follow those of the fatty acids which they contain, a fat containing an acid isomeric with linoleic or linolenic acid will be more fluid at any given temperature than one containing oleic acid in the same proportion. Hence, it is apparent that glycerides of the highly unsaturated and more fluid acids are physiologically adapted to the cold-blooded animals and it is found that they are especially abundant in fish fat; the acids of the series $C_nH_{2n-8}O_2$ have been obtained as yet only from fish oils.

COMPOSITION OF ANIMAL FAT

Just as we find the character of the fat in the cold-blooded animals adapted to the low temperature to which it is exposed, so to a less degree the character of the fat of warm-blooded animals appears to vary with its position in the body and with the temperature to which the body is subjected during the time that the fat is in process of formation. Thus Henriques and Hansen conclude from experiments with pigs that the thick layer of subcutaneous fat on the back, where it was not thoroughly warmed by the blood and therefore had an average temperature considerably below that of the interior of the body, was richer in unsaturated compounds (olein, etc.) and had a lower melting point than the fat of the body as a whole; while the fat from animals which had been grown in a warm room, or which had been heavily jacketed so that the skin was not exposed to cold air, contained near the skin fat of more nearly the same composition as in the interior of the body.

Moulton and Trowbridge have observed that the fat in beef animals becomes richer in olein and therefore softer with age, with fatness, and with nearness to the surface of the body.

Usually the nature of the fat found in the body is more or less characteristic of each species or group of closely related species. Herbivora contain as a rule harder fats than carnivora, land animals have harder fat than marine animals, and all warm-blooded animals have fats which are decidedly harder than those found in fishes.

The body fats of most land animals consist chiefly of glycerides of oleic, palmitic, and stearic acids. The differences in microscopic appearance which distinguish the fats of different species are due to variations, not only in the amounts of the fatty acids present, but also in the manner of their combination. A compound of glyceryl with three fatty acid radicles of the same kind is called a simple glyceride; one containing two or three different fatty acid radicles is known as a mixed gylceride. In cases where fats of nearly the same composition show quite distinct crystalline form, it is probable that this is largely due to the presence of different mixed glycerides in the different fats. This has been shown to be the case with regard to beef fat, whose microscopic appearance permits its detection when mixed with lard. The fats of different mammals were investigated by Schulze and Reineke, whose results[1] showed little variation from an average of carbon, 76.5 per cent; hydrogen, 12 per cent; oxygen, 11.5 per cent, as may be seen from the following: —

	CARBON	HYDROGEN	OXYGEN
Human fat	76.62	11.94	11.44
Beef fat	76.50	11.91	11.59
Mutton fat	76.61	12.03	11.36
Pork fat	76.54	11.94	11.52

Benedict and Osterberg[2] found in 8 samples of human fat an average of 76.08 per cent carbon and 11.78 per cent hydrogen.

The foregoing statements refer to the fat of the adipose

---

[1] Armsby: *Principles of Animal Nutrition*, p. 61.

[2] *American Journal of Physiology*, 4, 69.

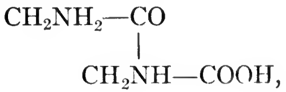
tissues. In the fat extracted from the liver, kidney, and heart, Hartley[1] finds fatty acids of the series $C_nH_{2n-4}O_2$, $C_nH_{2n-6}O_2$, and possibly $C_nH_{2n-8}O_2$.

Butter fat differs from body fat in containing fatty acids of lower molecular weight (particularly butyric acid, which is fairly characteristic of butter), and so shows a higher percentage of oxygen and lower percentages of carbon and hydrogen. The most abundant acids of butter fat are, however, palmitic, oleic, and myristic, and the ultimate composition is not very greatly different from that of body fats. A sample of butter fat analyzed by Browne[2] showed 75.17 per cent carbon, 11.72 per cent hydrogen; and 13.11 per cent oxygen.

PROTEINS

The proteins are very complex and usually amorphous compounds differing in composition and properties, but all of high molecular weight and unknown or incompletely known chemical structure, though now regarded as essentially anhydrides of amino acids.

The simplest of these amino acids is amino-acetic acid, commonly called glycocoll or glycin, $CH_2NH_2—COOH$. Two molecules of glycin combined by elimination of one molecule of water yield glycyl-glycin,



$$\begin{array}{l} CH_2NH_2\text{—}CO \\ \qquad\qquad\quad | \\ \qquad\qquad CH_2NH\text{—}COOH, \end{array}$$

---

[1] *Journal of Physiology*, **36**, 17.

[2] *Journal American Chemical Society*, 1899, **21**, 823.

which is the simplest of an immense group of anhydrides of amino acids, all of which are called "peptids." Dipeptids contain two amino-acid radicles, tripeptids contain three, etc. Fischer, by uniting 7 to 18 amino-acid radicles, has produced complex synthetic polypeptids which in some of their properties resemble the peptones. All of the typical proteins contain carbon, hydrogen, nitrogen, sulphur, and oxygen ; some also contain phosphorus and iron. The average ultimate composition of the better-known proteins of the body and of the food is approximately as follows: carbon, 53 per cent; hydrogen, 7 per cent; nitrogen, 16 per cent; sulphur, 1 per cent; oxygen, 23 per cent.

Proteins differ in their solubility in water, salt solutions, and alcohol; but are all insoluble in ether, chloroform, carbon tetrachloride, carbon bisulphide, benzene, and petroleum ether.

Since the proteins are conspicuously nitrogen compounds, it is important to realize that other nitrogen compounds also occur in the body and in the food. Among these are the alkaloids, the nitrogenous fats and essential oils, the so-called nitrogenous extractives, and, among inorganic nitrogen compounds, ammonium salts and nitrates. With the exception of certain of the "extractives," the amounts of these non-protein nitrogen compounds in foods or in the body tissues is usually quite small. The proteins and their immediate derivatives constitute therefore nearly all of the nitrogenous material involved in nutrition; and since the proteins are somewhat similar in nitrogen content, it has become customary in food analysis and nutrition work to take the total nitrogen as a measure of the protein, so that statements regarding percentages of proteins ordinarily mean the percentage of nitrogen multiplied by 6.25, this factor being based on the assumption that proteins contain approximately 16 per cent of nitrogen.

A few years ago an attempt was made in this country to use the term "proteids" for definite substances of the group which we are considering, and to reserve the term "protein" for the result obtained by multiplying figures for nitrogen by 6.25 or other conventional factor. This, however, was thought by some to be a cause of confusion, inasmuch as the German word "Proteid" designates only a portion of the compounds which in English were called "proteids." For this reason Halliburton and Hopkins, in behalf of the English physiological chemists, have submitted a revision of the terminology of these bodies in which the term "proteid" is dropped, and now a joint committee of the American Physiological Society and the American Society of Biological Chemists have concurred in this recommendation while proposing a terminology which differs in detail from any previously suggested and which, as indorsed by the two societies, is as follows: —

JOINT RECOMMENDATIONS OF THE COMMITTEES ON PROTEIN NOMENCLATURE

Since a chemical basis for the nomenclature of the proteins is at present not possible, it seemed important to recommend few changes in the names and definitions of generally accepted groups, even though, in many cases, these are not wholly satisfactory. The recommendations are as follows: —

First. — The word "proteid" should be abandoned.

Second. — The word "protein" should designate that group of substances, which consist, so far as at present is known, essentially of combinations of α-amino acids and their derivatives, *e.g.* α-amino acetic acid or glycocoll; α-amino propionic acid or alanin; phenyl-α-amino propionic acid or phenylalanin; guanidin-α-amino valerianic acid or arginin, etc.; and are therefore essentially polypeptids.

Third. — That the following terms be used to designate the various groups of proteins: —

I. *Simple Proteins.* — Protein substances which yield only α-amino acids or their derivatives on hydrolysis.

Although no means are at present available whereby the chemical individuality of any protein can be established, a number of simple proteins have been isolated from animal and vegetable tissues which have been so well characterized by constancy of ultimate composition and uniformity of physical properties that they may be treated as chemical individuals until further knowledge makes it possible to characterize them more definitely.

The various groups of simple proteins may be designated as follows: —

(*a*) *Albumins.* — Simple proteins soluble in pure water and coagulable by heat.

(*b*) *Globulins.* — Simple proteins insoluble in pure water but soluble in neutral solutions of salts of strong bases with strong acids.[1]

(*c*) *Glutelins.* — Simple proteins insoluble in all neutral solvents but readily soluble in very dilute acids and alkalies.[2]

(*d*) *Alcohol-soluble Proteins.* — Simple proteins soluble in relatively strong alcohol (70–80 per cent), but insoluble in water, absolute alcohol, and other neutral solvents.[3]

(*e*) *Albuminoids.* — Simple proteins which possess essentially the same chemical structure as the other proteins, but are characterized by great insolubility in all neutral solvents.[4]

(*f*) *Histones.* — Soluble in water and insoluble in very dilute ammonia, and, in the absence of ammonium salts, insoluble even in an excess of ammonia; yield precipitates with solutions of other proteins and a coagulum on heating which is easily soluble in very dilute acids. On hydrolysis they yield a large number of amino acids, among which the basic ones predominate.

(*g*) *Protamins.* — Simpler polypeptids than the proteins included in the preceding groups. They are soluble in water, uncoagulable by heat, have the property of precipitating aqueous solutions of other proteins, possess strong basic properties, and form stable salts with strong mineral acids. They yield com-

---

[1] The precipitation limits with ammonium sulphate should not be made a basis for distinguishing the albumins from the globulins.

[2] Such substances occur in abundance in the seeds of cereals and doubtless represent a well-defined natural group of simple proteins.

[3] The subclasses defined (*a*, *b*, *c*, *d*) are exemplified by proteins obtained from both plants and animals. The use of appropriate prefixes will suffice to indicate the origin of the compounds, *e.g.* ovoglobulin, myoalbumin, etc.

[4] These form the principal organic constituents of the skeletal structure of animals and also their external covering and its appendages. This definition does not provide for gelatin, which is, however, an artificial derivative of collagen.

paratively few amino acids, among which the basic amino acids greatly predominate.

II. *Conjugated Proteins.* — Substances which contain the protein molecule united to some other molecule or molecules otherwise than as a salt.

(*a*) *Nucleoproteins.* — Compounds of one or more protein molecules with nucleic acid.

(*b*) *Glycoproteins.* — Compounds of the protein molecule with a substance or substances containing a carbohydrate group other than a nucleic acid.

(*c*) *Phosphoproteins.* — Compounds of the protein molecule with some, as yet undefined, phosphorus-containing substance other than a nucleic acid or lecithin.[1]

(*d*) *Hemoglobins.* — Compounds of the protein molecule with hematin or some similar substance.

(*e*) *Lecithoproteins.* — Compounds of the protein molecule with lecithins (lecithans, phosphatids).

III. *Derived Proteins.*

1. *Primary Protein Derivatives.* — Derivatives of the protein molecule apparently formed through hydrolytic changes which involve only slight alterations of the protein molecule.

(*a*) *Proteans.* — Insoluble products which apparently result from the incipient action of water, very dilute acids, or enzymes.

(*b*) *Metaproteins.* — Products of the further action of acids and alkalies whereby the molecule is so far altered as to form products soluble in very weak acids and alkalies, but insoluble in neutral fluids.

This group will thus include the familiar "acid proteins" and "alkali proteins," not the salts of proteins with acids.

(*c*) *Coagulated Proteins.* — Insoluble products which result from

---

[1] The accumulated chemical evidence distinctly points to the propriety of classifying the phosphoproteins as conjugated compounds, *i.e.* they are possibly esters of some phosphoric acid or acids and protein.

(1) the action of heat on their solutions, or (2) the action of alcohols on the protein.

2. *Secondary Protein Derivatives.*[1] — Products of the further hydrolytic cleavage of the protein molecule.

(*a*) *Proteoses.* — Soluble in water, uncoagulated by heat, and precipitated by saturating their solutions with ammonium sulphate or zinc sulphate.[2]

(*b*) *Peptones.* — Soluble in water, uncoagulated by heat, but not precipitated by saturating their solutions with ammonium sulphate.[3]

(*c*) *Peptids.* — Definitely characterized combinations of two or more amino acids, the carboxyl group of one being united with the amino group of the other, with the elimination of a molecule of water.[4]

NOTES ON SOME OF THE MORE IMPORTANT PROTEINS

Albumins and *globulins* are very often associated, as, for example, in blood serum and in the cell substance. The typical albumins are richer in sulphur than the typical globulins. As a rule the albumins are the more abundant in animal fluids (blood, etc.), while the globulins predominate

---

[1] The term secondary hydrolytic derivatives is used because the formation of the primary derivatives usually precedes the formation of these secondary derivatives.

[2] As thus defined, this term does not strictly cover all the protein derivatives commonly called proteoses, *e.g.* heterproteose and dysproteose.

[3] In this group the kyrins may be included. For the present we believe that it will be helpful to retain this term as defined, reserving the expression "peptid" for the simpler compounds of definite structure, such as dipeptids, etc.

[4] The peptones are undoubtedly peptids or mixtures of peptids, the latter term being at present used to designate those of definite structure.

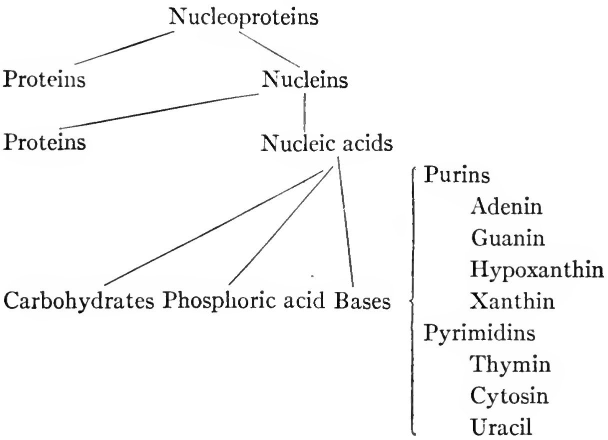
over albumins in animal tissues and in plants. There appears to be no sharp dividing line between the albumins and the globulins. While the globulins are insoluble in pure water, a water extract of animal tissue (muscle, for example) will contain, in addition to albumin, a considerable amount of globulin carried into solution by the salts present in the tissue, and if the salts are removed as completely as possible by dialysis, some of the globulin still remains in solution; separations based upon saturation with neutral salts are also apt to be unsatisfactory (Howell).

Alcohol-soluble proteins and *glutelins* are chiefly important as constituents of the cereal grains. The best-known examples of the respective groups are gliadin and glutenin of wheat flour. These proteins resemble each other in ultimate composition, but differ not only in solubilities, but also in their cleavage products. They are much the most important of the proteins of the wheat kernel, the gliadin making up about 50 per cent and the glutenin about 40 per cent of the total protein present. These, of course, are approximate average figures. In individual samples of wheat considerable variation in the proportions of both gliadin and glutenin may be found. The gliadin and glutenin together constitute the gluten of wheat flour. The elasticity and strength of the gluten and therefore the baking qualities of the flour are influenced by the proportions of gliadin and glutenin present, about twice as much gliadin as glutenin being usually considered desirable in bread flour.

Albuminoids have often been classified in a group apart from the "true proteins" not so much on account of their known chemical or physical properties as because it was found that gelatin, which was considered typical of the group, did not alone satisfactorily support the protein metabolism of the body (see Chapters VII and XI). This distinction has lost much of its force since proteins of other groups fed singly have also in some cases been found unable to support protein metabolism, and the albuminoids are now reassigned to a place among the true proteins.

Nucleoproteins are the characteristic proteins of cell nuclei and are therefore especially abundant in the highly nucleated cells of the glandular organs, such as the thymus, the pancreas, and the liver. They are compounds of simple proteins with nucleic acid or nuclein. On digestion with pepsin-hydrochloric acid nucleoprotein splits, with the formation, first, of a simple protein and a nuclein. The latter on further decomposition yields a simple protein and nucleic acid. Nucleic acid is therefore the characteristic constituent, and a number of different forms, all rich in phosphorus, have been described under such names as thymonucleic acid, tritico-nucleic acid, guanylic acid, etc. On hydrolytic decomposition they yield some of the purin bases (xanthin, adenin, guanin, etc.), some pyrimidin derivatives (uracil, thymin, cytosin), a carbohydrate group, and phosphoric acid.

The cleavage products of nucleoproteins may therefore be represented as follows: —



Phosphoproteins occur especially in milk and eggs, the foods most obviously intended to provide the material for growth and development. The phosphorus, while probably present in the form of a more or less modified phosphoric acid radicle, appears to be more closely bound in these than in the nucleoproteins. Casein of milk and vitellin of egg-yolk (ovo-vitellin) are the most prominent members of the group. These are sometimes classed with simple proteins under the name nucleoalbumins. Phosphoprotein preparations show on analysis small amounts of iron, which has usually been neglected as an impurity, but which is not improbably an essential constituent.

Hemoglobins consisting of combinations of simple proteins with coloring matter serve as carriers of oxygen from the air to the tissues. On boiling or heating with acids or alkalies they split up into their constituent parts: for example, ordinary hemoglobin yields about 4 per cent of hematin, $C_{32}H_{32}N_4FeO_4$, and a residue of globin which was formerly considered a globulin but is now assigned to the histone group.

Proteoses and *peptones* are products derived from other proteins by digestion or by simple hydrolysis. They are soluble in water and not coagulated by boiling their aqueous solutions. No sharp line can be drawn either between proteoses and peptones, or between peptones and the simpler nitrogen compounds which result from prolonged digestion. As the terms are generally used, *peptones* may be considered as the products of digestion or hydrolysis which are still proteins as judged by certain color reactions and are precipitated by strong alcohol, but not by saturation of their solutions with zinc or ammonium sulphate, as is the case with proteoses. *Proteoses* (albumoses) are intermediate products between meta-protein and peptones. In addition to the protein reactions shown by peptones, the proteoses are precipitated from aqueous solutions at ordinary temperatures by adding acetic acid and potassium ferrocyanide, or by saturating the solution with zinc or ammonium sulphate.

The term " peptone " was formerly applied to all digestion products not coagulated by boiling, and is still popularly used in the same sense, the best commercial "peptones" consisting largely of proteoses.

In the main the composition of the peptones agrees fairly well with the assumption that they are essentially hydrolytic products. The changes in composition are, however, not entirely such as would result from simple hydrations alone, both Chittenden and Kruger having found that the change from original protein to peptone resulted in a loss of sulphur entirely out of proportion to the diminution in the nitrogen content. This probably indicates that sulphur compounds simpler or less easily precipated than the peptones are split off comparatively early in the hydrolysis of proteins.

It has been said that the proteins are now regarded as essentially anhydrides of amino acids (the principal amino acids of proteins are listed below). Synthetic anhydrides of amino acids have been prepared and are called "peptids" with a prefix to indicate the number of amino-acid radicles in the molecule. Regarding the relation of peptones to these synthetic products of known structure Abderhalden (*Physiological Chemistry*, translated by Hall, p. 184) says: "We must admit that many analogies exist between the synthetic polypeptids and the peptones. We can make no sharp distinction in this direction. We must not lose sight of the fact that we are comparing a sharply defined chemical compound with a mixture. The name 'peptone' does not indicate any definite compound; in fact, may not even represent distinctly analogous cleavage products of protein. It is much better to assume that the peptones represent all stages of decomposition between that of albumoses and the amino acids."

COMPOSITION AND CONSTITUTION OF PROTEINS

The ultimate composition of some typical proteins is shown in the following table: —

COMPOSITION OF SOME TYPICAL PROTEINS ACCORDING TO OSBORNE

	CARBON PER CENT	HYDROGEN PER CENT	NITROGEN PER CENT	OXYGEN PER CENT	SULPHUR PER CENT	IRON PER CENT	PHOSPHORUS PER CENT
Egg-albumin	52.75	7.10	15.51	23.024	1.616		
Lact-albumin	52.19	7.18	15.77	23.13	1.73		
Leucosin	53.02	6.84	16.80	22.06	1.28		
Serum-globulin	52.71	7.01	15.85	23.32	1.11		
Myosin	52.82	7.11	16.67	22.03	1.27		
Edestin	51.50	7.02	18.69	21.91	0.88		
Legumin	51.72	6.95	18.04	22.905	0.385		
Casein	53.13	7.06	15.78	22.37	0.80	—	0.86
Ovovitellin	51.56	7.12	16.23	23.242	1.028	—	0.82
Gliadin	52.72	6.86	17.66	21.733	1.027		
Zein	55.23	7.26	16.13	20.78	0.60		
Oxyhemoglobin	54.64	7.09	17.38	20.165	0.39	0.335	—

From the results of ultimate analysis an approximate indication of the minimum molecular weight may often be obtained by a very simple calculation. Thus, oxyhemoglobin contains only 0.335 per cent of iron, and since there must be at least one iron atom in the molecule, it is obvious from a simple proportion making use of the atomic weight of iron: —

$$0.335 : 56 :: 100 : x$$

that the molecular weight of hemoglobin must be in the neighborhood of 16,800 or a multiple of this.

To take an example from the simple proteins, zein contains 0.60 per cent of sulphur, of which one third is much more readily split off than the other two thirds, from which it appears that the molecule contains three, or a multiple of three, sulphur atoms. Then by the proportion

$$0.60 : (32 \times 3) :: 100 : x,$$

it is found that about 16,000 or a multiple thereof is the probable molecular weight of zein.

Our knowledge of the structure of the protein molecule is derived mainly from studies of the products obtained by hydrolytic cleavage. Investigations in this direction are being pursued very actively, and no comprehensive summary of the results as a whole can be given in concise form at present. Some idea of the complexity of the proteins and of the great differences which must exist in their inner structure, may, however, be obtained from an enumeration of the amino acids most commonly resulting from hydrolysis of proteins and from a comparison of the yields obtained in a few typical cases.

The more prominent amino acids are: —

Monamino Acids:

Monobasic:

Glycin = amino-acetic acid, $CH_2(NH_2) \cdot COOH$.

Alanin = α-amino-propionic acid, $CH_3CH(NH_2) \cdot COOH$.

Serin = α-amino-β-hydroxy-propionic acid,

$$CH_2(OH)\cdot CH(NH_2)\cdot COOH.$$

Valin = α-amino-isovaleric acid,

$$(CH_3)_2CH\cdot CH(NH_2)\cdot COOH.$$

Leucin = α-amino-caproic acid (α-amino-isobutyl-acetic acid),

$$(CH_3)_2CH\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

Phenylalanin = phenyl-α-amino-propionic acid,

$$C_6H_5CH_2\cdot CH(NH_2)\cdot COOH.$$

Tyrosin = oxyphenyl-α-amino propionic acid,

$$C_6H_4(OH)\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

Dibasic :

Aspartic acid = amino-succinic acid,

$$COOH\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

Glutamic (glutaminic) acid = amino-glutaric acid,

$$COOH\cdot CH_2\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

Diamino Acids:

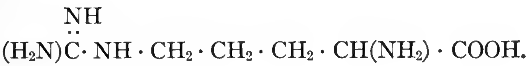
Ornithin = α, δ, diamino-valeric acid,

$$CH_2(NH_2)\cdot CH_2\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

Lysin = α, ε, diamino-*n*-caproic acid,

$$CH_2(NH_2)\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

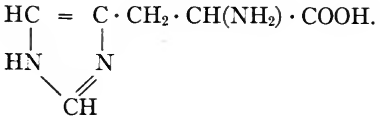
Arginin = δ-guanidino-α-amino-valeric acid,



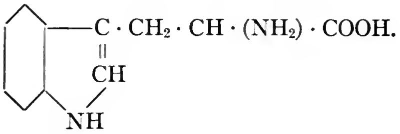
$$(H_2N)\overset{\overset{NH}{:}}{C}\cdot NH\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH(NH_2)\cdot COOH.$$

Heterocyclic Amino Acids:

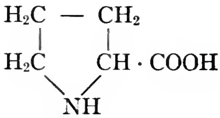
Histidin = α-amino -β imidazol propionic acid,



Tryptophan = indol-amino-propionic acid,

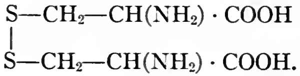


Prolin = Pyrrolidin-carboxylic acid,



Thio-amino Acid:

Cystin = dicystein = union of two molecules of amino-thiolactic acid,



$$\begin{array}{l} S-CH_2-CH(NH_2)\cdot COOH \\ | \\ S-CH_2-CH(NH_2)\cdot COOH. \end{array}$$

The percentages of amino acids thus far found in the products of hydrolysis are given below for a few proteins, while the corresponding data for several others will be found in Chapter XI.

Per cent of amino acids from different proteins

	Casein[1]	Hordein[2]	Globin[1]	Gelatin[3]
Glycin . . .	0	0	0	16.5
Alanin . . .	0.9	0.43	4.2	.8
Valin . . .	1.0	0.13	—	1.0
Leucin . . .	10.5	5.67	29.0	2.1
Prolin . . .	3.1	13.73	2.3	5.2
Phenylalanin .	3.2	5.03	4.2	.4
Glutamic acid	11.0	36.35	1.7	.9
Aspartic acid .	1.2	present	4.4	.6
Cystin . . .	.06	present	.3	—
Serin . . .	.23	—	.6	.4
Tyrosin . .	4.5	1.67	1.5	0
Tryptophan .	1.5	present	present	0
Oxyprolin . .	.25		1.0	3.0
Lysin . . .	5.80	0	4.3	2.81
Arginin . .	4.84	2.16	5.4	7.61
Histidin . .	2.59	1.28	11.0	0.41
Ammonia . .	1.95	4.87	—	0.4
Summation .	52.62	71.32	69.9	42.1

These figures, in addition to illustrating the complexity of the protein molecules, show wide differences among the proteins as regards the amounts of certain amino acids which they yield. These differences in cleavage products represent divergencies of structure which in all probability should be recognized in comparing the nutritive values of different articles of food. To what extent the animal body can convert one amino acid into another and to what extent it is

---

[1] Abderhalden and associates.
[2] Osborne and associates.
[3] Fischer and associates.

directly dependent upon the food for the particular amino acids needed for the construction of its proteins has not yet been determined in detail, but some discussion of this question will be found in Chapter XI.

REFERENCES

ABDERHALDEN. Textbook of Physiological Chemistry, Lectures 2 to 13 (1908).
ARMSTRONG. The Simple Carbohydrates and the Glucosides (1910).
COHEN. Organic Chemistry (1907).
FISCHER. Untersuchungen ueber Aminosäuren, Polypeptide und Proteine (1906).
HAMMARSTEN. Textbook of Physiological Chemistry, 6th American edition (1911).
HARTLEY. On the Nature of the Fat contained in the Liver, Kidney and Heart, *Journal of Physiology*, **38**, 353–374 (1909).
HAWK. Practical Physiological Chemistry, 2d edition (1909).
HOLLEMAN. Textbook of Organic Chemistry, 3d English edition (1910).
LEATHES. Die Synthese der Fette im Tierkörper. *Ergebnisse der Physiologie*, **8**, 356–370 (1909).
LEWKOWITSCH. Oils, Fats, and Waxes, 3d edition (1904).
LIPPMANN. Chemie der Zuckerarten, 3d edition (1904).
MANN. Chemistry of the Proteids (1906).
OSBORNE. The Vegetable Proteins (1909).
—— Die Pflanzenproteine. *Ergebnisse der Physiologie*, **10**, 47–215 (1910).
PLIMMER. Chemical Constitution of the Proteins, I and II (1908).
SCHRYVER. The General Character of the Proteins (1909).
TOLLENS. Handbuch der Kohlenhydrate, Band I (1888). Band II (1895).
ULZER AND KLIMONT. Allgemeine und Physiologische Chemie der Fette (1906).

CHAPTER II

THE GENERAL COMPOSITION OF FOODS AND THE ACTION OF FERMENTS

Since the important articles of food contain in most cases more than one kind of foodstuff, it is not feasible to classify them in the same manner as the individual nutrients, and for convenience of reference the examples given in this chapter may be grouped as in the standard tables[1] in the order: meats, fish, eggs, dairy products, grain products and breadstuffs, sugars and starches, vegetables, fruits and nuts.

The edible matter of food is commonly assumed to consist of water, proteins, fats, carbohydrates, and ash. When an article of food also contains inedible matter or refuse, this may be stated separately and the composition of the edible portion then given, or the percentages of refuse and of edible nutrients in the original matter may be given so as to show directly the percentage of each edible nutrient obtained in the material as purchased. For example, 100 lb. of beef contains 16 lb. of bone and 84 lb. of moist flesh of which

---

[1] *The Chemical Composition of American Food Materials*, by W. O. Atwater and A. P. Bryant, Bull. 28 (revised), Office of Expt. Stations, U. S. Dept. Agriculture; and König, *Chemie der menschliche Nahrungs- und Genuss-mittel.*

15.4 lb. are protein, 15 lb. fat, 53 lb. water, and 0.6 lb. ash. The composition may be stated in either of the following forms: —

COMPOSITION OF BEEF

REFUSE PER CENT	WATER PER CENT	PROTEIN PER CENT	FAT PER CENT	ASH PER CENT
16.0	53.0	15.4	15.0	0.6

COMPOSITION OF BEEF

REFUSE	EDIBLE PORTION			
per cent	Water per cent	Protein per cent	Fat per cent	Ash per cent
16.0	62.9	18.3	17.9	0.7

In order to avoid confusion and possible errors in taking data from tables of composition it is important to note in which form the percentages are stated. Data given in either form are of course readily convertible into the other. Thus in the above example since the beef contains 16 per cent of refuse and 84 per cent of moist edible matter, the percentage of protein or fat in the material as purchased divided by 0.84 gives the percentage in the edible portion; and the percentage in the edible portion multiplied by 0.84 gives the percentage in the material as purchased.

The average proximate composition of the edible portion of some typical food materials is shown in the following table: —

Composition of Edible Portion of Typical Foods[1]

Food Materials	Water per cent	Protein per cent	Fat per cent	Carbohydrate per cent	Ash per cent
Beef, free from visible fat	73.8	22.1	2.9	—	1.2
Beef, round steak, lean[2]	70.0	21.0	7.9	—	1.1
Ham, smoked, lean	53.5	20.2	20.8	—	5.5
Bacon, smoked	20.2	9.9	64.8	—	5.1
Codfish, fresh	82.6	15.8	0.4	—	1.2
Salmon	64.6	21.2	12.8	—	1.4
Eggs	73.7	14.8	10.5	—	1.0
Milk	87.0	3.3	4.0	5.0	0.7
Butter	11.0	1.0	85.0	—	3.0
Oatmeal	7.3	16.1	7.2	67.5	1.9
Rice	12.3	8.0	0.3	79.0	0.4
Wheat flour	11.9	13.3	1.5	72.7	0.6
Bread, white	35.3	9.2	1.3	53.1	1.1
Asparagus	94.0	1.8	0.2	3.3	0.7
Beans, dried	12.6	22.5	1.8	59.6	3.5
Beans, string	89.2	2.3	0.3	7.4	0.8
Beets	87.5	1.6	0.1	9.7	1.1
Cabbage	91.5	1.6	0.3	5.6	1.0
Carrots	88.2	1.1	0.4	9.3	1.0
Celery	94.5	1.1	0.1	3.3	1.0
Corn, green	75.4	3.1	1.1	19.7	0.7
Lettuce	94.7	1.2	0.3	2.9	0.9
Potatoes	78.3	2.2	0.1	18.4	1.0
Spinach	92.3	2.1	0.3	3.2	2.1
Tomatoes	94.3	0.9	0.4	3.9	0.5
Turnips	89.6	1.3	0.2	8.1	0.8
Apples	84.6	0.4	0.5	14.2	0.3
Bananas	75.3	1.3	0.6	22.0	0.8
Currants, dried	17.2	2.4	1.7	74.2	4.5
Oranges	86.9	0.8	0.2	11.6	0.5
Peaches	89.4	0.7	0.1	9.4	0.4
Pineapple	89.3	0.4	0.3	9.7	0.3
Plums	78.4	1.0	—	20.1	0.5
Prunes, dried	22.3	2.1	—	73.3	2.3
Raisins	14.6	2.6	3.3	76.1	3.4
Strawberries	90.4	1.0	0.6	7.4	0.6
Almonds	4.8	21.0	54.9	17.3	2.0
Chestnuts	45.0	6.2	5.4	42.1	1.3
Peanuts	9.2	25.8	38.6	24.4	2.0
Olive oil			100.0		

A more comprehensive table will be found in the Appendix.

---

[1] Based on Bull. 28, *loc. cit.*, to which the reader is referred for

With few exceptions the nutrients thus composing the ordinary articles of food are not of a nature to be utilized advantageously by the body tissues in the exact form in which they are eaten, but must usually undergo more or less extensive alteration in the digestive tract. In so far as these digestive changes are chemical they are brought about mainly by the action of soluble ferments, or enzymes.

ENZYMES AND THEIR ACTIONS

It may be said that all fermentations are brought about either directly or indirectly by the activities of animal or vegetable organisms or cells. When an organism or a cell acts directly and the chemical changes occur only in its presence, the fermentation is said to be due to an organized ferment. When the action is not brought about directly by the cell itself, but by means of a substance secreted by the cell but acting apart from it, this substance is called a soluble or unorganized ferment, or (more commonly now) an enzyme.

The distinction between fermentations due to organized ferments and those caused by enzymes was for a time considered quite sharp, but was considerably shaken when Büchner, in 1896–1897, showed that alcoholic fermentation,

---

analyses of other articles of food and for the composition of food materials as purchased, including refuse.

[1] Since much of the fat of these meats is ordinarily trimmed off, the composition of medium lean cuts is given here as representing what is usually eaten.

which had been considered typical of the fermentations due to organisms, might be induced by an expressed juice of the yeast entirely free from living cells. The yeast enzyme which thus produces alcoholic fermentations is called zymase. Further experiments have shown that many other fermentations formerly supposed to be due to the direct action of organisms can be produced in sterile media by enzymes obtained from the organisms with which the fermentation is ordinarily associated. The present tendency is therefore to ascribe fermentations in general to enzymes, although not all fermentations have yet been shown to take place in the absence of living matter. It has been suggested that enzymes be designated as *intracellular* or *extracellular* according as they normally operate within or without the cell by which they are formed, notwithstanding the fact that it is possible by artificial means to cause intracellular enzymes to act independently of cells.

Enzymes as Catalyzers. — Under favorable conditions the amount of material which may be changed by a given amount of enzyme is so great as to indicate that the enzyme acts as a catalyzer, and is not used up in the reaction which it brings about. Thus, one part of Hammarsten's rennin coagulated 400,000 to 800,000 parts of milk and must therefore have produced a distinct chemical change in at least 10,000 to 20,000 times its weight of protein; while Petit has described the preparation of a pepsin powder which in seven hours dissolved 500,000 times its weight of fibrin.

A catalyzer is usually considered to alter the velocity of a reaction but not to initiate it. Thus hydrogen peroxide decomposes spontaneously into water and oxygen. In a pure aqueous solution this change goes on slowly, but it is very greatly accelerated by the presence of a minute amount of colloidal platinum. Blood and tissue extracts contain enzymes which accelerate the decomposition of hydrogen peroxide apparently in much the same way as does platinum, and the present tendency is to regard the enzymes generally as acting quite like the inorganic catalyzers in altering by their presence the velocity of certain reactions. Some of the best-known enzyme actions, however, fit into this view only theoretically; for example, proteins in water at ordinary temperature do not appear to split up spontaneously into the products formed by pepsin, and if the pepsin be considered as simply accelerating a reaction already taking place, it must also be considered that at ordinary temperatures the reaction is infinitely slow so that it cannnot be demonstrated. At sufficiently high temperatures, however, protein undergoes in water alone a change similar to that of peptic digestion.

Specificity of Enzymes. — As compared with most inorganic catalyzers the enzymes are strikingly specific in their action. Thus the hydrolysis of sucrose may be accelerated by hydrochloric acid or by the enzyme sucrase; but while the acid similarly accelerates the hydrolysis of the greatest variety of other substances, the enzyme acts upon sucrose alone and appears to be inactive towards all other substances, even though they may be readily susceptible to hydrolysis.

Fischer suggests that this specificity of the different enzymes may be related to the geometrical structure or special configuration of the substance acted upon, each enzyme being adapted to act only upon a molecule of a certain definite structure, to which it is fitted as a key to its lock.

On the basis of the properties which have been outlined, Oppenheimer suggests and Howell adopts the following descriptive definition: An enzyme is a substance produced by living cells, which acts by catalysis. The enzyme itself remains unchanged in this process, and it acts specifically — that is, each enzyme exerts its activity only upon substances whose molecules have a definite structural and stereochemical arrangement. The enzymes of the body are organic substances of a colloidal structure whose chemical composition is unknown.

Classification. — Enzymes are classified according to their effects, some of the better-known groups being as follows: —

1. The hydrolytic enzymes.
    - *a.* Proteolytic or protein-splitting enzymes.
    - *b.* Lipolytic or fat-splitting enzymes.
    - *c.* Amylolytic or starch-splitting enzymes.
    - *d.* Sugar-splitting enzymes.
2. The coagulating enzymes, such as thrombin or thrombase (the fibrin ferment), and rennin, which causes the clotting of sweet milk.

3. The oxidizing enzymes, or "oxidases" (which, if the oxidation be accompanied by a splitting off of amino groups, may be called "deamidizing" or "deaminizing" enzymes).

4. The reducing enzymes or "reductases."

5. Those which produce carbon dioxide without using free oxygen — such as the zymase of yeast.

6. Enzymes causing a breaking down of a larger into a smaller molecule of the same composition, as in the production of lactic acid from glucose.

Terminology. — In the terminology of the enzymes no uniform system has yet been adopted. Most writers follow in the main the suggestion of Duclaux that each enzyme be designated by the name of the substance upon which it acts with the suffix *ase* (*e.g.* protease, lipase, amylase, maltase); but a few of the enzymes which have been longest known continue to be called by their original names — ptyalin, pepsin, trypsin, etc. Lippmann, referring particularly to the enzymes of the carbohydrates, proposes that the name of the enzyme be compounded from that of the substance acted upon and that of the substance produced (*e.g.* amylo-maltase, malto-glucase); but such a terminology would become unwieldy if an attempt were made to apply it to enzymes in general.

Digestive Enzymes. — The action of digestive enzymes upon the foodstuffs consists in splitting the latter into substances of lower molecular weight which are more readily soluble and diffusible and better fitted for absorption. The principal digestive enzymes attacking the three groups of organic foodstuffs are: (1) ptyalin of the saliva, amylopsin of the pancreatic juice, and the sucrase, maltase, and lactase of the intestinal juice, all of which act upon carbohydrates; (2) the lipases of the gastric and pancreatic juices, which act upon fats; (3) pepsin, trypsin, and erepsin of the gastric, pancreatic, and intestinal juices respectively, all of which act upon proteins.

The enzymes are soluble in water, moderately soluble in glycerin, insoluble in strong alcohol. Heated to boiling in water solution, any enzyme permanently loses its activity, but preparations which have been carefully desiccated are only weakened and not destroyed by heating in a dry state to 100°.

Some enzymes are very sensitive to the reaction of the medium in which they act, while others are much less so; thus pepsin requires a certain acidity, while trypsin works best in an alkaline medium but is also moderately active in neutral or even faintly acid solutions.

Since all enzymes are soluble in water and exert their activity in solution, the speed of an enzyme action is much greater when the substance attacked is also in solution than when it is in an insoluble state. In the latter case, however, the action may be greatly accelerated by finely dividing the insoluble substance so as to expose a large surface to the action of the solution containing the enzyme. Since fats are practically insoluble in water, it follows that a sufficient contact of an enzyme with the fat to bring about any rapid hydrolysis of the latter can occur only when the fat is emulsified so as to expose a very large surface. For this reason the fat-splitting enzyme of the gastric juice can cause an appreciable digestion of fat in the stomach provided the fat is eaten in an emulsified form (*e.g.* milk, cream, or egg-yolk), but not otherwise. In the small intestine, the conditions are extremely favorable for the emulsification as well as for the splitting of the fat, so that here even relatively large masses of fat may be broken up and digested.

Zymogens and Activating Substances.—Within the cell producing it an enzyme often exists in an inactive form known as the zymogen, or antecedent of the active enzyme. The zymogen may be stored in the cell in the form of granules which are converted into active enzyme at the time of secretion, or the secretion may be poured out with the zymogen not yet completely changed to active enzyme, or sometimes in a form which requires the action of some other substance in order to render it active. In this case the latter substance is said to "activate" the enzyme. The pancreas furnishes an example of a zymogen in its external and of an activating substance in its internal secretion.

If the pancreatic juice be collected directly from the duct and in such a way as to avoid all contact with intestinal contents or intestinal mucous membrane, it is without effect on coagulated protein, because the juice as secreted by the pancreas contains no trypsin, but a precursor of trypsin called trypsinogen. This trypsinogen is converted into trypsin by the action of intestinal juice or by contact with the intestinal mucous membrane. The substance derived from the cells of the intestinal wall which thus activates the proteolytic power of the pancreatic juice is known as *enterokinase*, and appears to be an enzyme, since its activity is stopped by too much acid or alkali, or by heating to 67°.

The pancreas, in addition to its external secretion, which it pours out into the intestine through the pancreatic duct as pancreatic juice, also produces an internal secretion which does not collect in any distinct duct, but is carried away by the blood which circulates through the gland. This internal secretion of the pancreas contains a substance (more stable to heat than enterokinase and probably not an enzyme) which activates the glucose-splitting enzyme of the muscles and which appears to be essential to the normal metabolism of carbohydrates in the body.

Reversibility of Enzyme Action. — The activity of an enzyme may be stopped, even when all other conditions are favorable, by the accumulation of the product of its action; and in certain circumstances the action of the enzyme may be reversed so as to accelerate a change in the opposite direction to that in which it ordinarily acts. Thus Croft Hill showed it to be possible to reverse the ordinary action of maltase so as to make it bring about a conversion of mono- into di-saccharide, Pottevin synthesized triolein by means of the pancreas ferment, and Taylor and others have demonstrated a partial reversion of the tryptic digestion of proteins.

Summary of Occurrence and Action of Enzymes of Digestion and Nutrition. — The following tabular summary of the occurrence and action of some of the better-known enzymes of digestion and metabolism is essentially as given by Howell in his *Textbook of Physiology:* —

	Enzyme	*Where chiefly found*	*Action*
Act on Carbohydrates	Ptyalin (salivary amylase)	Salivary secretions	Converts starch to maltose
	Amylopsin (pancreatic amylase)	Pancreatic juice	Converts starch to maltose
	Liver diastase	Liver	Converts glycogen to glucose
	Muscle diastase	Muscles	Converts glycogen to glucose
	Invertase (Sucrase)	Intestinal juice	Converts sucrose to glucose and fructose
	Maltase	Intestinal juice	Converts maltose to glucose
	Lactase	Intestinal juice	Converts lactose to glucose and galactose
	Glycolytic enzymes	Muscles, etc.	Split and oxidize glucose
Act on Fats	Lipases	Gastric and pancreatic secretions, blood, and tissues	Split fats to fatty acids and glycerin

Act on Proteins	Pepsin	Gastric juice.	Splits proteins to proteoses and peptones
	Trypsin	Pancreatic juice	Splits proteins to proteoses, peptones, polypeptids and amino acids
	Erepsin	Intestinal juice	Splits peptones to amino acids and ammonia
	Autolytic enzymes	Tissues generally	Split proteins to simpler compounds
Act on Purins	Guanase	Thymus, adrenals, pancreas	Changes guanin to xanthin
	Adenase	Spleen, pancreas, liver	Changes adenin to hypoxanthin
	Oxidases	Lungs, liver, muscles, etc.	Cause oxidation as of hypoxanthin to xanthin and of xanthin to uric acid

Since in the preceding pages the digestive enzymes have been chiefly cited to illustrate the properties of enzymes in general, these being the best understood and their functions recognized as predominating in the digestive changes, it should also be stated in conclusion that the processes of metabolism are probably equally dependent upon similar enzymes contained in the cells, and that some of the transformations which take place in the body are most readily explained on the ground of the reversibility of enzyme action.

REFERENCES

ATWATER. Principles of Nutrition and Nutritive Value of Foods. Farmer's Bull. 142, U. S. Dept. Agriculture.

ATWATER AND BRYANT. The Chemical Composition of American Food Materials. Bull. 28 (Revised), Office of Experiment Stations, U. S. Dept. Agriculture.

BAYLISS. The Nature of Enzyme Action (1908).

BREDIG. Die Elemente der chemischen Kinetik, mit besonderer Berücksichtigung der Katalyse und der Ferment-wirkung. *Ergebnisse der Physiologie*, 1, 134–212.

COHEN. Organic Chemistry (1907), Chapter IX.

GREEN. Soluble Ferments and Fermentation (1904).

HUTCHISON. Food and Dietetics.

KÖNIG. Chemie der menschlichen Nährungs- und Genussmittel.

LEACH. Food Inspection and Analysis, 2d ed. (1909).

OPPENHEIMER. Ferments and their Actions (1901).

VERNON. Intracellular Enzymes (1908).

WILEY. Foods and their Adulteration (1907).

CHAPTER III

THE COURSE OF THE FOOD THROUGH THE DIGESTIVE TRACT

THE eating of food induces a flow of saliva from great numbers of minute glands in the lining membrane of the mouth and from the three pairs of large salivary glands. That these latter glands receive their stimulus through the nervous system is shown by the fact that actual contact of any part of the body with the food is not necessary, since secretion may be started by the sight or odor or even the thought of food, and further that mechanical or electrical stimulation of the proper nerves will cause a rapid flow of saliva when there is no suggestion of food, and even in the case of an animal completely under the influence of ether or chloroform. Mixed human saliva has usually a faintly alkaline reaction and always contains ptyalin (salivary amylase), although its amylolytic power appears to vary considerably with individuals and with the same individual at different times of the day. As the chewing of food mixes it with saliva, the digestion of starch and dextrin under the influence of the ptyalin begins at once. The mode of attachment of the jaw permits a variety of movements in chewing, but as mastication is an entirely voluntary act, the thoroughness with which the food becomes mixed with saliva is subject to wide variations.

Usually the food stays too short a time in the mouth for the starch to be acted upon there to any great extent, and until recently it was supposed that salivary digestion must cease almost as soon as the food reaches the stomach, since the activity of ptyalin is quickly checked by even small amounts of free hydrochloric acid. It was supposed that the food mass must soon be mixed with the gastric juice under the influence of the "churning" of the stomach contents by the muscular contraction of the stomach walls, which was so interestingly described by Dr. Beaumont about eighty years ago as the result of his observations upon Alexis St. Martin, the French-Canadian trapper who had received a gunshot wound in the stomach which on healing was found to be closed only by a valve which had developed over it. Dr. Beaumont succeeded in retaining St. Martin in his employ for a number of years, and thus enjoyed the unique opportunity of frequently observing the course of gastric digestion by looking directly into an otherwise normal human stomach. From the nature of the case Dr. Beaumont's observations were made entirely at one point in the stomach. Here he found during digestion a vigorous muscular churning and mixing of the food mass with the gastric juice, and for a long time this was supposed to represent the state of the entire stomach contents. This view has now been abandoned as the result of a number of recent investigations, among which those of Cannon and of Grützner are of especial interest.

When a small amount of an inert metallic compound such as bismuth subnitrate is mixed with the food, it becomes possible to photograph the food-mass within the body by means of the Roentgen rays. By the use of this method Cannon has carried out an extended series of observations upon the movements of the stomach and intestines during digestion,[1] upon the results of which the statements concerning the mechanism of digestion in this chapter are chiefly based.

Cannon's observations, confirmed by those of other investigators, show that the vigorous muscular movements described by Beaumont, and which generally begin 20 to 30 minutes after the beginning of a meal, occur only in the middle and posterior, or pyloric, portion of the stomach; while the anterior portion, or fundus, which serves as a reservoir for the greater portion of the food, is not actively concerned in these

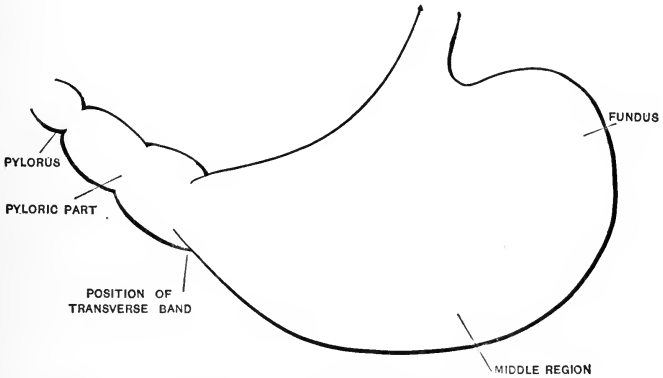


Fig. 1. — Diagram to show the different parts of the stomach.

---

[1] *American Journal of Physiology*, **1**, 359; **6**, 251; **12**, 387. These papers are fully abstracted in Fischer's *Physiology of Alimentation*.

movements and does not rapidly mix its contents with the gastric juice.

That there is no general circulation and mixing of the entire stomach contents during or immediately following a meal is further shown by the experiments of Grützner, who fed rats with foods of different colors and on killing the animals and examining the stomach contents found that the portions which had been eaten successively were arranged in definite strata. The food which had been first eaten lay next to the walls of the stomach and filled the pyloric region, while the succeeding portions were arranged regularly in the interior in a concentric fashion. In describing this result Howell says: "Such an arrangement of the food is more readily understood when one recalls that the stomach has never any empty space within; its cavity is only as large as its contents, so that the first portion of food eaten entirely fills it, and successive portions find the wall layer occupied and are therefore received into the interior. The ingestion of much liquid must interfere somewhat with this stratification."

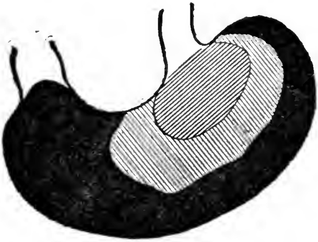


FIG. 2. — Section of frozen stomach of rat during digestion to show the stratification of food given at different times. (*Grützner.*) The food was given in three portions and colored differently. Reproduced from Howell's *Textbook of Physiology*, published by the W. B. Saunders Co.

In considering the mechanism of gastric digestion it is convenient to regard the stomach as having three regions of somewhat different characteristics: (1) the cardiac end, or fundus, which the food enters when swallowed; (2) a middle region usually considered as belonging also to the fundus; and (3) the pyloric part, terminating at the pylorus through which the food passes from the stomach to the small intestine. Certain cells of the stomach wall in all three regions have the power of secreting gastric juice, but the character of the secretion, especially as regards its acidity, varies considerably in the different parts. In the middle region the secretion is rich in acid, while both in the cardiac region and at the extreme pyloric end, the "border cells" or "cover cells" (from which the secretion of the acid appears to take place) are few in number or entirely lacking, and the juice secreted in these regions may be neutral or, according to Howell, even slightly alkaline.

The nature and extent of the muscular movements also vary greatly in the different regions of the stomach. The peristaltic waves of muscular constriction which bring about the thorough mixing of the food with the gastric juice begin in the middle region and travel toward the pylorus. Over the pyloric part of the stomach (that portion which is posterior to the "transverse band"), when food is present, constriction waves are continually coursing toward the pylorus. The food in this portion is first pushed forward by the running wave and then by pressure of the stomach wall is returned through the ring of constriction. Thus the food *in this* *portion* of the stomach is thoroughly mixed with the gastric juice and is forced by an oscillating progress toward the pylorus.

The food in the cardiac end of the stomach is not moved by peristalsis, and so comes only slowly into contact with the gastric juice; and since the juice secreted here contains little if any free acid, a large part of the food mass remains for some time (variously estimated at from 30 minutes to 2 hours or more) in approximately the same faintly alkaline condition in which it was swallowed, and salivary digestion continues in this part of the stomach without interruption. Thus, if the food has been thoroughly subdivided and mixed with saliva before swallowing, much if not most of its starch may be converted into dextrin and maltose in the cardiac region of the stomach before the activity of the ptyalin is stopped by contact with the acid of the gastric juice.

The fundus, however, is not entirely inactive, but acts as a sort of reservoir which is distended by and slowly contracts upon the food mass, thus gradually tending to move the posterior portions and particularly the more fluid portion into the pyloric region. As digestion proceeds, the pylorus opens more frequently and the stomach tends to empty itself more and more freely, until at the very end of gastric digestion the pylorus may open to allow the passage of particles which have not been acted upon by the gastric juice. Whether the stomach will thus completely empty itself of one meal before the eating of the next will depend of course upon the length of the interval and the amount and character of the food composing the meal.

The time required for complete passage of the food from the stomach probably varies greatly with circumstances. Small test meals may disappear in from 1 to 4 hours, but in cases in which a dog or a pig has been fed 500 grams of lean meat at a time, at least 12 hours have elapsed before the entire disappearance of the food from the stomach. In experiments upon men, test meals less abundant than an ordinary hearty dinner have disappeared entirely from the stomach only after 7 hours.

In studying the passage of food from the stomach into the intestine Cannon found that the pylorus does not open at the approach of each wave of constriction which passes over this part of the stomach, but only at irregular intervals. When the observations made by means of the Roentgen rays were supplemented by chemical examinations of stomach and intestinal contents removed at different stages, it appeared that the presence of free acid in the pyloric part of the stomach causes the pylorus to open, and its presence in the small intestine causes the pylorus to close. Thus it would appear that under normal conditions it is only when the protein of the food has become more or less completely saturated with hydrochloric acid and some of the latter remains in the free state, that the food is allowed to pass into the intestine. Ordinarily, when each is fed separately, protein food stays longer in the stomach than carbohydrate, and this is doubtless due to the combination of the acid of the gastric juice with the protein of the food delaying the appearance of free acid at the pylorus; for when protein food was acidulated before feeding and carbohydrate food was made alkaline, the protein was found to leave the stomach more rapidly than the carbohydrate. That the passage of food from stomach to intestine is governed mainly by the degree of acidity reached in the pyloric part of the stomach is a strong indication of the importance to the organism of the action of the acidity of the gastric juice in effecting a partial disinfection of the food aside from its digestive action. It will be seen also that the acidity of the chyme as it passes the pylorus has an important influence upon the secretion of the pancreatic juice.

The gastric juice as obtained through a stomach fistula is of course the mixed secretion of the glands in the different regions of the stomach wall. It is a thin, colorless or nearly colorless liquid whose most important characteristics are the presence of free hydrochloric acid and of pepsin. While other acids may be found in stomach contents, the acidity of gastric juice appears to be due entirely to hydrochloric acid. Normal human gastric juice contains about 0.2 to 0.3 per cent of free hydrochloric acid. The stimuli which bring about secretion of gastric juice are both psychical and chemical. Psychical stimulation results from the sensations of eating and may also be due to the sight and odor of food. The psychical secretion is studied chiefly by means of the fictitious

— or sham — feeding experiments in which food is given to dogs which have been prepared with esophageal openings through which the swallowed food escapes without entering the stomach. When such a dog is fed with meat, for example, there is a considerable secretion of gastric juice in spite of the fact that no food reaches the stomach. Such a flow of gastric juice is due to impulses received through the nervous system and specifically through the vagus nerve, for fictitious feeding has been found to cause a flow of gastric juice when the vagi are intact, but not after they have been cut. Secretion produced in this way reflexly as the result of the sensation of taste, odor, etc., is called by Pawlow a "psychic secretion" or "appetite juice." When the secretion is once started, even if no food enters the stomach, the flow of juice may continue for some time after the stimulus has ceased.

Similar observations have been made upon a boy who had a stricture of the esophagus and a fistula in the stomach. Food when chewed and swallowed did not reach the stomach, but was regurgitated; yet it caused an active secretion of gastric juice (Howell).

In an ordinary meal the psychic secretion insures the beginning of gastric digestion. Stimulations arising within the stomach itself supplement the psychic influences and provide for the continued secretion of the gastric juice long after the mental effects of a meal have disappeared. This second stimulation is chemical and depends upon the production in the pyloric mucous membrane of a specific substance, or *hormone*, which acts as a chemical messenger to all parts of the stomach, being absorbed into the blood and thence exciting the activity of the various secreting cells of the gastric glands (Starling). Meat extracts, soups, etc., are particularly active in exciting the secretion which depends upon chemical stimulation; milk causes less secretion; white of egg is said to have no effect.

Under normal conditions, the amount of nutritive material absorbed from the stomach is insignificant as compared with the amount absorbed from the intestine. Nearly all the food eaten is passed from the stomach into the intestine in the form of chyme, having been more or less perfectly liquefied and acidulated by its thorough mixing with the gastric juice in the middle and pyloric regions of the stomach.

Digestion in the Small Intestine. — It has been seen that the pylorus does not open at the approach of each wave of constriction of the stomach wall, but only at intervals. When it opens, food, now reduced to liquid chyme, is projected into the upper part of the small intestine. Careful watching of this food shows that usually it lies for some time in the curve of the duodenum, until several additions have been made to it from the stomach and a long thin string of food material is formed. While the food rests here the bile and pancreatic juice are poured out upon it, and here also, as well as in other parts of the small intestine, a certain amount of intestinal digestive juice ("succus entericus") is secreted by the glands of the lining membrane and mixed with the intestinal contents. While for purposes of description the pancreatic and intestinal juices and the bile may be discussed separately, it is to be remembered that in normal digestion they always act together. Cannon's observations showed that after a certain amount of food and digestive juices has accumulated as just described in the first loop of the small intestine, the mass all at once becomes segmented by constrictions of the intestinal walls, and the segmentation is repeated rhythmically for several minutes, thoroughly mixing the digestive juices with the food.

In this part of the intestine the alternate positions of the segments are sometimes far apart, so that the individual portions are subjected to relatively extensive and energetic to-and-fro movement, which is doubtless very important, not only in securing thorough mixing of the food with the secretions, but especially in facilitating the emulsification of fat.

Finally the segments unite into a single mass or form in groups and begin to move forward. The peristalsis here is much more rapid than that which normally occurs further along in the intestine. The masses go forward swiftly and continuously for some distance, and then begin to collect in thicker and longer strings which are seen characteristically in the other coils of the small intestine.

The activity most commonly seen by Cannon in these coils is the simultaneous division of the food mass in any given coil, into small segments, and a rythmic repetition of the segmentation — in cats, at the rate of 30 segmentations per minute. The effects of the muscular constrictions which cause the segmentation are (1) a further mixing of food and digestive juices, (2) the bringing of the digested food into contact with the absorbing membrane, (3) the emptying of the venous and lymphatic radicles in the membrane, the material which they have absorbed being forced into the veins and lymph vessels by the compression of the intestinal wall. After a varying length of time the segmentation ceases and the small segments are carried forward individually by the peristaltic movement, or join and move on as a single body.

The fluid food mass which the stomach pours into the duodenum contains a small amount of free hydrochloric acid besides a larger amount combined with protein and sometimes organic acids from the food as eaten, or from bacterial fermentation of carbohydrates in the stomach. The pylorus having closed, the alkalinity of the bile, the pancreatic juice, and the intestinal juice combine to neutralize the acids present.

In man the main duct of the pancreas (duct of Wirsung) and the common bile duct unite and empty into the small intestine about 8 to 10 cm. (3 to 4 inches) below the pylorus. The pancreatic juice is a clear liquid having an alkalinity probably equivalent to a 0.5 per cent solution of sodium carbonate and containing three important enzymes or their zymogens — trypsin, amylopsin, and steapsin or lipase.

The rate of flow of the pancreatic juice varies with the period of digestion and is to some extent dependent upon the nature of the food. After a meal of bread alone the maximum secretion occurs earlier than after a meal of meat, probably because carbohydrate food is passed from the stomach into the intestine more rapidly than is protein food. It is stated that the composition of the pancreatic juice varies with, and tends to adapt itself to, the character of the food eaten; but the suggestion has not been thoroughly worked out. Acids brought in contact with the mucous membrane of the duodenum result in a stimulation of the secretion of the pancreatic juice. This action begins at once when any of the acid stomach contents passes through the pylorus, and has been shown by Bayliss and Starling to be due to a definite chemical substance, *secretin*, a typical hormone produced as the result of the action of the acid upon some constituent of the intestinal mucous membrane, which is absorbed and carried by the blood to the pancreas and there stimulates the flow of pancreatic juice. A concise and interesting account of the discovery and significance of secretin is given by Starling in his *Recent Advances in the Physiology of Digestion,* pp. 85–93. Starling considers that the chemical mechanism, namely, the formation of hormones and their circulation through the blood to the reactive tissue, suffices to account for the whole of the activity of the pancreas, and that it is doubtful whether the nervous system plays any part in this activity.

Human bile, which, as already stated, enters the intestine through the same duct with the pancreatic juice, is a slightly alkaline solution containing, in addition to water and salts, bile pigments, bile acids (as salts), cholesterin, lecithin, and a peculiar protein derived from the mucous membrane of the bile ducts and gall bladder. The presence of the bile in the intestinal contents greatly increases the solubility of the fatty acids, while at the same time it diminishes the surface tension between watery and oily fluids. Thus bile aids the digestion of proteins and carbohydrates and both the digestion and the absorption of fats. The bile acids are themselves absorbed to a considerable extent and again secreted by the liver. The secretion of bile by the liver, although variable in amount, is continuous. Its ejection from the gall bladder into the intestine occurs, however, only during digestion, and appears to be excited by the passage of chyme through the pylorus, and to run parallel to the outpouring of the pancreatic juice. According to Starling, the rapid flow of bile during intestinal digestion is due not only to the pouring out of what was previously stored in the gall bladder, but also to an increased rate of secretion to which the liver is stimulated by the same chemical mechanism which stimulates the flow of pancreatic juice.

The intestinal juice is a distinctly alkaline liquid secreted by the tubular glands (crypts of Lieberkühn) with which the small intestine is lined. It contains at least five enzymes: enterokinase, by the action of which trypsinogen is converted into trypsin; erepsin, which produces further cleavage of the proteoses and peptones; and the three enzymes, invertase (or invertin), maltase, and lactase, which hydrolyze respectively the three disaccharides, sucrose, maltose, and lactose. The secretion of intestinal juice is probably stimulated by secretin, and possibly also by another hormone whose production is dependent upon the presence of pancreatic juice.

The very discordant statements which have been made regarding the reaction of the contents of the small intestine are no doubt largely due to the failure of observers to take account of the differing behavior of the various indicators. Careful observations were made by Moore and Bergin in 1897. Samples taken through a fistula immediately above the ileocæcal valve were always alkaline to methyl-orange, lacmoid, and litmus, but acid to phenolphthalein. Hence neither hydrochloric acid, nor any appreciable amount of the stronger organic acids such as acetic, butyric, or lactic, could have been present in the free state. The acid reaction shown by phenolphthalein was probably due either to traces of organic acids, or possibly to dissolved carbonic acid, or to acid-protein compounds not yet completely digested and absorbed. It seems probable that this fairly represents the condition as to reaction which exists throughout the greater part of the small intestine. Under such conditions all three classes of foodstuffs would be readily attacked by the digestive enzymes present, and brought into condition for absorption.

Absorption takes place very readily in the small intestine — more readily and completely than can be explained by the purely mechanical laws of diffusion. Thus if blood serum were introduced into an isolated loop of small intestine, it should, according to mechanical analogy, have no tendency to pass through the intestinal wall, since the fluid on the two sides of this wall would then be of the same nature; yet in such experiments almost complete absorption is found to take place. It has also been found that the rapidity of absorption of salts from the intestine stands in no direct relation to their diffusion velocity (Wallace and Cushing). When the intestinal wall is injured by the action of sodium fluoride or potassium arsenate, its absorption power is diminished, and absorption then follows the laws of diffusion and osmosis (Howell). On account of these facts the normal process is sometimes called "resorption" to distinguish it from the passive process of absorption which takes place with a dead or poisoned membrane.

Observations have been made upon a patient having a fistula at the end of the small intestine. In this case it was found that 85 per cent of the protein matter of the food was absorbed before this point was reached, and the absorption of the other foodstuffs is probably equally complete. For this patient the food began to pass the ileocæcal valve in from 2 to 5¼ hours after eating, but the time required from the eating of the food until the last portions had passed into the large intestine was 9 to 23 hours.

The rate of passage of different foodstuffs from the stomach and through the small intestine has been studied by Cannon with the aid of the Roentgen rays, according to the general method already described. Fat, carbohydrate, and protein foods, uniform in consistency and in amount (25 cc.), were fed to cats which had been fasted for 24 hours. At regular intervals for 7 hours after feeding, the shadows of the stomach and intestinal contents were observed by means of the Roentgen rays. It was found that, when fats were fed alone, the discharge of fat from the stomach began slowly and continued at nearly the same rate at which it left the small intestine by absorption and by passage into the large intestine, so that there was never any great accumulation of fat in the small intestine where its emulsification and digestion chiefly take place. Carbohydrate foods (fed alone) began to leave the stomach much earlier and passed out more rapidly. Proteins frequently did not begin to leave the stomach during the first half hour, and in general a meal of proteins remained in the stomach about twice as long as a meal of carbohydrates. When carbohydrates were fed first and proteins immediately after, the presence of the proteins in the cardiac end of the stomach did not materially check the departure of the carbohydrate food lying at the pylorus; but when proteins were fed first, their presence in the pyloric region delayed considerably the onward passage of any carbohydrate which may have been swallowed later. When protein and carbohydrates were mixed in equal parts before feeding, the mixture passed through the stomach more rapidly than protein alone and less rapidly than carbohydrate. Either protein or carbohydrate when mixed with fat passed out of the stomach more slowly than when fed alone. The process of rhythmic segmentation above described was seen with all three kinds of foodstuffs, and the frequency of its occurrence corresponded roughly to the amount of food present in the intestine. The interval between the feeding and the first appearance of food in the large intestine was variable, but in these experiments with cats the mean for carbohydrates was about 4 hours, for proteins about 6 hours, and for fats about 5 hours.

Digestion in the Large Intestine. — We have seen that in the small intestine the conditions are very favorable both for digestion and for absorption, and that very much the greater part of the available nutrients has been absorbed before the food mass reaches the ileocæcal valve. It may, however, still contain incompletely digested food and active digestive enzymes, and so digestion may continue in the large intestine. Studying the behavior of the food mass here by the same methods as in the stomach and small intestine, Cannon finds that the ileocæcal valve is physiologically "competent" for food which passes through it normally from the small intestine, *i.e.* the food which has reached the large intestine in the natural way is ordinarily never forced back into the small intestine again. This is important because in the anterior portion of the large intestine the waves which appear most frequently are those of antiperistalsis — *i.e.*

tend to force the food back toward the small intestine. Since the ileocæcal valve prevents the food passing back, these antiperistaltic waves result in thoroughly churning the food in this part of the large intestine and constantly bringing fresh portions in contact with the intestinal wall so that the conditions here are still favorable for absorption. Moreover, the walls of the large intestine furnish an alkaline secretion which further aids the completion of the digestive changes already begun. So far as known, the large intestine secretes no digestive enzyme of its own.

The material which has passed through the ileocæcal valve remains in the large intestine for a comparatively long time (generally 1 to 2 days — often longer); for the peristaltic movements which carry the material onward, while stronger than the waves of antiperistalsis, are of less frequent occurrence, at least in the first part of the large intestine. During this time there is a marked absorption of water, along with the remaining products of digestion, and the products of bacterial activity. The residual material gradually becomes more solid and takes on the character of feces.

The fecal matter passed per day varies considerably in health, but, on an ordinary mixed diet of digestible food materials, is usually between 100 and 200 grams of fresh substance containing 25 to 50 grams of solids. The feces contain any indigestible substances swallowed with the food and any undigested residues of true food material, but ordinarily they appear to be largely composed of residues of the digestive juices, together with certain substances which have been formed in metabolism and excreted by way of the intestine, and the bodies of bacteria, most of which are apt to be dead before the feces are passed.

Prausnitz studied the feces of 6 persons placed alternately on meat and on rice diets and found that, although the solids of the meat were about ten times as rich in nitrogen as the solids of the rice, the two diets yielded feces whose solids were of practically the same composition. Prausnitz considers that "normal" feces have essentially the same composition irrespective of the food, the quantity of food residues in such "normal" feces being negligible. From this point of view the feces show not so much the extent to which the food has been absorbed as whether it is a large or a small feces-former. On the other hand, so far as the nitrogen compounds of the feces are concerned, it is probably true, as generally assumed, that they represent material either lost or expended in the work of digestion, and therefore that the nitrogen of the feces is to be deducted from that of the food in estimating the amount available for actual tissue metabolism. This, however, is by no means equally true of the ash constituents, many of which after being metabolized in the body are eliminated mainly by way of the intestine rather than through the kidneys.

The feces produced in fasting have been found to contain about 2 to 4 grams of solids including 0.1 to 0.3 gram of nitrogen per day. On a diet consisting entirely of non-nitrogenous food the amount of nitrogen in the daily feces was 0.5 to 0.9 gram per day, or much more than in fasting, and also more than is sometimes found in feces from food furnishing enough protein to meet all the needs of the body. Thus the expenditure of nitrogenous material in the digestion of fats and carbohydrates may be larger than in the digestion of protein food.

The feces always contain fat (or at least substances soluble in ether) as well as protein. Fasting men have eliminated 0.57 to 1.3 grams of fat per day; and when the diet is very poor in fat, the feces may contain as much as was contained in the food. As the fat content of the food rises the actual amounts in the feces increase, but the relative amounts decrease, so that up to a certain point the apparent percentage utilization of the fat becomes higher. The limit to the amount of fat which can be thus well digested varies with the individual and with the form in which the fat is given. Quantities up to 200 grams per day have been absorbed to within 2 to 3 per cent when given in the form of milk, cheese, or butter.

In addition to protein and fat the feces always contain various other forms of organic matter which in the routine proximate analyses usually made in connection with feeding experiments are collectively reported as "carbohydrates determined by difference."

With these facts in mind one may make use of the so-called "coefficients of digestibility" without being misled by them.

These coefficients show the relation between the constituents of the food consumed and the corresponding constituents of the feces. Thus if the feces from a given diet contain 5 per cent as much protein as was contained in the food, this proportion is assumed to have been lost or expended in digestion, and the coefficient of digestibility of the protein of the diet is stated to be 95 per cent. While as just shown this assumption is not entirely correct, yet it is approximately true of the organic nutrients that the difference between the amounts in the food and in the feces represent what is available to the tissues of the body, and thus these coefficients serve a useful purpose in the computation of the nutritive values of foods.

From the results of hundreds of digestion experiments Atwater computed the coefficients of digestibility of the organic nutrients of the main groups of food materials, when used by man as part of a mixed diet, to be as follows: —

COEFFICIENTS OF DIGESTIBILITY OF FOODS WHEN USED IN MIXED DIET (ATWATER)

	PROTEIN PER CENT	FAT PER CENT	CARBOHYDRATES PER CENT
Animal foods	97	95	98
Cereals and breadstuffs	85	90	98
Dried legumes	78	90	97
Vegetables	83	90	95
Fruits	85	90	90
Total food of average mixed diet	92	95	98

In some cases these figures are higher than have been reported for similar foods by other observers, the differences being due mainly to the fact (not formerly recognized) that a food may be more perfectly utilized when fed as part of a simple mixed diet than when fed alone. Milk is an example of such a food, and has when consumed as part of a mixed diet a much higher coefficient of digestibility than is often assigned to it on the basis of earlier experiments.

It will be seen that the coefficients differ less for the different types of food than might be expected from popular impressions of "digestibility" and "indigestibility." It is also noteworthy that the coefficients of digestibility are less influenced by the conditions under which the food is eaten and vary less with individuals than is generally supposed.

In explanation of this it may be noted that general impressions of digestibility relate mainly to *ease* of digestion and particularly to ease and rapidity of gastric digestion, and that there is little direct relation between the ease with which a food is digested in the stomach and the extent to which it is ultimately digested in its passage through the entire digestive tract. Substances which are resistant to gastric digestion will tend to remain long in the stomach and will probably excite a greater flow of gastric juice. Thus a greater amount of acid chyme will enter the duodenum, and this will result in the secretion of a greater amount of pancreatic juice also.

Similarly an increase in the amount of food eaten will increase the work of digestion, but may have little effect upon the coefficient—the percentage of the ingested foodstuff which is ultimately absorbed. In a series of four experiments by the writer the diet consisted of crackers and milk in uniform relative proportions throughout, but with marked variation in the amounts eaten,—the daily diet for the first and third experiments being 150 grams of crackers and 1500 grams of milk, and for the second and fourth experiments, 300 grams of crackers and 3000 grams of milk. In this case it was found that the doubling of a small diet decreased the coefficient of digestibility by less than 1 per cent. Snyder reports that as between medium and large amounts of oatmeal and milk, the protein was 7 per cent and the fat 6 per cent more completely absorbed in the case of the medium ration.

Bacterial Action in the Digestive Tract. — In the preceding we have considered the course of the food through the digestive tract without reference to the presence and activities of bacteria. These may, however, materially modify the digestive process in certain cases. The digestive tract of an infant contains no bacteria at birth, but usually some gain access during the first day of life. In the average adult it is estimated that each day's food in its passage through the digestive tract is subjected to the action of over one hundred billion bacteria.

Since bacteria are regularly present in the digestive tract in such large numbers, it has been questioned whether they may not perform some essential function in connection with the normal processes of digestion. Experiments to demonstrate whether animals are independent of such bacteria are beset with many difficulties, and have sometimes led to the belief that bacteria were essential; but Nuttall and Thierfelder kept sterile for several days the digestive tracts of young guinea pigs delivered by Cæsarian section and fed upon thoroughly sterilized food, and as the animals thus treated lived and gained in weight, the experimenters concluded that intestinal bacteria are not essential to normal nutrition. This view has recently received strong support from the observations of Levin, who examined the intestinal contents of Arctic animals in Spitzenberg. The digestive tracts of white bears, seals, reindeer, eider ducks, and penguin were found to be in most cases free from bacteria, showing that the latter are not essential to the normal processes of digestion and nutrition.

If it were possible to exclude absolutely all bacteria from the digestive tract, it is probable that the well-being of the body would be in no wise impaired; yet under such conditions as ordinarily exist, the bacteria which usually predominate in the digestive tract of the healthy man probably render an important service in helping to protect the body against occasional invasions of obnoxious species.

A few species, such as *B. lactis aërogenes*, *B. coli*, *B. bifidus*, have adapted themselves so well to the conditions existing in the human digestive tract that they are ordinarily not harmful to the host unless present in abnormally large numbers, and being able to hold their own against newcomers they are occasionally able to do a distinct service by giving rise to conditions which check the development of other types of organisms, capable of doing injury, which under ordinary conditions man can hardly prevent from occasionally gaining ingress through food or drink.

According to Herter: "The presence in the colon of immense numbers of obligate micro-organisms of the *B. coli* type may be an important defense of the organism in the sense that they hinder the development of that putrefactive decomposition which, if prolonged, is so injurious to the organism as a whole. We have in this adaptation the most rational explanation of the meaning of the myriads of colon bacilli that inhabit the large intestine. This view is not inconsistent with the conception that under some conditions the colon bacilli multiply to such an extent as to prove harmful through the part they take in promoting fermentation and putrefaction."

If for our present purpose we consider only the bacteria which are prominent in producing decomposition of foodstuffs in the digestive tract, and these only with reference to this one property, we may regard as the three main types: (1) the bacteria of fermentation, such for example as the lactic acid bacteria; (2) the putrefactive bacteria, such as the anaërobic *B. aërogenes capulatus;* (3) bacteria of the *B. coli* type, showing some of the characters of both the fermentative and putrefactive types, but tending in general to antagonize the putrefactive anaërobes.

Among cases of excessive bacterial decomposition in the digestive tract the fermentation of carbohydrates with production of organic acids (and possibly also alcohol) is most likely to occur in the stomach, while the putrefaction of proteins occurs mainly in the large intestine. While it is true that the products of fermentation tend to restrict putrefaction, yet, since the two processes take place for the most part at such widely separated points of the digestive tract, there may be excessive fermentation and excessive putrefaction in the same individual at the same time. Among the conditions which favor excessive fermentation are: diminished tone and motility of the stomach, dilation, diminution or absence of free hydrochloric acid in the gastric juice, and excessive use of carbohydrate food — especially sucrose and glucose, which are more susceptible to fermentation in the stomach than are lactose and starch.

In the normal human stomach the conditions are quite unfavorable for the development of anaërobic putrefactive bacteria, not only because of the presence of air, but also owing to the action of the gastric juice; and favorable conditions are not found in the anterior portion of the small intestine. In the lower third of the small intestine the numbers of bacteria increase and among them sometimes putrefactive forms. In the large intestine the conditions are much more favorable for the anaërobic putrefactive bacteria, and these may produce marked decomposition in any protein still remaining unabsorbed. In general the greater the amount of digestible but undigested or unabsorbed protein and the longer the material stays in the large intestine, the greater the amount of putrefactive decomposition. Not infrequently excessive fermentation in the stomach causes local sensitiveness which results in the taking of less bulky food (or such as has less indigestible residue), which in turn tends to stagnate in the intestine and thus render the conditions more favorable for intestinal putrefaction. According to Herter there sometimes results from the eating of large quantities of meat and sugar a type of fermentation in which oxalic acid is produced and which must therefore be highly injurious; but ordinarily the products of fermentation are only irritating, while putrefaction gives rise to products which are more distinctly toxic. These include indol, skatol, phenol, and cresol, which are for the most part absorbed into the system and finally execreted in combination with sulphuric acid as "ethereal" or "conjugated" sulphates. Of these the best known is potassium indoxyl sulphate, commonly known as "indican." The amounts of conjugated sulphates and of indican in the urine are valuable indications of the intensity of the putrefactive process in the intestine.

REFERENCES

Cannon. The Movements of the Stomach studied by Means of the Roentgen Rays. *American Journal of Physiology*, **1**, 259.

—— The Movements of the Intestines studied by Means of the Roentgen Rays. *American Journal of Physiology*, **6**, 251.

—— Salivary Digestion in the Stomach. *American Journal of Physiology*, **9**, 396.

CANNON. The Passage of Different Foodstuffs from the Stomach and through the Small Intestine. *American Journal of Physiology*, **12**, 387.

—— The Acid Control of the Pylorus. *American Journal of Physiology*, **20**, 283.

FISCHER. Physiology of Alimentation (1907).

GERHARDT. Ueber Darmfäulnis. *Ergebnisse der Physiologie*, **3**, I, 107–154 (1904).

HERTER. Chemical Pathology (1902).

—— Bacterial Infections of the Digestive Tract (1907).

HOWELL. Textbook of Physiology, 2d ed. (1907).

OPPENHEIMER. Handbuch der Biochemie, Vol. 3, Part 2 (1909).

PAWLOW. The Work of the Digestive Glands (1910).

SCHAEFER. Textbook of Physiology (1898).

SCHMIDT AND STRASSBURGER. Die Faezes des Menschen im normalen und krankhaften Zustande, 2d edition (1905).

STARLING. Recent Advances in the Physiology of Digestion (1907).

CHAPTER IV

THE FATE OF THE FOODSTUFFS IN METABOLISM

CARBOHYDRATES

As soon as the saliva becomes mixed with the food its amylase (ptyalin) begins to act upon the starch and dextrin, and this action continues, as has been explained, for some time after the food reaches the stomach, and normally it doubtless results in the digestion by the saliva of a large proportion of the starch eaten. Ptyalin has no action on the disaccharides or monosaccharides, nor does the gastric juice so far as is known contain any enzyme which can attack these sugars. Sucrose may be partially hydrolyzed in the stomach, but this effect appears to be produced by the free hydrochloric acid of the gastric juice and not by an enzyme. These statements, of course, refer only to the digestive ferments, and not to the bacteria which may be present in the stomach and may attack the sugars.

On reaching the small intestine the starch and dextrin are attacked by the pancreatic amylase (amylopsin) and hydrolyzed to maltose. At the same time that it is undergoing pancreatic digestion the food mass is exposed to the action of the intestinal juice, which contains specific ferments having the property of hydrolyzing the disaccharides into monosaccharides. Maltose, as already explained, yields 2 molecules of glucose; cane sugar, 1 molecule each of glucose and fructose (levulose); and milk sugar, a molecule each of glucose and galactose. It is possible that the splitting of the lactose (milk sugar) may occur in the intestinal wall rather than in the food mass.

The bulk of the carbohydrate of the food, having been converted into monosaccharides in the intestine, is taken up by the capillary blood vessels of the intestinal wall and passes from them into the portal vein. After a meal rich in carbohydrate the blood of the portal vein is rich in glucose (sometimes reaching twice its normal glucose content) and may show levulose and galactose as well as glucose. In the blood of the general circulation, however, only glucose is found, and this remains small in quantity — about one tenth of one per cent — even after a meal rich in carbohydrates, so that a considerable part of the carbohydrate taken must be stored temporarily in the liver and given up gradually to the blood in the form of glucose, thus keeping nearly constant the glucose content of the blood of the general circulation. The carbohydrate thus stored in the liver cells is deposited in the form of glycogen, which, after an abundant meal, may reach 10 per cent of the weight of the liver (or, in rare cases, an even higher figure) and may fall to nearly nothing when no carbohydrate food has been taken for some time. To a less extent the muscles store glycogen in a similar way, their glycogen contents varying from traces to about 2 per cent.

However, the fact that the carbohydrate stored in the liver after a meal is usually converted into glucose and passes into the blood current before the next meal, while the glucose content of the blood remains small and nearly constant, indicates that the glucose of the blood must be quite rapidly used, and from our present standpoint the most important question of the carbohydrate metabolism is the fate of the glucose carried to the tissues by the blood.

Of the glucose which the blood carries away from the liver, the greater part disappears in the muscles. It has often been shown by comparison of the arterial with the venous blood that in its passage through the muscles the blood becomes poorer in glucose and oxygen and richer in carbon dioxide, and that this change is greater when the muscle is active than when it is at rest. It is not likely that the glucose is burned in the muscle directly to carbon dioxide and water; a certain amount of lactic acid is always produced by working muscle, and this has long been regarded as an intermediate product of the breaking down of the glucose. A few years ago it was rather commonly held that the glucose brought to the tissues by the blood became an actual part of the living cell substance before being oxidized. It is now more generally believed to be broken down by enzymes acting within the cells (intracellular enzymes) and that these enzymes are influenced in their action by an internal secretion of the pancreas, since removal of the pancreas results in the escape of glucose through the kidneys as in diabetes. Cohnheim states that, while the juices obtained by pressure from muscles and from pancreas have little effect upon glucose when tested separately, yet when they are combined and glucose added they cause a marked disappearance of the glucose. The inference from this result is that the pancreas furnishes a substance which "activates" the glycolytic enzyme or enzymes of the muscles and thus makes possible the normal consumption of glucose in the body. Since pancreas extracts do not lose this property upon boiling, it is evident that the activating substance is not an enzyme, but some more stable compound.

At least two kinds of enzymes are believed to be involved in the consumption of glucose in the tissue cells: (1) cleavage enzymes, which split the molecule into fragments more easily oxidized; and (2) oxidizing enzymes, or oxidases, which stimulate the oxidation of the cleavage products. Both kinds of enzymes are widely distributed through the body and are believed to be normal constituents of all the active cells. Whatever the exact mechanism of the process, a large part of the glucose brought by the blood is oxidized in the muscles to furnish energy, which appears as external or internal work.

In general, the rate at which combustion takes place in the tissues depends upon the activity of the tissue cells, rather than upon the supply either of combustible matter or of oxygen. When a sufficient supply of oxygen is provided, any further increase has little effect upon the rate of combustion, and, as we have seen, any excess of carbohydrate instead of being burned is stored as glycogen. But while the absorption of an abundance of carbohydrate does not greatly change the amount of combustion taking place in the body, it may result in the use of carbohydrate as fuel almost to the exclusion of fat for the time being, as is shown by observations upon the respiratory quotient.

The respiratory quotient is the quotient obtained by dividing the volume of carbon dioxide given off in respiration by the volume of oxygen consumed. That is —

$$\frac{\text{Volume of } CO_2 \text{ produced}}{\text{Volume of } O_2 \text{ consumed}} = \text{“Respiratory quotient.”}$$

The numerical value of this quotient will evidently depend upon the elementary composition of the materials burned. Carbohydrates will yield a quotient of 1.0, since they contain hydrogen and oxygen in proportions to form water, so that all oxygen used to burn carbohydrate goes to the making of carbon dioxide, and each molecule of O_2 so consumed will yield one molecule of CO_2, occupying (under the same conditions of temperature and pressure) the same amount of space as the oxygen consumed to produce it. Thus in burning a molecule of glucose, six molecules of oxygen are consumed and six molecules of carbon dioxide produced: —

$$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O.$$

Here the volumes of oxygen and of carbon dioxide are equal and the respiratory quotient is 1.0.

Fats contain much more hydrogen than can be oxidized by the oxygen present in the molecule, and therefore a part of the oxygen used to burn fat goes to form water, so that the volume of oxygen consumed is considerably greater than the volume of carbon dioxide produced, which gives a respiratory quotient lower than 1.0. The common fats of the body and of the food give quotients approximating 0.7. Thus the oxidation of stearin is represented by the equation: —

$$2\ C_{57}H_{110}O_6 + 163\ O_2 = 114\ CO_2 + 110\ H_2O.$$

Since 163 volumes of oxygen are consumed and 114 volumes of carbon dioxide produced, the respiratory quotient is

$$\frac{114}{163} = 0.699.$$

Proteins give quotients intermediate between those of carbohydrates and fats, but if the amount of protein used in the body be determined by other methods (see Chapter VII) and allowed for, one may then deduce from the respiratory quotient the proportions of carbohydrates and fats which are being burned in the body at any given time. The body will show a respiratory quotient of 1.0 when burning carbohydrate alone; of 0.7 when burning fat alone; and of an intermediate value when both fat and carbohydrate are being burned. If, now, the respiratory quotient rises soon after the eating of carbohydrate food, it can only mean that the carbohydrate is being used more freely and fat less freely than before.

In an experiment by Magnus-Levy the subject before taking food showed a quotient of 0.77. He then ate 155 grams of cane sugar, after which the quotient was determined at intervals of an hour for 7 hours with the following results: 1.01, 0.89, 0.89, 0.92, 0.82, 0.82, 0.79. The quotient here shows that within an hour after the sugar was eaten the body was making use of the carbohydrate to such an extent that fat either was not being used at all or was being formed from carbohydrate as fast as it i.e. the fat was burned; and that for seven hours after the meal the body continued to use carbohydrate to a greater, and fat to a less, extent than was the case at the beginning of the experiment.

It has been pointed out that, when carbohydrate is absorbed in larger quantity than is required to meet the body's immediate needs for fuel, the surplus normally accumulates as glycogen, which is stored conspicuously in the liver, but also to a considerable extent in the muscles and other organs. The amount of carbohydrate which will be stored in the entire body after rest and liberal feeding is estimated at 300–400 grams,[1] of which the liver will probably contain about one half.

Production of Fat from Carbohydrate. — When the supply of carbohydrate is so abundant that it continues in excess

---

[1] Thus the total amount of carbohydrate which can be stored as such in the body is no more than is frequently taken in one day's food.

of the needs of the body and accumulates until the liver and muscles have no tendency to increase their store of glycogen; the further surplus of carbohydrate tends to be converted into fat.

Although the readiness with which some farm animals are fattened on essentially carbohydrate food would seem to have been sufficient to convince early observers of the transformation of carbohydrate into fat in the body, this evidence appears to have been overlooked because of the idea, for a long time prevalent, that simpler substances are built up into more complex compounds only in the plant, and not in the animal organism. In recent years it has become necessary to abandon this latter assumption completely, and there is now abundant evidence that the animal body synthesizes fat from carbohydrate.

The most obvious method of demonstrating the conversion of carbohydrate into fat is that followed by Lawes and Gilbert. Several pigs of the same litter and of similar size were selected; some were killed and analyzed as "controls," while the others were fed on known rations and later weighed, killed, and analyzed to determine the kinds and amounts of material stored in the body. In several cases the amounts of fat stored during such feeding trials were found to have been much larger than could be accounted for by all of the fat and protein fed, so that at least a part, and in some cases the greater part, of the body fat must have been formed from the carbohydrate of the food. Many similar experiments have been made, and the transformation of carbohydrate into fat has been demonstrated by this method in carnivorous as well as herbivorous animals.

Recently it has also been shown that carbohydrates contribute to the production of milk fat. Jordan and Jenter kept a milch cow for fifty-nine days upon food from which nearly all of the fat had been extracted. During this period about twice as much milk fat was produced as could be accounted for by the total fat and protein of the food, and in addition the cow gained in weight and her appearance showed that she had more body fat at the end than at the beginning of the experiment.

Instead of determining directly the fat formed in the animal fed on carbohydrate, the production of fat from carbohydrate may be demonstrated by keeping the animal experimented upon in a respiration chamber so arranged that the total carbon given off from the body may be determined and compared with the total carbon of the food. If in such a case the body is found to store more carbon than it could store as carbohydrate or protein, it is safe to infer that at least the excess of stored carbon is held in the form of fat. Many such experiments upon dogs, geese, and swine have shown storage of carbon very much greater than could be accounted for on any other assumption than that a part of the carbon of the carbohydrates eaten remained in the body in the form of fat.

Further evidence of the transformation of carbohydrate into fat is obtained from the respiratory quotient. As noted above, observations made after a fast tend to show quotients approaching that of fat, while after feeding carbohydrates the quotient may rise rapidly. If the quotient reaches 1.0, it shows that the body as a whole is using carbohydrate and not fat as fuel; and a quotient greater than 1.0 can only mean that the carbohydrate is itself supplying part of the oxygen, which appears as carbon dioxide, or, in other words, that it is breaking down in such a way that a part is burned while another part goes to form in the body a substance more highly carbonaceous and having a lower respiratory quotient than the carbohydrate itself. In many cases it is certain that this substance can be nothing but fat. Respiratory quotients greater than 1.0 have been observed after liberal carbohydrate feeding in many animals, including men. Each such observation furnishes evidence of a conversion of carbohydrate into fat.

The formation of fat from carbohydrate in the animal body is therefore established by four distinct lines of experimental evidence: (1) by determination of the amounts of body fat formed, (2) by determination of the milk fat produced, (3) by observation of the amount of carbon stored, (4) by observations upon the respiratory quotient.

FAT

The gastric juice contains a fat-splitting enzyme; but if the fat is swallowed in any other than a finely emulsified state, it is but little changed in the stomach. Emulsified fat may, however, be quite largely digested by the gastric juice. Volhard found 78 per cent of the fat of egg yolk to be digested into fatty acids and glycerol in the stomach. The gastric juice also digests a large part of the fat of milk, and it is probably through the action of the gastric lipase that infants are able to digest relatively large amounts of milk fat before the pancreatic juice becomes active. Fat is split by the digestive lipases into glycerol and fatty acid, of which the former is readily soluble in water, and the latter is soluble in bile, so that it may be said that in intestinal digestion the fat is split to soluble products and probably absorbed in solution.

Whether the splitting of all fat into fatty acid and glycerol is absolutely essential to its absorption is still undecided; but recent work indicates that, as a rule at least, the fat eaten is thus hydrolyzed in the stomach or intestine and is absorbed as fatty acid and glycerol which recombine in their passage through the intestinal wall. Very likely this recombination is also stimulated by lipases, since these enzymes show to a marked degree the property of being able to accelerate a reaction in either direction according to circumstances ("reversible action of enzymes"). The fat thus absorbed is taken up by the lymph vessels rather than the capillary blood vessels, and is poured with the lymph into the blood, so that the blood plasma may become turbid or even milky after a meal rich in fat. In the blood the neutral fat appears to be changed into an unknown, soluble, dialyzable modification and passes in this state through the capillary walls into the tissues, where it reverts to ordinary insoluble fat and can be seen as microscopic droplets or larger masses lying in the cell. In this way the fat which renders the blood plasma turbid at the height of absorption will usually have disappeared after a few hours, having been partly deposited in various organs, and partly burned as fuel. The fat thus burned as fuel is for the most part utilized by the tissues for the production of energy. In experiments with isolated working muscles, it is not so easy to show the direct utilization of the fat, as of the carbohydrate, and so Chaveau and some other physiologists have held that fat is not used by the muscles directly, but is first broken down (probably in the liver) with the formation of glucose, and that the latter is then carried to the muscles and used by them as already described. That the liver cells can use fat as well as glycogen and protein for the manufacture of glucose to keep up the normal composition of the blood is probably true, but it is not true (as was thought by Chaveau) that the value of fat as a source of energy for muscular work is only proportional to the dextrose which could be obtained from it according to the reaction:—

$$2\,C_{57}H_{110}O_6 + 67\,O_2 = 16\,C_6H_{12}O_6 + 18\,CO_2 + 14\,H_2O,$$

which would involve a loss of about one third of the fuel value of the fat. The average results of a very complete series of experiments by Atwater and his associates indicated that the potential energy of fat was 95.5 per cent as efficient as that of carbohydrates for the production of muscular work.

In discussing the formation of body fat from carbohydrate it was shown that often the greater part of the fat stored is manufactured in the body from carbohydrate. So striking were the results of some of the experiments demonstrating the synthesis of fat from carbohydrate, that physiologists came to question for a time whether any of the fat deposited in the tissues comes directly from the food. Abundant evidence that food fats may be directly deposited in the body has been obtained by feeding characteristic fats to dogs and showing that these fats can afterwards be recognized in the tissues of the animals. Experiments of this kind have been made, using linseed oil, rapeseed oil, or mutton tallow, any of which is easily distinguishable by its chemical and physical properties from the fat normally found in the body of the dog. Munk starved a dog for 19 days, and then for 14 days fed a mixture of the fatty acids obtained from mutton tallow, as a consequence of which about one half of the weight lost by fasting was regained. The dog was then killed and yielded on dissection 1100 grams of fat melting at 40°, which is about the melting point of mutton tallow, whereas normal dog fat melts at about 20°. In another experiment by Munk rape oil was fed and the fat obtained from the dog was found to contain 82.4 per cent of oleic and erucic acids and 12.3 per cent of solid acids, whereas normal dog fat had only 65.8 per cent oleic, no erucic, and 28.8 per cent of solid fatty acids.

The occurrence in the body fat of properties usually characteristic of some particular fat which has been fed is now very well known and is recognized in establishing standards of purity for fats of animal origin. Thus, the lard obtained from swine which have been fed cottonseed meal shows the characteristic color reactions of cottonseed oil, and more elaborate tests must be made in order to determine whether cottonseed fat has actually been mixed with the lard.

European food officials sought to establish an easy method of distinguishing between butter and its substitutes by requiring manufacturers of any butter substitute to use a certain proportion of sesame oil in the preparation, sesame oil having a characteristic color reaction which can be very easily demonstrated without the use of laboratory facilities. It was found, however, that the same sesame oil reaction might be exhibited by a perfectly pure butter fat from cows which had been fed upon sesame meal.

Evidence of the formation of body fat from food fat has also been obtained by experiments upon the total amount of fat formed in the body when the amount and composition of the food eaten was accurately known. Hoffmann starved a dog until its weight had decreased from 26 to 16 kilograms, so that it must have been almost devoid of fat. He then fed small amounts of meat and large amounts of fat for five days, after which the dog was killed and analyzed. The body contained 1353 grams of fat, of which not over 131 grams could have come from proteins, and only a few grams at most from the small amount of carbohydrates in the meat fed, so that about nine tenths of the fat which the animal had laid on must have come from the fat of the food. Whether fat once deposited in the tissues will remain and accumulate or be returned to the circulation and used as fuel, will depend upon the balance between the food consumption and the food requirements of the organism as a whole. In this respect, there is no difference between fat consumed and deposited as such and fat formed in the body from other food materials.

Formation of Carbohydrate from Fat. — That fat which has been deposited in the body can be drawn upon for the production of carbohydrate would appear probable from the fact that hibernating animals seem to use their stored fat to maintain the constant glucose content of the blood. In addition to this, experiments are on record in which the actual amount of glycogen in the body has been found to increase (apparently at the expense of the body fat) during the period of hibernation (Hill).

The formation of carbohydrate from fat appears also to have been shown by observations in which the respiratory quotient has been found to be less than 0.7 at times when the body was known to be using up considerable quantities of fat. Since it is not conceivable that any large amount of material having a respiratory quotient materially less than

0.7 can have been directly available for combustion in the body, this low quotient appears to be due to the fact that fat may be broken down in such a way as to be transformed in part into carbohydrate (respiratory quotient 1), the remainder of the fat molecule undergoing oxidation and giving for the time being the unusually low respiratory quotient. It will be seen that this is evidence of exactly the same kind as was cited in discussing the formation of fat from carbohydrates in the body. Since carbohydrate has a respiratory quotient of 1, fat of 0.7, and protein an intermediate respiratory quotient, and since the protein metabolism can be estimated by other methods and allowed for, it is evident that a quotient greater than 1 will indicate a transformation of carbohydrate into fat, and a quotient less than 0.7 similarly indicates a transformation of fat into carbohydrate.

In phloridzin poisoning, however, where there is abundant evidence of the formation of glucose from protein, there is not equally strong evidence of its formation from fat; and some physiologists doubt the ability of the animal body to form carbohydrate from fat beyond what can be derived from the glyceryl radicle, and explain the respiratory quotient of less than 0.7 as due to a storage of oxygen. Starling, on the other hand, is of the opinion that "there is no evidence that the body in any of its tissues is able to store oxygen," and that while many physiologists might not agree with this statement, all would agree that the power of living tissues to store oxygen is extremely limited.

It is well known that many plants lay up a store of food in the seeds in the form of fat and that on germination this fat is transformed into carbohydrate and carried as carbohydrate to the growing parts of the young plant.

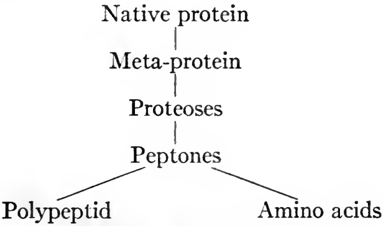
The greater part of the evidence appears to favor the view that animals as well as plants can change fat into carbohydrate, but this is by no means so conclusively demonstrated as the formation of fat from carbohydrate or of carbohydrate from protein.

PROTEINS

So long as the swallowed food remains in an alkaline or neutral condition in the stomach, and until it becomes mixed with gastric juice, the proteins are unchanged. Little by little, as described above (Chapter III), the food becomes mixed with the gastric juice, which, as secreted in the middle portion of the stomach under normal conditions, always contains free hydrochloric acid. This free acid acts upon the proteins of the food, converting them into the meta-protein acid-albumin ("syntonin"), which in turn under the influence of pepsin splits down with the formation of proteoses, and these by further hydrolysis yield peptones.

Ordinarily the food mass is passed from the stomach into the intestine before the digestion of protein has gone very far. In artificial digestion experiments with pepsin ordinarily only a part of the protein is split to the form of peptone, most of it going no farther than the proteose stage. Moreover, gastric digestion of proteins is not strictly essential, for it has been found by experiments on animals, and observations upon men, that digestion of proteins takes place after complete removal of the stomach. The stomach digestion of proteins is thus less important than was formerly supposed, but probably facilitates their more extensive digestion in the intestine.

On reaching the small intestine the proteins are attacked by trypsin, the proteolytic enzyme of the pancreatic juice. Trypsin works best in an alkaline, but can work in a neutral or slightly acid, medium. Its activity is retarded, but it is not destroyed, by small amounts of hydrochloric acid, hence the entrance of the acid stomach contents into the intestine can do no more than temporarily check tryptic digestion. Generally speaking, the conditions are favorable to the action of trypsin throughout the whole length of the small intestine, and its action is supplemented by that of the erepsin of the intestinal juice. The action of trypsin on protein is first to form proteoses. These are then hydrolyzed to peptones, which are in turn split down by the continued action of the trypsin, but more particularly by erepsin, with the formation of amino acids. Different views are held as to how far the splitting of protein actually goes in normal digestion. Some believe that it is entirely split to amino acids, especially since the enzyme erepsin has been shown to be a normal constituent of the intestinal juice and to have the specific function of splitting proteoses and peptones to amino acids and ammonia. An objection to this view is that it requires the assumption that all the protein in the body has been synthesized (either during or after absorption) from simple amino acids, which would therefore appear to have an equal nutritive value with the proteins themselves, a conclusion as yet hardly satisfactorily supported by feeding experiments. The results of feeding experiments with the products of hydrolytic cleavage of proteins are somewhat conflicting, but according to the data at present available it appears to be possible to support the protein metabolism of dogs with the products of pancreatic digestion (carried to the point of disappearance of the biuret reaction), but not with the products of acid hydrolysis. Abderhalden, one of the most active investigators in this field, holds that while a large amount of amino acid is formed in normal digestion, there always remains and is absorbed a polypeptid nucleus which serves as a starting point for the rebuilding of proteins in the body. According to Abderhalden's view, the digestion of protein might be represented as follows: —



Abderhalden says: "It is at present uncertain as to how far the disintegration goes in individual cases, as to whether polypeptids with a small number of amino acids result, or that the digestion stops while the chains are more complicated. . . . We can draw no conclusion as to the extent of the decomposition simply on account of the appearance of free amino acids. More complex substances may be present at the same time."

Henriques,[1] however, holds that a mixture of amino acids without polypeptids may suffice to maintain the animal organism in nitrogen equilibrium.

The digestion products of the proteins pass on by absorption mainly into the capillary blood vessels and thence to the portal vein. It was formerly stated that either in passing through the intestinal epithelium, or perhaps under the influence of the blood, the digestion products are changed to serum albumin and serum globulin. While such a statement must not be accepted too literally or regarded as a complete explanation of what occurs, it is still commonly held that the first proteins built in the body from the digestion products circulate in the blood and finally serve as a basis for the synthesis of the more complex protein bodies found in the various tissues and secretions, several of which are characteristic of the particular organs or groups of cells in which they are found. The fact that Howell has recently obtained positive reactions for amino acids in the blood emphasizes the importance of these compounds in metabolism and indicates that they are

---

[1] *Zeitschrift f. physiologische Chemie*, 1907, **54**, 406; Lusk, *Science of Nutrition*, 2d ed., p. 116.

not entirely synthesized to protein immediately upon absorption.

Autolytic enzymes, capable of breaking down the proteins of the body tissues and fluids with production of amino acids apparently identical with those formed in digestion, are found in all of the organs, and it is not improbable that protein synthesis also may be brought about by every living cell. In a recent discussion of the subject, Chittenden says: "We can well imagine that in the life and death of tissue cells autolytic decompositions are constantly taking place whereby cell protein is broken down into its component parts, while at the same time a synthesis of protein may be occurring from other amino acids brought by blood or lymph, with a possible utilization of some of the fragments liberated by the autolysis."

Abderhalden from an equally advanced viewpoint sees a new indication of the synthesis of body proteins in the intestinal wall, in experiments in which horses were bled, fasted, and bled again, then fed with gliadin, a protein which contains about 37 per cent of glutamic acid, whereas the blood proteins contain only about 8 per cent. The amounts of glutamic acid obtainable from the blood of the horses remained very constant throughout, in spite of the fact that the horses while supplied only with gliadin had to replace the protein material removed in bleeding. Abderhalden therefore considers that "the protein of the food must certainly have undergone a complete change before it entered into the circulation."

Whatever the mechanism of their assimilation, the absorbed proteins soon become available for the nutrition of the body, and among other functions they, like the carbohydrates and fats, may be burned as fuel for muscular work. Pflüger proved that protein may serve as a source of muscular energy by feeding a dog for 7 months exclusively upon meat practically free from fat and carbohydrate, and requiring it throughout the experiment to do considerable amounts of work, the energy for which must in this particular case have been derived largely from the protein consumed.

Until recently it was generally believed that a large part, if not the greater part, of the protein was built up into body material of some sort before being broken down, but since protein does not accumulate in the grown body, except under special conditions, it is evident that the building up, or anabolic process, if it occurs so extensively, must be either accompanied or immediately followed by a breaking down, or katabolism, of protein. By experiment it has been found that if a meal extra rich in protein be eaten an increased elimination of nitrogenous end products can be observed within 2 or 3 hours, and probably much the greater part of the surplus nitrogen will have been excreted within 24 hours of the time it was taken into the stomach. It does not follow, however, that the whole of the protein molecule is broken down and eliminated so quickly, and experiments have shown that the carbon of extra protein fed does not leave the body so rapidly as does the nitrogen. Evidently, the nitrogenous radicles of the protein may be split off in such a way as to leave a non-nitrogenous residue in the body, and the study of protein metabolism involves a consideration of the fate of both the nitrogenous and the non-nitrogenous derivatives. The fate of the latter may conveniently be considered first on account of its relation to the metabolism of carbohydrates and fats.

It can be readily calculated that to provide for the elimination of all the nitrogen of protein in the form of the usual end products would require much the smaller part of the carbon, hydrogen, and potential energy of the original protein. While such a calculation gives no picture of the actual mechanism of protein katabolism, it suffices to show the quantitative significance of the non-nitrogenous residue which the protein molecule may yield, and the importance of determining to what extent this residue may be actually transformed into carbohydrate or fat in the body.

Formation of Carbohydrate from Protein. — As early as 1876 Wolffberg tested the formation of carbohydrate from protein by fasting fowls for two days in order to free them from glycogen and then feeding for two days with meat powder which had been washed free from carbohydrate. Two of the fowls were killed soon after this protein feeding and showed more glycogen in their livers and muscles than could be accounted for except as derived from the protein fed. Two similar fowls killed 17 and 24 hours after feeding showed much less glycogen. This formation of glycogen from protein was fully confirmed by Kulz in a long series of experiments in which the food consisted of chopped meat thoroughly extracted with warm water (Lusk).

Independent evidence of the production of carbohydrates from protein is found in the work of Seegen, who chopped and mixed the liver of a freshly killed animal and determined the amount of carbohydrate in it by analysis of a portion, while the remainder was kept at body temperature and sampled for analysis from time to time. The percentage of carbohydrate was found to increase, showing that the liver cells can form carbohydrate from their own protein substance.

The most striking evidence of the origin of carbohydrate from protein in the animal body is found in the many observations and experiments which have been made in cases of diabetes, and in experimental glycosuria produced either by administration of phloridzin or by removal of the pancreas. In such cases large amounts of carbohydrate may be given off in the form of glucose even when there is little body fat and no carbohydrate or fat is fed. The glucose must therefore result from the metabolism of protein. In Lusk's exhaustive experiments upon dogs rendered diabetic by phloridzin, 58 per cent of the total weight of protein broken down in the body (whether in fasting or on a meat diet) was eliminated in the form of glucose. According to Lusk: "After ingestion of protein in the normal organism this sugar becomes early available and may be burned before the nitrogen belonging to it is eliminated, or, if the sugar be formed in excess, it may be stored as glycogen in the liver and muscles for subsequent use.

In this way it is obvious that at least half the energy in protein may be independent of the curve of nitrogen elimination, but may rather act as though it had been ingested in the form of carbohydrate." While Lusk's conclusions are based mainly upon the results of experiments with phloridzinized dogs, there seems to be no doubt that in healthy men also a large part of the protein eaten may take the form of carbohydrate in the course of its metabolism in the body.

Recently Lusk has experimentally demonstrated some of the ways in which the production of carbohydrate from protein may take place. Alanin, one of the prominent cleavage products of protein, yields by hydrolysis lactic acid and ammonia, and the lactic acid is convertible into glucose. In the case of a dog which had been sufficiently treated with phloridzin so that no glucose was burned in the body, Lusk recovered in the urine an amount of glucose quantitatively proportional to the amount of alanin fed. The production of glucose from glutamic acid has also been studied by Lusk, who concludes that this acid probably yields in its metabolism a molecule of lactic acid, which in turn may be converted into glucose.

We have therefore abundant evidence from the work of independent investigators, using different methods, that the animal body may form carbohydrates readily and in large proportion from the protein of the food; and the mechanism of the process is beginning to be fairly well understood.

Production of Fat from Protein. — There has been much controversy regarding the formation of fat from protein in the animal body. A number of observations by Voit which were believed to demonstrate such a production of fat have since been subjected to vigorous criticism by Pflüger and apparently shown to be capable of other interpretations. New experiments in Voit's laboratory by Cremer appear, however, to establish the formation of body fat from protein food beyond reasonable doubt. A cat after a preliminary period of fasting was placed in a respiration apparatus and fed liberally with lean meat for eight days. The amount of protein broken down in the body was estimated from the nitrogen eliminated. The carbon eliminated was also measured, and it was found that 58.4 grams of carbon had been retained in the body. This would correspond to 130 grams of glycogen, but the total amount of glycogen in the body at the end of the experiment was only 35 grams, hence about three fourths of the carbon retained by the cat from the protein food must have been stored as body fat.

The evidence of formation of milk fat in part from protein, while perhaps not amounting to a mathematical demonstration, is still very strong.

For practical purposes the outcome of the controversy as to the direct formation of fat from protein is of minor importance, since there is already abundant experimental evidence of the production of carbohydrate from protein and of the transformation of carbohydrate into fat, so that it is evident that protein food can indirectly, if not directly, contribute to the formation of fat in the body.

The Fate of the Nitrogen in Protein Metabolism. — The fate of the nitrogen of the protein molecule from the time of its absorption until it reaches the forms in which it is eliminated from the body — or, as it is now commonly called, the intermediary metabolism of protein — has received much attention during the past few years. As the subject is still under very active investigation, it seems inadvisable at this time to attempt to summarize the results as a whole, and for the purposes of the present discussion it will suffice to consider only so much of the fate of the protein nitrogen as is shown by the more important end products eliminated through the kidneys.

In man the principal end product is urea, but together with this there always occurs an elimination of other nitrogenous compounds, most of which are less highly oxidized than urea. These less highly oxidized end products are of interest from different points of view: they represent a loss of potential energy greater than that which would occur if the nitrogen were eliminated entirely as urea, and so affect the estimation of the fuel value of the protein; they may to some extent be regarded as intermediate products of metabolism of protein, and may thus throw light upon the changes through which the nitrogen of protein passed before reaching the urea stage; considered as products of incomplete metabolism, they may serve to indicate a condition of diminished power of oxidation, or perhaps more frequently a condition in which the normal oxidizable cleavage products are not formed (probably through failure of certain hydrolytic enzymes); and they may be regarded as imposing an additional burden upon the organs of elimination. The protein metabolism has generally been considered to be qualitatively better in proportion as a larger percentage of the total nitrogen is eliminated as urea and a smaller percentage in other forms. This, however, as will be shown below, is largely a matter of the amount of protein consumed. The most important nitrogenous end products other than urea are ammonium salts, purin bodies, and creatinin. Hippuric acid and other nitrogen compounds are normally also present in small amounts.

Urea. — The proteins, on being metabolized in the body, yield varying amounts of arginin which may undergo hydrolysis into ornithin and urea. In this way an appreciable part of the nitrogen of protein may reach the urea stage through a series of direct cleavages. It is altogether probable, however, that the greater part of the urea eliminated arises as follows: The protein in katabolism is split to amino acids, which are "deaminized" by hydrolysis as in the conversion of alanin to lactic acid above mentioned, the nitrogen of the amino group being split out as ammonia, which with the carbonic acid constantly being produced in metabolism forms ammonium carbonate. Loss of one molecule of water yields ammonium carbamate, which in turn on loss of one molecule of water yields urea, and it is probable that the greater part of the urea eliminated is formed from ammonium carbonate or carbamate in the liver.

$$(NH_4)_2CO_3 = NH_4CO_2NH_2 + H_2O.$$
$$NH_4CO_2NH_2 = CO(NH_2)_2 + H_2O.$$

Chloride or sulphate of ammonia evidently cannot be changed to urea in this way; and experiments show that if hydrochloric or sulphuric acid is introduced into the blood, it is eliminated by the kidneys largely as ammonium salt, and the quantity of urea is correspondingly decreased. In diseased conditions of the liver the organic salts of ammonia (which normally should be burned to carbonate and then converted as above) may also pass through and be eliminated without being changed to urea. In health and on a full protein diet about 82 to 88 per cent of the total nitrogen excreted by the kidneys is usually in the form of urea. On a low protein diet the percentage is lower.

Ammonia. — As already noted, ammonia is evidently a normal precursor of urea, being changed to the latter in its passage through the liver. In accordance with this view we find that the elimination of nitrogen as ammonia may be notably increased at the expense of urea: (1) in structural diseases of the liver; (2) after injecting mineral acids which combine with ammonia in the body, forming stable ammonium salts; (3) in cases of a pathological excess of acids in metabolism, such as often occurs in diabetes and in fevers. All of these are, of course, abnormal conditions. Normally, about 2 to 6 per cent of the total nitrogen eliminated is in the form of ammonium salts, the amount depending largely upon the relation between the amounts of acid-forming and of base-forming elements in the food, which will be discussed in connection with the study of the ash constituents of food and of mineral metabolism.

Uric Acid and the Purin Bases. — The formation of purin bases in the cleavage of nucleo-protein has already been mentioned. The chemical relations of these bodies to each other, to uric acid, and to the nucleus purin from which the group takes its name are indicated by their formulæ: —

Purin, $C_5H_4N_4$.
Adenin, $C_5H_3N_4NH_2$ = amino-purin.
Guanin, $C_5H_3N_4ONH_2$ = amino-oxy-purin.
Hypoxanthin, $C_5H_4N_4O$ = oxy-purin.
Xanthin, $C_5H_4N_4O_2$ = dioxy-purin.
Uric acid, $C_5H_4N_4O_3$ = trioxy-purin.

Uric acid is the most highly oxidized of these purins and is the one chiefly found in the urine. In man and other mammals the uric acid eliminated comes from purin bodies which have either been taken as such in the food, or formed in the body mainly by breaking down of nucleo-protein,[1] and the proportion of nitrogen given off in this form may be varied enormously by changes in the diet, and especially in the amounts of flesh foods eaten. Usually 1 to 3 per cent of the eliminated nitrogen will be found in the form of uric acid,

---

[1] It is possible that under certain (abnormal) conditions uric acid may also be formed synthetically.

together with a very much smaller amount in the form of purin bases. So much of the uric acid as arises from the metabolism of body tissue and would be excreted even on a purin-free diet (usually about 0.3 to 0.4 gram per day) is spoken of as "endogenous," while that arising from the purins of the food is called "exogenous" uric acid. In neither case, however, does the amount excreted represent the entire extent of the purin metabolism, since the purin bodies formed in, or introduced into, the body are oxidized to a considerable extent. The extent to which uric acid and other purins are destroyed in the body varies with different species of animals. The human body in health oxidizes about one half of the purins introduced and excretes about one half, mainly in the form of uric acid. Recent work has developed the successive steps in the purin metabolism in much greater detail and shown them to be referable to specific enzymes, the functions of which Lusk gives as follows: "Summarizing these results, it may be said that nucleic acid may be broken up by nuclease, a ferment found in all tissue. On the liberation of the purin bases, guanin and adenin are deaminized by guanase and adenase wherever these enzymes are found. Oxidizing enzymes, the xanthin oxidases, now convert hypoxanthin and xanthin into uric acid, while a uricolytic ferment of varying potency in different tissues and in different animals may break up and destroy the uric acid." Mendel, as the result of extended investigation, holds that the formation of uric acid takes place throughout the body and that its partial destruction is accomplished by the muscles, the kidneys, and especially by the liver.

Creatinin.— The normal urine usually contains about 1.5 grams creatinin per day. The quantity is fairly constant for the individual, averaging about 0.02 gram per kilogram of body weight per day. The origin and significance of creatinin and especially its physiological relations to creatin (of which it is chemically the anhydride) is still unsettled, despite much recent research.[1] Since the amount of creatinin excreted is not governed by the amount of protein consumed, the percentage of urinary nitrogen appearing in this form will evidently increase as the total nitrogen diminishes, and *vice versa.* On ordinary mixed diet the creatinin nitrogen usually constitutes 3 to 7 per cent of the total nitrogen of the urine.

The above statements regarding the distribution of the eliminated nitrogen among the different end products refer to results obtained upon an ordinary mixed diet containing the usual amount of protein. Folin has shown by a careful and extended study of the urines of healthy men living first upon high and then upon low protein diets, that the distribution of the nitrogen between urea and the other nitrogenous end products depends very largely upon the absolute amount of nitrogen metabolized. In the case of a man who on one day consumed high protein diet free from meat, and a week later was living on a diet of starch and cream, which furnished

---

[1] See Lusk, *Science of Nutrition* (2d ed.), pp. 138–140, for outline of recent results and references to original publications.

in all about 6 grams of protein per day, the distribution of end products was changed as shown in the following table: —

	On High Protein Diet (Free from Meat)		On Low Protein Diet (Starch and Cream)	
	Grams	Per cent	Grams	Per cent
Total nitrogen . . .	16.8		3.6	
Urea nitrogen . . .	14.7	87.5	2.2	61.7
Ammonia nitrogen .	0.49	3.0	0.42	11.3
Uric acid nitrogen .	0.18	1.1	0.09	2.5
Creatinin nitrogen .	0.58	3.6	0.60	17.2
Undetermined nitrogen	0.85	4.9	0.27	7.3

Thus, on passing from the high protein to the low protein diet (both being free from meat products) there was a marked decrease in both the absolute and the relative amounts of urea, and a decrease in the absolute, but increase in the relative, amount of uric acid, while the absolute amount of creatinin remained unchanged, so that its relative amount was greatly increased.

REFERENCES

Abderhalden. Textbook of Physiological Chemistry.

Armsby. Principles of Animal Nutrition, Chapter 2.

Chittenden. The Nutrition of Man, Chapters 1 and 2.

Connstein. Ueber fermentative Fettspaltung. *Ergebnisse der Physiologie*, **3**, 1, 194–232 (1904).

Folin. A Theory of Protein Metabolism. *American Journal of Physiology*, **13**, 117–138.

Hammarsten. Textbook of Physiological Chemistry.

Hill. Recent Advances in Physiology and Biochemistry, Chapters 11 and 12.

Howell. Textbook of Physiology, Chapters 47 and 48.

Lusk. The Fate of the Amino Acids in the Organism. *Journal of the American Chemical Society*, **32**, 671–680 (1910).

Oppenheimer. Handbuch der Biochemie, **4**, I.

Von Noorden. Metabolism and Practical Medicine, Vol. I, pp. 64–127, 153–168.

Wells. Chemical Pathology, Chapter 21 — Uric Acid Metabolism.

CHAPTER V

THE FUEL VALUE OF FOOD AND THE ENERGY REQUIREMENT OF THE BODY

We have seen that carbohydrate after its absorption into the body may be burned as such, or stored as glycogen, or transformed into fat; that fat may be burned or stored as such and probably may be converted into carbohydrate; and that protein may either be used as such, or may yield carbohydrate, or may (either directly or indirectly) contribute to the production of fat. It has also been shown that any or all of these foodstuffs may be utilized as fuel for muscular work.

These facts (as well as others which will appear in the chapters which follow) make it plain that the body is not restricted to the use of any one foodstuff for the support of any one kind of work, but on the contrary has very great power to convert one nutrient into, or use it in place of, another, and so to utilize its resources that the total potential energy of all of these nutrients is economically employed to support the work of all parts of the organism. Thus the carbohydrates, fats, and proteins stand in such close mutual relations in their service to the body that for many purposes we may properly consider the food as a whole with reference to the total nutritive requirements, provided a common measure of values and requirements can be found. Since the most conspicuous nutritive requirement is that of energy for the work of the body, and since these organic nutrients all serve as fuel to yield this energy, the best basis of comparison is that of fuel value, expressed most conveniently in terms of calories.

The calorific value or heat of combustion of any substance, *i.e.* the amount of energy liberated by the burning of a given quantity of the combustible material, is best determined by means of the bomb calorimeter devised by Berthelot. The particular form of Berthelot bomb which has been most used in the examination of food materials and physiological products is that of Atwater and Blakeslee.

This instrument and the method of its use have been fully described by Atwater and Snell in the *Journal of the American Chemical Society* for July, 1903. In outline it consists of a heavy steel bomb with a platinum or gold-plated copper lining and a cover held tightly in place by means of a strong screw collar. A weighed amount of sample is placed in a capsule within the bomb, which is then charged with oxygen to a pressure of at least 20 atmospheres (300 pounds or more to the square inch), closed, and immersed in a weighed amount of water. The water is constantly stirred and its temperature taken at intervals of one minute by means of a differential thermometer capable of being read to one thousandth of a degree. After the rate at which the temperature of the

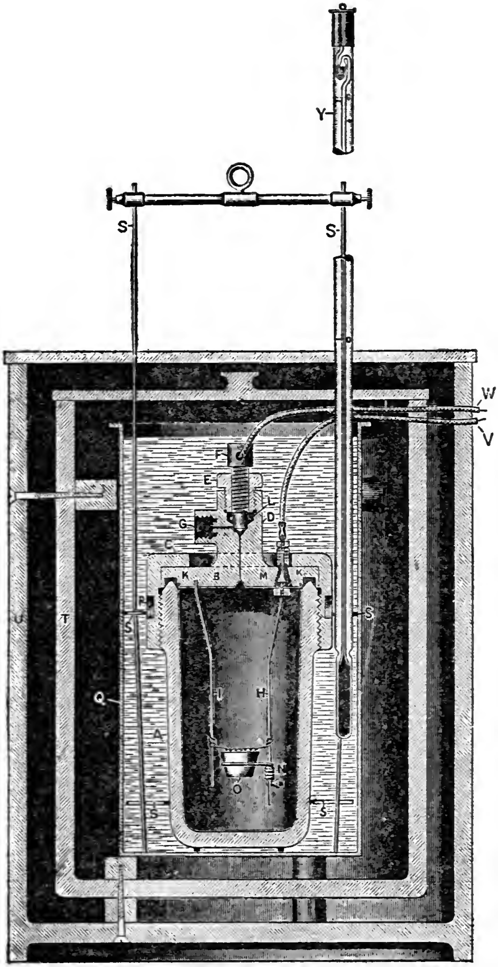


FIG. 3.—Bomb calorimeter; apparatus as used for determinations of heats of combustion. (Atwater and Blakeslee.)

water rises or falls has been determined, the sample is ignited by means of an electric fuse, and, on account of the large amount of oxygen present, undergoes rapid and complete combustion. The heat liberated is communicated to the water in which the bomb is immersed and the resulting rise in temperature is accurately determined. The thermometer readings are also continued through an "after period," in order that the "radiation correction" may be calculated and the observed rise of temperature corrected accordingly. This corrected rise, multiplied by the total heat capacity of the apparatus, and the water in which it is immersed, shows the total heat liberated in the bomb. From this must be deducted the heat arising from accessory combustions (the oxidation of the iron wire used as a fuse, etc.) to obtain the number of calories[1] arising from the combustion of the sample.

The heat of combustion of organic substances is closely connected with their elementary composition. One gram of carbon burned to carbon dioxide yields 8.08 calories and 1 gram of hydrogen burned to water yields 34.5 calories. If a compound consisting of carbon and hydrogen only be burned, it gives nearly the amount of heat which these would give if burned separately.

On the other hand, carbohydrates and fats, being com-

---

[1] When the term "calorie" is used in this work it will be understood to mean the greater calorie, *i.e.* the amount of heat required to raise the temperature of one kilogram of water one degree centigrade. This is very nearly the same as the heat required to raise four pounds of water one degree Fahrenheit.

posed of carbon, hydrogen, and oxygen, the carbon and hydrogen are already partly oxidized by the oxygen present in the molecule; so that 100 grams of glucose, for example, containing 40 grams carbon, 6.7 grams hydrogen, and 53.3 grams oxygen, would yield considerably less heat than would be obtained by burning 40 grams of pure carbon and 6.7 grams of pure hydrogen to carbon dioxide and water respectively.

Proteins when burned in the calorimeter give off their carbon as carbon dioxide, their hydrogen as water, and their nitrogen as nitrogen gas. Thus the nitrogen contributes nothing to and takes nothing from the heat of combustion; and the latter is dependent here, as in the case of carbohydrates and fats, upon the amount of carbon and hydrogen present and the extent to which they are already combined with oxygen. A little additional heat is obtained by the burning of the small amount of sulphur present in the protein.

The relation between the elementary composition and heat of combustion will be made clearer by the following table, which includes a number of typical compounds found in the food or formed in the body.

HEATS OF COMBUSTION AND APPROXIMATE ELEMENTARY COMPOSITION OF TYPICAL COMPOUNDS

	Heat of Combustion Calories per Gram	Carbon per Cent	Hydrogen per Cent	Oxygen per Cent	Nitrogen per Cent	Sulphur per Cent	Phosphorus per Cent
Glucose	3.75	40.0	6.7	53.3			
Sucrose	3.96	42.1	6.4	51.5			
Starch Glycogen	4.22	44.4	6.2	49.4			
Body fat	9.60	76.5	12.0	11.5			
Butter fat	9.30	75.0	11.7	13.3			
Edestin	5.64	51.4	7.0	22.1	18.6	0.9	
Legumin	5.62	51.7	7.0	22.9	18.0	0.4	
Gliadin	5.74	52.7	6.9	21.7	17.7	1.0	
Casein	5.85	53.1	7.0	22.5	15.8	0.8	0.8
Albumin	5.80	52.5	7.0	23.0	16.0	1.5	
Gelatin	5.30	50.0	6.6	24.8	18.0	0.6	
Creatinin	4.58	42.5	6.2	14.1	37.2		
Urea	2.53	20.0	6.7	26.7	46.6		

Since the body gets its energy from the oxidation of the same kinds of compounds which exist in foods, that is, essentially from carbohydrates, fats, proteins, and their cleavage products, if we know the kinds and amounts of foodstuffs eaten and the extent to which they are oxidized in the body, we can estimate in terms of calories the amount of energy liberated.

The average heats of combustion are: —

Carbohydrates	4.1 cal. per gram.
Fats	9.45 cal. per gram.
Protein (nitrogen × 6.25)	5.65 cal. per gram.

In the body carbohydrates and fats burn to the same products as in the calorimeter and so yield the same amounts of heat. Protein, however, which burns in the bomb to carbon dioxide, water, and nitrogen, yields in the body no free nitrogen but urea and other organic nitrogen compounds which are eliminated as end products (see the preceding chapter). These organic nitrogenous end products are combustible; they represent a less complete oxidation of protein in the body than takes place in the bomb. The loss of potential energy calculated on the assumption that all nitrogen left the body as urea would be about 0.9 calories per gram of protein; but on account of the elimination of other substances of higher heat of combustion (creatinin, uric acid, etc.), the actual loss in the form of combustible end products is considerably greater and averages about 1.3 calories for each gram of protein broken down in the body (equivalent to about 1.2 calories for each gram of protein in the food).

Hence, when the body burns material which it has previously absorbed, it obtains: —

From carbohydrates	4.1 cal. per gram.
From fats	9.45 cal. per gram.
From protein (5.65 – 1.30 =)	4.35 cal. per gram.

In calculating the fuel value of the food, however, allowance must be made for the fact that a part of each of the materials is lost in digestion.[1]

---

[1] The expression "lost in digestion" is here used in the sense explained in Chapter III.

The approximate averages on mixed diet are: —

Carbohydrates	2 % lost,	98 % absorbed.
Fats	5 % lost,	95 % absorbed.
Protein	8 % lost,	92 % absorbed.

The approximate *physiological fuel values* of the food constituents are then: —

Carbohydrates	4.1 × 98 %	= 4. calories per gram.
Fats	9.45 × 95 %	= 9. calories per gram.
Protein	4.35 × 92 %	= 4. calories per gram.

The figures given by Rubner as representing the fuel values of food constituents are as follows: —

Carbohydrates	4.1
Fats	9.3
Protein	4.1

These were derived from experiments with dogs fed on meat, starch, sugar, etc., and therefore do not allow for so much loss in digestion as has been found to occur with men living on ordinary mixed diet.

FUEL VALUE OF FOOD

If the composition of a food is known, its approximate fuel value is easily computed by means of the above factors. Thus milk of about average grade contains: —

Protein, 3.3 per cent; fat, 4.0 per cent; carbohydrate, 5.0 per cent.

One hundred grams of such milk will furnish in the form of protein (3.3 × 4. =) 13.2 calories, of fat (4.0 × 9. =) 36.0 calories, of carbohydrate (5.0 × 4. =) 20.0 calories; total for 100 grams of milk, 69.2 calories.

Eggs contain[1] on the average, in the edible portion, 13.4 per cent protein, 10.5 per cent fat, and no appreciable amount of carbohydrate. They would then furnish per 100 grams $(13.4 \times 4) + (10.5 \times 9) = 148.1$ calories.

Milk and eggs are sufficiently similar to be used interchangeably in the adult dietary within reasonable limits, but evidently they furnish, weight for weight, very different amounts of nutrients and energy. A unit weight of material is therefore not a satisfactory basis of comparison in foods. Neither would equal weights of dry matter be equivalent, for a gram of egg solids would have somewhat more food value than a gram of milk solids. Ordinarily the quantities to be taken as equivalent or mutually replaceable are those which furnish equal fuel value, *e.g.* 100-calorie portions, the weights of which may be calculated directly from the fuel values of 100 grams.

Thus, for milk — 100 grams furnish 69.2 calories; then, if x be the number of grams which furnish 100 calories: —

$$100 : 69.2 :: x : 100; \quad x = 145.$$[2]

---

[1] These and all similar statements of average composition are based on Bull. 28, Office of Experiment Stations, U. S. Dep't. Agriculture.

[2] It is considered sufficiently accurate to state these quantities to the nearest whole number of grams.

Similarly for eggs: —

$$100 : 148 :: x : 100; \quad x = 68.$$

And since the two extremes in the proportion are always the same, the weight in grams of the 100-calorie portion may always be found by dividing 10,000 (the product of the extremes) by the number of calories per 100 grams.

The fuel value of foods is often stated in calories per pound. Thus in the same table (Bull. 28) from which the above figures for composition are taken, the fuel value of milk is given as 325 calories per pound. Since 453.6 grams furnish 325 calories, —

$$453.6 : 325 :: x : 100; \quad x = 139.6,$$

the number of grams required to furnish 100 calories. This figure is about 3 per cent less than the one found above because it is based on a fuel value computed by Rubner's factors, which are 2.5 to 3.3 per cent higher than the factors based on more recent work. (See above.)

The following figures for a few common food materials are based upon the more recent factors, and show the weight of the 100-calorie portion in grams and ounces, and the distribution of the calories between proteins, fats, and carbohydrates: —

TABLE OF 100-CALORIE PORTIONS OF FOOD MATERIAL BASED ON THE FACTORS — PROTEIN, 4; FAT, 9; CARBOHYDRATE, 4

FOOD MATERIAL (EDIBLE PORTION)	WEIGHT OF PORTION		DISTRIBUTION OF CALORIES		
	Grams	Ounces	In protein	In fat	In carbohydrates
Beef, free from visible fat	86	3.0	80.4	19.6	
Beef, round steak . . .	64	2.3	54.5	45.5	
Beef, corned	33	1.3	20.9	79.1	
Ham, lean	37	1.2	29.7	70.3	
Ham, fat	19	0.7	11.1	88.9	
Bacon, smoked	16	0.6	6.7	93.3	
Codfish	143	5.0	95.0	5.0	
Salmon	49	1.7	43.3	56.7	
Eggs	67	2.3	36.1	63.9	
Milk	145	5.1	19.0	52.0	29.0
Butter	14	0.5	0.5	99.5	
Corn meal	27	1.0	9.0	11.4	79.6
Oatmeal	25	0.9	16.1	16.2	67.7
Rice	28	1.0	9.1	0.7	90.2
Wheat, "entire" . . .	28	1.0	14.7	3.5	81.8
Wheat flour	28	1.0	11.8	2.8	85.4
Bread, white	38	1.3	14.1	4.5	81.4
Sugar	25	0.9			100.0
Asparagus	450	16.0	32.4	8.2	59.4
Beans, dried	29	1.0	26.1	4.7	69.2
Beans, string	240	8.4	22.2	6.5	71.3
Beets	216	7.4	13.8	2.0	84.2
Cabbage	317	11.1	20.3	8.6	71.1
Carrots	220	7.7	9.7	7.9	82.4
Celery	540	19.1	23.8	4.8	71.4
Corn, green or canned .	99	3.2	12.2	9.8	78.0
Lettuce	523	18.4	25.2	14.1	60.7
Potatoes	120	4.2	10.5	1.2	88.3
Spinach	418	14.7	35.1	11.3	53.6

Food Material (Edible Portion)	Weight of Portion		Distribution of Calories		
	Grams	Ounces	In protein	In fat	In carbohydrates
Tomatoes	438	15.5	15.7	15.7	68.6
Turnips	253	8.9	13.2	4.6	82.2
Apples	159	5.6	2.5	7.2	90.3
Bananas	101	3.5	5.2	5.4	89.4
Currants, dried	31	1.1	3.0	4.7	92.3
Oranges	194	6.8	6.2	3.5	90.3
Peaches	242	8.5	6.8	2.2	91.0
Pineapple	232	8.2	3.7	6.3	90.0
Plums	118	4.1	4.7		95.3
Prunes, dried	33	1.2	2.8		97.2
Raisins	29	1.0	3.0	8.6	88.4
Almonds	15	0.5	13.0	76.4	10.6
Chestnuts	43	1.5	10.7	16.6	72.7
Peanuts	18	0.6	18.8	63.4	17.8
Olive Oil	11	0.4		100.0	

Since proteins and carbohydrates have the same average fuel value and the ash of food usually does not constitute a large percentage, the striking differences in the weights of the various foods required to furnish 100 calories are usually referable to differences in water content or fat content or both. That beans have nearly 20 times the fuel value of celery is essentially due to the difference in moisture, while the difference in fuel value between lean beef and bacon, or between codfish and salmon, is chiefly a matter of fat content. Meat free from fat is about three-fourths water and one-fourth protein and so has a fuel value of about one calorie per gram, while clear fat has a fuel value about nine times as great.

Fuel values of meats as given in the standard tables are apt to be somewhat misleading, inasmuch as they allow for all the fat ordinarily found on the various cuts as taken from the animal, whereas in many cases a considerable part of this fat is trimmed off by the butcher and treated as a by-product; and often much of the remaining layers of fat is removed either in the kitchen or at the table. If a pound of steak consists of 14 ounces of clear lean, and 2 ounces of clear fat, and the fat is not eaten, at least half of the total fuel value of the pound of steak is lost.

Many vegetables are more watery than lean meats and so contrast even more strikingly with the fats. An ounce of clear fat pork is equal in fuel value to about two pounds of cabbage; an ounce of olive oil to over three pounds of lettuce.

In connection with such comparisons of fuel value, however, it should be emphasized that the fuel value of a food, while of primary importance, is not alone a complete measure of its nutritive value, which will depend in part also upon the amounts and forms of nitrogen, phosphorus, iron, and various other essential elements furnished by the food.

In order to indicate relative richness in nitrogenous constituents (protein), it is not uncommon to state the "nutritive ratio" along with the fuel value of a food. The "nutritive ratio" or "nutrient ratio" is the ratio of nitrogenous to non-nitrogenous nutrients, compared on the basis of fuel values. Since the fuel values of carbohydrates and protein are taken as equal (4 calories per gram), and that of fats as $2\frac{1}{4}$ times as great (9 calories per gram), the nutritive or nutrient ratio may be shown as follows : —

$$\text{Protein} : \text{Carbohydrate} + 2\tfrac{1}{4}\ \text{Fat} :: 1 : x\,;$$

or the ratio may be expressed in the form of a fraction : —

$$\frac{\text{Carbohydrate} + 2\tfrac{1}{4}\ \text{Fat}}{\text{Protein}}.$$

These expressions can, of course, be applied equally well to percentages or to weights of nutrients.

The same information as is given by the statement of fuel value per pound and nutritive ratio may be obtained by comparing the weight of 100-calorie portions and the percentages of calories supplied by protein as shown in the above table. The statement that 19 per cent of the calories of milk are furnished by protein is equivalent to giving the nutritive ratio of milk as 1 : 4.3.

So far as concerns merely the protein and energy values of a dietary, foods which show similar percentages of calories from protein are interchangeable in the quantitative proportions indicated by the weights of the 100-calorie portions. It thus becomes easy to determine which is really the more economical of any two foods which may be regarded as interchangeable in the dietary. If the foods are in fact interchangeable, then that one will be more economical which furnishes more calories for a given expenditure.

ENERGY REQUIREMENT IN METABOLISM — METHODS OF STUDY AND AMOUNTS REQUIRED FOR MAINTENANCE AT REST

We know definitely from accurate experiments that the "physiological fuel values" which have been deduced represent the energy which is actually obtained by the body from the food and which appears as muscular work or as heat; and we have every reason to suppose that under ordinary conditions the carbohydrates, fats, and proteins each supply the body with the kinds of energy needed for its maintenance and for its work, approximately in proportion to their fuel values as calculated above. We do not now believe that any one nutrient is used to the exclusion of others as a source of energy for any particular function, nor indeed that the body makes any particular distinction between the foodstuffs as sources of energy. The fuel value of the diet as a whole is utilized to meet the energy requirements of the whole body. For the present, therefore, it is the fuel value of the day's dietary which we have to consider rather than the distribution of this as regards protein, fats, and carbohydrates.

The total food (or energy) requirement is best expressed in calories per day, either for the whole body or per kilogram of body weight, and for convenience of discussion it is usually assumed that the average body weight (without clothing [1]) is

---

[1] The average weight of a man's clothing is usually estimated at about 10 pounds; of a woman's, about 8 pounds.

for men 70 kilograms (154 pounds) and for women eight tenths as much, 56 kilograms (123 pounds).

There are four important methods of studying the food requirements of man:[1] —

1. By observing the amount of food consumed (dietary studies).
2. By observing the amount of oxygen consumed — preferably also the respiratory quotient (respiration experiments).
3. By determining the balance of intake and output (carbon and nitrogen metabolism experiments).
4. By direct measurement of heat given off by the body (calorimeter experiments).

Dietary Studies. — Most dietary studies give little more than a general indication of the food habits of the people studied; but in cases where persons have maintained for a long time the same dietary habits and other conditions of life, and the body weight has remained practically constant, it may be fairly safe to assume that the food has furnished just about the right amount of energy for the maintenance of the body under the observed conditions.

Great care must be taken in drawing inferences from the body weight because of the readiness with which the body gains or loses moisture. Athletes often lose 2 or 3 pounds in

---

[1] For an account of the historical development of the principles which underlie the measurement of metabolism, see the introductory chapter of Lusk's *Elements of the Science of Nutrition.*

an hour of vigorous exercise and regain it in less than a day. Gain or loss of body weight during short periods, therefore, does not by any means necessarily imply a corresponding gain or loss of fat. The body may lose fat and at the same time maintain its weight through gaining water, or *vice versa*. When, however, the weight remains nearly the same for months at a time, it may usually be assumed that there is no important gain or loss of tissue and that the body is receiving just about the proper amount of total food for its needs. Under these conditions an accurate observation of the food consumed may give valuable indications as to the actual food requirement. Of such dietary studies perhaps the most useful individual example is that of Neumann, who reduced his diet to what appeared to be just about sufficient for his needs and then recorded all food and drink taken during a period of 10 months in which the body weight was nearly constant but showed a slight gain. The average daily food furnished:[1] —

Nutrients	Factors	Calories	Total Calories per Day
Protein	66.1 grams × 4.	= 264.4	2242
Fat	83.5 grams × 9.	= 751.5	
Carbohydrate[2]	306.5 grams × 4.	= 1226.0	

The 2242 calories per day were evidently fully sufficient to meet the energy requirements of this man, whose weight

---

[1] The data are taken from Chittenden's *Nutrition of Man*, p. 286.

[2] Including some alcohol (taken in the form of beer), which is estimated as equivalent in fuel value to 1.75 times its weight of carbohydrates.

was 66.5 to 67 kilograms (about 147 pounds) and who was engaged at his usual (mainly sedentary) professional work in the Hygienic Institute at Kiel.

Later, when his weight had increased to 71.5 kilograms (157 pounds) as the result of following for a time a more liberal diet (furnishing about 2600 calories per day), he again observed his dietary while taking what was supposed to be an amount of food sufficient for the maintenance of the body and no more. This second dietary study was continued for 8 months, during which the average daily food consumption was found to be: —

NUTRIENTS	FACTORS	CALORIES	TOTAL CALORIES PER DAY
Protein	76.2 grams × 4.	= 304.8	2000
Fat	109.0 grams × 9.	= 981.0	
Carbohydrates[1]	178.6 grams × 4.	= 714.4	

These results indicate that this subject, a man of average size, living a normal professional life involving no manual labor in the ordinary sense, but not excluding such muscular movements as are naturally incidental to a sedentary occupation, found his energy requirements satisfied with food furnishing 2000 to 2250 calories per day.

Respiration Experiments. — Since the foodstuffs yield their energy through being burned in the body, *i.e.* by uniting with oxygen, it is evident that a measure of the energy metabolism can be obtained by finding either the amount of foodstuffs

---

[1] Including some alcohol (taken in the form of beer), which is estimated as equivalent in fuel value to 1.75 times its weight of carbohydrates.

or the amount of oxygen which is consumed in the process. The apparatus devised and used by Zuntz[1] for this purpose provides a mask fitting air-tight over the mouth and nose and connected by means of valved pipes with apparatus for measuring and analyzing the inspired and expired air. In this way one can determine the volume of oxygen entering, and the volume leaving, the lungs. The difference is the volume consumed in the body.

A given volume of oxygen used in the body may liberate somewhat different amounts of heat, according as it oxidizes fat, carbohydrate, or protein.

1000 cc. oxygen burn approximately	0.5 gram fat,	yielding 4.7 calories.
1000 cc. oxygen burn approximately	1.34 grams glucose,	yielding 5.0 calories.
1000 cc. oxygen burn approximately	1.05 grams protein,	yielding 4.6 calories.

For accurate estimations of the energy liberated it is therefore necessary to know the kind of material oxidized, as well as the amount of oxygen consumed. This is accomplished by measuring the volume of carbon dioxide evolved as well as of oxygen consumed, and calculating the respiratory quotient.

Since the amount of protein broken down in the body can be found by other methods as described below, the determina-

---

[1] For description of a new form of apparatus for studying the respiratory exchange see Benedict, *American Journal of Physiology*, **24**, 345 (1909).

tion of the respiratory quotient along with the oxygen consumption shows the extent of the combustion in the body and the proportions of fat and carbohydrate burned. From these data the energy liberated can be calculated.

This method of studying the total metabolism permits of experiments being carried out very quickly, and is therefore especially useful for the direct investigation of conditions which affect metabolism at once, *e.g.* muscular work, work of digestion, etc. Moreover, the apparatus can be made portable and thus be carried by the subject like a knapsack in experiments on marching, mountain climbing, or bicycling. The observations cannot be made continuous, but the probable results for the 24 hours' metabolism can be estimated by the data obtained during frequent short periods at different times of the day and night. For a critical comparison of this method with the Pettenkofer and Voit method of studying metabolism by the determination of the carbon balance, the reader is referred to the discussion by Magnus-Levy in Von Noorden's *Metabolism and Practical Medicine,* Vol. I, pp. 186–198.

From the results of many observations by this method, Magnus-Levy estimates the minimum metabolism of a man of average size kept absolutely motionless and fasting at 1625 calories per day. Food barely sufficient for maintenance would increase this by 175, and such incidental muscular movements as would ordinarily be made by a man at rest in bed would involve another 200, making a total of 2000 calories as the estimated food requirement of a man at rest with a maintenance diet. Magnus-Levy further estimates that the man, if doing no work (in the ordinary sense), but allowed to move about the room instead of remaining in bed, would require 2230 calories per day.

Metabolism or Balance Experiments. — By determining the constituents of the food consumed and of the substances eliminated from the body, the material actually oxidized and the energy liberated in the oxidation can be found by a comparison of the intake and output.

The "intake" is found by weighing and analyzing all food eaten; the "output" by collecting and determining the end products eliminated through the lungs, the kidneys, the intestines, and sometimes (in very exact experiments) the skin. The time unit in experiments upon the intake and output is almost always 24 hours, the experimental day beginning preferably just before breakfast. The intestinal residues belonging to the experimental days are marked and separated usually by giving a small amount of lampblack with the food as in ordinary digestion experiments, while the end products given off by the lungs and kidneys during an experimental day are taken as measuring the material broken down in the body during the same period. In the case of the carbon dioxide given off by the lungs, there can be very little error in this assumption, for carbon dioxide is eliminated almost as rapidly as it is formed, and if, on account of exercise or for any other reason, the formation should exceed the elimination during the active part of the day, any excess of carbon dioxide left in the body would almost certainly be given off during the night.

More time is of course required for the elimination of the nitrogenous end products through the kidneys. This unavoidable "lag" in the elimination of nitrogen may introduce an error in determining the nitrogen balance unless the subject has been kept for a few days in advance upon the same diet which is to be used in the experiment.

Assuming that the total nitrogen and carbon of the absorbed food existed in the form of protein, fat, and carbohydrate, and that the amount of carbohydrates in the body is constant from day to day, it is only necessary to determine the carbon dioxide of the expired air and the carbon and nitrogen of the waste products, in order to calculate the amounts of material oxidized and of energy liberated in the body. Experiments of this sort have played a most important part in the development of our knowledge of nutrition. The calculations are usually based on the following average analyses of protein and body fat: —

	PROTEIN	FAT
Carbon	53	76.5
Nitrogen	16	
Hydrogen	7	12
Oxygen	23	11.5
Sulphur	1	
	100	100

The following data were obtained with a man on ordinary mixed diet: —

CALCULATION OF ENERGY METABOLISM FROM CARBON AND NITROGEN BALANCE. MAN OF 64 KILOGRAMS AT REST IN ATWATER RESPIRATION APPARATUS

INTAKE	GRAMS PER DAY				
	Protein	Fat	Carbohydrate	Nitrogen	Carbon
Total in food	94.4	82.5	289.8	15.1	239.0
Lost in digestion	5.4	3.7	3.2	0.9	7.4
Absorbed	89.0	79.8	286.6	14.2	231.6
OUTPUT					
By lungs					207.3
By kidneys				16.2	12.2
Metabolized				16.2	219.5
Balance				− 2.0	+ 12.1

A loss of 2.0 grams body nitrogen indicates (2.0 × 6.25 =) 12.5 grams body protein burned. Also there were 89.0 grams absorbed from food, and, therefore, in all 101.5 grams total protein burned.

Since the respiratory quotient showed that the body was in carbohydrate equilibrium at the beginning and end of each experimental day, *i.e.* at seven o'clock each morning, it may be concluded that the amount of carbohydrate burned was the same as that absorbed from the food, viz. 286.6 grams per day.

From the carbon balance, therefore, we estimate the amount of fat burned as follows: —

12.5 grams body protein yield (12.5 × 53 per cent =)	6.6 grams carbon
And there were in the absorbed food . . .	231.6 grams carbon
∴ total available was	238.2 grams carbon
But total katabolized was only	219.5 grams carbon
∴ the body stored in the form of fat . . .	18.7 grams carbon

Since fat contains 76.5 per cent carbon, 1 gram carbon = 1.307 grams fat. ∴ 18.7 grams carbon = 24.4 grams fat.

The body therefore absorbed	78.8 grams fat
stored	24.4 grams fat
burned	54.4 grams fat

In all, the body burned per day —

101.5 grams protein, yielding	(101.5 × 4.35[1] =)	442 calories
54.4 grams fat, yielding	(54.4 × 9.45[1] =)	515 calories
286.6 grams carbohydrate, yielding	(286.6 × 4.1[1] =)	1175 calories
		2132 calories

Sonden and Tigerstedt studied by means of the carbon and nitrogen balance the energy metabolism of eight resting men between nineteen and forty-four years of age, with results which varied for the different subjects from 1853 to 2292 calories per day. Many experiments by other workers might be cited in confirmation of this result.

---

[1] Here the factors for fuel value are not reduced to allow for loss in digestion, because this loss has already been deducted in computing the amount of each nutrient actually absorbed and rendered available.

Calorimeter Experiments. — Although several forms of apparatus have been employed to measure the output of heat from the human body, it was not until the development of the Atwater-Rosa-Benedict respiration calorimeter that complete and satisfactory data covering periods of one to several days had been obtained. This apparatus consists of an air-tight copper chamber, surrounded by zinc and wooden walls with air-spaces between, and is large enough for a man to live in without discomfort, being about 7 feet long, 4 feet wide, and 6½ feet high. An opening in the front of the apparatus, which is sealed during an experiment, serves as both door and window and admits sufficient light for reading and writing. A smaller opening in the rear wall, having tightly fitting caps on both ends, is used for passing food, drink, excreta, etc., into and out of the chamber. The chamber is furnished with a folding bed, chair, and table, and is ventilated by means of a current of air which passes usually at the rate of about 2½ cubic feet per minute. At first this ventilating air current was maintained and measured by means of a specially constructed meter pump which also automatically took samples of the air for analysis. Recently the apparatus has been so modified as to make use of the same air throughout an experiment, the carbon dioxide and water given off by the subject being removed by circulating the air through purifying vessels, and the oxygen which the subject uses being replaced by adding weighed amounts of oxygen to the air current as required. By this means it is possible to carry out, in the calorimeter, metabolism experiments in which the oxygen and hydrogen as well as the carbon and nitrogen balances are determined, and from these data the gain or loss of carbohydrate as well as of protein and fat can be determined.

The ventilating air current is so regulated that it enters and leaves the calorimeter at the same temperature; and between the copper and zinc walls are placed a large number of thermoelectric junctions connected with a delicate galvanometer by means of which each wall is tested every four minutes, day and night, during the progress of an experiment, and the minute amounts of heat which may pass to or from the calorimeter through its walls are quickly detected and made to balance each other. Thus there is no gain or loss of heat either through the walls of the chamber or by the ventilating air current, and the heat given off by the subject can leave only by the means especially provided for carrying it out and measuring it. A part of the heat liberated is carried from the chamber in latent form by the water vapor in the outgoing air, which is accurately determined. The rest of the heat is brought away by means of a current of cold water circulating through a copper pipe coiled near the ceiling of the chamber. The quantity of water which passes through the pipe and the difference between the temperature at which it enters and that at which it leaves the coil are carefully determined and show how much heat is thus brought out of the chamber.

By means of this apparatus, for an adequate description of which reference must be made to the publications of Atwater and Benedict,[1] it is possible to measure the heat production or energy metabolism of a man for a period of a day, or of several days, with a much greater degree of accuracy than was possible by the earlier methods. The discrepancy between the theoretical heat and that actually measured by this apparatus rarely reaches 2 per cent in any single experiment, while in the average of 45 experiments covering 143 experimental days the theoretical heat was to the heat actually measured as 10,000 to 9999. The results obtained by this method of experimenting are more convincing than those reached in any other way.

At the time of writing there are available the completed data of experiments upon 6 different men who lived in the calorimeter at comparative rest, taking as a rule but little more exercise than was involved in dressing and undressing, folding and unfolding the bed, table, and chair, taking samples and observations pertaining to the experiment, writing, etc., in short, the life of a healthy man, confined to one small room.

The average daily metabolism of each of the subjects was as in the following table.

---

[1] Publication No. 42, Carnegie Institution of Washington, and Bulletins of the Office of Experiment Stations, U. S. Dept. of Agriculture.

SUBJECT	AGE YEARS	WEIGHT AVERAGE	NUMBER OF EXPERIMENTS	TOTAL EXPERIMENTAL DAYS	CALORIES PER DAY
E. O.	31–34	70 K. (154 lb.)	13	42	2283
A. W. S. . . .	22–25	70 K. (154 lb.)	4	9	2337
J. F. S. . . .	29	65 K. (143 lb.)	4	12	2133
J. C. W. . . .	21	76 K. (168 lb.)	1	4	2397
H. F.	54	70 K. (154 lb.)	1	3	1904
B. F. D. . . .	23	67 K. (147 lb.)	1	3	2228
Mean of individual averages	. . .	. . .	. . .	. . .	2213

Extreme deviations from the mean, + 184 to − 309 calories,
or + 8.4 to − 14 per cent.

Omitting the results obtained with the one subject who was considerably older than the others, the figures become as follows: —

Mean of individual averages, 2277 calories.
Extreme deviations from mean, + 120 to − 144 calories,
or + 5.2 to − 6.3 per cent.
Deviations in body weight, + 8.7 to − 7.1 per cent.

The subject "H. F.," aged fifty-four, who for a number of years had practiced a very restricted diet and believed that he consumed only half the usual amount of food, had a food requirement about 15 per cent less than that of the younger men averaging about the same weight. That several years' effort to live upon a diminished amount of food should have resulted in no greater change than might have been due to his age alone is striking evidence of the fixed character of the food requirement. The five younger men varied in age from twenty-one to thirty-four years, were natives of three different countries, and had been accustomed to very different dietary habits and modes of life, yet they differed less in food requirements than in body weight.

[Since the above was written Benedict and Carpenter have published data for other men who differed more in age and physique and showed somewhat larger individual differences in metabolism.]

Equally interesting is the close agreement between these results and those reached by the methods previously described. A general view of the results obtained by all four of the methods leads to the conclusion that the food requirements of a young to middle-aged man of average size, kept strictly at rest, approximates 2000 calories per day, and that such muscular activity as is incidental to very quiet living indoors may be expected to raise this requirement to 2200 or 2300 calories per day. The very close agreement in results reached by many independent investigators, using four distinct methods of study, must be taken as establishing the approximate average food requirement of a man at rest beyond any reasonable doubt.

Next will be considered the principal conditions which influence the total metabolism and food requirement.

REFERENCES

ARMSBY. Principles of Animal Nutrition, Chapters 7 to 10.

ATWATER. Methods and Results of Investigations on the Chemistry and Economy of Food. Bull. 21, Office of Experiment Stations, U. S. Dept. Agriculture (1895).

—— Neue Versuche ueber Stoff- und Kraft-wechsel. Ergebnisse der Physiologie, **3** (1904).

ATWATER AND BENEDICT. A Respiration Calorimeter with Appliances for the Direct Determination of Oxygen. Publication No. 42, Carnegie Institution of Washington (1905).

BENEDICT AND CARPENTER. The Metabolism and Energy Transformations of Healthy Man During Rest. Publication No. 126, Carnegie Institution of Washington (1910).

FISHER. A new method for indicating Food Values. *American Journal of Physiology*, **15**, 417.

LUSK. Elements of the Science of Nutrition, 2d. ed. pp. 17–45 (1909).

NAGEL. Handbuch der Physiologie des Menschen, pp. 331–375 (1909).

OPPENHEIMER. Handbuch der Biochemie, **4**, II, 1–92.

TIGERSTEDT. Textbook of Physiology, Chapter 4 (1906).

RUBNER. Der Energiewert der Kost des Mencshen. *Zeitschrift für Biologie* (n.f.), **24**, 261–308 (1901).

—— Die Gesetze der Energieverbrauches bei der Ernahrung (1902).

VON NOORDEN. Metabolism and Practical Medicine, Vol. I, pp. 185–207.

CHAPTER VI

CONDITIONS AFFECTING THE TOTAL FOOD REQUIREMENT

Activity, age, and size are the most important factors influencing the total food requirement of the body. The food requirement of the adult being more accurately known than that of the growing organism, it will be convenient to consider the demands of work, and of other conditions affecting the adult first, and those of growth later.

The muscular movements of the body have for their object the performance of work of three kinds: —

1. The work of the voluntary muscles, including all of the "external work" in the sense in which the term is ordinarily used.

2. The work of digestion and assimilation, which, once the food is swallowed, is involuntary, but which is external in the sense of being done upon material which is not yet a part of the body.

3. The work which goes on in the body independently of either of these, and which is internal in a strict physiological sense — such, for example, as the work of the circulation and of the maintenance of muscular elasticity.

Experimentally it is possible to control the work of the first and second kinds; but the true internal work cannot be stopped during the life of the animal and in some cases cannot be greatly modified, except by radical departure from normal conditions. Attempts to differentiate quantitatively between the different kinds of internal work are therefore attended with much difficulty. The maintenance requirement in the sense in which the term has been used here covers the work of digestion and assimilation as well as the true internal work, but excludes as far as practicable the external work of the voluntary muscles.

A systematic analysis of the maintenance requirement of the body with reference to its principal functions has not yet been made, but results obtained by Armsby, Atwater, Benedict, Magnus-Levy, Rubner, Zuntz, and others indicate that about

8–12 per cent of the maintenance requirement of energy is expended upon the work of digestion and assimilation, including any direct response of the body to the food (specific dynamic effect),
5–10 per cent upon the circulation,
10–20 per cent upon the respiration,
30–50 per cent upon the maintenance of muscular tension, elasticity, or "tone,"
? per cent upon the work of the secreting cells other than those of digestion and other forms of intracellular work.

These estimates, while not final, are helpful in considering the influence of food consumption, muscular activity, and other factors upon the energy metabolism and the resulting food requirement.

INFLUENCE OF FOOD CONSUMPTION UPON METABOLISM

Comparison of Feeding and Fasting Experiments. — The direct effect of the consumption of food upon the general metabolism is most conveniently observed by means of the Zuntz respiration apparatus already mentioned, because of the ease with which changes occurring in short periods can be measured by means of this apparatus. Using this method, Magnus-Levy, by determining the oxygen consumption per hour throughout the daytime, found that this was 23 to 40 per cent higher during the first two hours after meals than while fasting early in the morning. The rate of metabolism had returned to the early morning value within 4–5 hours after breakfast and supper and within 6–7 hours after a noon dinner. The total food taken furnished 2400 to 2500 calories, and the increased metabolism in the hours following meals amounted in all to 190 to 200 calories, or about 8 per cent of the energy furnished by the food.

Atwater and Benedict determined directly by means of the respiration calorimeter the heat production of the same man during five fasting experiments of one to two days each, and during a four-day experiment with food about sufficient for maintenance. The average total metabolism on the fasting days was about 9 per cent lower than on the days when food was taken.

In a more recent series of experiments Benedict has found that, if the fast is sufficiently prolonged, there may be a somewhat greater decrease in heat production. Thus, a man who weighed at the start 59.5 kilograms (131 pounds), metabolized on the successive days of a seven-day fast, 1765, 1768, 1797, 1775, 1649, 1553, and 1568 calories respectively. Naturally in such a long fast other factors than the simple sparing of the work of digestion come into play.

Tigerstedt has studied by means of the carbon and nitrogen balance the metabolism of a man who fasted for five days and for the next two days took a very liberal diet. The heat production for the first two days of fasting could not be estimated so accurately as for the other days, since at this time the body was losing an unknown amount of glycogen. The following data were obtained: —

	Body Weight Kilos	Calculated Total Metabolism Calories	Calories per Kilo
1st fast day	67.0	2220[1]	33.2[1]
2d fast day	65.7	2102[1]	32.0[1]
3d fast day	64.9	2024	31.2
4th fast day	64.0	1992	31.1
5th fast day	63.1	1970	31.2
Fed 4141 calories	64.0	2437	38.1
Fed 4141 calories (2d day) .	65.6	2410	36.8

These results show for man (as had previously been shown with dogs) that in fasting the total metabolism continues

---

[1] These figures are slightly too high because the loss of carbon on these days was due in part to combustion of glycogen, but is calculated as if due simply to protein and fat.

at a fairly constant rate in spite of the fact that the energy is obtained entirely at the expense of body material. In this case, the diet given at the end of the fasting period (4141 calories) was approximately double what would have been required for maintenance, thus making the work of digestion and assimilation presumably twice as great as when a maintenance diet is taken. The observed increase of metabolism (22.5 per cent) is therefore little, if any, greater than could be explained by the work of digestion and assimilation alone, the balance of the increase (if any) being probably due to the internal work involved in the regrowth of the tissues, since during these two days the body regained 20 per cent of the protein, 36 per cent of the fat, 71 per cent of the water, and 69 per cent of the ash which it had lost during the five days of fasting.

The results of fasting experiments thus make it evident that the total metabolism of any given man at rest tends to remain fairly constant, and that the body has but little power in the direction of adjusting its energy metabolism to its food supply.

Specific Dynamic Action of the Foodstuffs. — Rubner found that each type of food exerted a more or less specific influence upon the energy metabolism, so that when the foodstuffs were fed separately, somewhat different energy values were required for the maintenance of body equilibrium. Thus, if the total metabolism of a dog fasting at 33° C. be represented by 100 calories, he must be fed, in order to prevent loss of body substance, about 106.5 calories of sugar, or 114.5 calories of fat, or 140 calories of protein. A man observed by Rubner metabolized in fasting 2042 calories; when fed 2450 calories in the form of sugar alone, he metabolized 2087 calories; when fed 2450 calories in the form of meat alone, he metabolized 2566 calories. It is not yet clear why the eating of protein should increase the metabolism so much more than does the eating of the same number of calories in the form of carbohydrate and fat. It would seem that there is in any case a certain reaction of the body to the food which it receives, which may perhaps be due to the work of digestion and assimilation, but that in the case of protein there is an additional specific stimulation due to the nature of the foodstuff or the products of its metabolism. Whatever the cause of this specific dynamic action of protein, it is at present believed that there is here involved a liberation of energy which has not come into the service of the tissues and which does not directly contribute to the support of their activities, though it may aid in the maintenance of body temperature. On an ordinary mixed diet, however, this apparent loss of a part of the fuel value of protein is not a very important factor in the total metabolism, since this specific dynamic action and the work of digestion and assimilation together make the total daily metabolism of energy only about one tenth higher on a maintenance ration than when no food is eaten.

INFLUENCE OF MUSCULAR WORK UPON METABOLISM AND FOOD REQUIREMENTS

Muscular work is much the most important of the factors which raise the food requirements of adults above the 2000 calories (or thereabouts) necessary for maintenance at rest.

Accurate measurements by means of the calorimeter have shown that the average total metabolism of a man sitting still is about 100 calories per hour; while the same man working actively increases his metabolism up to about 300 calories per hour; and a well-trained man working at about his maximum capacity metabolizes material enough to liberate 600 calories per hour, *i.e.* his metabolism may be six times as active during the hours actually spent in such work as when he is at rest. If during 24 hours a man works as hard as this for 8 hours and spends 2 hours in such light exercise as going to and from work, his food requirement for the day will be somewhat over 6000 calories, or three times the maintenance requirement. Thus, work may increase the day's metabolism as much as 200 per cent, whereas we saw that liberal feeding at the end of a fast increased the metabolism only 22.5 per cent, or one ninth as much. Only a few exceptional occupations, such as that of lumbermen, for example, involve such heavy work as to cause a metabolism of 6000 calories per day. More often the man who works eight hours a day at manual labor will increase his metabolism by 1000 to 2000 calories above what is needed for maintenance at rest, making his total food requirement 3000 to 4000 calories.

Voit estimated the food requirement of a "moderate worker" at about 3050 calories; and Atwater, in adapting this standard to American conditions, increased the allowance to 3400–3500 calories in the belief that the American works more rapidly and therefore with a greater expenditure of energy. The mistake is often made of supposing that these estimates were intended for every one who leads an active life, whereas they really contemplate a long day of manual labor, for Voit's definition of "moderate worker" was a man laboring 9 or 10 hours a day at an occupation such as that of a carpenter, mason, or joiner.

Quantitative Relation between Work performed and Total Metabolism. — Theoretically it is possible to determine the mechanical efficiency of a man by dividing the mechanical effect of his work by the increase of energy metabolism which the work involves. This gives the basis on which to ascertain how much extra food would be necessary to supply the energy required for the performance of any given task. In practice it is extremely difficult to measure the efficiency or even the exact mechanical value of the muscular work performed.

Since increased muscular work involves a simultaneous increase of oxidation in the body, and the carbon dioxide which is the principal oxidation product, escapes very rapidly through the lungs, the immediate influence of work upon metabolism is most conveniently shown by respiration experiments in which the periods of observation can be reduced to cover only the time of actual muscular effort. Experiments of this kind (made especially by use of the Zuntz apparatus already described) are discussed at some length by Magnus-Levy in Von Noorden's *Metabolism and Practical Medicine*, and some of the deductions drawn from them may be summarized as follows: —

The amount of oxygen consumed during work in excess of that during rest was regarded as a measure of that expended upon the work. As a rule the increased consumption of oxygen during work is relatively greater than the increased volume of air breathed, so that a greater proportion of the oxygen of the inspired air must be taken up by the lungs. As an example of the increase of oxygen consumption with muscular work the data obtained by Katzenstein in experiments upon the work of walking up an inclined plane may be given. The figures were as follows: —

	OXYGEN CONSUMED PER MINUTE	RESPIRATORY QUOTIENT	HORIZONTAL DISTANCE	ASCENT
	cc.		Meters	Meters
At rest	263.75	0.801	——	——
Walking on very slight incline	763.00	0.805	74.48	0.58
Walking up incline with 10.8 per cent rise	1253.2	0.801	67.42	7.27

The constancy of the respiratory quotient indicates that here there was no change in the nature of the material burned in the body on passing from rest to gentle, or from gentle to active exercise. The greatly increased work did not lead to the burning of any one nutrient in preference to another.

The weight moved (that of the subject and his clothing) was in this case 55.5 kilograms. From these data it was calculated that a consumption of energy equivalent to 0.223 kilogram-meters was required to move 1 kilogram of weight horizontally over a distance of 1 meter; and 2.924 kilogram-meters of energy to raise 1 kilogram through a vertical distance of 1 meter.

Experiments upon several other subjects gave similar results, indicating that these men who, while not trained in an athletic sense, were physically sound and thoroughly accustomed to this form of exercise, were able to perform 1 kilogram-meter of work in the ascent of the incline with an expenditure of only about 3 kilogram-meters of energy over that required at rest, so that the work was done with a mechanical efficiency of about 33 per cent. It is to be noted, however, that this applies only to walking done under the most favorable conditions, and not carried to the point of fatigue; also that robust men unaccustomed to this form of exercise showed only two thirds to three fourths as high an efficiency until after several days' practice. The energy expended in forward progression was about one thirteenth of that required to raise the body through the same distance.

On this basis it might be estimated that a man of average weight in walking one mile on level ground would do 8000–9000 kilogram-meters of work, or about the mechanical equivalent of 20 calories. If this were accomplished with an efficiency of 33 per cent, it would involve an expenditure of only 60 calories, but at an efficiency of 20 per cent 100 calories per mile would be required. These figures, while only approximate, may be helpful in estimating the food requirements of men who neither do active physical labor nor take vigorous exercise, yet move about more freely than in the so-called rest experiments already described. If, for example, it be assumed that a healthy man would require 2200 calories per day when remaining in one room, and that the total additional muscular movements of a day at business and recreation were equivalent to walking five miles on level ground, his total food requirement for the day would become 2500 to 2700 calories (36 to 39 calories per kilogram), while activity equivalent to walking ten miles on level ground would bring the total daily requirements to 2800 to 3200 calories (40 to 46 calories per kilogram).

By means of the respiration calorimeter, Atwater and Benedict have studied the question of mechanical efficiency with more accurate measurements of the energy involved than in the experiments with the Zuntz apparatus, but with a less favorable form of muscular work. For work experiments there is placed in the calorimeter chamber an ergometer, which consists of a fixed bicycle frame having in place of the rear wheel a metal disc which is revolved against a measured amount of electrical resistance, so that the mechanical effect of the muscular work is very accurately determined. The expenditure of energy involved in the performance of this work is estimated by comparing the total metabolism of a working day with that of the same man when living in the calorimeter chamber at rest. The average results obtained with three different men were as follows: —

Subject and Nature of Experiment	Energy transformed		Heat Equiv. of Work performed	Mechanical Efficiency
	Total per day	Excess over that at rest		
	calories	calories	calories	per cent
Subject E. O.				
Average 13 rest experiments (42 days)	2279			
Average 3 work experiments (12 days)	3892	1613	214	13.3
Subject J. F. S.				
Average 4 rest experiments (12 days)	2119			
Average 6 work experiments (18 days)	3559	1440	233	16.2
Subject J. C. W.				
Average 1 rest experiment (4 days) .	2357			
Average 14 work experiments (46 days)	5143	2786	546	19.6

That the efficiency here shown is inferior to that found by the Zuntz method is probably due to a number of causes. The work upon the ergometer would naturally be less familiar and therefore less economically done than that of walking. Experiments of three or four days' duration (as in the calorimeter) are not long enough to ensure a maximum of training; while on the other hand, the working time of each day and the rate at which the subject worked on the ergometer were probably both in excess of what would show the highest percentage efficiency. Four hours of work in the morning and four in the afternoon was usual on working days in the calorimeter experiments, in which for other reasons it was desired that the work be made about as active as the subject could perform without undue fatigue. Leo Zuntz has, however, shown that during such a ride there is a marked decline of efficiency. When he cycled for four successive hours at an average rate of 15 to 17 kilometers (about 9 miles) per hour, he experienced no feeling of fatigue; but his determinations showed that the expenditure of energy necessary to produce a given effect had increased about 9, 13, 10, and 23 per cent at the end of 1, 2, 3, and 4 hours respectively. This is because if the same kind of work be performed for a series of hours, auxiliary muscles are gradually brought increasingly into action, partly for the performance of the work itself, partly for the fixation of the bodily framework. These auxiliary muscles work less economically than those which first and most naturally come into play. For the same reasons there is a lower efficiency in the case of work which is from the first of too fatiguing a nature because of being either excessive or unsuitably distributed over the muscular system. Similarly auxiliary muscles come into play, and the metabolism therefore increases whenever the onset of pain enforces a restriction in the action of the muscles at work. In one case the metabolism during a march was increased about 20 per cent in consequence of an inflammation of the foot. A steep gradient or an increase in the rate of work lowers the efficiency. Thus, Leo Zuntz found that increasing his speed 2.4 times increased the metabolism 4.3 times (Magnus-Levy).

These considerations explain the difference in efficiency found in the two series of investigations above cited, and indicate that the lower figures as determined by Atwater and Benedict will doubtless more nearly represent the efficiency to be expected in ordinary muscular labor.

In practice, it is usually so difficult to estimate the mechanical equivalent of muscular work performed that, as yet, it is still often necessary to make use of such indefinite terms as "active," "severe," etc., to describe the intensity of the exertion and thus indicate in a general way the amount of work done. From the results of many work experiments with vigorous young men in the respiration calorimeter, Atwater and Benedict have derived the following estimates of the average rate of metabolism under different conditions of activity.

Man sleeping	65 calories per hour.
Man sitting at rest	100 calories per hour.
Man at light muscular exercise	170 calories per hour.
Man at active muscular exercise	290 calories per hour.
Man at severe muscular exercise	450 calories per hour.
Man at very severe muscular exercise	600 calories per hour.

By the use of these estimates the probable food requirement may be calculated very simply, as, for instance, in the following example: —

8 hours of sleep at 65 calories = 520 calories
2 hours' light exercise[1] at 170 calories = 340 calories
8 hours' active exercise at 290 calories = 2320 calories
6 hours' sitting at rest at 100 calories = 600 calories
Total food requirement for the day, 3780 calories

---

[1] Going to and from work, for example.

If the eight working hours be spent at severe muscular work, the day's food requirement would be estimated at 5060 calories; while, on the other hand, if they were exclusively spent sitting still at a desk, the estimate would be only 2260 calories per day (about 32 calories per kilogram).

Tigerstedt, in his *Textbook of Physiology*, gives estimates of food requirements for different degrees of activity, indicating the intensity of the work by means of typical occupations. According to Tigerstedt: —

2001–2400 calories suffice for a shoemaker.
2401–2700 calories suffice for a weaver.
2701–3200 calories suffice for a carpenter or mason.
3201–4100 calories suffice for a farm laborer.
4101–5000 calories suffice for an excavator.
Over 5000 calories suffice for a lumberman.

These general estimates may be useful in checking the results obtained by means of the factors of Atwater and Benedict given above.

Before leaving the subject of the relation of muscular activity to metabolism, it may be well to point out that the expenditure of energy in the muscles does not depend simply upon the muscular movements performed, but also to a considerable extent upon the degree of tension, or tone, maintained in the muscle while it is apparently at rest. That every living muscle is always in a state of tension is obvious from the fact that it gapes open if cut. It is equally evident that the degree of tension (and therefore the expenditure of energy required to maintain it) varies greatly under different conditions. The differences observed by Atwater and Benedict between the metabolism of the sleeping hours and that of the hours spent sitting up without muscular movement (65 and 100 calories respectively) are largely due to the more complete relaxation of the muscles during sleep. Thus, there is in the resting muscle a continual expenditure of energy which first takes the form of muscular tension, or tone, but ultimately appears as heat, so that the heat production, or energy metabolism, of the body at rest depends to a considerable extent upon the degree of tension which still persists in the muscles.

THE REGULATION OF TEMPERATURE

The influence of surrounding temperature upon metabolism and the relation of metabolism to the regulation of body temperature are fully discussed by Lusk in his *Science of Nutrition*, and no attempt will here be made to treat the subject systematically, but only to indicate very briefly the more important bearings upon the question of food requirement. It is evident that the maintenance of the body at a temperature above that of its ordinary environment involves a continual output of heat. This output of heat may be regulated in either of two ways: (1) By variations in the quantity of blood brought to the skin which tend to control the loss of heat by radiation, conduction, and sweating; this is called the *physical regulation.* (2) By an increase in the rate of oxidation in the body in response to the stimulus of external cold; such a change in the rate of oxidation is known as a *chemical regulation.* The extra heat production which follows the taking of food and which has been mentioned under the heading of the specific dynamic action of the foodstuffs may take the place of the "chemical regulation" and so help to protect the body from the necessity of burning material simply for the maintenance of its temperature. The presence of a layer of adipose tissue under the skin as well as the custom of covering the greater part of the external surface with clothing also tends to keep down the loss of heat to the point where "physical regulation" will suffice. Lusk cites experiments by Rubner upon a man whose metabolism was determined when kept in the same cold room but with different amounts of clothing, and observes that when the man was sufficiently clothed to be comfortable the "chemical regulation" was eliminated (*Science of Nutrition,* 2d ed., p. 106).

In general it seems probable that people warmly clothed and living (in winter) in heated houses are not called upon to exercise "chemical regulation" to any considerable extent; in other words, they probably do not burn any considerable amount of material merely for the production of heat, the heat required for the maintenance of body temperature being obtained in connection with the metabolism which is essential to the maintenance of the muscular tension and the various other forms of internal work. If, however, the body be exposed to cold it may be forced to employ "chemical regulation" with a resulting increase of the food requirement, and this will occur more readily in a thin person than in one who is well protected by subcutaneous fat.

The extra heat required in cold weather is probably obtained for the most part through the activities of the muscles. It is a matter of general experience that one instinctively exercises the muscles more vigorously in cold weather than in warm, and if one attempts to endure much cold without muscular exercise there results shivering — a peculiar involuntary form of muscular activity whose function appears to be to increase heat production through increasing the internal work of the body.

To a large extent therefore the regulation of body temperature, even under exposure to cold, is accomplished through the activity and tension of the muscles, the relations of which to metabolism and food requirement have been considered in the preceding section.

THE INFLUENCE OF SIZE AND SHAPE OF THE BODY

For different adults of the same species the energy metabolism and therefore the total food requirement as a rule increases with the size, but not to the same extent that the body weight increases; so that the requirement, though greater in absolute amount, is less per unit of body weight in the larger individual than in the smaller. The energy metabolism increases in proportion to the surface rather than the weight. Thus, Rubner collected the following data from experiments upon seven different dogs: —

No.	Body Weight Kilogram	Heat Production in Calories per Day		
		Total	Per kilogram	Per square meter
I	3.10	273.6	88.25	1214
II	6.44	417.3	64.79	1120
III	9.51	619.7	65.16	1183
IV	17.70	817.7	46.20	1097
V	19.20	880.7	45.87	1207
VI	23.71	970.0	40.91	1112
VII	30.66	1124.0	36.66	1046

Here the heat production in calories per kilogram was over twice as great in the smallest as in the largest dog, but the total metabolism was nearly proportional to the surface area throughout. Probably the most satisfactory explanation of this relation is that offered by von Hösslin, who holds[1] that the internal work and the consequent heat production in the body are substantially proportional to the two-thirds power of its volume, and since the external surface bears the same ratio to the volume, a proportionality necessarily exists between heat production and surface.

The above data obtained upon dogs show these relations strikingly because of the great differences in size, the largest dog having practically ten times the weight of the smallest.

---

[1] Quoted from Armsby's *Principles of Animal Nutrition*, p. 368.

In the human species where the variation in size among adults is much less, the discrepancies in heat production per unit of body weight are much smaller, and for most purposes it is sufficient to consider the resting metabolism of the normal adult as practically proportional to the body weight. In those cases in which the surface area is to be considered, it is usually computed from the weight as follows: —

For solids of the same shape the surface is proportional to the two-thirds power of the volume; and if the density is also constant, the surface will be proportional to the two-thirds power of the weight. Hence, if S represents the surface, W the weight, and C a constant dependent upon the shape and density of the solid, we have $S = C\sqrt[3]{W^2}$ in which (according to Meeh) the value of C for man is 12.3.

The assumption that the form is constant in the same species is of course not strictly correct. A tall, thin man exposes more surface for a given weight than does a short, stout man. Normal men may vary as much as ten per cent from the average in the relation of surface to weight. The thin man, besides having a greater surface, also differs from the stout man in that a larger percentage of his body is actual protoplasm. Since the metabolism of the body depends upon its weight of protoplasm (active tissue) rather than its total weight, we have here an important reason for believing that the food requirement will be greater in a tall, thin man than in a shorter and fatter man of the same weight. Von Noorden tested this question by observing the metabolism (for one day without food) of two men of different build but nearly the same weight. The results were as follows: —

1st man, thin and muscular, weight 71.1 kilograms; 2392 calories = 33.6 calories per kilogram.

2d man, stout, weight 73.6 kilograms; 2136 calories = 29.0 calories per kilogram.

For the great majority of persons, however, we may proceed in dietary calculations as if the form and composition of the body were constant without introducing serious error.

THE INFLUENCE OF AGE AND SEX

From the fact that in animals of the same species, but of different size, the heat production is proportional to the surface rather than to the weight, it would follow that children must have a greater food requirement per unit of weight than adults. By observation it is found that the heat production (and therefore the food requirement) is not only greater per unit weight, but is also somewhat greater per unit of surface, in the child than in the adult. The total metabolism at rest is approximately half as great in a child of 2 years weighing 25 pounds as in an adult of six times the weight. Here the food equivalent per unit of weight is three times as great for the young child as for the resting man.

The following data, adapted from Tigerstedt, illustrate the relative intensity of metabolism at different ages: —

SUBJECT	KILOGRAMS	METABOLISM PER DAY		
		Total, calories	Per kilogram, calories	Per sq. meter, calories
Child, 2 weeks . .	3.2	258	81	1000
Child, 10 weeks . .	5.0	420	84	1200
Child, 10 years . .	23.2	1462	63	1499
Man at rest . . .	70.0	2240	32	1071

According to these data the metabolism per unit of weight is greatest in infancy and declines steadily with increasing size; but calculated per unit of surface, it is distinctly less in infancy than in children of 10 years, probably because the infant sleeps a greater proportion of the time and the tension (tonus) of its muscles is not yet fully developed.

Camerer made a large number of observations upon the food consumption of boys of different ages with the following average results: —

AGE, YEARS	WEIGHT, KILOGRAMS	METABOLISM		
		Total, calories	Per kilogram, calories	Per sq. meter, calories
5–6	18	1386	77	1680
7–10	24	1488	62	1440
11–14	34	1598	47	1250
15–16	53	2120	40	1220
17–18	59	2242	38	1200

Magnus-Levy and Falck observed the oxygen consumption of subjects of various ages while lying at complete rest and fasting. The following are typical of the results obtained with boys: —

AGE	WEIGHT	OXYGEN CONSUMPTION		
		Total	Per kilogram	Per kilogram compared with adults
years	kilograms	cc.	cc.	per cent
2½	11.5	112.2	9.76	285
6	18.4	139.9	7.61	223
10	30.6	192.0	6.28	184
14	36.1	188.1	5.21	152
16	57.5	235.6	4.10	120
22–43	66.7	227.9	3.41	100

Sonden and Tigerstedt compared the metabolism of men and boys by determining the carbon dioxide production while sitting up and at only a short time after a meal. Under these conditions (quite different from those obtaining in the experiments of Magnus-Levy and Falck) they obtained results as follows: —

AGE	WEIGHT	CARBON DIOXIDE PER HOUR		
Years	Kilograms	Total	Per kilogram	Per square meter
9⅔	28	33	1.21	29.9
10½	30	33	1.11	28.2
11½	32	34	1.06	27.5
12½	34	34	1.00	26.5
14	45	45	1.00	27.6
14½	45	44	0.96	26.7
15½	51	42	0.81	23.5
17	56	45	0.81	24.2
19½	60	43	0.72	21.8
23	65	38	0.58	18.6
25	68	38	0.57	18.5
35	68	35	0.52	16.9

Here the intensity of metabolism as measured by the carbon dioxide production per unit of surface as well as per unit of weight decreases steadily with increasing age from the nine-year-old child to the adult. In these cases the absolute production of carbon dioxide per hour (and therefore presumably the food requirement per day) was greater between the ages of 14 and 19 than with the adult of considerably greater weight. This may be explained in part by the rapidity of growth, which would involve increased general metabolism and in part by the higher muscular tension of boys of this age as compared with most men.

The results of Magnus-Levy and Falck and those of Sonden and Tigerstedt point to the same conclusions except that the latter found a more intense metabolism in boys of 14 to 19 years than the former, probably on account of the fact that their observations were made upon boys fully fed and in a higher state of muscular tone. They found in boys a carbon dioxide production about 40 per cent higher than in girls of the same weight, which also was attributed to the greater muscular tension and restlessness of the boys. This difference is not perceptible in the data obtained by Magnus-Levy and Falck with children fasting at complete rest nor in those of Sonden and Tigerstedt for individuals over 30 years of age. In general, it appears that the food requirements of men and women of equal activity are in proportion to their body weights. Women on the average weigh about 0.8 as much as men, and it is commonly assumed that if equally active their food requirements will stand in the same proportion.

In computing the results of dietary studies and in apportioning the food of a family to its different members it has become customary to make use of some such conventional factors as the following: Taking the food requirement of a man as 1, that of women and of boys 14–17 years old is taken as 0.8; of girls, 14–17 years old, 0.7; children of 10–13 years, 0.6; of 6–9 years, 0.5; of 2–5 years, 0.4; of less than 2 years, 0.3. These factors are based upon the food requirements of men engaged in moderately active work (in the sense in which Voit and Atwater have used the expression), and if applied to the family of a business or professional man would probably result in too low an estimate of the food requirements of the children. The food requirement of a man varies so greatly, according to occupation, that it seems hardly logical to make this a basis for estimating the dietary needs of a family. It is perhaps more satisfactory to say that a woman requires the same number of calories per kilogram (or per pound) of body weight as does a man of equal activity; and that children of normal size, development, and activity will require about as follows: —

Boys of 14–17 years	2500–3000 calories.
Girls of 14–17 years	2200–2600 calories.
Children of 10–13 years	1800–2200 calories.
Children of 6–9 years	1400–2000 calories.
Children of 2–5 years	1200–1500 calories.
Children of 1–2 years	900–1200 calories.

On account of the differences in size among children of the same age, it is desirable to give the food requirement in terms of body weight as well as of the average individual. Approximate estimates on this basis are as follows: —

Under 1 year	100	calories per kilogram.
1–2 years	100–90	calories per kilogram.
2–5 years	90–80	calories per kilogram.
6–9 years	80–70	calories per kilogram.
10–13 years	70–60	calories per kilogram.
14–17 years	60–45	calories per kilogram.

The fuel value of children's dietaries should always be liberal in order to provide amply for muscular activity and for a more intense general metabolism than that of the adult, as well as because throughout the period of growth the food must supply a certain amount of material to be added to the body in the form of new tissue in addition to all that which is oxidized to support metabolism.

With the elderly, on the other hand, the intensity of metabolism is diminished, and the body not only needs less food, but has less ability to deal with excess, so that the food requirement gradually declines and may become 10, 20, or 30 per cent lower than in middle life. Ekholm found in the average of 10 experiments upon persons of 68 to 81 years of age an average metabolism of 902 calories per square meter of surface, whereas the usual estimate for the adult is 1071 calories.

Von Noorden allows for the normal nutrition of young to middle-aged men and women: —

At complete rest	30–35	calories per kilogram per day.
With light exercise	35–40	calories per kilogram per day.
With moderate exercise	40–45	calories per kilogram per day.
With hard muscular labor	45–60	calories per kilogram per day.

He states that for children these figures are to be raised about one third and for the aged they are to be lowered about one fourth.

Remembering that children should normally be reckoned as taking at least moderate exercise, while the aged will probably be either at rest or with only very light exercise, it will be seen that as regards the influence of age Von Noorden's estimate and that above given are in substantial agreement.

In the following table are given the estimated heights, weights, and food requirement of an average man at different ages, the figures for height and weight being based upon the data given by Hill for males of the Teutonic races (*Recent Advances in Physiology and Biochemistry*, p. 284): —

AGE, YEARS	HEIGHT		WEIGHT		FOOD REQUIREMENT WITHOUT MUSCULAR LABOR	
	Meters	Feet and inches	Kilos	Pounds	Total per day, calories	Per kilogram per day, calories
1	0.70	2 : 3	10	22	1000	100
5	1.00	3 : 3	17	37	1400	82
10	1.28	4 : 2	26	57	1800	70
15	—	—	50	110	2800	56
20	1.71	$5:7^{+}$	65	143	3000	46
30	1.72	$5:8^{-}$	69	152	2750	40
40	1.71	$5:7^{+}$	70	154	2500	36
60	—	—	65	143	2200	34
80	—	—	60	132	1600	27

These estimates of food requirements are intended to represent approximate averages of available data and to allow for such exercise as would naturally be taken at the age, exclusive of anything which would ordinarily be considered physical labor. They thus illustrate in an approximate way the rate at which the amount of food required for healthy maintenance per unit of body weight declines from infancy to old age.

REFERENCES

Armsby. Principles of Animal Nutrition, Chapters 6 and 11.

Atwater. Neue Versuche ueber Stoff- und Kraft-wechsel. *Ergebnisse der Physiologie*, 3 (1904).

Atwater, Benedict, *et al.* Respiration Calorimeter Experiments, Bulls. 44, 63, 69, 109, 136, 175, Office of Experiment Stations, U. S. Dept. Agriculture.

Benedict. The Influence of Inanition on Metabolism. Publication No. 77, Carnegie Institution, Washington (1907).

Benedict and Carpenter. The Influence of Muscular and Mental Work on Metabolism and the Efficiency of the Human Body, as a Machine. Bull. 208, Office of Experiment Stations, U. S. Dept. Agriculture (1909).

Hill. Recent Advances in Physiology and Biochemistry, Chapters 8, 9, 10, 15.

Hutchison. Food and Dietetics, Chapters 2 and 3.

Jaquet. Der respiratorische Gaswechsel. *Ergebnisse der Physiologie*, 2, 457–574.

Lusk. Elements of the Science of Nutrition.

Nagel. Handbuch der Physiologie des Menschen, pp. 375–480.

Rubner. Die Gesetze der Energieverbrauches bei der Ernahrung.

Von Noorden. Metabolism and Practical Medicine, Vol. I, pp. 208–282.

CHAPTER VII

PROTEIN METABOLISM AND THE PROTEIN REQUIREMENT

ANIMAL cells under all conditions of life are constantly breaking down proteins into simpler substances which the body eliminates. This breaking down or "katabolism" of protein does not stop either in fasting or under the most liberal feeding with fats and carboyhdrates, so that there is always a need for protein whatever the supply of other food.

The protein metabolism differs widely from the total metabolism in the conditions which determine its amount, for the protein metabolism is governed mainly by the food, and to only a slight extent by the muscular exercise; whereas the total metabolism is governed mainly by the amount of exercise, and to only a slight extent by the food. By giving food rich in fats and carbohydrates but poor in protein, the protein metabolism of a healthy man can easily be brought to 50 grams per day, and then, by changing to a diet rich in protein, it may be increased to 150 or even 200 grams per day; *i.e.* the rate of protein metabolism can be increased 200 to 300 per cent in a few days by a change in diet alone, all other conditions remaining the same.

Since the diet has such a great influence upon the amount of protein metabolized, it might be expected that the essential protein metabolism could be observed best in fasting. But in fasting, the energy metabolism of the body is only a little lower than with food; the amount of combustion continues nearly the same although only body material is available; and since the body must consume so much of its own substance as fuel in fasting, there is always a chance that the protein may be burned simply as fuel and thus that the protein metabolism in fasting may be greater than that which represents the needs of the body when properly fed, while on the other hand it may be abnormally low through the effort of the body to adjust itself to the abnormal condition.

The amount of protein broken down in fasting is much influenced by the previous habit as regards protein consumption, and by the metabolism of stored glycogen and stored fat.

The direct effect of the habit of protein metabolism established by the feeding of the days preceding the fast is shown in the following data obtained by Voit in experiments upon a dog weighing 35 kilograms: —

Influence of Previous Diet on Nitrogen Elimination in Fasting (Voit)

	Grams of Urea per Day Food of Preceding Days		
	Meat 2500 grams	Meat 1500 grams	Bread
Last day with food	180.8	110.8	24.7
First day of fasting	60.1	29.7	19.6
Second day of fasting	24.9	18.2	15.6
Third day of fasting	19.1	17.5	14.9
Fourth day of fasting	17.3	14.9	13.2
Fifth day of fasting	12.3	14.2	12.7
Sixth day of fasting	13.3	13.0	13.0

The influence of the metabolism of the previously stored glycogen upon the amount of protein metabolized in fasting is well illustrated by the following three experiments with one individual:[1] —

Experiment	First Day of Fasting		Second Day of Fasting	
	Glycogen metabolized	Nitrogen eliminated	Glycogen metabolized	Nitrogen eliminated
	grams	grams	grams	grams
I	181.6	5.84	29.7	11.04
II	135.3	10.29	18.1	11.97
III	64.9	12.24	23.1	12.45

It will be seen that the nitrogen output was less when there was available for metabolism a considerable supply of previously stored glycogen. Since most of the stored glycogen is used up on the first day of fasting, its influence upon the protein metabolism is short-lived as compared with that of the stored fat.

The influence of the available supply of body fat upon the protein metabolism of fasting is shown by the following observations of Falck on the protein metabolism of two fasting dogs — the one lean, the other fat.

A rise in protein metabolism of the lean dog after the 8th day showed that from this time he used protein largely as fuel — so largely that the results were fatal in 25 days of fast-

---

[1] Benedict, *Influence of Inanition on Metabolism.* Carnegie Institution of Washington, 1907.

Falck's Lean Dog		Falck's Fat Dog	
Katabolized on days	Grams protein per day	Katabolized on days	Grams protein per day
1–4	26.1	1–6	29.9
5–8	24.6	7–12	26.7
9–12	33.9	13–18	26.1
13–16	38.0	19–24	22.3
17–20	31.9	25–29	20.0
21–24	3.9	30–34	16.8
On the 25th day the dog died.		35–38	15.7
		40–44	13.0
		45–50	13.6
		55–60	12.2
		Dog still healthy after 60 days.	

ing. The fat dog, having plenty of other fuel in the form of fat, used protein to a much smaller extent, so that he was able gradually to accommodate himself to a lower level of protein metabolism and to endure a fast of 60 days' duration.

The professional faster, Succi, starting with a good store of body fat, fasted 30 days with the following results: —

Five days on ordinary food	101.4 grams protein per day.
1– 5th days fasting	80.4 grams protein per day.
6–10th days fasting	53.1 grams protein per day.
11–15th days fasting	36.2 grams protein per day.
16–20th days fasting	33.1 grams protein per day.
21–25th days fasting	29.3 grams protein per day.
26–30th days fasting	33.3 grams protein per day.

Since Succi's health remained good throughout his fast, it might be thought that the necessary waste of protein from his body was not greater than the smallest figure found for any period — in this case about 30 grams per day. On the other hand, it may well be supposed that, since the body increases its protein metabolism to an abnormally high rate under influence of excessive protein feeding, so under the influence of fasting the body may be able to adjust itself to an abnormally low rate of protein metabolism; and the fact that the protein metabolism continues to diminish for such a long time in fasting gives weight to the supposition that the body is here gradually adapting itself to an abnormal condition. One might assume that in the first or second five-day period of Succi's fast the effect of previous feeding might have worn off sufficiently, and the conditions not yet have become abnormal as the result of the fasting, in which case the expenditure of protein during one of these periods would represent his normal requirement. Any such assumption must, however, be more or less arbitrary.

Of interest in this connection are the data of nitrogen excretion obtained by Benedict in his recent study of the metabolism of several subjects during fasting periods of 2 to 7 days' duration. There were great irregularities in the results for the first day, probably due in large part to the previous conditions of feeding. The average of all observations for the second day of fasting shows 12.8 grams of nitrogen corresponding to 80 grams of protein, and for all observations of subsequent days 11.8 grams of nitrogen or 74 grams of protein, whereas Succi metabolized during the first to fifth days of his fast 80 grams and during the sixth to tenth days 53 grams of protein per day. Such data of protein metabolism during fasting (of which many more might be cited) undoubtedly throw light upon the requirement, but, as suggested above, they may be interpreted in such different ways as to make it doubtful how far they should be accepted as indicating the amount of protein which the food should normally furnish.

An idea of the *normal dietary need* is best obtained by determining experimentally how much protein must be contained in the daily food in order to keep the body in protein (or nitrogen) equilibrium.

The estimation of the nitrogen balance has already been referred to as one factor in the determination of the total food requirement by means of metabolism experiments; and it has been shown that the balance may be found either by comparing the total intake with the total output, or by comparing the amount absorbed with the amount katabolized and eliminated through the kidneys.[1] A plus balance indicates a storage of nitrogen and therefore of protein in the body; a minus balance indicates a loss of body protein. When the balance is 0, or so near 0 as to be within the

---

[1] Theoretically the elimination through the skin should also be determined and included in the calculation; practically this is usually neglected unless on account of warm weather or vigorous exercise the subject has perspired profusely. For data on nitrogen in perspiration see Benedict, *Journal of Biological Chemistry*, 1, 263 (1906).

limits of experimental error, the body is said to be in *nitrogen (or protein) equilibrium.*

The healthy full-grown body tends to establish nitrogen equilibrium by adjusting its rate of protein katabolism to its food supply within wide limits. The time required by the body for this adjustment depends mainly upon the extent to which the diet is changed.

The following observations by Von Noorden illustrate the establishment of equilibrium after only moderate changes in the diet.

A young woman weighing 58 kilograms (128 pounds) at rest in bed was given food furnishing protein, 106 grams; fat, 71.6 grams; carbohydrate, 200 grams; fuel value, 1860 calories per day.

Total nitrogen in food	16.96 grams
Lost in digestion	.94 grams
Absorbed	16.02 grams

Katabolized and Eliminated through Kidneys		Balance
	grams	grams
1st day	18.2	− 2.18
2d day	17.0	− 0.98
3d day	15.8	+ 0.22
4th day	16.0	+ 0.02
5th day	15.7	+ 0.32

Here there was practical equilibrium after the second day. The small amount of nitrogen represented as stored on the third, fourth, and fifth days was very likely lost through the skin. This was a case of adjustment to a lowered protein intake, for the food previously taken, although not accurately observed, was known to have been rich in protein.

Another experiment was made by Von Noorden with the same patient to show the time required to reach equilibrium after increasing the intake of protein. In this case the food furnished 2030 calories per day and the nitrogen balance was as follows: —

DAY	NITROGEN IN FOOD	LOST IN DIGESTION	ABSORBED	KATABOLIZED	BALANCE
	grams	grams	grams	grams	grams
1	14.40	0.70	13.70	13.60	+ 0.10
2	14.40	0.70	13.70	13.80	− 0.10
3	14.40	0.70	13.70	13.60	+ 0.10
4	20.96	0.82	20.14	16.80	+ 3.34
5	20.96	0.82	20.14	18.20	+ 1.94
6	20.96	0.82	20.14	19.50	+ 0.64
7	20.96	0.82	20.14	20.00	+ 0.14

Here where the amount of protein fed was increased from 90 to 130 grams without change in the total fuel value of the diet, the body reached equilibrium on the fourth day.

It is apparent therefore —

(1) That the body tends to adjust its protein katabolism to its protein supply.

(2) That when the body is accustomed to a certain rate of protein katabolism, it requires an appreciable length of time to adjust itself to a higher or lower rate.

Hence the rate of protein katabolism on any given day will depend in part upon the protein intake for that day and in part upon the rate of katabolism to which the body has been accustomed upon the preceding days. When the protein supply is constant for a few days, the effect of previous habit disappears and equilibrium is established as in the above cases. When the protein supply varies from day to day, the katabolism for each day is influenced by both the factors, with the net result that the elimination equals the intake when averaged for a sufficiently long period, although the data for any particular day might show a distinct gain or loss.

A transitory loss of nitrogen from the body is apt to be due simply to the taking of less than the usual amount of protein food, but a persistent loss indicates that the diet is insufficient, either in total food (calories) or in protein, to enable the usual adjustment to take place.

A transitory storage of nitrogen in the body may occur as the result of an increase either of the protein or of the total fuel value of the food, but a persistent storage occurs, as Von Noorden has pointed out, only under the following conditions: —

(1) In the growing body (or in pregnancy) where new tissue is being constructed.

(2) In cases where increased muscular exercise calls for enlargement of the muscles.

(3) In cases where, owing to previous insufficient feeding

or to wasting disease, the protein content of the body has been more or less diminished and consequently any surplus available is utilized to make good the loss.

It has already been shown that the fuel value of the food has a great influence upon the protein metabolism by determining whether or not the body must draw upon its own tissues for fuel. That the rate of protein katabolism can be decreased by the feeding of carbohydrates or fats was known before the development of our present conceptions of the energy metabolism, and this property of the carbohydrates and fats was designated their "protein sparing" or "protein protecting" power. Thus the loss of protein which occurs in an insufficient diet may be diminished or even stopped by adding carbohydrates or fat to the food; and if carbohydrate or fat be added to the diet of a man in nitrogen equilibrium, there results a temporary decrease in nitrogen output with a corresponding storage of protein in the body. For an account of the earlier experiments on this subject, especially those of Voit and Rubner upon dogs, the reader is referred to Lusk's *Elements of the Science of Nutrition.* Only some of the more important of the experiments upon men will be described here.

Lusk,[1] experimenting upon himself, showed the susceptibility of the protein metabolism to the sudden withdrawal of carbohydrate food. In one experiment a liberal mixed diet containing 20.55 grams of nitrogen was taken until the body was nearly in nitrogen equilibrium, and then, without any

---

[1] *Zeitschrift für Biologie,* **27**, 459 (1890).

other change, 350 grams of carbohydrate were withdrawn from the daily food. On the first day the body protein was largely protected by the carbohydrate previously stored in the body in the form of glycogen, but on the second day the nitrogen metabolism had risen from 19.84 to 27.00 grams per day. In another experiment, upon a diet containing less protein, withdrawal of carbohydrate increased the nitrogen excretion from 11.44 to 17.18 grams per day.

From the data of these and three similar experiments tabulated by Von Noorden it appears that the extra protein metabolized as the result of withdrawal of carbohydrate furnished 7 to 17 per cent of the energy of the carbohydrate withdrawn, so that if there was no change in the energy metabolism, the body must have obtained the other 83 to 93 per cent of the deficit from combustion of its own fat. In these cases, as in the fasting experiments, the loss of body protein was less in those subjects having a good store of body fat than in those which were thin.

Kayser[1] compared the efficiency of carbohydrates and fats as sparers of protein by observing the effect upon the nitrogen balance of replacing the carbohydrates of the food by such an amount of fat as would furnish the same number of calories, and then after three days resuming the original diet. The observer, who served as his own subject, was 23 years old,

---

[1] This experiment and that of Tallquist which follows are given somewhat fully, as they illustrate well the methods and results of investigations based mainly upon the question of nitrogen equilibrium.

of good physique, with a small store of body fat, and weighed 67 kilograms. In the first and third periods he ate meat, rice, butter, cakes, sugar, oil, vinegar, and salad. In the second period the diet was changed so as to consist of meat, eggs, oil, vinegar, and salad, so that practically all the carbohydrate was withdrawn and replaced by fat. The two diets had practically the same fuel value and protein contents. The results of this experiment are shown in the following table: —

KAYSER'S TABLE SHOWING NITROGEN BALANCE WHEN FEEDING ISODYNAMIC QUANTITIES OF CARBOHYDRATE AND FAT

DAY	INTAKE				OUTPUT TOTAL NITROGEN	NITROGEN BALANCE
	Total Nitrogen	Fat	Carbohydrates	Fuel value		
	grams	grams	grams	calories	grams	grams
1	21.15	71.1	338.2	2590	18.66	+ 2.46
2	21.15	71.8	338.2	2596	20.04	+ 1.11
3	21.15	71.8	338.2	2596	20.59	+ 0.56
4	21.31	71.8	338.2	2600	21.31	± 0.00
5	21.51	221.1	0	2607	23.28	− 1.77
6	21.55	217.0	0	2570	24.03	− 2.48
7	21.55	215.5	0	2556	26.53	− 4.98
8	21.10	70.4	338.2	2581	21.65	− 0.55
9	21.10	70.4	338.2	2581	19.20	+ 1.89
10	21.10	70.4	338.2	2581	19.65	+ 1.45

It is evident from the nitrogen balance of the first period that the amount of protein in the food was here greater than necessary, but that equilibrium was fully established in four days. On substituting fat for carbohydrate there is a marked increase of protein katabolism with corresponding loss of nitrogen from the body, and what is especially noteworthy, there is no evidence of any tendency to regain equilibrium during this period, but on the contrary the loss of nitrogen became greater each day the fat diet was continued; whereas, upon returning to the mixed diet, not only was the loss of protein stopped, but the body almost at once began replacing the protein it had lost, although the nitrogen and calories of the food were practically unchanged.

Tallquist[1] compared the protein-protecting powers of isodynamic amounts (amounts having equal energy value) of carbohydrates and fats when only a part of either was replaced by the other. The subject was Tallquist himself, a man 28 years old, in good health, and weighing about 80 kilograms. The experiment was performed in Rubner's laboratory, and the diet contained such an amount of total food as was estimated by Rubner to be just about sufficient to supply the energy requirements of the body, viz. 36 calories per kilogram per day. The experiment covered 8 days divided into two equal periods. In the first four-day period the diet was rich in carbohydrates, in the second period it was rich in fats. An excellent feature of this experiment is that there was no change in the nature of the protein fed. All foods furnishing any significant amount of nitrogen were the same in the two periods of the experiment.

[1] *Archiv für Hygiene*, 41, 177.

The food of the first period consisted of meat, milk, butter, bread, sugar, coffee, beer. That of the second period contained the same amounts of meat, milk, bread, coffee, and beer, but less sugar, more butter, and some bacon. The same amount of salt was taken in each case. The principal data of the experiment may be summarized as follows: —

Day	Intake					Output Nitrogen	Nitrogen Balance
	Total nitrogen	Fat	Carbohydrate	Alcohol	Fuel value		
	grams	grams	grams	grams	calories	grams	grams
1	16.27	44.0	466	18.5	2867	17.11	− 0.84
2	16.27	44.0	466	18.5	2867	14.40	+ 1.86
3	16.27	44.0	466	18.5	2867	14.65	+ 1.62
4	16.27	44.0	466	18.5	2867	15.58	+ 0.69
5	16.08	140.0	250	19.0	2873	17.66	− 1.58
6	16.08	140.0	250	19.0	2873	17.32	− 1.24
7	16.08	140.0	250	19.0	2873	15.94	+ 0.14
8	16.08	140.0	250	19.0	2873	16.22	− 0.14

Here only a part of the carbohydrate, about half of that present, and an amount representing about one third of the total fuel value of the diet, was replaced by fat. The change evidently had an unfavorable influence upon the nitrogen balance, but the loss of body protein was relatively small and continued only 2 days.

Landergren [1] also found that it is only when the carbohy-

---

[1] *Skandanavisches Archiv für Physiologie*, 14, 112 (1903); Abstract *Experiment Station Record*, 14, 1099.

drate of the diet is entirely replaced by fat that the comparison is so strikingly against the fat as it seemed to be in Kayser's experiment. In Landergren's experiments the condition studied was not one of approximate equilibrium, but rather of nitrogen hunger. He fed men diets of adequate fuel value but containing only about one gram of nitrogen daily, and found that by four days of such feeding the urinary nitrogen may be reduced to about 4 grams per day. In one experiment in which the daily food contained 750 grams of carbohydrates the urine of the fourth day showed 3.76 grams of nitrogen. The carbohydrate was then entirely replaced by fat, with the result that the following days' urines contained respectively 4.28, 8.86, and 9.64 grams of nitrogen. Evidently in the case of a man accustomed to feeding largely upon carbohydrates the complete replacement of carbohydrate by fat leads to a loss (or an increased loss) of body protein. But by subsequent experiments of the same series it was found that a diet containing nearly half its calories in carbohydrate, and nearly half in fat, had apparently the same protein-sparing power as one made up almost exclusively of carbohydrates.

The explanation offered by Landergren is that when the diet supplies no carbohydrate, the glycogen of the body soon becomes exhausted and the carbohydrate needed to keep up the constant glucose content of the blood is obtained largely by the breaking down of proteins, which presumably yield carbohydrate in metabolism more readily than do the fats.

Atwater[1] compared the protein-sparing power of carbohydrate and fat in experiments in which the subject, an athletic young man of 76 kilos, performed a considerable amount of work. The experiments were carried out in the respiration calorimeter and covered in all 15 experimental days upon a diet rich in carbohydrates, arranged in four periods which were alternated with four equal periods in which the diet was rich in fats. The change from carbohydrate to fat and *vice versa* involved about 2000 calories or nearly half the fuel value of the diet. The average results per day for the entire series of experiments were as follows: —

	On Diet Rich in Carbohydrates	On Diet Rich in Fat
Available calories in food	4532	4524
Heat equivalent of work performed, calories	558	554
Nitrogen in food, grams	17.5	17.1
Nitrogen in feces, grams	2.5	1.7
Nitrogen in urine, grams	16.6	18.1
Nitrogen balance, grams	−1.6	−2.7

Here again there is a difference in favor of the carbohydrate, but one which is so small as to be of almost no practical significance.

It appears that the carbohydrate of the food cannot be entirely replaced by an equal number of calories in the form

---

[1] *Ergebnisse der Physiologie*, 3, Part I, p. 497.

of fat without an unfavorable effect upon the nitrogen balance, but that when the replacement is such as to affect not over one half of the total calories, the difference in protein-sparing power is but slight, and that ordinarily on a normal mixed diet the same number of calories has practically the same protein-sparing effect whether taken mainly as carbohydrate or mainly as fat. Hence, in considering the influence of the fuel value of the food upon the amount of protein katabolized, it is usually sufficient to know the total calories without regard to the extent to which they are derived from carbohydrates or from fats.

Different observers investigating the protein requirement by means of experiments upon nitrogen equilibrium have reached very different conclusions, largely because they have used diets of very different fuel values. Thus, Neumann with a diet furnishing 2780 calories required about 80 grams of protein, while Klemperer, whose food had a fuel value of 5600 calories, was able to maintain equilibrium on about 25 grams of protein per day. Ordinarily there could be no advantage in thus reducing the protein katabolism to an abnormally low level by the use of an enormous excess of fats and carbohydrates.

For practical purposes, therefore, we may eliminate the question of how far the protein metabolism can be restricted by the use of excessive amounts of other food and reduce the problem to this: When the total food is properly adjusted to the muscular activity of the subject so that there is ample but not excessive fuel to meet all the energy requirements, how much protein must the daily food contain in order to keep the body in nitrogen equilibrium?

A number of investigations bear more or less directly upon this problem. Among the earliest and most striking of these is that of Siven, who, experimenting upon himself (body weight 60 kilograms), found that with a diet furnishing 41.4 calories per kilogram per day he could maintain equilibrium upon 39 grams of protein, while with the same fuel value and 28 grams of protein or with 43 calories per kilogram and only 25 grams of protein per day, the loss of body nitrogen, though persistent, was small — only 0.3 to 0.4 gram of nitrogen, corresponding to a loss of 2 or 2.5 grams of protein per day. Undoubtedly Siven's protein requirement was less than that of most men.

The most extended investigation on the protein requirements of men receiving food of normal fuel value is that of Chittenden.[1]

The general plan followed by Chittenden was to have each man reduce his protein food gradually without any great change in his other habits. This gradual reduction of the protein intake was continued sometimes for several weeks, sometimes for several months, before any comparison of intake and output was attempted. During this long preliminary period upon a restricted diet there was in almost every case

---

[1] See Chittenden's *Physiological Economy in Nutrition* and *Nutrition of Man.*

a loss of weight, and from many previous observations[1] under similar conditions we may safely assume that there was a considerable loss of body protein. But after a sufficiently long period of loss, there was usually a tendency for the body weight and the rate of protein metabolism (measured by the amount of nitrogen eliminated through the kidneys) to become fairly constant, indicating that the body had adjusted itself to the new conditions. When this point had been reached, a nitrogen balance experiment was made, and the balance of intake and output determined by weighing and analyzing for nitrogen all food consumed and all nitrogenous material given off from the body except that in the perspiration. At the same time the fuel value was calculated by means of figures taken from standard tables. Assuming that these calculated fuel values are approximately correct, it appears that the total food consumed by Chittenden's subjects was in general about equal to the usual estimates of the food requirements for similar occupations. In a considerable proportion of these balance experiments the subjects were found to be too far out of nitrogen equilibrium to make the data useful from our present point of view. The results of nine experiments, in which the fuel value was known and there was a fairly close approach to nitrogen equilibrium,[2] are given in the following table, which

---

[1] Neumann, for example, in 35 days on insufficient diet lost 96 grams of nitrogen corresponding to 600 grams of protein, equivalent to about 2.5 kilograms (5.5 pounds) of muscle tissue.

[2] A small plus balance sufficient to cover the probable loss through

shows results for individual subjects whose food contained amounts of nitrogen varying from 40 to 72 grams of protein per day: —

TOTAL FOOD, PROTEIN, AND NITROGEN BALANCE PER DAY (CHITTENDEN)

SUBJECT	WEIGHT	FUEL VALUE	PROTEIN	NITROGEN BALANCE
	kilograms	calories	grams	grams
C.	57	1613	40.0	+ 0.165
M.	70	2448	53.2	+ 0.38
U.	61	2068	55.2	+ 0.158
Be.	61	2152	63.1	+ 0.34
O. (I)	64	2509	59.4	+ 0.509
O. (II)	64	2840	53.9	− 0.292
Br.	60	2840	54.2	+ 0.152
D.	62	2450	55.2	+ 0.089
S.	75	2809	71.7	+ 0.339

As Chittenden's subjects varied considerably in size and most of them at the time the experiments were completed were below average weight, the results should perhaps be calculated to the basis of a man weighing 70 kilograms (154 pounds) for comparison with each other and with other data. On this basis the experiments indicate that men of average weight would be able to maintain equilibrium on from 49 to 72 grams of protein per day under the conditions of these experiments.

Chittenden bases his estimate of the protein requirement,

the skin is quite as good evidence of equilibrium as a result in which the nitrogen of the food is exactly balanced by that of the feces and urine.

not only upon the nitrogen balances, but also upon the amounts of nitrogen observed to be eliminated daily through the kidneys over long periods in which the body may or may not have been in complete equilibrium, but in which health and efficiency were certainly maintained. The first men to serve as subjects in this investigation were Chittenden himself and his associates, who all continued their professional work and either reported no effect or felt benefited by the change to the low protein diet. Similar experiments were then made upon a squad of soldiers, who during the test were quartered near the laboratory and were given regular exercise in the gymnasium in addition to their light duties about their quarters. These men showed marked improvement in physical condition during the test, probably due in part to their more regular habits of life and their gymnastic instruction. In order to eliminate this factor while still applying the low protein diet to young and physically active men, the investigation was extended to cover a group of university athletes who were already well trained and in prime physical condition at the beginning of the dietary experiments. These athletes not only maintained, but in many cases improved, their gymnastic records while on the low protein diet, one of them winning an all-round gymnastic championship during the time. In a recent summary[1] Chittenden states that his data "are seemingly harmonious in indicating that the physiological needs of the body are

---

[1] *Nutrition of Man*, pp. 226, 272.

fully met by a metabolism of protein matter equal to an exchange of 0.10 to 0.12 grams of nitrogen per kilogram of body weight per day, provided a sufficient amount of non-nitrogenous foods is taken to meet the energy requirements of the body." This would correspond to 44 to 53 grams of protein per day for a man of average weight, and Chittenden considers that for such a man an allowance of 60 grams of protein per day should certainly be entirely adequate.

It may be recalled that this allowance is based upon observations on men, some of whom were not in equilibrium and all of whom had already been on the restricted diet for some weeks or months and had doubtless lost body protein in coming to this low level of protein metabolism. It follows that to maintain nitrogen equilibrium *with the full store of protein which is carried on an ordinary diet*, must necessarily call for a somewhat larger amount of protein than was used in Chittenden's experiments, probably in the neighborhood of 75 grams of protein per man per day.

INFLUENCE OF MUSCULAR EXERCISE

At one time it was supposed that muscular power was generated at the expense of muscle substance, and this, of course, necessitated the belief that muscular work always increased protein katabolism. Now that we know that the muscles work quite as well at the expense of carbohydrates and fats as of protein, the conclusion that muscular work necessarily increases the katabolism of protein is far from inevitable. It is only necessary to observe the effects of regular muscular exercise, either in athletic training or in normal labor, to see that the muscles do not waste away when thus used, but rather tend to become larger. Such a growth of the muscles tends toward a storage rather than a loss of protein. Usually, however, muscular work also results in increased appetite, and it is difficult to separate the effects of the exercise from those of the extra food.

Whether muscular work acts directly to increase the amount of protein katabolized in the body can only be determined by experiments in which sufficient extra fats and carbohydrates are fed to furnish the extra fuel required on the working days. But since fats and carbohydrates are "protein sparers," the feeding of these in any excess over just what is necessary to provide for the increased energy requirement would tend to decrease the katabolism of protein and counteract any effect which the muscular work might otherwise have in increasing protein katabolism. Hence, in order to show conclusively whether muscular work of itself has any influence upon the protein metabolism, it would be necessary to determine the mechanical efficiency of the man, then to bring him into equilibrium with an amount of food just sufficient for his needs, and finally to have him perform a measured amount of work at the same time adding to his diet an amount of fats and carbohydrates just sufficient to furnish the extra energy required for the work performed. Such elaborate experiments have not yet been made, but we have sufficient data to show that they are not necessary for practical purposes. Many experiments have shown conclusively that increased work, when accompanied by a sufficient increase in the amount of fats and carbohydrates fed, does not necessarily increase the katabolism of protein.

The following data from Atwater (*Report of the Storrs, Connecticut, Agricultural Experiment Station for 1902–1903*, page 127) show the average results of a long series of rest and work experiments with men in the respiration calorimeter: —

NATURE OF EXPERIMENT	AVERAGE METABOLISM PER DAY					
	PER PERSON		PER KILOGRAM BODY WEIGHT		PER SQUARE METER SURFACE	
	Energy, calories	Protein, grams	Energy, calories	Protein, grams	Energy, calories	Protein, grams
Rest: Food generally sufficient for equilibrium; 5 subjects, 27 experiments, covering 82 days . . .	2310	103.8	33.5	1.51	1116	50.1
Work: 8 hours per day. Food generally not quite sufficient for equilibrium; 3 subjects, 24 experiments, covering 76 days .	4556	108.1	62.9	1.49	2129	50.5

Taking account of the small difference in average size, *i.e.* comparing the figures per unit of weight or of surface rather than per person, it will be seen that muscular work sufficient to nearly double the energy metabolism had no appreciable effect upon the amount of protein metabolized. Considering the large amount of exceptionally accurate research represented in these average figures, they seem to justify the conclusion that if muscular work has any tendency to increase the "wear and tear" of muscle substance, such effect is normally balanced by the tendency of the muscles to grow (and therefore store protein) when exercised.

Moreover, it is certain that any effect which muscular work might have in increasing protein metabolism would be very much less than its effect in increasing the total metabolism. If, then, starting with a diet which maintains protein equilibrium at rest, the total food is increased sufficiently to provide for the muscular work, and the increase in the diet is accomplished by adding any reasonable combination of food materials, we may feel sure that these will supply plenty of protein to meet any possible increase in the protein requirement. Hence, in planning the diet of a man at hard muscular work, any reasonable combination of foodstuffs given in sufficient abundance to meet the energy requirement will almost certainly supply an ample amount of protein.

PROTEIN REQUIREMENT IN RELATION TO AGE AND GROWTH

If a man at moderately active work takes a diet which furnishes 3000 calories and 75 grams of protein, he is taking 10 per cent of his calories in the form of protein. Of course the protein requirement cannot bear a fixed relation to the calorie requirement, since the latter is largely influenced by activity, while the former is not. Most men, when at complete rest, would require more than 10 per cent of their calories in the form of protein because the lack of exercise would not reduce the protein requirement to the same extent as the energy requirement. On the other hand, most Americans are accustomed to take more than 10 per cent of their calories as protein regardless of whether they require it or not. If, then, the active man's need for protein is met by supplying him with 10 per cent of his needed calories in the form of protein, this will serve as a convenient starting point in considering the requirements of a child. Let this be compared with the normal dietary of an infant. Human milk averages about 1.6 per cent protein, 4.0 per cent fat, 7.0 per cent carbohydrate. Here about 9 per cent of the calories are taken in the form of protein, or about the same proportion as has been allowed for the full-grown active man. During the suckling period the growth is relatively more rapid than at any other age. Mendel[1] gives the following figures: —

---

[1] *Childhood and Growth*, p. 18.

The Relative Daily Gain in Body Weight of Children,

In the first month is about	1.00 per cent
At the middle of the first year	0.30 per cent
At the end of the first year	0.15 per cent
At the fifth year	0.03 per cent
Maximum in later years	
for boys	0.07 per cent
for girls	0.04 per cent

If, then, the full-grown man and the child at the time of most rapid growth each requires but 10 per cent of his calories in the form of protein, it seems probable that this proportion is also sufficient for any intermediate age, so long as the diet is of ample fuel value, and the protein of a kind well adapted for conversion into body tissue. Just as the child requires more calories per unit of weight than the adult, so it requires more protein per unit of weight, but not necessarily a diet richer in protein in the usual sense of containing a larger proportion of protein to total food.

Since the relative rate of growth is so much greater during the suckling period than at any later time, it would be unreasonable to suppose that the demands of growth would at any time call for a diet richer in protein (relatively to calories) than human milk, though for other reasons it is decidedly advisable to feed children during the first year or two after weaning very largely upon cow's milk, which furnishes about 19 per cent of its calories in the form of protein. Such a surplus of protein in the dietary of a child, while not strictly necessary, cannot be regarded as objectionable if taken in the form of milk. The kind of protein for children's dietaries is of great importance, since under favorable conditions the growth may be such as to call for a conversion of 30 to 40 per cent of the food protein into body material. Ordinarily it is best to use milk as the main source of protein throughout the whole of infancy and early childhood. Young and middle-aged people usually utilize quantities of protein considerably greater than they require. The arguments for and against such a surplus of protein in the diet will be reviewed briefly in the next chapter; at present we are concerned with the effect of age rather than the general question of high or low protein diet.

Elderly people show both a diminished protein requirement and a diminished power of dealing with excess. Surplus protein taken in the food is not so rapidly absorbed and katabolized, and, while there appears to be no essential difference in the form in which the nitrogen is finally excreted, the susceptibility to excessive putrefaction of protein appears to be increased. It would seem that in the dietary of the aged the protein should be reduced to at least as great an extent as are the calories.

REFERENCES

Atwater and Benedict. Comparison of Fats and Carbohydrates as Protectors of Body Material. Bull. 136, (pp. 176–187). Office of Experiment Stations, U. S. Dept. Agriculture.

Benedict. The Influence of Inanition on Metabolism. Publication No. 77, Carnegie Institution of Washington.

Chittenden. Physiological Economy in Nutrition.

—— The Nutrition of Man.

Hammarsten. Textbook of Physiological Chemistry.

Lusk. Elements of the Science of Nutrition.

Siven. [On Protein Requirement.] *Skandinavisches Archiv f. Physiologie,* **10**, 91; **11**, 308.

Von Noorden. Metabolism and Practical Medicine, Vol. I, pp. 283–383.

CHAPTER VIII

FOOD HABITS AND DIETARY STANDARDS

HAVING considered in the last two chapters the need of the body for food, in terms of calories and of protein, we may now inquire how the food requirements thus determined compare with actual food habits and what should be the standard of a desirable diet, both as to total food and proportional amounts of the different foodstuffs.

The earliest attempts to set dietary standards in terms of nutrients were those of the German physiologists, among which the most authoritative and influential was that of Voit. Voit suggested as a proper allowance of foodstuffs for a man at moderate muscular work: —

Protein,	118 grams.
Fat,	56 grams.
Carbohydrates,	500 grams.

This dietary would have a fuel value of approximately 3000 calories. The allowance of 118 grams of protein, which has since provoked considerable discussion, is said to have been based upon the average protein metabolism of many laboring men who were living apparently upon unrestricted diet, so that it was practically the result of dietary study. In the division of the remaining calories between fat and carbohydrate, Voit made the allowance of fat low and of carbohydrates high in order to cheapen the dietary.

Playfair, in England, recommended as a standard for a man at moderate work: —

Protein,	119 grams.
Fat,	51 grams.
Carbohydrate,	531 grams.

This would yield 3060 calories and is evidently based quite directly upon Voit's recommendations.

In France, Gautier has proposed as a standard for men with little muscular work: —

Protein,	107 grams.
Fat,	65 grams.
Carbohydrate,	407 grams.

This allowance of nutrients — which is based in part upon carbon and nitrogen balance experiments, in part upon studies of French families selected as typical, and in part upon the statistics of food consumed in Paris for a period of ten years — would supply 2630 calories.

In America dietary standards have been discussed chiefly by Atwater, Chittenden, and Langworthy. Atwater, in his later writings,[1] ceasing to make distinction between fats and carbohydrates as sources of energy in ordinary dietaries, but making allowances for different degrees of muscular activity, recommended the following standards: —

---

[1] Farmer's Bulletin No. 142, U. S. Department of Agriculture. Also *Fifteenth Annual Report Agricultural Experiment Station*, Storrs, Conn., 1903.

	Protein, Grams	Fuel Value, Calories
Man with hard muscular work	150	4150
Man with moderately active muscular work	125	3400
Man at sedentary or woman with moderately active work	100	2700
Man without muscular exercise or woman at light to moderate work	90	2450

That these standards were not intended simply as expressions of the actual needs of the body is plainly shown by the allowance of 150 grams of protein for a man at hard work, as against 100 grams for a sedentary man. By his own experiments with men at rest and at work in the respiration calorimeter Atwater had demonstrated, as shown in the preceding chapter, that muscular work need not increase protein metabolism if a sufficient amount of fuel be provided in the form of carbohydrates and fats. Hence, when, in providing for muscular work, he proposes to increase the protein in practically the same ratio as the calories, the idea evidently is not that such an increase is necessary, but simply that it was considered advisable on general grounds not to alter very greatly the nature of the diet in increasing its amount.

In explanation of the liberality of his standards Atwater suggested that "the standard must vary not only with the conditions of activity and environment, but also with the nutritive plane at which the body is to be maintained. A man may live and work and maintain bodily equilibrium on either a higher or a lower nitrogen level, or energy level. One essential question is, What level is most advantageous? The answer to this must be sought, not simply in metabolism experiments and dietary studies, but also in broader observations regarding bodily and mental efficiency and general health, strength, and welfare."

Langworthy, maintaining a similar point of view, has collected the data of large numbers of dietaries believed to be fairly representative of the food habits of people of different occupations in the United States and other countries, and stated them in terms of protein and calories per man per day with the following results:—

LANGWORTHY'S COMPILATION OF RESULTS OF DIETARY STUDIES

OCCUPATION OF HEAD OF FAMILY	FOOD PER MAN[1] PER DAY	
	Protein, grams	Fuel value, calories
United States:		
Man at very hard work (average 19 studies) . .	177	6000
Farmers, mechanics, etc. (average 162 studies) .	100	3425
Business men, students, etc. (average 51 studies)	106	3285
Inmates of institutions, little or no muscular work (average of 49 studies)	86	2600
Very poor people, usually out of work (average of 15 studies)	69	2100
Canada: Factory hands (average 13 studies) . .	108	3480

---

[1] As explained in Chapter VI, it is assumed that women consume 0.8 as much food as men, and children of different ages from 0.3 to 0.8 as much as the man of the family.

Occupation of Head of Family	Food per Man per Day	
	Protein, grams	Fuel value, calories
England: Workingmen	89	2685
Scotland: Workingmen	108	3228
Ireland: Workingmen	98	3107
Germany: Workingmen	134	3061
Professional men	111	2511
France: Men at light work	110	2750
Japan: Laborers	118	4415
Professional and business men	87	2190
China: Laborers	91	3400
Egypt: Native laborers	112	2825
Congo: Native laborers	108	2812

Langworthy states that, while the figures given for American dietaries are averages of available data, general averages were not available for other countries, and it was necessary to choose such studies as seemed similar in purpose and method to the American work and which, so far as could be judged, represented usual and normal rather than abnormal or experimental conditions. He concludes that the results obtained, the world over, for persons of moderate activity, "do not differ very markedly from a general average of 100 grams of protein and 3000 calories of energy, and that it is fair to say that, although foods may differ very decidedly, the nutritive value of the diet in different regions and under different circumstances is very much the same for a like amount of muscular work." Langworthy points out that in some cases this may not be apparent until allowance is made for differences in body weight. Thus he estimates the average weight of the Japanese professional and business men at 105 pounds, so that their food consumption of 87 grams protein and 2190 calories corresponds to 105 grams protein and 3120 calories for a man of 150 pounds, which agrees well with the American average for similar employment.

As a standard for men with more muscular activity, such as mechanics at moderately active work, Langworthy suggests : —

For food purchased,	115 grams protein ;	3800 calories.
For food eaten,	105 grams protein ;	3500 calories.

Chittenden differs from those whose standards have been quoted in giving almost no weight to the results of dietary studies, holding that these serve chiefly as a measure of self-indulgence, and that the true measure of what the body will most profitably use is to be found in the results of experiments upon the protein metabolism, such as have been described in the preceding chapter. On the basis of these experiments he proposes as a standard allowance for the man of 70 kilograms body weight, 60 grams of protein and 2800 calories per day. For business and professional men such as Chittenden evidently has in mind, the allowance of 2800 calories is in substantial agreement with earlier estimates. Sixty grams of protein for a man of 70 kilograms is, however, decidedly lower than any standard previously current.

In order to afford a concrete comparison there are given below (1) a dietary arranged to agree with the Atwater standard, (2) a dietary suggested by Chittenden in his *Nutrition of Man.*

EXAMPLE OF DIETARY FOR BUSINESS MAN BASED ON ATWATER STANDARDS

ARTICLES OF FOOD	WEIGHT OF FOOD		FUEL VALUE	PROTEIN	
	Ounces	Grams	Calories	Calories	Grams
Breakfast:					
Bananas	3.5	100	100	5.2	1.3
Oatmeal (weighed dry)	1.0	28	111	18.7	4.7
Sugar	1.0	28	111		
Cream	2.0	56.5	110	5.6	1.4
Eggs (2)	3.5	100	150	54.0	13.5
Toast	2.0	56.6	200	28.0	7.0
Roll	1.0	28	75	10.6	2.7
Butter	0.5	14	100	0.5	0.1
Luncheon:					
Bluefish	4.0	113	100	88.0	22.0
Potato	4.2	120	100	10.5	2.6
Rolls	2.0	56.5	150	21.2	5.3
Butter	1.0	28	200	1.0	0.2
Milk	5.0	142	100	19.0	4.8
Apple pie	4.0	113	300	15.0	3.8
Dinner:					
Steak	4.0	113	200	108.0	27.0
Potatoes	4.0	113	95	10.0	2.5
Corn, canned	3.5	100	100	12.2	3.0
Celery	4.0	113	20	6.0	1.5
Bread	2.0	56.5	150	21.2	5.3
Butter	1.0	28	200	1.0	0.2
Baked apple	5.5	155	100	2.5	0.6
Cream	4.0	113	220	11.2	2.8
Total			2992		112.3

CHITTENDEN'S SUGGESTED DIETARY FOR MAN OF AVERAGE WEIGHT

(From *The Nutrition of Man*)

ARTICLES OF FOOD	WEIGHT Grams	FUEL VALUE Calories	PROTEIN Grams
Breakfast:			
One shredded wheat biscuit	30	106	3.15
One teacup of cream	120	206	3.12
One German water roll	57	165	5.07
Two 1-inch cubes of butter	38	284	0.38
Three fourths cup of coffee	100	—	0.26
One fourth teacup of cream	30	51	0.78
One lump of sugar	10	38	
Lunch:			
One teacup homemade chicken soup	144	60	5.25
One Parker-house roll	38	110	3.38
Two 1-inch cubes of butter	38	284	0.38
One slice lean bacon	10	65	2.14
One small baked potato (about 2 ounces)	60	55	1.53
One rice croquette	90	150	3.42
Two ounces of maple syrup	60	166	
One cup of tea with one slice lemon			
One lump of sugar	10	38	
Dinner:			
One teacup cream-of-corn soup	130	72	3.25
One Parker-house roll	38	110	3.38
One inch cube of butter	19	142	0.19
One small lamb chop, broiled lean meat	30	92	8.51
One teacup of mashed potato	167	175	3.34
Apple-celery-lettuce salad with Mayonnaise dressing	50	75	0.62
One Boston cracker, split	12	47	1.32
One half teacup of bread pudding	85	150	5.25
One half-inch cube American cheese	12	50	3.35
One *demi-tasse* coffee			
One lump of sugar	10	38	
Total		2729	58.07

The general impression that equally competent authorities differ widely in their estimates of the desirable amount of food seems to call for some consideration of the apparent discrepancies between standards which have been proposed.

STANDARDS FOR FUEL VALUE

It has been shown in a previous chapter that different normal individuals of similar age and physique are substantially alike in their energy requirement when performing equivalent amounts of muscular work, and that it is primarily the muscular activity, and not personal idiosyncrasy or the amount of food eaten, which determines the amount of energy transformed in the body. A dietary standard of high fuel value, and designed to maintain metabolism on a high energy level provides, therefore, primarily for a large amount of muscular work. If this work is not performed and the food continues to be eaten and digested, we may expect to find a storage of fuel in the body chiefly in the form of fat, and this is true whether the surplus food eaten is carbohydrate, fat, or protein. Thus the store of body fat which a person carries is the most reliable indication as to whether the amount of food habitually eaten is or is not properly adjusted to the work performed. The storage of fat does, however, in itself modify the food requirement. While it is true, as has been shown, that, as between a lean and a fat man having the same weight, the lean man will have the greater food requirement, yet it is also true that when any given man becomes fat, his increased size of body calls for increased metabolism of energy. The work involved in walking, for example, will increase in proportion to the weight moved (*i.e.* to the weight of the body as a whole); and the work of respiration will increase about in proportion to the weight of that part of the body which must be moved with the expansion and contraction of the lungs; while, if fat is deposited in such a way as to interfere directly with the free play of the muscles, there may be an actual lowering of muscular efficiency, so that a larger expenditure of energy may be required in order to produce a given amount of work. If the liberal diet is continued and the digestion remains normal, the storage of fat will continue until it raises the energy expenditure of the body to a point where the food is no longer in excess. If the store of fat carried when this point is reached is excessive, the fuel value has been too high; if the store of fat is not excessive, the fuel value of the diet, although greater than would have been necessary to maintain the body at its former weight, has not been too high, and the body has acquired an asset whose utility may not always be recognized in health, but which may be of great value in case of accident, illness, exposure, or any unusual strain.

Opinions differ as to the desirable degree of fatness as indicated by the relation of height to body weight.

According to Hägler,[1] the insurance company at Basel is very cautious in its dealings with individuals of less than 340 grams or more than 530 grams of weight per centimeter of

---

[1] Cabot's *Diseases of Metabolism*, p. 158.

body height, and such are usually rejected. In English units this rule would require the weight to be between 1.90 and 2.97 pounds to the inch. For a height of 5 feet 8 inches this would mean a range of body weight from 130 to 202 pounds.

Hill[1] estimates the average height at 25 years of age as 5 feet 3 inches for women and 5 feet 8 inches for men, and the corresponding average weights as 119 and 150 pounds respectively. He considers that variations of 10 to 15 per cent above or below the average should be considered normal. According to this estimate the woman of 5 feet 3 inches should weigh not less than 102–107, nor more than 131–136 pounds, and the man of 5 feet 8 inches not less than 128–135, nor more than 165–173 pounds. These figures are exclusive of clothing. Hill considers as "fat" those persons whose weight exceeds the average by 15 to 30 per cent, and as "over fat" those who exceed by more than 30 per cent, *i.e.* over 155 pounds for a woman 5 feet 3 inches or over 195 pounds for a man 5 feet 8 inches.

The Basel life insurance company would thus accept persons whom Hill regards as over fat and would exclude as being too thin some of those whom Hill regards as normal.

Recently Symonds has published[2] the average relation of height to weight in both men and women at different ages, as

---

[1] *Recent Advances in Physiology and Biochemistry.*

[2] *Medical Record,* Sept. 5, 1908; and *McClure's Magazine,* January, 1909.

computed from the records of accepted applicants for life insurance in the United States and Canada. The results are found in the following tables; that for men being based on 74,162 and that for women on 58,855 cases. In all these cases the height includes shoes and the weight includes ordinary clothing.

SYMONDS'S TABLE OF HEIGHT AND WEIGHT FOR MEN AT DIFFERENT AGES

BASED ON 74,162 ACCEPTED APPLICANTS FOR LIFE INSURANCE

(*Medical Record*)

AGES	15–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69
5 ft. 0 in.	120	125	128	131	133	134	134	134	131	
1 in.	122	126	129	131	134	136	136	136	134	
2 in.	124	128	131	133	136	138	138	138	137	
3 in.	127	131	134	136	139	141	141	141	140	140
4 in.	131	135	138	140	143	144	145	145	144	143
5 in.	134	138	141	143	146	147	149	149	148	147
6 in.	138	142	145	147	150	151	153	153	153	151
7 in.	142	147	150	152	155	156	158	158	158	156
8 in.	146	151	154	157	160	161	163	163	163	162
9 in.	150	155	159	162	165	166	167	168	168	168
10 in.	154	159	164	167	170	171	172	173	174	174
11 in.	159	164	169	173	175	177	177	178	180	180
6 ft. 0 in.	165	170	175	179	180	183	182	183	185	185
1 in.	170	177	181	185	186	189	188	189	189	189
2 in.	176	184	188	192	194	196	194	194	192	192
3 in.	181	190	195	200	203	204	201	198		

Symonds's Table of Height and Weight for Women at Different Ages

BASED ON 58,855 ACCEPTED APPLICANTS FOR LIFE INSURANCE

(*McClure's Magazine*).

Ages	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64
4 ft. 11 in.	111	113	115	117	119	122	125	128	128	126
5 ft. 0 in.	113	114	117	119	122	125	128	130	131	129
1 in.	115	116	118	121	124	128	131	133	134	132
2 in.	117	118	120	123	127	132	134	137	137	136
3 in.	120	122	124	127	131	135	138	141	141	140
4 in.	123	125	127	130	134	138	142	145	145	144
5 in.	125	128	131	135	139	143	147	149	149	148
6 in.	128	132	135	137	143	146	151	153	153	152
7 in.	132	135	139	143	147	150	154	157	156	155
8 in.	136	140	143	147	151	155	158	161	161	160
9 in.	140	144	147	151	155	159	163	166	166	165
10 in.	144	147	151	155	159	163	167	170	170	169

From a study of the records of body weight in relation to the mortality records Symonds concludes that among young people the greatest vitality coincides with a weight somewhat above the accepted average, while with middle-aged and elderly people a condition of slightly less than average fatness is most favorable to vitality and longevity. Another way of stating the same facts is: That the average of healthy men and women keep themselves slightly too thin while young, and allow themselves to grow slightly too stout as they grow older.

Evidently, however, the optimum is very near the average of the accepted applicants as shown in the tables, and Symonds uses these figures as standards in his computations and discussions of the influence of overweight and underweight on longevity and on mortality from specific diseases. Symonds's data therefore support the opinion that the average degree of fatness of healthy American people is just about the most advantageous fatness for them to maintain. Whatever we accept as the ideal relation of weight to height, it is obvious that the proper standard for fuel value of the diet is that which will preserve the desired degree of fatness while sustaining the desired amount of activity. If good authorities differ in standards for fuel value, it is because, consciously or unconsciously, they contemplate different amounts of muscular activity or the maintenance of a different physique.

The Appetite as a Dietary Standard.—It is sometimes asked whether a normal appetite does not indicate, as well as can any dietary standard, the amount of food which is desirable for the individual in the given circumstances.

If by following the appetite one becomes unduly stout, or is visited by digestive disturbances which are an obvious effort on the part of the body to free itself of a part of the food eaten, or, on the other hand, if one becomes unduly thin, or does not get sufficient fuel to support a full day's work, it is certain that some standard other than that of appetite would be of decided advantage. But if from year to year the body keeps in good condition for its work and maintains a fairly constant weight, which bears such a proportion to the height as to show that a desirable store of fat is being carried, it is reasonably certain that the amount of food eaten in the course of the year is substantially that which is suited to the degree of activity maintained; and, while it is possible that still further benefits might accrue from a different selection of food materials, it is not likely that any advantage could result from a material change in the amount (fuel value) of food consumed. Especially is it in the highest degree improbable that in such a case the same work could be done and the same weight maintained on food of much lower fuel value, however selected, prepared, or eaten.

It is of interest to note that a well-ordered appetite may not only serve as an indication of the amounts of food needed over long periods and under different conditions of activity, but also when the conditions of life are fairly uniform may be highly efficient in determining a regular intake of calories from day to day. Thus, a healthy young woman living on unrestricted diet with menus varied daily and eating simply according to appetite was found to take on five successive days 2140, 2025, 2040, 2250, 2255 calories respectively.

STANDARDS FOR PROTEIN

In attempting to set a standard for the amount of protein in the dietary we find no such definite and satisfactory basis for judgment as in the case of total food (or fuel) value. There is no indication that any kind of work necessarily increases the expenditure of protein as muscular work increases the expenditure of fuel, and the body cannot store up protein to anything like the extent that it stores fuel in the form of fat; the feeding of protein above what is required for maintenance increases only slightly the store of protein which the body carries.

When one writer proposes an amount of protein but little above the minimum required for equilibrium, while another advocates a much larger amount, there is implied a difference of view regarding protein such as no longer exists with respect to the energy metabolism. The difference, it is true, is hardly so great as might appear from a casual examination of the proposed standards. It may perhaps be most fairly expressed in terms of the relation between protein and energy in the different standards. Protein would contribute, according to the standards of Voit, Playfair, and Gautier, about 16 per cent of the fuel value of the food; of Atwater, about 15 per cent; of Langworthy, 12 per cent; of Chittenden, $8\frac{1}{2}$ per cent.

It will be of interest to examine some of the arguments which have been advanced in favor of a high protein or of a low protein diet. The following extracts are given in chronological order. References for more detailed reading are given at the end of the chapter, arranged, as usual, alphabetically by authors, though if several are to be read they may best be taken up chronologically.

OPINIONS REGARDING THE VALUE OF LIBERAL PROTEIN DIET

Liebig believed that fats and carbohydrates were burned in the body primarily to supply it with warmth, and that protein alone served as the source of muscular work and other forms of tissue activity. He therefore classed the non-nitrogenous as "respiratory" and the nitrogenous as "plastic" foodstuffs, and treated the proteins as playing a "nobler" part in nutrition than can be taken by fat or carbohydrate. Although it was soon demonstrated that carbohydrates and fats as well as protein serve the body in the production of muscular energy, yet the influence of Liebig's teaching, and of the great attention given to protein in Voit's classical researches on nutrition, together with the fact that protein is the most prominent constituent of protoplasm, has resulted in a strong tendency to associate high protein feeding with increased stamina and muscular power.

The reasoning of those who appreciated the results of more recent experimental work, and yet believed the general attitude of Liebig and Voit to have been largely sustained by experience, is well expressed by Von Noorden, who wrote in 1893:[1] —

"When one considers that the dietary habits of peoples are the results of biological laws, it would seem that the action of these laws, extending through the thousands of years of existence of the species, would have resulted in the establishment of suitable habits regarding the amounts of protein consumed. The data gathered by Voit may be taken as showing that this normal habit involves the consumption of about 105 grams of digestible protein[2] per day, a smaller protein consumption being usually asso-

---

[1] Freely translated from the first edition of Von Noorden's *Pathologie der Stoffwechsel.*

[2] Corresponding to Voit's allowance of 118 grams of total protein when the food for the sake of economy, as contemplated by Voit, is taken somewhat largely from vegetable sources.

ciated with weak individuals or inactive peoples. While men can maintain equilibrium on less, still it can rightly be said that a liberal protein consumption makes for a full development of the man. A single individual may for years, or even decades, offend against this biological law unpunished. When, however, the small consumption of protein continues for generations, there results a weak race."

Von Noorden, however, is careful to add: —

"On the other hand, the importance of protein must not be overestimated. A diet is not necessarily good because the amount of protein is right; it must have the proper proportions of the non-nitrogenous nutrients as well, since the protein is not to be depended upon for the necessary fuel value. Better somewhat less protein with a liberal amount of total food than more protein with insufficient fuel value; the latter brings a rapid loss of strength, the former can be endured very well, at least for a long time, and very likely throughout the life of the individual."

Hutchison, in the first edition of his *Food and Dietetics*, took similar ground regarding the desirability of liberal protein feeding and distinctly taught that large amounts of protein tend toward a higher degree of health, vigor, and ability to resist disease.

Chittenden, in 1905, had reached exactly the opposite conclusion, — that the products of protein metabolism are a constant menace to the well-being of the body, and that any excess of protein over what the body actually needs is likely to be directly injurious, and at best puts an unnecessary and useless strain upon the liver and kidneys. Chittenden had satisfied himself by his numerous and long-continued experiments that both physical and mental stamina are promoted by decreasing the amount of protein in the food: "Greater freedom from fatigue, greater aptitude for work, greater freedom from minor ailments, have gradually become associated in the writer's mind with this lowered protein metabolism and general condition of physiological economy. . . . The ordinary professional man who leads an active and even strenuous life, with its burden of care and responsibility, need not clog his system and inhibit his power for work by the ingestion of any such quantities of protein food as the ordinary dietetic standards call for." (*Physiological Economy in Nutrition*, pp. 51, 127.)

Hutchison, in the second edition of his *Food and Dietetics*, does not withdraw his indorsement of the old high protein standard, but follows it with a statement to the effect that in view of Chittenden's work it can no longer be regarded as resting on an entirely satisfactory foundation. More recently he has concluded (*Chemical News*, **94**, 104, August 31, 1906) that the normal amount of protein in a diet furnishing 3000 calories should be placed at about 75 grams. This allows some margin above the results of Chittenden's experiments and agrees with the relation of protein to calories in mother's milk, which Hutchison regards as nature's hint as to the proper balance of nitrogenous and non-nitrogenous food for the human species.

Folin holds that the argument for a high protein diet based on the fact that large amounts of protein are commonly eaten by those who can afford it, can be equally well applied to the dietetic use of alcoholic beverages and is no more convincing in one case than in the other; while on the other hand, study of protein metabolism has given rather strong evidence that the body has no need of such amounts as are commonly eaten; for when protein is fed the nitrogen which it contains is usually eliminated more quickly than the carbon, and further study indicates that a considerable part of the nitrogen absorbed from the alimentary tract never reaches the tissues at all, but is converted into urea on its first passage through the liver.

The loss of body nitrogen which occurs in the early periods of restricted protein feeding, and which was not determined nor specifically discussed by Chittenden, is treated by Folin as follows: "All the living protoplasm in the animal organism is suspended in a fluid very rich in protein, and on account of the habitual use of more nitrogenous food than the tissues can use as protein, the organism is ordinarily in possession of approximately the maximum amount of reserve protein in solution that it can advantageously retain. When the supply of food protein is stopped, the excess of reserved protein inside the organism is still sufficient to cause a rather large destruction of protein during the first day or two of protein starvation, and after that the protein katabolism is very small, provided sufficient non-nitrogenous food is available. But even then, and for many days thereafter, the protoplasm of the tissues has still an abundant supply of dissolved protein, and the normal activity of such tissues as the muscles is not at all impaired or diminished. When 30 grams or 40 grams of nitrogen have been lost by an average-sized man during a week or more of abstinence from nitrogenous food [but with an abundance of carbohydrate and fat] the living muscle tissues are still well supplied with all the protein that they can use. That this is so is indicated on the one hand by the unchanged creatinin elimination, and on the other by the fact that one experiences no feeling of unusual fatigue or of inability to do one's customary work. Because the organism at the end of such an experiment still has an abundance of available protein in the nutritive fluids, it is at once seemingly wasteful with nitrogen when a return is made to nitrogenous food. This is why it only gradually and only under prolonged pressure of an excessive supply of food protein again acquires its original maximum store of this reserve material. If the interpretation just given for the phenomenon of nitrogen equilibrium is correct, it constitutes at the same time a definite reason why the so-called standard diets are unnecessarily rich in protein. Nitrogen enough to provide liberally for the endogenous metabolism and for the maintenance of a sufficient supply of the reserve protein is shown to be necessary; but it ought neither to be necessary nor advantageous for the organism to split off and remove large quantities of nitrogen which it can neither use nor store up as reserve material. In the case of carnivorous animals, the uncertainty of the food supply has evidently led to the development of a capacity to store a certain amount of protein in the form of increased muscle substance, but in man this capacity seems not to exist. The slowness with which the normal human organism stores nitrogen after having lost only very moderate amounts does not mean that the human organism can replace lost muscle tissue only slowly and with difficulty. When the organism really has suffered a loss of such tissue, as for example during typhoid fever, we know that during convalescence there is an astonishingly rapid recovery of weight and a correspondingly extensive retention of nitrogen. . . . In the light of the theory developed in this paper concerning the double nature of protein metabolism and the explanation of the phenomenon of nitrogen equilibrium, the following objection can perhaps be made to the use of large quantities of protein. The excess of nitrogen furnished with the food is normally quickly converted into urea and eliminated, and is therefore normally harmless. The continuous excessive use of protein may lead, however, to an accumulation of a larger amount of reserve protein than the organism can with advantage retain in its fluid media. It is entirely possible that the continuous maintenance of such an unnecessarily large supply of unorganized reserve material may sooner or later weaken one, or another, or all of the living tissues. At any rate, it seems scarcely conceivable that the human organism, having all the time access to food, can gain in efficiency on account of such an excess of stored protein. The carrying of excessive quantities of fat is considered as an impediment, the carrying of excessive quantities of unorganized protein may be none the less so because more common and less strikingly apparent." (*American Journal of Physiology*, **13**, 131–132, 136–137.)

Haliburton, in discussing the work of Chittenden and of Folin, concedes that "the prevalence of dyspeptic troubles and uric acid disorders (among the English-speaking peoples) should make us hesitate before we conclude that our diet has reached the stage of perfection, and should rather lead us to admit that the majority of well-to-do people eat too much protein," but adds: "Any change in the practice of years and of generations should be accomplished gradually, not suddenly. Those who are young and vigorous may remember that the liver is the largest organ we possess, its function is to turn nitrogenous metabolites which may be harmful into urea which is harmless and easily disposed of, and may gain comfort from the reflection that the organ is adequate in health to deal with large quantities of material. If all of us were to reduce immediately our diet to the Chittenden level, we might be living perilously near the margin; any unusual strain, such as privation or a severe illness, would then find us without any reserve of nutrient energy, and we should probably suffer more severely in consequence." (*Annual Reports on Progress of Chemistry*, II, pp. 215–218.)

Benedict argues that general experience in animal feeding favors the use of liberal quantities of protein, and that "while men may for some months reduce the proportion of protein in their diet very markedly and apparently suffer no deleterious consequences, yet, nevertheless, a permanent reduction of the protein beyond that found to be the normal amount for man is not without possible danger. The fact that a subject can so adjust an artificial diet as to obtain nitrogenous equilibrium with an excretion of nitrogen amounting to about 2 or 3 grams per day is no logical argument for the permanent reduction of the nitrogen in food for the period of a lifetime. . . . Dietary studies all over the world show that in those communities where productive power, enterprise, and civilization are at their highest, man has instinctively and independently selected liberal rather than small quantities of protein." (*American Journal of Physiology*, 16, 409.)

A similar position is taken by Meltzer, who compares the appetite for a liberal surplus of protein with the liberal way in which the body is provided with organs and tissues for nearly all of its functions, and concludes that "valuable as the facts which Chittenden and his co-laborer found may be, they do not make obvious their theory that the minimum supply is the optimum — the ideal. The bodily health and vigor which people with one kidney still enjoy does not make the possession of only one kidney an ideal condition. The finding that the accepted standard of protein diet can be reduced to one half can be compared with the finding that the inspired oxygen can be reduced to one half without affecting the health and comfort of the individual, but no one deduces from the latter fact that the breathing of air so rarefied would be the ideal. . . . The storing away of protein, like the storing away of glycogen and fat, for use in expected and unexpected exceptional conditions is exactly like the superabundance of tissues in an organ of an animal, or like an extra beam in the support of a building or a bridge — a factor of safety. I therefore believe that with regard to the function of supply of tissues and energy by means of protein food nature meant it should be governed by the same principle of affluence which governs the entire construction of the animal for the safety of its life and the perpetuation of its species." (*Science*, **25**, 481.)

In view of the arguments of Benedict and of Meltzer, it is of especial interest that in his later book Chittenden says: "It is certainly just as plausible to assume that increase in the consumption of protein food follows in the footsteps of commercial and other forms of prosperity, as to argue that prosperity or mental and physical development are the result of an increased intake of protein food. Protein foods are usually costly and the ability of a community to indulge freely in this form of dietetic luxury depends in large measure upon its commercial prosperity." Moreover, Chittenden contends that his allowance of 60 grams of protein per day for a man of average size is a perfectly trustworthy figure, with a reasonable margin of safety; that "dietetic requirements, and standard dietaries, are not to be founded upon the so-called cravings of appetite, but upon reason and intelligence reënforced by definite knowledge of the real necessities of the bodily machinery"; that "we must be ever mindful of the fact, so many times expressed, that protein does not undergo complete oxidation in the body to simple gaseous products like the non-nitrogenous foods, but that there is left behind a residue not so easily disposed of"; and that "there are many suggestions of improvement in bodily health, of greater efficiency in working power, and of greater freedom from disease, in a system of dietetics which aims to meet the physiological needs of the body without undue waste of energy and unnecessary drain upon the functions of digestion, absorption, excretion, and metabolism in general. . . ." (*The Nutrition of Man*, pp. 160, 164, 227, 269.)

Plainly the dietary habit of well-to-do people and the dietary standards which have been generally accepted in the past tend to be decidedly liberal with respect to protein, and to prescribe it in quantities which may be believed to be beneficial but certainly are not known to be necessary. It does not seem advisable, however, to adopt as a standard the lowest amount of protein to which the body can adjust itself, but rather to regard as the normal requirement an amount which will enable the body to maintain not only its equilibrium, but also some such reserve store of protein as we are accustomed to carry. Where a low protein diet is desired either for physiological or economical reasons, we would suggest an allowance of about 75 grams of protein per man per day, and for an average diet about 100 grams per man per day.

A reasonable surplus of protein, from suitable food materials, can hardly be injurious and may be advantageous. Whether such a surplus should be especially recommended or not is largely an economic question. Where little can be spent for food and there is danger that too little food may be eaten, it would be a mistake to use a surplus of protein which could economically be replaced by other food of greater fuel value. In such cases one must not be misled by the popular statement that "protein builds tissue" into supposing that a liberal amount of protein can keep the body strong in spite of a deficiency in the total food. This impression is still somewhat general, but is certainly incorrect.

The body is weakened through getting too little food, because body material must then be burned for fuel. So long as the total food be deficient, the loss of body substance will continue, because not only the food protein, but body tissues as well, must be burned to meet the energy requirement. To strengthen the body through the diet we must increase, not the protein alone, but primarily the total calories.

Strengthening or weakening of the body by feeding ordinarily depends much more upon the sufficiency or insufficiency of the total food than upon the amount of protein which it contains. The nature of the protein is also important (Chapter XI), and particularly so in the case of the growing child and in pregnancy and lactation. No less important is it that the food shall furnish, along with the protein, proper amounts and proportions of the so-called ash constituents which are considered in the chapters which follow.

REFERENCES

ATWATER. The Demands of the Body for Nourishment and Dietary Standards. Fifteenth Report of the Storrs (Conn.) Agricultural Experiment Station, pp. 123–146 (1903).

BENEDICT. The Nutritive Requirements of the Body. *American Journal of Physiology*, **16**, 409 (1906).

CHITTENDEN. Physiological Economy in Nutrition (1905).

—— The Nutrition of Man (1907).

FOLIN. A Theory of Protein Metabolism. *American Journal of Physiology*, **13**, 117 (1905).

HUTCHISON. Food and Dietetics.

LANGWORTHY. Food and Diet in the United States. Reprinted from the Yearbook of the U. S. Department of Agriculture for 1907.

LUSK. Science of Nutrition, Chapter 9, 2d ed. (1909).

MELTZER. Factors of Safety in Animal Structure and Animal Economy. Harvey Society Lectures, Vol. 1906–1907, and *Science*, **25**, 481 (1907).

PATON. On Folin's Theory of Protein Metabolism. *Journal of Physiology*, **33**, 1 (1905).

U. S. Department of Agriculture, Office of Experiment Stations, Bulls. Nos. 21, 29, 31, 38, 46, 52, 53, 55, 71, 75, 84, 91, 98, 107, 116, 129, 132, 149, 150, 221, 223 (data and discussion of dietary studies).

CHAPTER IX

IRON IN FOOD AND ITS FUNCTIONS IN NUTRITION

So far we have considered the food requirement with reference to proteins, fats, and carbohydrates only. In terms of the elements, only nitrogen, carbon, hydrogen, and oxygen have been considered. That other elements are essential is of course well known, and in view of recent investigations it is not safe to assume that they will be present in sufficient quantity in any diet which furnishes the requisite amounts of proteins, fats, and carbohydrates. It has become necessary to consider the so-called ash constituents much more carefully than has been customary in the past.

In many respects the compounds of iron may be regarded as a connecting link between the organic and the inorganic foodstuffs and body constituents. The human body of 60 to 70 kilograms is supposed to contain about 3 grams of iron, the greater part of which exists as a constituent of the hemoglobin of the red blood corpuscles, while much of the remainder is contained in the chromatin substance of the cells. The iron compounds of the body are therefore very prominent in the general metabolism and oxidative processes of the organism as a whole, and apparently also in the particular activities of the secreting and other specialized cells.

It has long been known that iron is essential to the nutrition of animals as well as of plants, and that small amounts of the oxide or phosphate of iron occur in the ash of all natural food materials. A few decades ago it was assumed that the iron exists in the food as oxide or phosphate, and that hemoglobin is formed in the body by the combination of protein with inorganic iron. This view was hardly consistent with the ideas of animal metabolism taught by Liebig and generally held at the time, but appeared to be supported by the successful use of inorganic iron in the treatment of anemia.

Important changes of view in regard to the metabolism of iron have followed so closely and have depended so directly upon the progress of experimental methods that it seems desirable, in this case, to review in chronological order some of the more important steps in the development of our present knowledge.

DEVELOPMENT OF MODERN VIEWS

The results obtained in a number of investigations published between 1854 and 1884 threw doubt upon the utilization of inorganic iron for the production of hemoglobin, since they indicated that iron salts when injected act as poisons and are quickly eliminated from the blood, and when given by the mouth reappear almost quantitatively in the feces, little, if any, evidence of absorption being obtained except when the doses were so large or long continued as to cause irritation of the intestine.

In the attempt to harmonize this result with clinical experience it was suggested that the inorganic iron might act by absorbing the hydrogen sulphide of the intestine, thus protecting the food iron from waste.

The view that medicinal iron acts by stimulation of the absorbing membrane was also advocated at about this time. It was held that the amount of iron in the ordinary food is always sufficient for the needs of the body, but that sometimes the intestinal mucous membrane becomes so bloodless that it cannot properly perform its functions of absorption. Under such conditions inorganic iron was believed to stimulate and tone up the membrane so that in a short time the increased absorption of food iron makes good the deficiency in the blood.

A very suggestive discussion of the metabolism of iron, the effects of a lack of iron in the food, and the amounts of iron required for the maintenance of the body in health was published by Von Hösslin in 1882, and long before this some attention had been given to the iron content of food materials by Boussingault. Boussingault's figures, however, are not sufficiently accurate to be of value at the present time, and little attention was given to the subject discussed by Von Hösslin until it was reopened by Bunge about two years later.

Bunge, in 1884, doubting the ability of the animal body to form hemoglobin from inorganic iron, undertook the study of the iron compounds of food materials in order to find in what form iron is normally absorbed and from what sort of iron compounds the growing organism ordinarily forms its hemoglobin. Practically all of the iron of eggs was found to be in the yolk. Yolk of egg does not contain any hemoglobin, but it must contain substances from which hemoglobin can be formed, since the incubation of the egg results in the development of hemoglobin without the introduction of anything from without. Bunge found no inorganic iron in egg yolk, but isolated considerable amounts of the precursor of hemoglobin, which he called "hematogen," and which exhibited the properties of a phospho-protein containing about 0.3 per cent of iron in such firm "organic" combination that it gives none of the ordinary reactions of iron salts. In milk, cereals, and legumes similar organic compounds of iron and only traces of inorganic iron were found. At this time Bunge distinctly stated that iron occurs in food solely in the form of complicated organic compounds which have been built up by the life processes of plants. In this form, said Bunge, is the iron absorbed and assimilated, and from these compounds hemoglobin is produced.

In 1890 and subsequently, the absorption and assimilation of iron was studied by several experimenters, usually with particular reference to the question whether inorganic or synthetic organic compounds of iron are absorbed and assimilated, and especially whether such preparations contribute directly to the formation of hemoglobin. This question is, of course, extremely important, not only in connection with the therapeutic use of medicinal iron, but also in its bearing upon the iron requirements in health: for if inorganic iron could be utilized in the body in exactly the same way as the complex organic iron compounds of the food, it would follow that the iron of drinking water could replace that of food, and the supplying of food iron would be a matter of indifference to a man whose drinking water supplied a few milligrams of iron per day. In opposition to this view, Bunge held that little if any inorganic iron is assimilated and that any effect of medicinal iron should be attributed to its action in protecting the food iron from loss in digestion, principally by absorbing the sulphur liberated as sulphid through intestinal putrefaction.

Socin demonstrated the superiority of the iron of egg yolk over iron chloride by dividing a number of mice into groups, some of which were fed on a mixture of iron-free food and iron chloride, while others received the same iron-free food with the addition of egg yolk. None of the mice fed without organic iron lived for more than thirty-two days, while some of those receiving egg yolk lived as long as the experiments were continued (sixty to ninety-nine days), and gained in weight.

Gottlieb, recognizing the fact that iron might be absorbed and used by the body, yet finally excreted with the feces, determined the intestinal elimination of iron in dogs before and after subcutaneous and intravenous injections of known amounts of iron salts. From the results obtained it was estimated that practically all of the injected iron was eliminated by the intestines.

Selensky fed dogs upon rice and observed the effect upon the hemoglobin content of the blood. In one experiment the percentage of hemoglobin fell from 18.5 to 13.1 in nine days; in another, from 14.8 to 11.3 in six days, and on continuing the diet the anemia became more pronounced, and the dog died at the end of seventeen days on the rice diet.

Voit studied the metabolism of iron in dogs by direct observations of absorption and elimination in isolated sections of the small intestine. Opening the peritoneal cavity, he separated the desired section, removed the contents, closed the ends, and left the sac thus formed in its normal position after having reunited the remainder of the intestine. Under these conditions the isolated section of intestine, while not coming in direct contact with anything taken by the mouth, would still receive its proportional share of anything eliminated from the body through the intestinal wall. By killing and examining animals which had been kept for some time after such an operation, Voit was able to compare the amount of iron eliminated through the intestinal wall with the amounts contained in food and feces, and thus to infer the extent to which the iron taken by the mouth was absorbed and returned to the intestine for elimination. In fasting, the daily elimination found for each square meter of intestinal surface was 6 milligrams in the feces and the same amount (per square meter of surface) in the isolated loop of intestine. On food poor in iron the feces contained in each of two cases 10 milligrams, the isolated loops 6 and 9 milligrams, of iron per square meter of intestinal surface; while on food rich in iron the corresponding figures for two experiments were 43 and 78 milligrams in the feces, and 8 and 6 milligrams in the isolated portion of the intestine. Hence it appears that the iron eliminated in the feces during fasting or on food poor in iron came from the body through the intestinal wall, while most of the extra iron given with the food in the last two experiments passed through the alimentary canal without being absorbed and metabolized.

Stockman, in a paper upon the metabolism of iron, published in 1893, while discussing mainly the therapeutics of chlorosis (a type of anemia occurring in girls and young women) undertook to solve the question of the absorption of inorganic iron. He reasoned as follows: —

If inorganic iron preparations given hypodermically will cure chlorosis, there can in such cases be no possibility of the iron exerting its effect by the stimulation of the alimentary canal or by combining with hydrogen sulphide in the intestine.

If iron sulphide given by the mouth cures chlorosis, it must be through absorption of the iron, since ferrous sulphide has no stimulating effect and cannot take up more sulphur.

If bismuth, manganese, etc., take up hydrogen sulphide as readily as iron, but are inert in chlorosis, a further indirect evidence of absorption of iron is obtained.

Stockman made experiments and observations upon hospital patients (of which he cites nine cases) which appeared to substantiate each of the three propositions, and thus to establish the fact that inorganic iron preparations cure chlorosis through being absorbed and utilized in the formation of hemoglobin.

During the years 1894–1897 several investigators studied the absorption of different forms of iron by microchemical methods. Suitable stains having been found for the identification of iron in the microscopic sections of tissue, it was possible by examination of the intestinal wall and the various organs and tissues of the body to follow the absorption, storage, and elimination of the iron given medicinally or occurring in the food. Macallum investigated in this manner the behavior of inorganic salts of iron, iron albuminates, and the iron compound of the egg yolk, and found that iron taken in any of these forms may be absorbed from the small intestine.

Woltering compared microchemically and by quantitative determination the amounts of iron in the livers of mice, rabbits, and dogs, fed with and without sulphate of iron, and reported an increase in the iron content of the liver and in the hemoglobin and red corpuscles of the blood as the result of feeding the iron salt.

Gaule, using principally microchemical methods, found no reaction for iron in the chyle under normal conditions; but a distinct reaction appeared in the lymph nodes, and extended to the spleen soon after the feeding of iron salt to rabbits. This absorption of inorganic iron was followed by an increase in the number of red corpuscles and percentage of hemoglobin in the blood.

In the meantime, Kunkel and Egers studied especially the influence of iron salts upon the regeneration of blood after hemorrhage. Kunkel kept two dogs on a limited milk diet, but gave one of them, in addition to the milk, iron in the form of albuminate. Each of the animals was bled every seven days, about one third of the total blood being taken each time. The iron in the drawn blood was determined and ascertained to be greater than the amount supplied by the milk, but less than the total iron received by the dog which was fed with albuminate. The experiment was continued seven weeks, at the end of which time the blood and organs of the dog which had been kept on milk alone were poorer in iron than those of the dog which had received the iron albuminate. Only one animal was fed in each way, and no determinations of hemoglobin are recorded. According to Egers, the regeneration of blood after severe losses (one third of the estimated total) is very slow on food poor in iron, unless medicinal iron is also given, when the rate of regeneration becomes better, but not so good as on a diet supplying an abundance of food iron alone. Even when the diet was rich in food iron, however, Egers found that medicinal iron appeared to aid the regeneration of blood after hemorrhage.

These investigations having shown that inorganic iron is at least to some extent absorbed and carried to organs which take part in the production of hemoglobin, it became of especial importance to determine by long-continued feeding experiments whether the inorganic iron thus absorbed can take the place of food iron in the production of hemoglobin under normal conditions.

This question was studied by Häusermann in an extended series of experiments in Bunge's laboratory. The general plan of these experiments was to feed young animals from the end of the normal suckling period upon food poor in iron, usually milk and rice. One half of the animals, however, received ferric chloride in addition to this food. After the animals had been thus fed for one to three months and had usually doubled in weight, they were killed, and the amount of hemoglobin in the entire body was estimated; also, in the case of small animals, the total amount of iron. Experiments were carried out in this way upon 24 rats, 17 rabbits, and 14 dogs. The results are summarized essentially as follows by Bunge:[1] —

The rats all became highly anemic, for at the end of the experiment the percentage of hemoglobin was diminished to about half that of animals from the same litter which had received their normal food, namely, meat, flies, yolk of egg, fruit, and vegetables. The rats which had taken ferric

---

[1] *Physiological and Pathological Chemistry*, Blakiston's edition, Philadelphia, 1902, p. 379.

chloride in addition to the milk and rice contained no more hemoglobin than those which had received milk and rice only. Moreover, the amount of iron was in each case the same. In one experiment alone, in which the addition of ferric chloride was continued for three months, was the iron found to be double as much in the animals which had received it as in those which had only milk and rice. But here again the proportion of hemoglobin remained the same in both instances. We thus see that some iron is absorbed if small doses of iron are persisted in for a long time, as well as if large amounts be suddenly administered. But this inorganic iron, when absorbed, is not utilized in the formation of hemoglobin to any appreciable extent, but remains unused in the tissues. Whether inorganic iron was absorbed in the experiments which lasted only from one to two months cannot be decided; it is possible that some of it was absorbed and was again eliminated in the same degree. Certainly no storing up nor increase of iron could be detected in the whole organism.

The experiments on rabbits gave less decisive results. The average proportion of hemoglobin in the animals that received inorganic iron was somewhat higher than that in the animals which were fed on milk and rice only. But when the great individual differences between various animals are taken into consideration, too much importance must not be ascribed to this slight divergence. At any rate, the amount of hemoglobin in the control animal, which received its normal diet — fresh green cabbage, bran, etc. — was nearly twice as high as in the animal which received the inorganic iron.

The experiments upon dogs were not attended with decisive results, as dogs are not suitable animals for these experiments, owing to the variation in individuals. Moreover, the growth of these animals after the period of lactation is at a much slower rate, and their appetite is so enormous that they might readily be able to assimilate sufficient hemoglobin even from a material so poor in iron as milk, while their appetite remained normal. Häusermann found the largest proportion of hemoglobin in a dog which had been fed exclusively upon milk. The animals which received ferric chloride in addition to a milk diet certainly contained no more hemoglobin than animals from the same litter which were fed on meat and bones.

Abderhalden, following Häusermann, studied the subject even more exhaustively. In order to ascertain whether and to what extent sulphides normally exist in the alimentary canal, — a question of special importance in connection with one view of the mode of action of inorganic iron, — Abderhalden killed and examined rats, mice, cats, dogs, guinea pigs, and rabbits in the following way: Immediately upon killing the animal, the abdomen was opened and the intestinal tract from the esophagus to the rectum was ligated in sections. The contents of each section were then removed and tested qualitatively for sulphides. Hydrogen sulphide was obtained from the contents of the large intestine but not from those of the small intestine nor of the stomach. Hence, if inorganic iron acts by improving the absorption of food iron, it must do so in some other way than by simply preventing its precipitation as sulphide, since this would not occur in the small intestine, where the principal absorption of iron takes place. The next step in the investigation was to study by microchemical methods the absorption of inorganic iron, its behavior in the body, and its elimination. Experiments were made upon 49 rats from 7 litters, 14 guinea pigs from 6 litters, 12 rabbits from 2 litters, 10 dogs from 3 litters, and 6 cats from 2 litters.

From all of these experiments, Abderhalden concluded that the complicated iron compounds of the normal food, the iron in the form of hemoglobin, and hematin, and the inorganic iron were all absorbed in the same general way, stored in the same organs, and eliminated by the same paths.

In studying the utilization by the body of the different forms of iron, Abderhalden fed animals from the end of the suckling period, or, in the case of guinea pigs, from birth, on food poor in iron, and divided each litter into two groups, one of which was given inorganic iron in addition. After a sufficient time the animals were killed, and the total hemoglobin in the body of each was estimated. Experiments of this kind were made upon 48 rats, 44 rabbits, 14 guinea pigs, 17 cats, and 11 dogs. The animals fed with food poor in iron plus an addition of inorganic iron were unable to produce as much hemoglobin as those receiving normal food.

In these experiments, Abderhalden had noticed some facts which indicated that the favorable influence of inorganic iron upon metabolism and blood formation was greater on a diet rich in food iron than when the amount of food iron was kept small. In order to test this, experiments were made with 66 rats, 10 rabbits, and 14 guinea pigs, in the manner already described, but with diets arranged to bring out this particular point. These experiments led to the conclusion that the greater the quantity of food iron present, the greater the influence of the inorganic iron upon the hemoglobin formation.

Abderhalden's experiments also showed that the production of hemoglobin was not stimulated indefinitely by inorganic iron, but only for a short time, and he concluded that, while inorganic iron may be absorbed and may favorably influence blood formation, it is not used as material for the production of hemoglobin. It has also been found clinically that medicinal iron gives better results when used intermittently than when used continuously, which indicates that the action is due to stimulation rather than to the inorganic iron actually going to form hemoglobin.

Tartakowsky has recently published a large number of microchemical observations in support of the older view that inorganic iron is used directly in blood formation, but such qualitative experiments appear to be outweighed by the careful quantitative work of Häusermann and of Abderhalden.

While it cannot yet be stated positively that inorganic iron is or is not used by the animal body as material for the production of hemoglobin, the best medical opinion appears to support the conclusion reached by Abderhalden, that hemoglobin is derived essentially from the organic iron compounds of the food, while inorganic iron acts mainly if not entirely as a stimulus. This view is strongly supported by Von Noorden in his treatise on chlorosis in Nothnagel's *Encyclopedia of Practical Medicine*, and Ehrlich and Lazarus, writing on anemia in the same work, state: —

> It is not very probable that the (medicinal) iron stored by the liver and spleen is directly employed in the formation of hemoglobin; on the contrary, the assumption first suggested by Von Noorden seems much more plausible, namely, that the iron exercises a direct irritative action on the function of the blood-making organs.

THE IRON REQUIREMENT OF THE BODY

A very brief summary of the leading facts regarding the normal nutritive relations of iron may well precede the discussion of the amount required.

Iron is an essential element of hemoglobin and of the chromatin substances, *i.e.* of the body constituents most directly concerned with the processes of oxidation, secretion, reproduction, and development. The substances thus fundamentally connected with metabolism processes contain their iron in firm organic combination, as a constituent of their characteristic proteins; and the normal materials for the production of these body constituents are the similar iron-protein compounds of the food.

The iron of the food is absorbed from the small intestine, enters the circulation by way of the lymph, and is deposited mainly in the liver, spleen, and bone marrow. Its final elimination takes place mainly through the walls of the intestines.

Both inorganic and synthetically prepared organic forms of iron are absorbed from the same part of the digestive tract, stored in the same organs, and eliminated by the same paths as the iron of the food. These medicinal forms of iron often stimulate the production of hemoglobin and red blood corpuscles.

Whether medicinal iron actually serves as material for the construction of hemoglobin is not positively known, but we have what appears to be ample evidence that food iron is assimilated and used for growth and for the regeneration of hemoglobin to much better advantage than are inorganic or synthetic forms, and that when medicinal iron increases the production of hemoglobin, its effect is more beneficial in proportion as the food iron is more abundant — a strong indication that the medicinal iron acts by stimulation rather than as material for the construction of hemoglobin.

Evidently, then, we must look to the food and not to medicines or mineral waters for the supply of iron needed in normal nutrition.

Comparatively few experiments upon the amount of food iron required for the maintenance of equilibrium in man have been made. Cetti and Breithaupt eliminated 0.0073 and 0.0077 gram per day, respectively, when fasting. Three men observed by Stockman while receiving in the food about 0.006 gram each per day eliminated 0.0063, 0.0093, and 0.0115 gram, respectively. Von Wendt found his requirements to range in a number of experiments on different diet from 0.008 to 0.016 gram per day, the largest amount being required in a case where the diet was deficient in calcium. In three experiments by Sherman in which the food contained 0.0057 to 0.0071 gram of iron there was metabolized 0.0055, 0.0087, and 0.0126 gram per day, respectively, and here also the amount of iron which sufficed for equilibrium when taken in the form of bread and milk (a diet rich in calcium) was insufficient when taken in the form of a diet (poor in calcium) consisting of bread and egg white, or bread alone. In this case, however, the difference in the economy of the metabolism of the iron may have been due not simply to the change in the calcium content of the food, but also to the fact that the digestion appeared better on the diet containing milk than on those without it.

Thus in the cases in which the intake and output of iron have been determined, the requirement appears to have varied with individuals and with the nature of the diet from

0.006 to 0.016 gram (6 to 16 milligrams) of iron per man per day.

We might conclude from these results that a daily allowance of 10 to 12 milligrams of food iron should suffice for the maintenance of iron equilibrium in an average man under favorable conditions, but until the conditions which determine a larger metabolism of iron are more clearly defined, it would seem desirable to set a higher standard, perhaps 15 milligrams of food iron per man per day.

In calculating the iron requirement for a family dietary, it is well to make the allowance for women and children more liberal than would be indicated by their total food requirement. A woman requiring eight tenths as much food as a man will probably require more than eight tenths as much iron, and a child requiring half as much food may easily require more than half as much iron; for the influence of menstruation, pregnancy, and lactation in women and of growth and development in children may reasonably be expected to affect the demand for iron to an even greater extent than they affect the requirement for total food. It is probable that pregnancy and lactation increase the iron requirement of the mother by at least 3 milligrams per day, and at other times the losses of blood in menstruation must call for a greater intake of iron than would be needed by a healthy man of equal energy and protein requirement.

Since milk is the sole food of young mammals during a considerable period of rapid growth, Bunge was surprised to find only small amounts of iron in milk ash. Comparing the composition of the ash of milk with that of the new-born animals of the same species, it was found that, while other constituents occurred in nearly the same relative proportions, the iron was six times as abundant in the ash of the young animal as in that of the milk on which it was nourished. That the suckling animal grows rapidly and increases its blood supply in spite of this apparent deficiency of iron in its food is due to the fact that the body contains a reserve supply of iron at birth. In confirmation of this statement Bunge and his pupils have published many analyses showing that the percentage of iron in the entire organism is highest at birth, and that during the suckling period the amount of iron in the body remains about constant, notwithstanding the increase in body weight.

In all cases in which the young depend entirely upon the milk of the mother during the suckling period the body constituents of the young must evidently be derived entirely from the maternal organism either before birth through the placenta or after birth through the milk glands of the mother and the digestive tract of the young. Since disordered digestion may readily lead to defective absorption of the iron of the food, nature apparently takes the precaution of conveying the necessary iron from mother to offspring mainly by the safer method, *i.e.* through the placenta. Hence in the case of animals which feed solely upon milk for some time after birth, a relatively large amount of iron is stored before birth for use in the formation of hemoglobin during the suckling period. This has been shown by analysis to be true of children, puppies, kittens, and rabbits. On the other hand, guinea pigs, which feed on green leaves or other food rich in iron from the first day of life, are born without this reserve store of iron (Bunge). From recent analyses it appears that the percentage of iron in the human body is about three times as high at birth as at maturity. If it be assumed, as indicated by Bunge's work, that during the milk feeding of infancy the amount of iron in the body remains about constant, it would follow that the percentage of iron in the child's body would be reduced to that in the adult when the body-weight becomes about three times what it was at birth,—usually when a little over one year old,—and that from this time on throughout the period of growth, care should be taken that the food is sufficiently rich in iron to provide not only for equilibrium, but also for the constantly increasing blood supply.

IRON IN FOODS

Little weight can be attached to such statements regarding the iron content of foods as are based upon the data obtainable from the ordinary tables of ash analyses, since these have usually been obtained by methods which are likely to greatly overestimate the amount of iron. In the following table are shown the approximate amounts of iron now believed to be present in the average edible portion of typical food materials expressed (1) in milligrams per 100 grams of material as purchased, (2) in milligrams per 100 grams of dry matter, (3) in milligrams per 100 grams of protein, (4) in milligrams per 3000 calories.

IRON IN TYPICAL FOOD MATERIALS

FOOD	IRON PER 100 GRAMS FRESH SUBSTANCE, MILLIGRAMS	IRON PER 100 GRAMS DRY SUBSTANCE, MILLIGRAMS	IRON PER 100 GRAMS PROTEIN, MILLIGRAMS	IRON PER 3000 CALORIES, MILLIGRAMS
Beefsteak, all lean	3.85	14	16	97
Beefsteak, medium fat	2.2	8	16	47
Eggs	3.0	11.4	21.5	57
Milk, whole	0.24	1.7	7.3	10
Milk, skimmed	0.25	2.5	7.3	20
Cream (18.5 per cent fat)	0.20	0.8	7.3	3.6
Barley flour, patent	1.0	1.1	12.8	8.3
Corn meal	1.15	1.3	12.5	9.5
Oatmeal	3.7	4.1	22.4	26.4
Rice, polished	0.7	0.8	10	5.8
Wheat, flour	1.5	1.6	14	12.8
Wheat, entire grain	5.2	5.7	37	42
Beans, lima, dried	7.2	8.0	40	60
Beans, navy, dried	6.7	7.5	30	55
Beans, string, fresh	1.6	14.8	70	112
Cabbage	0.9	11.0	56	84
Corn, sweet	0.8	3.2	26	23
Peas, dried	5.6	6.2	23	46
Potatoes	1.2	5.7	55	42
Spinach	3.8	37	135	350
Turnips	0.6	7.5	49	47
Apples	0.3	2.0	78	15
Prunes, dried	2.9	3.3	136	28
Raisins	3.6	4.2	137	30

Percentages of iron in some other foods will be found in the tables of ash constituents in the appendix. Using these recent data for iron in food materials, approximate estimates of the amounts of iron contained in 20 American dietaries have been made. The majority of these were found to furnish 12 to 19 milligrams of iron per man per day. Apparently therefore the typical American dietary does not contain any such surplus of iron as would justify the usual practice of leaving the supply of this element to chance. The available data rather indicate that foods should be selected with some reference to the kinds and amounts of iron compounds which they contain.

Meats. — In meat as ordinarily eaten the iron exists largely as hemoglobin, due to the blood contained in the muscular tissue as usually sold and prepared for the table. Muscular tissue washed free from blood contains iron, but the amount is comparatively small. Since fatty tissue contains much less iron, the iron content of fat meat is much lower than that of lean, and in order to establish any useful estimate of the amount of iron in meat it is practically necessary to consider the lean tissue alone or to refer the iron to the protein content rather than to the gross weight of the meat. When expressed on the former basis, the results will still be influenced by the extent to which the blood has been either accidentally or intentionally removed from the muscle.

For fresh lean beef containing the full proportion of blood, the results obtained by most investigators are in satisfactory agreement, and the average figure, 0.00375 per cent iron in the fresh meat free from visible fat, can be accepted with little danger of serious error. This corresponds to about 15 to 16 milligrams of iron per 100 grams of protein in beef, and since no certain differences in iron content in the flesh of different species has been shown, it is assumed for the present that approximately the same ratio of iron to protein will hold for meats in general.

The iron of meat, as already mentioned, is largely due to the blood retained in the muscular tissue. The nutritive value of blood is often questioned. So far as the iron compounds of the blood are concerned, it seems to be established that hemoglobin and hematin may be absorbed and assimilated to some extent, but probably not to such good advantage as the iron compounds of eggs, milk, and vegetable foods.

Eggs. — The edible portion of hens' eggs has shown as the average of several analyses 0.0030 per cent of iron. Whether the iron content of eggs can be increased by giving to poultry food rich in iron, is a disputed question.

There can be no doubt regarding the assimilation and utilization of the iron compounds of eggs, since they serve for the production of all the iron-holding substances of the blood and tissues of the chick, there being no possibility of the introduction of iron from without during incubation.

Milk. — Analyses of samples of cows' milk of various origin have given results varying from 0.0002 to 0.0003 per cent, and averaging 0.00024 per cent of iron in the fresh substance.

It cannot be doubted that the iron of milk is readily absorbed and assimilated, since this constitutes the sole natural source of iron for all young mammals during a period of rapid growth. Moreover, metabolism experiments indicate that the iron of milk is likely to be utilized to especially good advantage, perhaps on account of its association with a high proportion of calcium.

The question of the iron supply of infants fed upon diluted or modified cow's milk may, however, be considered at this point. It is now generally recognized that the best substitute for mother's milk is obtained by diluting cream with a solution of milk sugar, the product being usually known as modified milk. By varying the richness of the cream and the amounts of water and milk sugar added, the composition of the modified milk can be controlled at will. In order to ascertain whether the iron compounds in milk tend to condense upon the fat globules or for any other reason are altered in their distribution by the rising of the cream, a sample of milk was allowed to stand, and after the cream had risen, the iron and nitrogen contents were determined separately in the upper half containing all of the cream, and in the lower half which consisted of skimmed milk. These analyses showed in the upper half 0.000277 per cent of iron and 0.54 per cent of nitrogen; in the lower half 0.000293 per cent of iron and 0.59 per cent of nitrogen. It is evident, therefore, that the ratio of iron to nitrogen was practically the same in the cream as in the milk. It is therefore important to recognize that the iron content of cow's milk is little if any higher than that of human milk, while the protein content is at least twice as high; that any modification of cow's milk which reduces its protein content will reduce the iron content in practically the same proportion, and that an infant fed upon cow's milk, modified or diluted to contain less than 3 per cent of protein, is probably receiving food poorer in iron than human milk. According to present estimates an infant fed on any modification of cow's milk must consume the equivalent of nearly a quart of undiluted milk or cream in order to obtain as much iron as is supplied daily in the milk of the average healthy nursing mother. Since no such quantity of cow's milk can safely be fed in early infancy, it is to be expected that during the first months of life the artificially fed infant will use up the surplus store of iron with which it was born more rapidly than will the child of the same age which receives the milk of a healthy mother.

Grain Products. — Iron in combination with protein matter is found in considerable quantity in the cereal grains, but the greater part of it is in the germ and outer layers and so is rejected in the making of the "finer" mill products, such as patent flour, polished rice, and new-process corn meal. In view of the part which the iron of the germ takes in the sprouting of the seed and the nutrition of the young plant, there is little room for doubt that it is of value also in the animal economy. To test the value of the iron in the outer layers of the grain Bunge[1] carried out the following experiment: —

A litter of eight rats was divided into two groups of four

---

[1] *Zeitschrift für physiologische Chemie*, **25**, 36 (1898).

each, one group fed upon bread from fine flour, the other upon bread made from flour including the bran. At the end of the fifth, sixth, eighth, and ninth weeks, respectively, one rat of each group was killed, and the gain in weight, the total amount of hemoglobin, and the percentage of hemoglobin in the entire body were determined. The average results were as follows: —

EFFECT OF FEEDING DIFFERENT KINDS OF BREAD ON GROWTH AND IRON CONTENT OF BODY IN EXPERIMENTS WITH RATS

KIND OF RATION	GAIN IN WEIGHT OF BODY	TOTAL HEMOGLOBIN IN BODY	PROPORTION OF HEMOGLOBIN IN BODY
	grams	grams	per cent
White bread . .	4.81	0.2395	0.613
Bran bread . . .	20.76	0.3492	0.714

Here the bran-fed rats not only made a much greater general growth, but developed both a greater amount and a higher percentage of hemoglobin. There can be no doubt that the iron and other ash constituents of the outer layers of the wheat were well utilized in these cases.

Vegetables and Fruits. — Not many direct studies upon the iron compounds of the fruits and vegetables have been made, but Stoklasa has separated from onions an iron-protein compound very similar to the hematogen obtained by Bunge from egg yolk, but containing a considerably higher proportion of iron. Preparations similar in properties were also obtained from peas and from mushrooms.

In view of the fact that the herbivorous animals, which are less liable to anemia than the carnivora, obtain their normal food iron entirely from vegetable sources there is every reason to suppose that man makes good use of the iron of the fruits and vegetables in his diet. Moreover, since (as Herter has shown) anemic conditions and excessive intestinal putrefaction often go together, the bulkiness and laxative tendency of fruits and vegetables, along with their relatively high iron content, is advantageous in combating the conditions which give rise to excessive putrefaction, and at the same time increasing the supply of food iron.

Among typical food materials omitted from the above table because of containing little, if any, iron may be mentioned fat pork, bacon, lard and suet, butter, salad oil, sugars, starches, and confectionery. All of these foods have high fuel value, and many are economical and highly important elements in a normal dietary. Excessive use of these foods, however, would tend to satisfy the appetite and supply the body with the needed fuel without furnishing the desirable amount of iron. On the other hand, the fruits and fresh vegetables are often regarded as of low nutritive value because of their high water content and low proportions of protein and fat. But it is largely this property which makes them especially important as sources of food iron, because they can be added to the diet without replacing the staple foods of high calorific and protein value, and without making the total food consumption excessive. Thus the above table shows plainly that the ratio of iron both to protein and to fuel value is high in nearly all of the typical fruits and vegetables, so that in most cases it would be necessary to increase only slightly the amount of protein and fuel value derived from these sources, in order to effect a material increase in the iron content of the dietary. The iron content of eggs is also high, but the cost of these is often such as to restrict their use in families of limited means, while present methods of drying and preserving tend to equalize the cost and increase the available variety of fruits and vegetables throughout the year. The ratio of iron to fuel value is also high in lean meat, but here, as has already been pointed out, the iron exists largely in the form of hemoglobin, which appears to be of distinctly lower nutritive value than the iron compounds of milk, eggs, and foods of vegetable origin. Especially in families where there are young children it would be a mistake to rely too largely upon meat as a source of iron. Von Noorden, who is one of the strongest advocates of a liberal use of meat in the adult dietary, says in regard to the feeding of children: —

> The necessity of a generous supply of vegetables and fruits must be particularly emphasized. They are of the greatest importance for the normal development of the body and of all its functions. As far as children are concerned, we believe we could do better by following the dietary of the most rigid vegetarians than by feeding the children as though they were carnivora, according to the bad custom which is still quite prevalent. . . . If we limit the most important sources of iron, — the vegetables and the fruits, — we cause a certain sluggishness of blood formation and an entire lack of reserve iron, such as is normally found in the liver, spleen, and bone marrow of healthy, well-nourished individuals.

In an experimental dietary study made in New York City it was found that a free use of vegetables, whole wheat bread, and the cheaper sorts of fruits, with milk but without meat, resulted in a gain of 30 per cent in the iron content of the diet, while the protein, fuel value, and cost remained practically the same as in the ordinary mixed diet obtained under the same market conditions.

REFERENCES

ABDERHALDEN. Physiological Chemistry, Chapter 17.

BUNGE. Physiological and Pathological Chemistry, Chapter 25.

GAULE. Resorption von Eisen und Synthese von Haemoglobin. *Zeitschrift für Biologie*, **35**, 377 (1897).

GOTTLIEB. Ueber die Ausscheidungsverhältnisse des Eisens. *Zeitschrift für physiologische Chemie*, **15**, 371 (1891).

MACCALLUM. On the Absorption of Iron in the Animal Body. *Journal of Physiology*, **16**, 268 (1894); also *Proceedings Royal Society* (London), **50**, 277 (1891–1892); *Quarterly Journal of Microscopical Science* (London), **38**, 175 (1896).

NOTHNAGEL. Encyclopedia of Practical Medicine. Diseases of the Blood, pp. 17, 339 (1905).

SHERMAN. Iron in Food and its Functions in Nutrition. Bull. 185, Office of Experiment Stations, U. S. Dept. Agriculture (1907).

SOCIN. In welcher Form wird das Eisen resorbirt? *Zeitschrift für physiologische Chemie*, **15**, 93–139 (1891).

VON WENDT. Untersuchungen ueber den Eiweiss und Salz-Stoffwechsel beim Menschen. *Skandinavisches Archiv für Physiologie*, **17**, 211–289 (1905).

WOLTERING. Ueber die Resorbirbarkeit der Eisen-salze. *Zeitschrift für physiologische Chemie*, **21**, 186 (1895).

CHAPTER X

INORGANIC FOODSTUFFS AND THE MINERAL METABOLISM

THE eight chemical elements, iron, calcium, magnesium, potassium, sodium, chlorine, sulphur, and phosphorus, remain either wholly or in part in the ash of food materials when the latter are burned in the air; and when the food is metabolized in the body, they are (with perhaps the exception of iron) given off chiefly in the form of mineral matter. These elements and their compounds are therefore commonly referred to as ash constituents, and their metabolism as mineral metabolism. Some of these elements, however, enter the body and take part in metabolism as essential constituents of organic material, and become inorganic only as the organic matter is oxidized, while others enter and leave the body in the same inorganic form.

From various estimates by different writers the average elementary composition of the human body may be presumed to be approximately as follows: —

Oxygen, about	65. per cent.
Carbon, about	18. per cent.
Hydrogen, about	10. per cent.

Nitrogen, about	3. per cent.
Calcium, about	2. per cent.
Phosphorus, about	1. per cent.
Potassium, about	0.35 per cent.
Sulphur, about	0.25 per cent.
Sodium, about	0.15 per cent.
Chlorine, about	0.15 per cent.
Magnesium, about	0.05 per cent.
Iron, about	0.004 per cent.
Iodine	Very minute quantities.
Fluorine	
Silicon	

The so-called inorganic elements exist in the body and take part in its functions in at least three different ways: (1) as the constituents which give rigidity and comparative permanence to the skeleton; (2) as essential elements of the protoplasm of the active tissues; (3) as salts held in solution in the fluids of the body; giving these fluids their characteristic influence upon the elasticity and irritability of muscle and nerve, supplying the material for the acidity or alkalinity of the digestive juices and other secretions, and yet maintaining the neutrality or slight alkalescence of the internal fluids as well as their osmotic pressure and solvent power.

A man under average conditions of diet, activity, and health usually excretes daily from 20 to 30 grams of mineral salts, consisting essentially of chlorides, sulphates, and phosphates of sodium, potassium, magnesium, and calcium (as well as ammonium salts from the protein metabolism).

METABOLISM OF CHLORIDES — USE OF COMMON SALT

Practically all the chlorine involved in metabolism enters, exists in, and leaves the body in the form of chlorides; much the greater part as sodium chloride. The amount of sodium chloride which is ordinarily added to food as a condiment is so large that the amounts of sodium and chlorine present in the various foods in the fresh state become of little practical consequence to dietetics. Among animals the herbivora require salt and the carnivora do not, the latter obtaining sufficient salt for their needs from the flesh, and more especially from the blood, of their prey.

Sodium occurs (chiefly as chloride) abundantly in the blood and other fluids of the animal body and much less abundantly in the tissues. Potassium, on the other hand, occurs most abundantly in the soft solid tissues — in the corpuscles of the blood, the protoplasm of the muscles, and other organs, and also in the highly specialized fluids which some of the glandular organs secrete, *e.g.* milk — and to a greater extent as phosphate than as chloride. Since the cells are in constant contact with the circulating fluids, the abundance of potassium as phosphate in the cells and of sodium as chloride in the fluids makes it evident that the taking up of salts by the cells is an active or "selective" process. A conspicuous function of the salts in the tissues is the maintenance of the normal osmotic pressure, but solutions of different salts of equal osmotic pressure are by no means interchangeable, and it is not possible to replace successfully the potassium in the cell by an equivalent amount of sodium.

Attention is frequently called to the fact that sodium chloride is the only salt which man seems to crave in greater quantities than occur naturally in his food, and that he shares this appetite with the herbivorous animals. Bunge explains the relation between vegetable diet and craving for salt somewhat as follows: Most vegetables are rich in potassium, which is ultimately eliminated through the blood and urine in the form of mineral salts, largely as sulphate. Potassium sulphate in the blood reacts to some extent with sodium chloride forming potassium chloride and sodium sulphate, both of which are rapidly eliminated by the kidneys. Hence the greater the amount of potash in the food the greater the loss of sodium and chlorine from the blood and the greater the necessity for salt to keep up the normal sodium chloride content of the body. Bunge tested this theory upon his own person by taking 18 grams of potash (as phosphate and citrate) in one day. This increased the elimination of sodium chloride by 6 grams.

In his *Physiological and Pathological Chemistry* (Chapter VII), Bunge records extended and interesting observations and discussion upon the relation of diet to the craving for salt, and concludes that while one might live without the addition of salt to the food even on a diet largely vegetarian, yet without salt we should have a strong disinclination to eat much of the vegetables rich in potassium, such as potatoes. "The use of salt enables us to employ a greater variety of the earth's products as food than we could do without it." But also, according to Bunge; "We are accustomed to take far too much salt with our viands. Salt is not only an aliment, it is also a condiment and easily lends itself, as all such things do, to abuse." While Bunge's explanations may not be entirely adequate in detail, there seems to be little doubt as to the correctness of his main deductions.

Sodium and chlorine equilibrium can apparently be maintained on less than one fourth the amount of salt ordinarily eaten. Since the sodium chloride taken with the food passes through the body and is excreted by the kidneys without undergoing any chemical change, the rate of excretion quickly adapts itself to the rate of intake within wide variations. When no salt is taken, the rate of excretion falls rapidly to a point where the daily loss is extremely slight. In a recent experiment[1] upon a salt-free diet the chlorine excretion upon successive days was as follows: —

1st day	4.60 grams chlorine.	7th day	0.46 grams chlorine.
2d day	2.52 grams chlorine.	8th day	0.40 grams chlorine.
3d day	1.88 grams chlorine.	9th day	0.26 grams chlorine.
4th day	0.87 grams chlorine.	10th day	0.22 grams chlorine.
5th day	0.69 grams chlorine.	11th day	0.22 grams chlorine.
6th day	0.48 grams chlorine.	12th day	0.17 grams chlorine.
13th day	0.17 grams chlorine.		

---

[1] Goodall and Joslin, *Transactions of the Association of American Physicians*, **23**, 92–106 (1908).

Cetti in ten days of fasting excreted altogether 13.13 grams, and Belli in ten days on a diet poor in salt lost 11.8 grams of sodium chloride. Since the body is supposed to contain about 100 grams of sodium chloride, it will be seen that even when there was complete deprivation of salt for ten to thirteen days, the total losses did not exceed 10 to 15 per cent of the amount estimated as usually present in the body. The salt thus readily given off by the body has been regarded as a measure of the excess which the body has been forced to carry in consequence of the extravagant amounts of salt which are commonly taken with the food. Magnus-Levy, however, thinks that the reduced amount of sodium chloride left in the body after such a loss is "not a physiological optimum, but rather a physiological minimum."

Moderate variations in the amount of salt taken have no significant effect upon the protein metabolism; large amounts increase the quantity of protein katabolized, and, through overstimulating the digestive tract, may also interfere with the absorption and utilization of the food.

OCCURRENCE AND METABOLISM OF SULPHUR COMPOUNDS

Plants absorb sulphates from the soil and use the sulphur in the synthesis of proteins. Minute quantities of sulphates may be taken by man in food and drink, but much the greatest part of the sulphur concerned in metabolism enters the body in organic combination and, so far as known, chiefly as protein. The metabolism of sulphur is therefore a part of the protein metabolism, and in many respects the metabolism of sulphur runs parallel to that of nitrogen. In a series of ten experiments (each of 3 to 5 days' duration) upon man, in which the food consisted of bread and milk in varying amounts and proportions, the percentage absorption from the digestive tract was nearly the same for the sulphur as for the nitrogen of the food, and the excretion of the end products ran so closely parallel that in every case in which the body stored nitrogen it also stored sulphur, and *vice versa*.

It is of course well known that individual proteins show relatively much greater differences in sulphur than in nitrogen content, so that the ratio of nitrogen to sulphur varies widely, as is shown by the following examples selected from the data for pure proteins compiled by Osborne: —

KIND OF PROTEIN	NITROGEN PER CENT	SULPHUR PER CENT	RATIO OF NITROGEN TO SULPHUR
Legumin . . .	18.04	0.385	46.9 : 1
Zein	16.13	0.600	26.9 : 1
Edestin	18.69	0.88	21.2 : 1
Gliadin	17.66	1.027	17.2 : 1
Leucosin . . .	16.80	1.280	13.1 : 1
Casein	15.78	0.80	19.7 : 1
Myosin	16.67	1.27	13.1 : 1
Serum globulin .	15.85	1.11	14.3 : 1
Egg albumin . .	15.51	1.616	9.6 : 1

Thus, while many proteins approximate the usually assumed average of 16 per cent nitrogen and 1 per cent sulphur, there are considerable deviations from this ratio in both directions.

Under ordinary conditions, however, no protein is eaten in a pure state, but only as the material containing it is used as an article of food. It is therefore the proportion of sulphur to the total protein of the food which determines the ratio of sulphur to nitrogen available for nutrition.

The proportion of sulphur to total protein has been determined in a few samples of representative foods with the following results: —

Food Material	Sulphur in Percentage of Total Protein
Lean beef	0.95–1.00
Eggs	1.4
Milk	0.95–1.09
Wheat flour, crackers	1.15–1.29
Entire wheat	1.30
Oatmeal	1.55
Beans	0.69–1.00
Peas	0.80–0.94
Potatoes	1.07

Taking these figures as typical, it would appear that in those staple foods which contribute the greater part of the protein eaten, the ratio of protein to sulphur does not differ as greatly as among the pure proteins, and that in most cases of ordinary mixed diet there would be consumed not far from 1 gram of sulphur in each 100 grams of protein. We may therefore consider that in health and on an ordinary diet the sulphur requirement will be covered when the protein requirement is covered.

When proteins (or their cleavage products) are oxidized in the body, the sulphur becomes converted for the most part into sulphuric acid, which, of course, must be neutralized as rapidly as it is formed, since free sulphuric acid even in small concentration would be very injurious to the cells. The greater part of the sulphuric acid formed in metabolism appears in the urine as inorganic sulphates; a smaller part is found combined with organic radicles in the form commonly known as "ethereal" or "conjugated" sulphates. An ethereal sulphate consists of a molecule of sulphuric acid in which one hydrogen is replaced by potassium (or possibly sodium or ammonium) and the other by an aromatic body, ordinarily an indoxyl, skatoxyl, phenol, or cresol, derived from the intestinal putrefaction of protein. The amount of ethereal sulphate or the ratio of ethereal to inorganic sulphate is quite variable, depending mainly upon the amount and character of the intestinal putrefaction, which in turn is apt to be considerably influenced by the food. On ordinary mixed diet about one tenth or one twelfth of the sulphate sulphur in the urine ordinarily appears as ethereal sulphates; but when the meat in the diet is replaced by milk, the putrefaction is usually lessened and the proportion of ethereal sulphates lowered. In one case of a healthy man who had been on a bread and milk diet for a week, only one thirtieth of the sulphate sulphur was in the form of ethereal sulphates.

Not all of the metabolized sulphur is eliminated as mineral or ethereal sulphate; a part is given off in less completely oxidized forms. This "unoxidized" or "neutral" sulphur usually constitutes in healthy persons on full diet from 5 to 15 per cent of the total sulphur eliminated. In Folin's experiment upon very low protein diet, while the total sulphur metabolism was markedly decreased, the quantity of neutral sulphur excreted remained about constant, so that the relative proportion of sulphur appearing in this form was increased. In certain diseased conditions there may be marked increase both in the relative proportion and in the absolute amount of neutral sulphur.

OCCURRENCE AND METABOLISM OF PHOSPHORUS COMPOUNDS

The phosphorus compounds are as universally distributed in the body and as strictly essential to every living cell as are the proteins. Possibly because the crudity of the views formerly held and still sometimes met (especially in fraudulent advertisements of proprietary foods) tended to bring the subject into ridicule, the study of the phosphates and other phosphorus compounds in food and nutrition was very generally neglected, until quite recently, when the significance of phosphorus in the growth, development and functions of the organism is at last being adequately recognized and is attracting attention to its nutritive relations. Recent investigations, such as those of Forbes and Hart, make it appear probable that much of the malnutrition which has been attributed to low protein diet is really due to a deficiency of phosphorus (and possibly also of calcium) in the food.

PRINCIPAL GROUPS OF PHOSPHORUS COMPOUNDS

Phosphorus is taken in the food and is found in the body in at least four classes of compounds: —

1. Phosphorized proteins, including the nucleo-proteins of cell nuclei, the lecitho-proteins, and the true phosphoproteins such as casein and ovovitellin.

2. Phosphorized fats — lecithins, lecithans, kephalins, etc. These occur in large quantity in brain and nerve substances and in smaller amounts in other tissues. Egg yolk is conspicuous among food materials for its richness in phosphorized fats, but significant quantities are also found in other foods.

3. Simpler organic derivatives of phosphoric acid, such as the inosite-phosphoric acid ("phytic acid"), whose natural salts, which are collectively called "phytin" or "phytates," are the most abundant phosphorus compounds of wheat and probably also of the other grains and of the legumes.

4. Inorganic phosphates, of which potassium phosphate is probably the most abundant in the food and in the fluids and soft tissues of the body, while calcium phosphate is the chief mineral constituent of the bones.

Phosphates, Phospho-proteins and Phosphorized Fats. — Maxwell,[1] from observations upon germinating seeds and developing chick embryos, concluded that in each of these cases there was at first a synthesis of phosphorized fat, which then took an important part in the construction of the tissues of the growing organizm. Meischer studied the formation of complex from simpler phosphorus compounds in the adult animal body by observations upon the Rhine salmon, which during the breeding season remain a long time in fresh water, taking no food, but developing large masses of roe and milt at the expense of muscular tissue. This process evidently involves the formation of considerable amounts of phosphorized proteins and fats from simpler proteins, fats, and phosphorus compounds of the muscles. Paton [2] has studied the salmon of Scotland with similar results.

Chiefly on account of certain peculiarities which had been observed in the artificial digestion of casein, the digestibility and nutritive value of the phosphorized radicles of phosphoproteins was for some time in doubt. In 1897, however, Marcuse,[3] working in Rohmann's laboratory, showed by a series of digestion and metabolism experiments with dogs that about 90 per cent of the phosphorus of the casein fed was absorbed and utilized.

Steinitz,[4] followed by Zadik [5] and Leipziger,[6] continuing

[1] *American Chemical Journal*, **13**, 16; **15**, 135.

[2] *Journal of Physiology*, **22**, 333.

[3] *Archiv Physiologie* (*Pflüger*), **67**, 373.

[4] *Ibid.*, **72**, 75. [5] *Ibid.*, **77**, 1. [6] *Ibid.*, **78**, 402.

this work, studied, especially by metabolism experiments on dogs, the question whether the phospho-proteins, when fed to the exclusion of the phosphates, were able to support a storage of phosphorus in the body. Casein and ovovitellin were taken as typical phospho-proteins and compared with either myosin or edestin fed with inorganic phosphates. Rohmann[1] summarized the results as a whole and found a striking difference in the phosphorus balances in favor of the phospho-proteins as against the mixtures of simple proteins with inorganic phosphates. The storage of nitrogen was also more pronounced in the periods in which the phosphorized proteins were fed. The results appear to justify Rohmann's conclusion that the nutritive functions of phosphorized and phosphorus-free proteins are not entirely the same, the former being especially adapted to furnish the material for tissue growth.

Moreover, Ehrstrom[2] and Gumpert[3] have found, in experiments upon men, that a smaller amount of phosphorus will maintain phosphorus equilibrium when taken in the form of casein than when taken largely as dicalcium phosphate or as meat whose phosphorus is largely in the form of potassium phosphate.

It does not by any means follow, however, that the simple phosphates are without nutritive value. Keller[4] in a study

---

[1] *Berlin klinische Wochenschrift*, **35**, 789.

[2] *Skandinavisches Archiv für Physiologie*, **14**, 82.

[3] *Medische Klinik*, **1**, 1037.

[4] *Archiv für Kinderheilkunde*, **29**, 1.

of the phosphorus metabolism of young children found evidence that storage of phosphorus was favored by food (like milk) which contained a liberal supply of phosphates in addition to the organic phosphorus compounds; and Von Wendt found that the loss of phosphorus occurring on a diet very poor in ash could be greatly reduced by the addition of dicalcium phosphate to the food. Moreover, it has recently been shown independently by Forbes[1] and by Hart,[1] in experiments upon swine, that when a part of the phosphorus requirement is covered by organic phosphorus compounds, the remainder can be given in the form of calcium phosphates which are then utilized at least for the support of the skeleton; and McCollum[2] believes that, other things being satisfactory, all the phosphorus needed by an animal can be drawn from inorganic phosphates.

In cow's milk the greater part of the phosphorus appears to exist as phosphate, but there can be no doubt that the milk phosphorus as a whole is available for the needs of the young of the species, especially in view of the parallelism pointed out by Bunge and Abderhalden between the phosphorus and calcium content of milk and the rate of growth of the young of the species.

It is, however, not without possible significance that the phosphorus of human milk is mainly in organic forms (Söldner) and that, notwithstanding its much lower content

---

[1] See references at end of this chapter.

[2] Research Bulletin No. 8, Wisconsin Agricultural Experiment Station.

Species	No. of Days Required to Double the Birth Weight	Percentage Composition of Milk (Partial)			
		Protein	Ash	CaO	P_2O_5
Human	180	1.6	0.2	0.03	0.05
Horse	60	2.0	0.4	0.12	0.13
Cow	47	3.5	0.7	0.16	0.20
Goat	22	3.7	0.78	0.20	0.28
Sheep	15	4.9	0.84	0.25	0.29
Swine	14	5.2	0.80	0.25	0.31
Dog	9	7.4	1.33	0.45	0.51
Rabbit	6	14.4	2.50	0.89	0.99

of total phosphorus, human milk contains as high a percentage of lecithin as does cow's milk (Stoklasa). An infant fed on diluted cow's milk must therefore receive less lecithin and presumably less of other organic phosphorus compounds, while it may receive more total phosphorus than the breast-fed infant. As a source of organic phosphorus as well as iron and calcium, egg yolk holds an important place in the dietary of the child, particularly when artificial feeding has been practiced during the suckling period.

The phytates (*phytin*) and similar compounds, whose occurrence in food materials has only recently been appreciated, are still under active investigation, so that it would be premature to attempt to state their exact nutritive value and functions in metabolism. It is believed by some physiological chemists that these compounds, although easily mistaken for phosphates in their analytical behavior, are of greater nutritive value. This is doubted by some other investigators.

In either case, considering the quantities in which they occur in grains and other vegetable foods, the phytates must be regarded as one of the most important dietetic sources of phosphorus. For discussion of the results of feeding experiments with phosphates and phytates, see the recent publications of Jordan, Hart, Forbes, Cook, and their associates, several of which are included among the references given at the end of this chapter.

It is interesting to note that the phosphorus of wheat bran is mainly in the form of phytates, which are easily extracted and doubtless readily absorbed from the digestive tract. Washed bran fed to cows was found to be constipating, indicating that the laxative property of ordinary bran and whole wheat products is dependent not simply upon mechanical irritation, but largely, if not mainly, upon the phytates.

METABOLISM OF PHOSPHORUS IN MAN

Factors determining Phosphorus Metabolism. — The abundance of phosphorized fat in the brain and nerves led at one time to belief that the extent of the phosphorus metabolism was mainly determined by mental and nervous work or strain, but important as are the phosphorus compounds of the brain and nerves, their amount is too small to permit the belief that they are the chief factor in the phosphorus metabolism. According to Voit's estimate a man's skeleton contains about 1400 grams, his muscles about 130 grams, and his brain and nerves only about 12 grams of phosphorus.

The phosphorus of the tissues exists largely in the form of nucleoproteins, — the characteristic substances of cell nuclei, — and, as these are very active in metabolism, there was a tendency for a number of years to regard the phosphorus elimination as largely a measure of the metabolism of nucleoproteins somewhat as the nitrogen is taken as a measure of the metabolism of proteins in general. It is probable, however, that such a view of the phosphorus metabolism is of only very limited application, because of the influence of other factors. Voit showed that the material katabolized in fasting comes largely from the bones. Hence it cannot be assumed that the bones take no part in the daily metabolism and while they may undergo a less active exchange of material than the soft tissues, they possess such a large proportion of the phosphorus in the body that they probably contribute a considerable part of what is katabolized from day to day. Moreover, recent investigations indicate that the soluble phosphates of the blood and lymph share with the bicarbonates and the proteins the important functions of maintaining neutrality in the body, and that the neutralization of acid by conversion of di- into mono-phosphates is followed by an increased excretion of the acid phosphate in the urine. Finally, it is evident that the amount of phosphorus metabolized is very directly influenced by the amount taken in the food, much of which is in comparatively simple forms, and if not needed by the tissues is probably converted into phosphate and eliminated quite rapidly.

Since phosphorus compounds are essential to all the tissues of the body, the growth of new tissue requires a storage of phosphorus along with that of protein, but aside from this it is evident that the phosphorus metabolism presents a separate problem from the metabolism of protein.

Phosphorus Elimination.—The phosphorus which has been metabolized is excreted from the body almost entirely in the form of inorganic phosphates, the organic phosphorus of the urine constituting as a rule only 1 to 3 per cent of the total.[1] Carnivorous animals excrete phosphates mainly through the kidneys, but in the herbivora the excretion occurs almost entirely through the intestinal wall, whether the phosphate be taken by the mouth, or injected subcutaneously, or be formed by katabolism of organic phosphorus compounds in the body. In man, the elimination of metabolized phosphorus is partly through the kidneys and partly through the intestinal wall, the relative quantities in urine and feces varying within rather wide limits. As a rule, foods rich in calcium, or which yield an alkaline ash, tend to increase the proportion of phosphorus excreted by way of the intestine.

---

[1] Some investigators have doubted the occurrence of organic phosphorus in urine, while others have estimated it as high as 6 per cent of the total urinary phosphorus.

The Phosphorus Requirement.—Attempts have sometimes been made to estimate the phosphorus requirement from the amount excreted in the urine. The results thus obtained are too low, and are largely responsible for the fact that the amount of phosphorus required for the normal nutrition of man is seriously underestimated in many of the standard textbooks.

Since the excretion of metabolized phosphorus through the intestine is in man too large to be neglected, and too variable to be allowed for by calculation, we can expect reliable data on phosphorus requirements from those experiments only in which the amounts of phosphorus are actually determined in food, in feces, and in urine. In such experiments it is found (as in the case of nitrogen) that the output obtained upon the experimental days is influenced not only by the food taken at the time, but also by the rate of metabolism to which the body had been accustomed on the preceding days. This is shown by the following results obtained in a 12-day series of experiments upon a healthy man:—

PHOSPHORUS METABOLISM WITH DIFFERENT AMOUNTS OF PHOSPHORUS IN THE FOOD

EXPERIMENTAL PERIOD		PHOSPHORUS PER DAY				
No.	Duration	In food, grams	In feces, grams	In urine, grams	Output, grams	Balance, grams
I	3 days	0.40	0.45	0.70	1.15	− 0.75
II	6 days	0.77	0.19	0.72	0.91	− 0.14
III	3 days	1.51	0.50	0.99	1.49	+ 0.02

Here the output of phosphorus was greater in the first period with 0.40 gram in the food than in the second when the food furnished 0.77 gram, probably because the first period followed and was influenced by a preceding diet fairly rich in phosphorus, whereas the output in Period II was influenced by the low-phosphorus diet of Period I. For the same reason Period II offered favorable conditions for the establishment of equilibrium on a minimum diet, and the results show that in this case the subject was unable to reach equilibrium on 0.77 gram per day, the output averaging 0.91 gram. When the intake was increased to 1.51 grams, the output rose rapidly and averaged 1.49 grams. In this case the amount which would have been just sufficient for equilibrium evidently lay between 0.91 and 1.49 grams per day.

Study of the data from about 100 phosphorus balance experiments has shown two instances in which equilibrium was established upon as little as 0.8 to 0.9 gram of phosphorus (corresponding to about 2 grams of P_2O_5) per day, but in most cases 1.2 to 1.75 grams of phosphorus (corresponding to 2.75 to 4 grams of P_2O_5) have been required for equilibrium. It should be noted that most of these experiments were not arranged primarily to determine the minimum phosphorus requirement, and that the previous habit of the subject may in many cases have led to a rate of excretion higher than the minimum which would have sufficed had the experiments been conducted upon a plan similar to that followed by Chittenden in his study of the protein requirement.

The data at present available therefore indicate that it may be possible for man to establish equilibrium upon about 0.9 gram of phosphorus or 2 grams of phosphoric acid per day, but that at least 1.2 grams of phosphorus or 2.75 grams of phosphoric acid per day is usually needed to maintain equilibrium under ordinary conditions with a store of phosphorus such as the body carries when liberally fed.

Important light has recently been thrown upon the phosphorus requirement by Hart's experiments with swine. One lot of these animals was fed a ration which supplied 1.12 grams phosphorus (2.56 grams P_2O_5) per head per day, almost entirely in organic form, while other lots received the same ration with the addition of phosphates or phytates. It was found that the basal ration with its smaller amount of phosphorus was insufficient when the animals reached about 85 pounds in weight, while normal growth continued if they had in addition to this basal ration a further supply of phosphorus either as phosphates or as phytates.

If 2.5 grams of P_2O_5 is insufficient for a pig of 85 pounds, it would hardly seem a desirable amount for a growing child of the same size or for a man or woman. It is, however, important to know that with this much phosphorus in ordinary forms, the remainder could be supplied by calcium phosphates without disadvantage.

PHOSPHORUS IN FOOD MATERIALS AND TYPICAL DIETARIES

A comparison of the amounts of phosphorus contained in the food of typical American families with the amounts metabolized in the experiments above mentioned indicates that a freely chosen diet does not always furnish an abundance of phosphorus compounds. In 20 American dietaries of families or larger groups believed to be fairly representative, the estimated amount of P_2O_5 furnished per man per day was below 2.75 grams in 8 cases, while in only 2 cases was there less than 65 grams of protein per man per day and in only 4 cases less than 75 grams of protein. These results indicate that present food habits are more likely to lead to a deficiency of phosphorus compounds than to a deficiency of protein in the diet, and it is not improbable that many cases of malnutrition are really due to an inadequate supply of phosphorus compounds.

Since the different groups of phosphorus compounds are unequally distributed in food materials, and since they appear to differ somewhat in nutritive value, it is altogether probable that the choice of food will influence to some extent the amount of food phosphorus required. At present, however, our knowledge of these differences is not sufficiently exact as to either the nutritive values of the different forms or the quantitative proportions in which they occur in the various foods, to justify numerical comparison of a wide range of foods on any other basis than that of total phosphorus content.

The following table compares some staple foods as sources of phosphorus in the same way that they are compared as sources of iron in the preceding chapter.

APPROXIMATE AMOUNTS OF P_2O_5 IN FOOD MATERIALS

FOOD	P_2O_5 PER 100 GRAMS EDIBLE SUBSTANCE	P_2O_5 PER 100 GRAMS PROTEIN	P_2O_5 PER 3000 CALORIES
	grams	grams	grams
Beef, all lean	.50	2.2	12
Eggs	.37	2.7	7
Egg yolk	1.0	6.3	8
Milk	.215	6.4	9
Wheat, entire grain	.90	6.4	7.5
Patent flour	.20	2	1.7
Low-grade flour	.37	2.75	3.2
Rice, polished	.20	2.5	1.5
Oatmeal	.87	5.2	6.4
Beans, navy, dried	1.14	5.0	9.5
Peas, dried	.91	3.6	7.4
Beets	.09	5.6	5.6
Carrots	.10	9.5	6.3
Parsnips	.19	11.2	8.7
Potatoes	.14	6.5	4.7
Turnips	.12	9.2	8.5
Apples	.03	7	1.3
Bananas	.055	4.0	1.6
Oranges	.05	6.5	2.8
Pineapples	.06	15.6	4.2
Prunes, dried	.25	7.8	2.6
Almonds	0.87	4.1	4.0
Peanuts	0.90	3.5	4.8
Walnuts	0.77	4.2	3.2

Such a comparison should, of course, be interpreted with due regard to what is known of the character of the phosphorus compounds in the different types of food. Eggs contain liberal amounts of phospho-proteins and phosphorized fats. Milk contains less of the phosphorized fats, but is rich in phospho-protein and also in phosphates. The phosphorus of grains (both of the inner and outer portions) is present mainly as phytates which are readily available in digestion. In meats and fish the phosphorus exists (at least after cooking) so largely in the form of simple phosphates that it possibly should not be considered as of equal value with the phosphorus of other foods.

In general, therefore, the most practicable and economic method of securing an abundance of phosphorus in suitable forms is by the free use of milk, eggs, vegetables, and such cereal products and breadstuffs as contain at least a part of the outer layers as well as the inner portion of the grains.

SODIUM, POTASSIUM, MAGNESIUM, CALCIUM

The distribution of sodium and potassium in the body and their mutual relations in metabolism have been referred to in the section on the chlorides. Calcium and magnesium occur largely in the skeleton, but also as essential elements of the soft tissues and fluids of the body. The functions of calcium have been studied in much greater detail than those of magnesium. It is estimated that about 85 per cent of the mineral matter of bone, or at least three fourths of the entire ash of the body, consists of calcium phosphate. Over 99 per cent of the calcium in the body belongs to the bones, the remainder existing partly in organic combination with the proteins of the various tissues and partly as soluble salts in the blood and other fluids. That calcium salts are necessary to the coagulation of the blood has long been known and frequently cited as an example of the great importance of the calcium salts in the animal economy. Equally striking is the function of these salts in respect to their effect upon the contractility of muscular tissue as demonstrated particularly in the case of heart muscle.

It has long been known that heart muscle may be kept beating normally for hours after removal from the body when supplied under proper conditions with an artificial circulation of blood or lymph or a water solution of blood ash. Howell, Loeb, and others have studied the parts played by the several ash constituents. The sodium salts take the chief part in the maintenance of normal osmotic pressure and have also a specific influence. Contractility and irritability disappear if they are absent, but when present alone they produce relaxation of the muscle tissue. Calcium salts are present in very much smaller quantity, but are also absolutely necessary to the normal action of the heart muscle. When present in quantities above normal, they cause a condition of tonic contraction ("calcium rigor"). There is thus a sort of antagonism between calcium on the one hand and sodium (and potassium) on the other, and it is found that the alternate contractions and relaxations which constitute the normal beating of the heart are dependent upon the presence in the fluid which bathes the heart muscle of calcium salts not only in sufficient quantity, but also in the proper proportions to the amounts of sodium (and potassium) salts present. Other active tissues of the body doubtless have similar requirements as to the presence of proper proportions of the different inorganic salts in the fluids which bathe them.

Somewhat as Howell and others found an antagonistic action between sodium and calcium, so Meltzer and his associates have found that in some conditions there is also a distinct antagonistic action between calcium and magnesium. They have shown, for instance, that the injection of magnesium salts has a marked general inhibitory effect and that this can be quickly overcome by the subsequent injection of calcium salt. Summarizing the results of extended series of investigations by himself and others, Meltzer stated in the *Transactions of the Association of American Physicians* for 1908: —

> "Calcium is capable of correcting the disturbances of the inorganic equilibrium in the animal body, whatever the directions of the deviations from the normal may be. Any abnormal effect which sodium, potassium, or magnesium may produce, whether the abnormality be in the direction of increased irritability or of decreased irritability, calcium is capable of reëstablishing the normal equilibrium."

CALCIUM IN FOOD AND NUTRITION

All of the calcium compounds of foods, as well as of drinking waters, are capable of absorption, but not all with the same facility. Little systematic work has yet been done on the relative availability of the ash constituents of the different foods.

The amount of lime eliminated through the kidneys varies greatly, but probably does not average much over one tenth of that taken in the food. The fact that the greater part of the calcium in the food reappears in the feces has often been interpreted as meaning that the requirement of the body for calcium is low and the absorption of calcium from the food is poor. It is known, however, that the calcium of the feces comes from the body as well as the food. Elimination from the body through the intestinal wall has been proved for calcium as for iron.

Elimination of lime salts through the intestinal wall continues in fasting and is the principal way in which lime is lost from the body whenever the food supplies insufficient lime for equilibrium. In adults, lime may continue to be lost for a long time without the appearance of any distinct symptoms, doubtless because in such cases the bones are drawn upon to make good the losses from the soft tissues.

Effect of Insufficient Calcium. — Voit kept a pigeon for a year on food poor in calcium without observing any effects attributable to the diet until the bird was killed and dissected, when it appeared that, although the bones concerned in locomotion were still sound, there was a marked wasting of lime salts from other bones such as the skull and sternum, which in places were even perforated. The injurious effect of an insufficient intake of lime is of course more noticeable with growing than with full-grown animals. Abnormal weakness and flexibility of the bones (like rickets in children) has been produced experimentally by feeding puppies with lean and fat meat only, while others of the same litter, receiving the same food, but with the addition of bones to gnaw, developed normally. No animal is literally carnivorous in nature, that is, none lives on flesh alone; the animals called carnivora always eat more or less of the bones of their prey.

According to Herter[1] many cases of arrested development in infancy may be due to an insufficient assimilation of calcium from the food. Such a deficiency in the amount assimilated may be due to defective digestion or to a diet inadequate in calcium content.

The Calcium Requirement. — On account of the fluctuating distribution of the eliminated calcium between urine and feces, conclusions regarding the calcium requirement can properly be drawn only from those experiments upon calcium metabolism in which the amounts of this element in the food, in the feces, and in the urine have been directly determined. Not many such experiments have yet been made, and the reported results show considerable divergence, the amounts

---

[1] *On Infantilism from Chronic Intestinal Infection*, New York, 1908.

required for equilibrium apparently ranging from 0.4 to 1.0 gram of calcium oxide per day. The extreme figures may perhaps be due to exceptional conditions or in part to analytical errors. The experiments which appear most reliable indicate a requirement of about 0.7 gram calcium oxide per day as the smallest amount on which to obtain equilibrium in a healthy man accustomed to ordinary diet.

For much the same reasons as in the case of iron, liberal allowance should be made in calculating family dietaries. The need of an abundance of calcium for a rapidly growing skeleton is obvious. Before birth, and normally for several months after, this demand of the child is satisfied by the mother, whose lime requirement is thus greatly increased. The weakening of the bones and teeth which is said to be a common accompaniment of pregnancy and lactation is held by Bunge to be largely due to a preventable withdrawal of lime from these structures. After weaning and throughout the early childhood there are apt to be frequent disturbances of the absorption and metabolism of lime, in some cases due to distinct disorders of digestion, in other cases to more obscure irregularities in nutrition. In order that these fluctuations shall not interfere with the steady growth of the child, it is obvious that the food must furnish a fairly liberal surplus of calcium. Even under the most favorable conditions, a rapidly growing child will obviously need more bone-making material in proportion to its total food than did the men who served as subjects for the metabolism experiments. Camerer, in summarizing a long series of investigations upon the food requirements of children at different ages, concluded that the full amount of lime received by the average nursling is required to maintain a normal rate of growth, and Bunge, from a comparison of the calcium contents of different staple foods, points out that calcium more than any other inorganic element is likely to be deficient as the result of the change of diet from mother's milk to other forms of food.

If 0.7 gram is the minimum on which an average man can maintain equilibrium, it would seem that the food of a family should furnish at least 1 gram of calcium oxide per man per day. This is less than is advocated by such recent writers as Albu and Neuberg, Gautier, and Obendoerffer, yet the majority of the American dietaries which have so far been examined in this respect show less than 1 gram of calcium oxide per man per day, and about one third of them show less than 0.7 gram. Since inorganic forms of calcium are utilized in nutrition, the lime of the drinking water should be added to that of the food in calculating the amount consumed, and to this extent the actual nutritive supply is greater than the dietary studies show, but unless a very "hard" water be used for drinking, it is unlikely that the lime from this source will cover more than a small part of the calcium requirement. Apparently there should be more attention to the choice of such foods as will increase the calcium content of the dietary.

The following table shows the comparative richness in calcium of a number of staple articles of food.

APPROXIMATE AMOUNTS OF CaO IN FOOD MATERIALS

FOOD	CaO PER 100 GRAMS EDIBLE SUBSTANCE	CaO PER 100 GRAMS PROTEIN	CaO PER 3000 CALORIES
	grams	grams	grams
Beef, all lean	0.01	0.045	0.25
Eggs	0.09	0.66	1.7
Egg yolk	0.2	1.3	1.6
Milk	0.17	5.1	7.2
Wheat, entire grain	0.06	0.4	0.52
Patent flour	0.025	0.26	0.2
Low-grade flour	0.04	0.3	0.4
Rice, polished	0.01	0.1	0.08
Oatmeal	0.13	0.08	0.1
Beans, dried	0.22	1.0	1.9
Peas, dried	0.14	0.4	0.9
Beets	0.03	1.9	1.9
Carrots	0.08	7.6	5.2
Parsnips	0.09	5.3	4.1
Potatoes	0.02	0.9	0.7
Turnips	0.09	6.9	6.4
Apples	0.014	3.5	0.6
Bananas	0.01	0.7	0.3
Oranges	0.06	7.8	3.4
Pineapples	0.02	5.2	1.4
Prunes, dried	0.06	1.8	0.6
Almonds	0.30	1.4	1.4
Peanuts	0.10	0.4	0.5
Walnuts	0.11	0.6	0.5

It will be seen that there are enormous differences in the calcium content of different foods. Milk is so rich in calcium that one need take only 400 calories in this form to obtain 1 gram of lime, while to get the same amount of lime from round steak and white bread it would be necessary to take 10,000 calories. Polished rice and new process corn meal are even poorer in lime than patent flour. The difference between the whole grains and the "fine" mill products, while not so great as in the case of iron or phosphorus, is still considerable. The fruits and vegetables generally are fairly rich in calcium, and some of the green vegetables are strikingly so; but in most cases the intake of calcium depends mainly upon the extent to which milk (and its products other than butter) enters into the dietary. A quart of milk contains rather more calcium than a quart of clear saturated lime water, and by far the most practical means of insuring an abundance of calcium in the dietary is to use milk freely as a food.

RELATIONS OF THE ASH-CONSTITUENTS TO EACH OTHER

From this outline of the occurrence and functions of some of the individual ash constituents, it is evident that the prevalent custom of speaking of the ash of a food as if it were a more or less homogeneous substance is wholly illogical and incorrect. Even elements so closely related in chemical properties as sodium and potassium, or calcium and magnesium, are not only not interchangeable, but in some of their functions are mutually antagonistic. On the other hand, calcium appears to exert a favorable influence upon the economy of iron in metabolism, inasmuch as it appears to be possible to maintain equilibrium upon a smaller amount of iron when the food contains an abundance of calcium.

Another interesting relation is that of the acid-forming and base-forming elements of the diet. This is illustrated by experiments upon so-called ash-free diet. A diet of proteins, fats, and carbohydrates which has been freed from mineral matter and leaves no ash on burning in the air will introduce no fixed bases into the body, but will introduce sulphuric acid from the metabolism of the sulphur of the protein eaten, and is therefore an "acid-forming" diet.

Lunin fed mice with casein, fat, and cane sugar, the entire mixture being nearly free from ash. On this food with distilled water 5 mice died, respectively, after 11, 13, 14, 15, and 21 days. Other mice receiving the same food with addition of sodium chloride only, lived no longer (6, 10, 11, 15, 17, and 20 days). But when the food was given with addition of sodium carbonate to neutralize the acid formed in katabolism of the casein, the mice lived 16, 23, 24, 27, and 30 days, or at least 50 per cent longer than in either of the previous cases.

Taylor[1] lived for 9 days upon a practically ash-free diet consisting of 70–75 grams of purified egg albumen, 120 grams of washed olive oil, and 200 grams of sugar, and describes his

---

[1] University of California, Publications in Pathology, Vol. I, No. 7, pp. 71–86.

symptoms as essentially those of an acidosis resulting from lack of base-forming elements in the food.

Goodall and Joslin[1] have experimented with a diet similar to Taylor's, without obtaining similar evidence of acidosis. This would seem to indicate that there are considerable differences among individuals as regards susceptibility to the acids produced in metabolism. In the discussion of Goodall and Joslin's results, Ewing said: "Dr. Taylor withdrew the alkalis and got symptoms which he describes very clearly. It seems to me that this is just the central point in the whole doctrine of acid intoxication — how much disturbance of the tissue alkalis can be suffered without symptoms."

Wright,[2] who studied the epidemic of scurvy among the British garrison during the siege of Ladysmith, holds that the occurrence of the disease followed a diminished alkalinity of the blood resulting from food which furnished too litttle of the bases; and Gautier states that foods which, like the vegetables, have an alkaline ash act as preventives of scurvy, and that the outbreak of scurvy during the siege of Paris was connected, not with the use of salt meat, but with the exhaustion of the supply of vegetables. The latter statement is confirmed by several writers.

If susceptibility to scurvy and the injurious results of an ash-free diet are even partly due to the disturbance of the balance

---

[1] *Transactions of the Association of American Physicians*, **23**, 92–106 (1908).

[2] Cabot's *Diseases of Metabolism*, pp. 398–399.

of acid-forming and base-forming elements in the food (and it has been suggested that such disturbance may also be connected with other abnormalities of metabolism), it would seem to follow that the normal dietary should be so chosen as to furnish the body enough base-forming elements to neutralize the mineral acids produced in metabolism.

The balance of acid-forming and base-forming elements in foods may be studied by determining chlorine, sulphur, phosphorus, sodium, potassium, calcium, and magnesium, calculating the equivalent in acid of the first three elements, the equivalent in alkali of the last four, and finding the excess of acid or base as the case may be which would result from the complete oxidation of the food. While in actual metabolism the sulphur is not quite all oxidized to sulphate and the ammonia is not quite all changed to urea, yet the method suggested is quite satisfactory as a means of comparing foods in respect to their acid-forming or base-forming tendency in metabolism.

The tables on the opposite page show the relative predominance of acid-forming or base-forming elements in some typical food materials : —

Beef, free from fat, round steak, and bacon are here taken as representative of meats of different degrees of fatness. So far as known the lean portions of all other meats contain about the same excess of acid-forming elements as beef.

It will be seen that the grain products show either a practical balance or a slight predominance of the acid-forming elements. Milk shows a slight predominance of the bases. Meats and eggs yield a considerable excess of acid; vegetables

FOODS IN WHICH ACID-FORMING ELEMENTS PREDOMINATE

	ESTIMATED EXCESS ACID-FORMING ELEMENTS EQUIVALENT TO CC. NORMAL ACID PER 100 CALORIES.
Beef, free from visible fat	10
Eggs	9
Round steak	6.7
Oatmeal	3.2
Wheat flour	2.7
Wheat, entire grain	2.6
Rice	2.4
Bacon	1.0
Corn, entire grain (high protein)	0.1

FOODS IN WHICH BASE-FORMING ELEMENTS PREDOMINATE

	ESTIMATED EXCESS BASE-FORMING ELEMENTS EQUIVALENT TO CC. NORMAL ALKALI PER 100 CALORIES
Celery	40
Cabbage	10–13.6
Potatoes	9–12
Prunes	7.9
Turnips	6.6–12.5
Apples	5
Milk	3.3
Beans	2.9–6.8
Peas	1.9
Corn, entire grain (low protein)	0.8

and fruits a considerable excess of bases.[1] A diet in which the acid-forming elements greatly predominate must result in a withdrawal of fixed alkalies from the blood and tissues or an increased circulation of ammonia salts in the body, neither of which can be regarded as advantageous. While such a diet is more or less habitual with carnivora and may not be dangerous to man, it must put upon the body accustomed to mixed diet a tax which, however small, might better be avoided, especially as we have no reason to anticipate any disadvantage from a predominance of base-forming elements, which, if not used to neutralize stronger acids, would take the form of bicarbonates and thus aid in the maintenance of the normal and necessary neutrality or faint alkalescence of the blood and tissues. It therefore seems desirable that in constructing a dietary the foods in which the acid-forming elements predominate should be so balanced by foods having a predominance of bases that the diet as a whole may yield sufficient fixed bases to neutralize the mineral acids produced in its metabolism.

REFERENCES

Aberhalden. Physiological Chemistry, Chapter 16.
Albu and Neuberg. Mineralstoffwechsel (1906).
Bunge. Physiological and Pathological Chemistry, Chapters 7 and 8.

[1] That even the strongly acid fruits should yield an excess of bases on oxidation depends on the fact that the acidity of the fruit is due to an organic acid, usually not free, but in the form of an acid potassium salt, which when burned leaves the potassium in the form of carbonate or bicarbonate.

FORBES. The Mineral Elements in Animal Nutrition, Bull. 201, Ohio Experiment Station (1909).

—— Specific Effects of Rations on the Development of Swine. Bull. 213, Ohio Experiment Station (1910).

—— The Balance between Inorganic Acids and Bases in Animal Nutrition. Bull. 207, Ohio Experiment Station (1909).

HART, MCCOLLUM, AND FULLER. The Rôle of Inorganic Phosphorus in the Nutrition of Animals. Research Bull. No. 1, Wisconsin Experiment Station (1909).

HART, MCCOLLUM, AND HUMPHREY. The Rôle of the Ash Constituents of Wheat Bran in the Metabolism of Herbivora. Research Bull. No. 5, Wisconsin Experiment Station (1909).

HENDERSON. Das Gleichgewicht zwischen Basen und Saueren im thierischen Organismus. *Ergebnisse der Physiologie*, **8**, 254–325 (1909).

JORDAN, HART, AND PATTEN. Metabolism and Physiological Effects of Phosphorus Compounds of Wheat Bran. Technical Bull. No. 1, New York State Experiment Station; and *American Journal of Physiology*, **16**, 268 (1906).

OSBORNE. Sulphur in Protein Bodies. *Journal of the American Chemical Society*, **24**, 140.

SHERMAN, METTLER, AND SINCLAIR. Calcium, Magnesium, and Phosphorus in Food and Nutrition. Bull. 227, Office of Experiment Stations, U. S. Dept. of Agriculture.

SHERMAN AND SINCLAIR. The Balance of Acid-forming and Base-forming Elements in Food. *Journal of Biological Chemistry*, **3**, 307 (1907).

CHAPTER XI

CRITERIA OF NUTRITIVE VALUE AND ECONOMY OF FOODS

THE nutritive value of a food in the sense in which the term is here used, *i.e.* the value of the food as a source of energy for maintaining the work of the body and of material for preventing or replacing the waste of body substance or for growth, is chiefly judged (1) by its chemical composition, (2) by its behavior in digestion, (3) by its behavior in metabolism.

CHEMICAL COMPOSITION

In many cases the nutritive value of a food is assumed from the results of the chemical examination alone, and in routine work such an examination is commonly limited to a partial proximate analysis by the conventional method, according to which loss of weight at 100° C. is considered as *moisture*, residue on burning to whiteness as *ash*, total nitrogen multiplied by 6.25 as *protein*, material soluble in ether as *fat*, and the residual material (estimated by difference) as *carbohydrates*.

The accepted tables of composition and fuel value of foods, such as that in Bulletin 28, Office of Experiment Stations,

U. S. Department of Agriculture, are compiled chiefly from the results of analyses made by this method.

In the analysis of most of the well-known staple articles of food which ordinarily furnish the greater part of the nutrients in the diet, this conventional method of proximate analysis yields sufficiently serviceable results. On the other hand, in the analysis of numerous special articles of food or in an attempt to compare the food values of very dissimilar substances, the results obtained by this method may be seriously misleading. Nitrogen may be present in other forms than protein, the ether extract may contain other substances than fat, and the estimation of carbohydrates by difference may introduce large errors. It is possible to prepare a mixture of wet leather and petroleum jelly which, when subjected to the usual routine analysis, would yield the same results as meat; and a digestion experiment with sheep has been recorded in which the dried samples of the food and of the feces yielded almost identical analytical data. Moreover, it is becoming more and more apparent that even among staple foods there are many cases in which the ordinary routine analysis fails to differentiate substances which are quite different in nutritive value. In such cases it is not safe to conclude, as is sometimes done, that there are "differences which chemistry cannot show," for chemistry can show vastly more than is shown by the partial analyses usually made. By the employment of sufficiently intricate and time-consuming methods most of the individual organic substances which are usually divided only into the three groups of proteins, fats, and carbohydrates can be definitely differentiated.

Thus, while the grains and many of the vegetables contain most of their carbohydrate material in the form of starch, there are other vegetable foods in which the chief form of carbohydrate is inulin, mannan, galactan, or pentosan. In so far as the physiological behavior of these substances has been determined, a chemical analysis which shows their presence and amounts in a food may guide us to a correct estimate of its nutritive value, but as yet the knowledge of chemical relationship would not in itself enable us to predict the physiological relationships and comparative nutritive values.

In the case of the proteins, there has recently been much progress in chemical methods, both for separating the proteins from their natural mixtures in foods, and in determining the constituent radicles of the individual proteins. The knowledge of the chemical structure of the proteins which has thus been gained, while not yet complete in any instance, has already explained differences in nutritive value which were previously known, and has led to the discovery of new facts of great importance to nutrition and to our estimates of the nutritive values of foods.

Most of what we now know of the chemical structure of any protein is comprised in the statement of the amounts of the different amino acids which it yields on hydrolysis. In the following table are brought together the published results of hydrolyses of the principal proteins of a number of typical food materials: —

	Casein[1] (Milk)	Ovovitellin[2] (Egg)	Ovalbumin[2] (Egg)	Beef[2]	Chicken[2]	Halibut[2]	Scallop[2]	Gelatin[3]	Zein[2] (Maize)	Gliadin[2] (Wheat)	Glutenin[2] (Wheat)	Leucosin[2] (Wheat)	Phaseolin[2] (Bean)	Legumin[2] (Pea)	Amandin[2] (Almond)	Excelsin[2] (Brazil nut)
Glycin . .	0.0	0.00	0.00	2.06	0.68	0.00	0.00	16.5	0.00	0.00	0.89	0.94	0.55	0.38	0.51	0.6
Alanin . .	0.9	0.75	2.22	3.72	2.28	——	——	0.8	9.79	2.00	4.65	4.45	1.80	2.08	1.40	2.3
Valin . . .	1.0	1.87	2.50	0.81	——	0.79	——	1.0	1.88	0.21	0.24	0.18	1.04	?	0.16	1.5
Leucin . .	10.5	9.87	10.71	11.65	11.19	10.33	8.78	2.1	19.55	5.61	5.95	11.34	9.65	8.00	4.45	8.7
Prolin . .	3.1[4]	4.18	3.56	5.82	4.74	3.17	2.28	5.2[5]	9.04	7.06	4.23	3.18	2.77	3.22	2.44	3.6
Phenylalanin	3.2	2.54	5.07	3.15	3.53	3.04	4.90	0.4	6.55	2.35	1.97	3.83	3.25	3.75	2.53	3.5
Aspartic acid	1.2	2.13	2.20	4.51	3.21	2.73	3.47	0.6	1.71	0.58	0.91	3.35	5.24	5.30	5.42	3.8
Glutamic acid	11.0	12.95	9.10	15.49	16.48	10.13	14.88	0.9	26.17	37.33	23.42	6.73	14.54	16.97	23.14	12.9
Serin . . .	.23	?	?	?	?	?	?	0.4	1.02	0.13	0.74	——	0.38	0.53	?	——
Tyrosin . .	4.5	3.37	1.77	2.20	2.16	2.39	1.95	0.0	3.55	1.20	4.25	3.34	2.18	1.55	1.12	3.1
Cystin . .	.06	?	?	?	?	?	?	?	——	0.45	0.02	——	?	?	?	——
Histidin . .	2.59	1.90	1.71	1.76	2.47	2.55	2.02	0.41	0.82	0.61	1.76	2.83	1.97	1.69	1.58	1.5
Arginin . .	4.84	7.46	4.91	7.47	6.50	6.34	7.38	7.61	1.55	3.16	4.72	5.94	4.89	11.71	11.85	16.1
Lysin . . .	5.80	4.81	3.76	7.59	7.24	7.45	5.77	2.81	0.00	0.00	1.92	2.75	3.92	4.98	0.70	1.6
Ammonia .	1.95	1.25	1.34	1.07	1.67	1.33	1.08	0.4	3.64	5.11	4.01	1.41	2.06	2.05	3.70	1.8
Tryptophan	1.5	present	present	present	present	present	present	absent	absent	present	present	present	present	present	present	present

---

[1] Abderhalden and associates.

[2] Osborne and associates.

[3] Fischer and associates.

[4] Also 0.25 per cent of oxyprolin.

[5] Also 3.0 per cent of oxyprolin.

The absence of glycin from the products of hydrolysis of a protein is of no significance as regards its nutritive value, for we know that this amino acid is produced in the intermediary metabolism of protein in the animal body — presumably from the amino acids of greater molecular weight. When, however, an amino acid having a complex and characteristic radicle (such as phenylalanin, tyrosin, histidin, or tryptophan) is found to be almost or entirely absent, doubt is thrown upon the ability of the protein in question to supply everything needed for the replacement of katabolized body protein. The presence of all of these amino acids in measurable quantities in casein, and the general similarity of casein and ovovitellin, are in accord with the known superiority of milk and eggs as foods for supplying the materials needed for body tissue. On the other hand, it has long been known that gelatin as a sole protein food does not suffice for the maintenance of nitrogen equilibrium. When the development of protein chemistry had shown that gelatin differs from most other proteins in yielding on hydrolysis no tyrosin or tryptophan and little if any cystin, Kauffmann[1] tried the experiment of living upon a diet in which these three amino acids were eaten along with gelatin, no other protein being taken, and found that nitrogen equilibrium was maintained throughout the five days that this diet was continued. Recently it has been found that zein as a sole source of nitrogen cannot maintain growth in young mice, and it is believed that protein equilibrium cannot be

---

[1] Tigerstedt's *Textbook of Physiology*, p. 109.

supported by a diet devoid of the tryptophan group. A diet in which tryptophan was added to zein gave much better results than one in which the nitrogen was supplied by zein alone.[1]

Thus the proximate analysis of a food may be extended much beyond the scope of the usual routine analysis with correspondingly increased worth as a basis for judgment of nutritive value. It has been pointed out in the preceding chapter that a more thorough knowledge of the ultimate composition, such as is gained by the quantitative determination of the individual ash constituents, has also important bearings upon our judgment of nutritive values.

BEHAVIOR IN DIGESTION

Discussion of the behavior of a food in digestion should include consideration both of the digestibility of the food and the influence of the food upon the digestive process. The latter subject is usually treated as belonging to general physiological chemistry rather than specifically to nutrition; but certainly our judgments of the nutritive values of foods will often be too narrow if they fail to take account of the differences which exist among the articles of food as regards their influence in stimulating or retarding the flow of the digestive juices, the rate of discharge of the food from the stomach, the peristaltic activity of the intestine, and perhaps

---

[1] Willcock and Hopkins, *Journal of Physiology*, **35**, 88, 103 (1907); *Chemical Abstracts*, 1, 600.

other less obvious ways in which the digestive process is influenced by the bulk, flavor, mechanical condition, and characteristic chemical constituents of the food.

In studying the digestibility of a food one may employ either natural or artificial digestion, *i.e.* the food may be actually fed to a man or other animal, or it may be treated with a digestive solution outside of the body. Such artificial experiments have been applied more particularly to the study of the digestibility of protein, the food being treated sometimes with an acid solution of pepsin (an artificial gastric juice) alone, and sometimes first with such a solution and then with an alkaline solution of trypsin, in imitation of the pancreatic juice. As a rule these artificial digestion experiments are only partially satisfactory substitutes for the natural digestion test, but in some cases the artificial experiment gives information which would not be obtained by the method of actual feeding. Thus Grindley in one series of trials found no apparent effect of different methods of cooking meats upon the coefficients of digestibility when fed to healthy men, but by subjecting the samples of differently cooked meat to the action of artificial gastric juice for limited periods of time, and comparing the amounts digested after certain definite intervals, he found the lightly cooked samples more rapidly digested than the same meat fried, although when all were allowed to digest for twenty-four hours the differences tended to disappear.

Grindley's Summary of Results of Artificial Digestion Experiments with Raw and Cooked Beef (U. S. Dept. Agriculture, Office of Experiment Stations, Bull. 193, p. 75)

Description of Sample	Percentage Dissolved by Artificial Digestive Gastric Juice During —			
	1 hour	2 hours	6 hours	24 hours
Lean beef, round, raw . .	66.69	79.54	90.50	97.31
Lean beef, round, pan broiled	78.41	88.04	92.87	95.49
Lean beef, fried in hot lard .	67.69	80.45	91.14	95.07
Lean beef, cooked in water 2 hours	85.74	93.09	96.35	97.44
Lean beef, round, cooked in water 5 hours	76.12	81.73	95.32	96.95

Somewhat similar comparisons of rapidity of digestion can be made by feeding test meals, and after a definite interval withdrawing and examining the stomach contents; but such tests can hardly be made so strictly quantitative as are the artificial digestion experiments in which the undigested residue is accurately determined.

Another method of studying rapidity of actual digestion is to withdraw the partially digested food mass from the stomach or intestine through a fistula, but this is obviously of rather limited application.

Formerly the digestibility of a food was studied by feeding that food alone for a period of days, marking the feces belonging to this period by taking lampblack at the beginning and end or by some other method, and comparing the constituents of the food with those of the corresponding feces. It is now recognized that such "coefficients of digestibility" do not measure the digestibility of the food in a literal sense, but do give valuable indications as to the availability of its organic constituents for metabolism as explained in Chapter III; and that they should be determined by feeding the substance under investigation not as the sole food, but as a considerable part of a simple mixed diet, the digestibility of whose other constituents is already known. To what extent it is important that the experimental diet should be relished by the subject is a matter of considerable doubt. The brilliant work of Pawlow and his students upon the susceptibility of the digestive glands to psychic influences such as those which obtain in "sham feeding" experiments appear to support the popular belief that the enjoyment of the food is a very important factor in securing its proper digestion; but the data of quantitative digestion experiments upon healthy men afford little, if any, evidence in support of this view and much evidence that the coefficient of digestibility is but little influenced by the palatability of the food, or the monotony of a uniform diet, so long as the food is actually eaten and retained and does not undergo excessive bacterial decomposition. Continuance of a diet of crackers and milk alone for 12 days, and in another case for 18 days, resulted in no diminution of the coefficient of digestibility, and in a series of experiments in which the diet consisted largely of unpalatable so-called "canned roast beef" which could be eaten only by considerable effort, the coefficient of digestibility of the protein of this beef was found to be 92 per cent, while the protein of good fresh beef eaten as part of a well-relished diet shows about 97 or 98 per cent. In view of the fact that the extractives which are known to be highly efficient in stimulating the flow of gastric juice had been largely removed from the "canned roast beef," and that the amount of beef eaten was larger than would have been desired in any case, it would seem that but little depression of the coefficient of digestibility can be attributed directly to the lack of enjoyment of the food. It seems probable that the psychic influences affect the comfort and rapidity of the earlier stages of digestion much more than the final percentage utilization of the food.

The term "digestibility" of food may mean either the ease and comfort, or the rapidity, or the ultimate extent of its digestion. Foods which differ in their susceptibility to natural or artificial gastric juice or in the rapidity with which they leave the stomach may still show an equally complete digestion and absorption by the time they have passed through the intestine. On the other hand, the "coefficient of digestibility," which is simply a measure of the quantitative difference between food and feces, does not necessarily indicate the ease or rapidity of digestion, nor the extent to which the foodstuffs which appear to have been absorbed may have been decomposed by the bacteria of the digestive tract.

BEHAVIOR IN METABOLISM

Foods similar in chemical composition and equally well digested may or may not be of equal nutritive value.

Rutgers, in 1887, compared animal and vegetable protein by substituting beans and peas for the meat of a mixed diet which was so arranged as to keep the amounts of proteins, fats, and carbohydrates uniform. Each diet was continued for several weeks with determinations of the nitrogen balance on certain days, and the conclusion was reached that the protein of the legumes was equal in nutritive value to the meat protein which it displaced. The conclusion reached in this comparatively early work accords well with our present knowledge of the similarity of cleavage products of the meat and legume proteins (see table above).

Data obtained by Neumann in examining two commercial protein preparations illustrate the fact that foods which appear similar as ordinarily analyzed may differ in their behavior either in digestion or in metabolism. These protein preparations were fed in a simple mixed diet alternating with meat in such quantities as to maintain uniformity of nitrogen content and fuel value in the diet.

The results were as follows: —

Period No.	Duration Days	Principal Protein of Food	Nitrogen in Grams per Day			
			In food	In feces	In urine	Balance
1	4	Meat	14.02	2.06	12.09	− 0.13
2	8	Food A	14.02	2.14	14.49	− 2.61
3	5	Meat	14.02	2.17	12.25	− 0.40
4	9	Food B	14.02	3.14	12.29	− 1.41
5	4	Meat	14.02	2.26	12.30	− 0.54

Here both of the proprietary protein foods proved inferior in nutritive value to meat, one because of the greater amount of nitrogen in the feces (less favorable digestion), the other because of the greater amount of nitrogen in the urine (less favorable metabolism).

In experiments of this sort care must be taken that the fuel value is the same in the periods for which the nitrogen balance is to be compared, as otherwise the protein-sparing action of the carbohydrates and fats may vitiate the results. In fact, it is by means of nitrogen balance experiments that the protein-sparing powers of fats and carbohydrates were studied and compared, and the data of some of these investigations have been given in Chapter VII.

The nutritive value of non-nitrogenous foodstuffs may also be studied in a more direct way by means of the carbon or energy balance and in some instances by searching for evidence of the absorbed material, as, for example, by an increased storage of glycogen, by a change in the respiratory quotient, or (in the case of a carbohydrate) by elimination of the substance or its products of hydrolysis in the urine after phloridzin poisoning.

The following instances of investigations of different carbohydrates will illustrate the application of some of these methods of study.

Weiske[1] fed carob beans (which consist largely of mannan) with hay to sheep in comparison with a ration of starch and

---

[1] *Journal für Landwirthschaft*, 27, 321.

hay, and found such similar data of digestibility and nitrogen balance as to show that the mannan was well utilized. Oshima[1] cites an experiment with man in which the digestibility of konnyaku, consisting mainly of mannan, was found to be 82 per cent. Sawamura[2] has found a mannose in the digestive tracts of horses and swine, and it is known that mannose is well utilized in the animal organism so that; the nutritive value of at least some of the forms of mannan is fairly well established.

On the other hand, studies of inulin do not afford corresponding evidence of utilization. Although inulin is readily hydrolyzed to levulose by acids, it is not attacked by the saliva or pancreatic juice. Sandmeyer[3] after feeding 80 grams of inulin to a diabetic dog recovered 46 grams in the feces, and Mendel and Nakaseko[4] found that little if any glycogen resulted from feeding inulin to a rabbit. Mendel and Mitchell[5] further find that most of the inulin injected peritoneally can be recovered in the urine.

Galactans, as Mendel and Swartz have pointed out, are as a rule very incompletely digested, and, being at the same time resistant to bacteria and retentive of water in the in-

---

[1] U. S. Dept. Agriculture, Office of Experiment Stations, Bull. 159, pp. 35, 168, 173.

[2] *Bulletin College Agriculture,* Tokyo Imperial Univ., No. 5, p. 155; Swartz, Dissertation, Yale, 1909.

[3] *Zeitschrift für Biologie,* 31, 32 (1895).

[4] *American Journal of Physiology,* 4, 246.

[5] *Ibid.,* 14, 239.

testine, they are useful in the food in cases of chronic constipation, particularly when this is due to the extremely complete absorption of the food (and its accompanying moisture) and the consequent formation of hard, dry fecal masses. Some forms of galactan are, however, fairly well absorbed, and in three experiments Lohrisch found a rise of the respiratory quotient three or four hours after eating galactan, indicating a metabolism of the absorbed carbohydrate.

Lohrisch[1] also studied the question of the utilization of cellulose. When healthy men ate the tender cellulose of white cabbage, practically none of it was found in the feces, but on adding the same form of cellulose to the diet of diabetics, no increase of the sugar in the urine was found. Lohrisch then determined the respiratory quotient before, and at hourly intervals after, eating 76 grams of cellulose of which one fourth was apparently digested. Four hours after the cellulose was eaten there was a slight rise in the respiratory quotient, after which it gradually decreased and remained for some hours at about 0.7. Lohrisch interprets these results as indicating first a utilization of a part of the cellulose as carbohydrate and later a utilization of fatty acids derived from the cellulose — presumably by bacterial decomposition in the intestine. It should be noted, however, that the rise of respiratory quotient ob-

---

[1] *Zeitschrift physiologische Chemie*, **47** (1907); through Swartz, Dissertation, Yale, 1909.

served by Lohrisch in this case was no greater than may occur in the accidental fluctuations from hour to hour.

Experiments, such as have here been cited, upon the utilization of the organic nutrients have to do with the values of foods as sources of energy and protein, but these alone do not furnish a complete measure of nutritive value. This is illustrated by the following data of two metabolism experiments with the same man upon diets which furnished about the same fuel value and protein.

COMPARISON OF BALANCES OF DIFFERENT ELEMENTS

NATURE OF DIET	NATURE OF ELEMENT	AMOUNT IN GRAMS PER DAY			
		In food	In feces	In urine	Balance
Bread and milk	Nitrogen	10.10	0.46	13.09	− 3.45
Bread and egg white . . .	Nitrogen	10.69	.75	13.21	− 3.27
Bread and milk .	Phosphorus	1.55	.57	1.03	− 0.05
Bread and egg white . . .	Phosphorus	0.38	.22	.75	− 0.59
Bread and milk .	Calcium oxide	2.65	1.88	.21	+ 0.56
Bread and egg white . . .	Calcium oxide	0.14	.48	.10	− 0.44
Bread and milk .	Iron	0.0057	.0053	.0002	+ .0002
Bread and egg white . . .	Iron	0.0065	.0085	.0002	− .0022

Here, although the nitrogen balance was practically alike on the two diets, there was on the bread and milk diet practical equilibrium of phosphorus and iron and a storage of calcium, while on the diet of bread and egg white there were relatively large losses of all three of these elements.

Reference may be made to Chapters IX and X for the reasons for particularly considering these three elements, and also for examples of investigations in which the nutritive values of rations have been studied by long-continued feeding experiments instead of by the direct determination of intake and output. Further examples may be found in the works of Forbes and of Watson and Hunter which are included among the references at the end of this chapter.

Even these experiments upon growth and development, however, may not always exhaust the question of nutritive value in the broadest sense. Hunt has recently found great differences in the resistance of animals to certain poisons, which appear to be attributable to diet alone.

"In extreme cases mice after having been fed upon certain diets may recover from forty times the dose of acetonitrile fatal to mice kept upon other diets. It is, moreover, possible to alter the resistance of these animals at will and to overcome the effects of one diet by combining it with another. . . . The experiments with oats and oatmeal and eggs are of especial interest. In the earlier parts of this paper many experiments were quoted showing that a diet of oatmeal or of oats usually leads to a marked resistance of mice to acetonitrile; the experiments quoted in this section which show that the administration of certain iodine compounds with or subsequently to such a diet further increases this resistance, and the experiments previously reported showing that as far as the resistance toward acetonitrile is concerned iodine exerts its action through the thyroid gland, all point to the conclusion that the resistance caused by an oat diet is in part an effect exerted upon the thyroid. This effect is obtained much more markedly and constantly with young, growing mice. From these experiments and considerations it seems very probable that it is possible to influence, in a specific manner, by diet, one of the most important hormones in the body; this is a comparatively new principle in dietetics and one which may prove of much importance." (*The Effect of a Restricted Diet and of Various Diets upon the Resistance of Animals to Certain Poisons*, pp. 56, 73.)

COMPARATIVE ECONOMY OF FOODS

In studying the economy of an article of food we may well consider first its cheapness as a source of fuel. Using prices now or recently current in the retail markets of New York City and the fuel values given in Bulletin 28 of the Office of Experiment Stations, we find the cost of 3000 calories from any one of a number of typical food materials to be approximately as follows: —

FOOD	PRICE PER POUND	COST OF 3000 CALORIES
Flour	$0.04	$0.08
Oatmeal	.06	.10
Sugar	.06	.10
Potatoes	.01½ (.90 per bu.)	.14
Bread	.06	.15
Beans, dried	.08	.15
Clear fat pork	.20	.16
Potatoes	.02½ (1.50 per bu.)	.24
Bacon	.25	.27
Milk	.03 (.06 qt.)	.28
Raisins, seeded	.15	.30
Prunes, dried	.12	.30
Shredded wheat	.16	.28
Butter	.40	.33
Evaporated apples	.15	.33
Milk	.04 (.08 qt.)	.37
Olive oil	.55	.40
Milk	.05 (.10 qt.)	.46
Almonds (without shell)	.60	.60
Round steak, fat eaten	.20	.88
Eggs	.24 (.35 doz.)	1.13
Round steak, fat not eaten	.20	1.26
Oysters (without shell)	.15 (.30 qt.)	1.90

The differences in economy of staple articles of food compared on this basis are seen to be enormous.

These estimates are based upon the fuel values found by applying average factors to the data of ordinary proximate analyses, and do not take account of the different forms of proteins, fats, and carbohydrates present in the different foods, or of their differences of behavior in digestion and in metabolism, such as have been referred to in this chapter. If our comparisons of nutritive value are to be adequate, it is evident that all such factors should be taken into consideration along with the fact that the food while used primarily as fuel must also furnish the necessary elements of building material, among which, according to our present knowledge, nitrogen, phosphorus, iron, and calcium appear to require especial consideration. This broader conception of nutritive value supplies the economic justification for the purchase of certain foods which would appear expensive if considered simply as sources of proteins, fats, and carbohydrates, and, on the other hand, some foods which are economical sources of protein and energy are also of high nutritive value in other respects.

Making due allowance for all known factors which affect the nutritive values of foods, there remain large discrepancies between nutritive value and market cost and correspondingly ample opportunity for the exercise of true economy in the choice of food materials.

REFERENCES

ABDERHALDEN. Handbuch der Biochemischen Arbeitsmethoden, Bd. III (1910).

ATWATER. Methods and Results of Investigation on the Chemistry and Economy of Food. Bull. 21, Office of Experiment Stations, U. S. Dept. Agriculture (1895).

ATWATER. Neue Versuche ueber Stoff- und Kraftwechsel im menschlichen Körper. *Ergebnisse der Physiologie,* 3, I, 497–604 (1904).

ATWATER AND LANGWORTHY. A Digest of Metabolism Experiments. Bull. 45, Office of Experiment Stations, U. S. Dept. Agriculture (1898).

FORBES. Specific Effects of Rations upon the Development of Swine. Bull. 213, Ohio Agricultural Experiment Station, Wooster, Ohio, 1909.

HUNT. The Effects of a Restricted Diet and of Various Diets upon the Resistance of Animals to Certain Poisons. Bull. 69, Hygienic Laboratory, U. S. Treasury Department, 1910.

LUSK. Elements of the Science of Nutrition, 2d ed., 1909.

MENDEL AND SWARTZ. The Physiological Utilization of Some Complex Carbohydrates. *American Journal of the Medical Sciences*, March, 1910.

MURLIN. The Nutritive Value of Gelatin. *American Journal of Physiology*, **19**, 285–313; **20**, 234–258 (1907–1908).

NEUMANN. Die Wirkung des Alkohols als Eiweiss-sparer. *Archiv für Hygiene*, **41**, 85–118 (1902).

REITZ AND MITCHELL. On the Metabolism Experiment as a Statistical Problem. *Journal of Biological Chemistry*, **8**, 297–326 (1910).

RUTGERS. Haben vegetabilisches Eiweissstoffe den gleichen Nahrwerth für Menschen wie die Animalischen? *Zeitschrift für Biologie* (N. f.), **6**, 351–381 (1888).

STAEHELIN. (Physiological effects of vegetarian diet with bibliography.) *Zeitschrift für Biologie* (N. f.), **31**, 199–263.

TALLQUIST. Zur Frage des Einflusses von Fett und Kohlenhydrat auf den Eiweiss-umsatz des Menschen. *Archiv für Hygiene*, **41**, 177–189 (1902).

VOIT AND ZISTERER. Bedingt die verscheidene Zusammensetzung der Eiweisskörper auch einen Unterscheid in ihrem Nährwert? *Zeitschrift für Biologie* (N. f.), **35**, 457–498 (1910).

VON NOORDEN. Grundriss einer Methodik der Stoffwechsel-Untersuchungen. Berlin, 1892.

WATSON AND HUNTER. Observations on Diet. The Influence of Diet on Growth and Nutrition. *Journal of Physiology*, **34**, 111–132 (1906).

WILLCOCK AND HOPKINS. The Importance of Individual Amino Acids in Metabolism. *Journal of Physiology*, **35**, 88–102 (1906).

APPENDIX

TABLE I

Edible Organic Nutrients and Fuel Values of Foods[1]

Food		Protein (N×6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Almonds	[2] E. P.	21.0	54.9	17.3	2940	15
	[2] A. P.	11.5	30.2	9.5	1615	28
Apples	E. P.	.4	.5	14.2	285	159
	A. P.	.3	.3	10.8	214	212
Apricots	E. P.	1.1	—	13.4	263	174
	A. P.	1.0	—	12.6	247	184
Asparagus, fresh	A. P.	1.8	.2	3.3	100	450
cooked	A. P.	2.1	3.3	2.2	213	213
Bacon, smoked	E. P.	10.5	64.8	—	2840	16
	A. P.	9.5	59.4	—	2372	19
Bananas	E. P.	1.3	.6	22.0	447	101
	A. P.	.8	.4	14.3	290	156
Barley, pearled		8.5	1.1	77.8	1615	28
Beans, dried		22.5	1.8	59.6	1565	29
lima, dried		18.1	1.5	65.9	1586	29

---

[1] The percentages of nutrients are taken from Bull. 28, Office of Experiment Stations, U. S. Department of Agriculture. The fuel values are calculated from these percentages by the use of the factors explained in Chapter V, viz. — protein, 4 calories; fat, 9 calories; carbohydrate, 4 calories per gram.

[2] E. P. signifies edible portion; A. P. signifies as purchased.

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbo-hydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
lima, fresh	E. P.	7.1	.7	22.0	557	82
	A. P.	3.2	.3	9.9	250	182
string, fresh	E. P.	2.3	.3	7.4	184	241
	A. P.	2.1	.3	6.9	176	259
baked, canned	A. P.	6.9	2.5	19.6	583	78
string, canned	A. P.	1.1	.1	3.8	93	488
lima, canned	A. P.	4.0	.3	14.6	350	130
Beef brisket, medium fat	E. P.	15.8	28.5	—	1449	31
	A. P.	12.0	22.3	—	1130	40
chuck, average	E. P.	19.2	15.4	—	978	46
	A. P.	15.8	12.5	—	797	58
corned, average	E. P.	15.6	26.2	—	1353	34
	A. P.	14.3	23.8	—	1230	37
cross ribs, average	E. P.	15.9	28.2	—	1440	32
	A. P.	13.8	24.8	—	1262	36
dried, salted, and smoked	E. P.	30.0	6.5	.4	817	56
	A. P.	26.4	6.9	—	724	63
flank, lean	E. P.	20.8	11.3	—	838	54
	A. P.	20.5	11.0	—	821	55
fore quarter, lean	E. P.	18.9	12.2	—	842	54
	A. P.	14.7	9.5	—	655	69
fore shank, lean	E. P.	22.0	6.1	—	647	70
	A. P.	14.0	3.9	—	414	110
heart	E. P.	16.0	20.4	1.0	1140	40
	A. P.	14.8	24.7	.9	1292	35
hind quarter, lean	E. P.	20.0	13.4	—	907	50
	A. P.	16.7	11.2	—	757	60
hind shank, lean	E. P.	21.9	5.4	—	617	75
	A. P.	9.1	2.2	—	255	179

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
hind shank, fat	E. P.	20.4	18.8	—	1171	40
	A. P.	9.9	9.1	—	552	83
liver	E. P.	20.4	4.5	1.7	584	78
	A. P.	20.2	3.1	2.5	537	85
loin	E. P.	19.7	12.7	—	877	52
	A. P.	17.1	11.1	—	764	60
neck, lean	E. P.	21.4	8.4	—	732	62
	A. P.	15.1	5.9	—	493	93
neck, medium fat	E. P.	20.1	16.5	—	1040	44
	A. P.	14.5	11.9	—	749	61
plate, lean	E. P.	15.6	18.8	—	1051	43
	A. P.	13.0	15.5	—	867	52
porterhouse steak	E. P.	21.9	20.4	—	1230	37
	A. P.	19.1	17.9	—	1077	42
rib rolls, lean	A. P.	20.2	10.5	—	795	57
ribs, lean	E. P.	19.6	12.0	—	845	54
	A. P.	15.2	9.3	—	654	69
ribs, fat	E. P.	15.0	35.6	—	1721	26
	A. P.	12.7	30.6	—	1480	31
roast	A. P.	22.3	28.6	—	1576	29
round, lean	E. P.	21.3	7.9	—	694	64
	A. P.	19.5	7.3	—	649	70
round, free from visible fat		23.2	2.5	—	512	87
rump, lean	E. P.	20.9	13.7	—	940	49
	A. P.	19.1	11.0	—	796	57
rump, fat	E. P.	16.8	35.7	—	1763	26
	A. P.	12.9	27.6	—	1361	33
sides, lean	E. P.	19.3	13.2	—	890	51
	A. P.	15.5	10.6	—	715	64

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
sirloin steak	E. P.	18.9	18.5	—	1099	41
	A. P.	16.5	16.1	—	960	48
sweetbreads	A. P.	16.8	12.1	—	799	57
tenderloin	A. P.	16.2	24.4	—	1290	35
tongue	E. P.	18.9	9.2	—	717	63
	A. P.	14.1	6.7	—	529	86
Beets, cooked	E. P.	2.3	.1	7.4	180	252
fresh	E. P.	1.6	.1	9.7	209	217
	A. P.	1.3	.1	7.7	167	271
Blackberries	A. P.	1.3	1.0	10.9	262	173
Blackfish	E. P.	18.7	1.3	—	393	116
	A. P.	7.4	.7	—	176	279
Bluefish	E. P.	19.4	1.2	—	402	113
	A. P.	10.0	.6	—	206	220
Boston crackers		11.0	8.5	71.1	1835	25
Brazil nuts	E. P.	17.0	66.8	7.0	3040	15
	A. P.	8.6	33.7	3.5	1591	28
Bread, graham		8.9	1.8	52.1	1189	38
rolls, water		9.0	3.0	54.2	1268	36
toasted		11.5	1.6	61.2	1385	33
white, homemade		9.1	1.6	53.3	1199	38
milk		9.6	1.4	51.1	1158	39
vienna		9.4	1.2	54.1	1199	38
average		9.2	1.3	53.1	1182	38
whole wheat		9.7	.9	49.7	1113	41
Buckwheat flour		6.4	1.2	77.9	1580	29
Butter		1.0	85.0	—	3491	13
Buttermilk		3.0	.5	4.8	162	280
Butternuts	E. P.	27.9	61.2	3.5	3065	15

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Butternuts	A. P.	3.8	8.3	.5	417	109
Cabbage	E. P.	1.6	.3	5.6	143	317
	A. P.	1.4	.2	4.8	121	376
Calf's-foot jelly		4.3	—	17.4	394	115
Carrots, fresh	E. P.	1.1	.4	9.3	204	221
	A. P.	.9	.2	7.4	158	286
Cauliflower	A. P.	1.8	.5	4.7	139	328
Celery	E. P.	1.1	.1	3.3	840	542
	A. P.	.9	.1	2.6	676	672
Celery soup, canned		2.1	2.8	5.0	243	187
Cerealine		9.6	1.1	78.3	1640	28
Cheese, American pale		28.8	35.9	.3	1990	23
American red		29.6	38.3	—	2102	22
Cheddar		27.7	36.8	4.1	2080	22
Cottage		20.9	1.0	4.3	499	91
Full cream		25.9	33.7	2.4	1890	24
Fromage de Brie		15.9	21.0	1.4	1170	39
Neuchatel		18.7	27.4	1.5	1484	31
Pineapple		29.9	38.9	2.6	2180	21
Roquefort		22.6	29.5	1.8	1645	28
Swiss		27.6	34.9	1.3	1945	23
Cherries, fresh	E. P.	1.0	.8	16.7	354	128
	A. P.	.9	.8	15.9	337	134
canned	A. P.	1.1	.1	21.1	407	112
Chestnuts, fresh	E. P.	6.2	5.4	42.1	1098	43
	A. P.	5.2	4.5	35.4	920	49
Chicken, broilers	E. P.	21.5	2.5	—	493	92
	A. P.	12.8	1.4	—	289	157
Chocolate		12.9	48.7	30.3	2768	16

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Cocoa		21.6	28.9	37.7	2258	20
Cod, dressed	A. P.	11.1	.2	—	209	217
salt	E. P.	25.4	.3	—	473	96
	A. P.	19.0	.4	—	361	126
Consommé, canned	A. P.	2.5	—	.4	53	862
Corn, green	A. P.	2.8	1.2	19.0	455	102
Corn meal		9.2	1.9	75.4	1620	28
Cowpeas, dried		21.4	1.4	60.8	1550	29
green	E. P.	9.4	.6	22.7	603	76
Crackers, butter	A. P.	9.6	10.1	71.6	1887	23
cream	A. P.	9.7	12.1	69.7	1938	23
graham	A. P.	10.0	9.4	73.8	1905	24
soda	A. P.	9.8	9.1	73.1	1875	24
water	A. P.	10.7	8.8	71.9	1855	24
Cranberries	A. P.	.4	.6	9.9	212	212
Cream		2.5	18.5	4.5	883	50
Cucumbers	E. P.	.8	.2	3.1	79	575
	A. P.	.7	.2	2.6	68	666
Currants, fresh		1.5	—	12.8	259	175
dried Zante		2.4	1.7	74.2	1455	31
Dates, dried	E. P.	2.1	2.8	78.4	1575	29
	A. P.	1.9	2.5	70.6	1430	32
Doughnuts		6.7	21.0	53.1	1941	23
Eggplant	E. P.	1.2	.3	5.1	126	349
Eggs, uncooked	E. P.	13.4	10.5	—	672	68
	A. P.	11.9	9.3	—	594	76
Farina		11.0	1.4	76.3	1640	28
Figs, dried		4.3	.3	74.2	1437	32
Flounder	A. P.	5.4	.3	—	110	412

TABLE I, *continued*

Food		Protein (N×6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Flounder	E. P.	14.2	.6	—	282	161
Flour, rye		6.8	.9	78.7	1590	29
wheat, California fine		7.9	1.4	76.4	1585	29
wheat, entire		13.8	1.9	71.9	1630	28
wheat, graham		13.3	2.2	71.4	1628	28
wheat, patent roller process[1]		13.3	1.5	72.7	1623	28
wheat, straight grade		10.8	1.1	74.8	1608	28
wheat, average high and medium		11.4	1.0	75.1	1610	28
wheat, average low grade		14.0	1.9	71.2	1625	28
Fowls	E. P.	19.3	16.3	—	1017	45
	A. P.	13.7	12.3	—	752	60
Gelatin		91.4	.1	—	1660	27
Grape butter		1.2	.1	58.5	1088	42
Grapes	E. P.	1.3	1.6	19.2	437	104
	A. P.	1.0	1.2	14.4	328	138
Haddock	E. P.	17.2	.3	—	324	140
	A. P.	8.4	.2	—	160	283
Halibut steaks	E. P.	18.6	5.2	—	550	83
	A. P.	15.3	4.4	—	457	100
Ham, fresh, lean	E. P.	25.0	14.4	—	1042	44
	A. P.	24.8	14.2	—	1030	44
fresh, medium	E. P.	15.3	28.9	—	1458	31
	A. P.	13.5	25.9	—	1303	35
smoked, lean	E. P.	19.8	20.8	—	1209	38
	A. P.	17.5	18.5	—	1073	42
Herring, whole	E. P.	19.5	7.1	—	644	70
	A. P.	11.2	3.9	—	362	125

---

[1] Baker's grade.

TABLE I, *continued*

Food		Protein (N×6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Herring, smoked	E. P.	36.9	15.8	—	1315	35
	A. P.	20.5	8.8	—	731	62
Hominy		8.3	.6	79.0	1609	28
Honey		.4	—	81.2	1481	31
Huckleberries		.6	.6	16.6	336	135
Koumiss		2.8	2.1	5.4	234	194
Lamb, breast	E. P.	19.1	23.6	—	1311	35
	A. P.	15.4	19.1	—	1058	43
chops, broiled	E. P.	21.7	29.9	—	1614	28
fore quarter	E. P.	18.3	25.8	—	1385	33
	A. P.	14.9	21.0	—	1127	40
hind quarter	E. P.	19.6	19.1	—	1149	40
	A. P.	16.5	16.1	—	953	48
leg, roast		19.7	12.7	—	876	52
side	E. P.	17.6	23.1	—	1263	36
	A. P.	14.1	18.7	—	1015	45
Lard, refined		—	100.0	—	4086	11
Lemon juice		—	—	9.8	178	255
Lemons	E. P.	1.0	.7	8.5	201	226
	A. P.	.7	.5	5.9	140	323
Lettuce	E. P.	1.2	.3	2.9	87	525
	A. P.	1.0	.2	2.5	72	633
Liver, beef	E. P.	20.4	4.5	1.7	583	78
	A. P.	20.2	3.1	2.5	538	84
veal	E. P.	19.0	5.3	—	562	81
Lobster, whole	E. P.	16.4	1.8	.4	379	120
	A. P.	5.9	.7	.2	139	326
canned	A. P.	18.1	1.1	.5	382	119
Macaroni		13.4	.9	74.1	1625	28

TABLE I, *continued*

Food		Protein (N×6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Macaroons		6.5	15.2	65.2	1922	24
Mackerel	E. P.	18.7	7.1	—	629	72
	A. P.	10.2	4.2	—	356	127
salt	E. P.	21.1	22.6	—	1305	35
	A. P.	16.3	17.4	—	1005	45
Marmalade, orange		.6	.1	84.5	1548	29
Milk, condensed, sweetened		8.8	8.3	54.1	1480	31
skimmed		3.4	.3	5.1	167	273
whole		3.3	4.0	5.0	314	145
Mincemeat, commercial		6.7	1.4	60.2	1280	36
homemade		4.8	6.7	32.1	942	48
Molasses, cane		2.4	—	69.3	1302	35
Mushrooms	A. P.	3.5	.4	6.8	204	223
Muskmelons	E. P.	.6	—	9.3	180	252
	A. P.	.3	—	4.6	89	510
Mutton, fore quarter	E. P.	15.6	30.9	—	1543	29
	A. P.	12.3	24.5	—	1223	37
hind quarter	E. P.	16.7	28.1	—	1450	31
	A. P.	13.8	23.2	—	1197	38
leg	E. P.	19.8	12.4	—	863	52
	A. P.	16.5	10.3	—	718	63
side	A. P.	13.0	24.0	—	1215	37
	E. P.	16.2	29.8	—	1512	30
Nectarines	E. P.	.6	—	15.9	299	152
	A. P.	.6	—	14.8	280	162
Oatmeal		16.1	7.2	67.5	1811	25
Okra	E. P.	1.6	.2	7.4	172	264
	A. P.	1.4	.2	6.5	152	300
Olives, green	E. P.	1.1	27.6	11.6	1357	33

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbo-hydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Olives	A. P.	.8	20.2	8.5	995	46
ripe	E. P.	1.7	25.0	4.3	1130	40
	A. P.	1.4	21.0	3.5	947	48
Onions, fresh	E. P.	1.6	.3	9.9	220	206
	A. P.	1.4	.3	8.9	199	228
Oranges	E. P.	.8	.2	11.6	233	195
	A. P.	.6	.1	8.5	169	268
Oxtail soup, canned	A. P.	3.8	.5	4.2	166	274
Oysters	E. P.	6.2	1.2	3.7	228	199
in shell	A. P.	1.2	.2	.7	43	1065
canned	A. P.	8.8	2.4	3.9	328	138
Parsnips	E. P.	1.6	.5	13.5	294	154
	A. P.	1.3	.4	10.8	236	192
Pea soup, canned	A. P.	3.6	.7	7.6	232	196
Peaches, canned	A. P.	.7	.1	10.8	213	213
fresh	E. P.	.7	.1	9.4	188	242
	A. P.	.5	.1	7.7	153	297
Peanuts	E. P.	25.8	38.6	24.4	2490	18
	A. P.	19.5	29.1	18.5	1858	24
Pears, fresh	E. P.	.6	.5	14.1	288	158
	A. P.	.5	.4	12.7	245	185
Peas, canned	A. P.	3.6	.2	9.8	252	180
dried		24.6	1.0	62.0	1611	28
green	E. P.	7.0	.5	16.9	454	100
	A. P.	3.6	.2	9.8	252	180
Pies, apple		3.1	9.8	42.8	1233	37
custard		4.2	6.3	26.1	806	56
lemon		3.6	10.1	37.4	1156	39
mince		5.8	12.3	38.1	1300	35

TABLE I, *continued*

Food		Protein (N×6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Pies, squash		4.4	8.4	21.7	817	56
Pineapples, fresh	E. P.	.4	.3	9.7	196	232
canned	A. P.	.4	.7	36.4	695	65
Pignolias	E. P.	33.9	49.4	6.9	2748	16
Pistachios, shelled		22.3	54.0	16.3	2900	16
Plums	E. P.	1.0	—	20.1	383	118
	A. P.	.9	—	19.1	363	125
Pomegranates	E. P.	1.5	1.6	19.5	447	102
Pork, chops, medium	E. P.	16.6	30.1	—	1530	30
	A. P.	13.4	24.2	—	1230	37
chuck ribs and shoulder	E. P.	17.3	31.1	—	1585	29
	A. P.	14.1	25.5	—	1298	35
fat, salt	A. P.	1.9	86.2	—	3555	13
sausage	A. P.	13.0	44.2	1.1	2030	22
side	E. P.	9.1	55.3	—	2423	19
	A. P.	8.0	49.0	—	2123	21
tenderloin	A. P.	18.9	13.0	—	875	52
Potato chips	A. P.	6.8	39.8	46.7	2598	19
Potatoes, white, raw	E. P.	2.2	.1	18.4	378	120
	A. P.	1.8	.1	14.7	302	149
sweet, raw	E. P.	1.8	.7	27.4	558	81
	A. P.	1.4	.6	21.9	447	102
Prunes, dried	E. P.	2.1	—	73.3	1368	33
	A. P.	1.8	—	62.2	1160	39
Pumpkins	E. P.	1.0	.1	5.2	117	389
	A. P.	.5	.1	2.6	60	753
Radishes	E. P.	1.3	.1	5.8	133	341
	A. P.	.9	.1	4.0	91	488
Raisins	E. P.	2.6	3.3	76.1	1562	29

TABLE I, *continued*

Food		Protein (N×6.25) per cent	Fat per cent	Carbohydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Raisins	A. P.	2.3	3.0	68.5	1407	32
Raspberries, red		1.0	—	12.6	247	184
black		1.7	1.0	12.6	300	151
Rhubarb	E. P.	.6	.7	3.6	105	433
	A. P.	.4	.4	2.2	63	714
Rice		8.0	.3	79.0	1620	29
Salmon, dressed	A. P.	13.8	8.1	—	582	78
whole	E. P.	22.0	12.8	—	923	49
	A. P.	15.3	8.9	—	642	71
Sausage, bologna	E. P.	18.7	17.6	.3	1061	43
	A. P.	18.2	19.7	—	1135	40
farmer	E. P.	29.0	42.0	—	2240	20
	A. P.	27.9	40.4	—	2156	21
Shad, whole	E. P.	18.8	9.5	—	727	61
	A. P.	9.4	4.8	—	367	127
roe		20.9	3.8	2.6	582	78
Shredded wheat		10.5	1.4	77.9	1660	27
Spinach, fresh	A. P.	2.1	.3	3.2	109	417
Squash	E. P.	1.4	.5	9.0	209	217
	A. P.	.7	.2	4.5	103	443
Strawberries		1.0	.6	7.4	169	269
Succotash, canned		3.6	1.0	18.6	444	102
Sugar		—	—	100.0	1815	25
Tomatoes, fresh	A. P.	.9	.4	3.9	104	438
canned	A. P.	1.2	.2	4.0	103	443
Turkey	E. P.	21.1	22.9	—	1320	34
	A. P.	16.1	18.4	—	1042	43
sandwich, canned		20.7	29.2	—	1568	29
Turnips	E. P.	1.3	.2	8.1	178	256

TABLE I, *continued*

Food		Protein (N × 6.25) per cent	Fat per cent	Carbo-hydrate per cent	Fuel Value per Pound Calories	100 Calorie Portion Grams
Turnips	A. P.	.9	.1	5.7	124	367
Veal, breast	E. P.	20.3	11.0	—	817	56
	A. P.	15.3	8.6	—	629	72
cutlet	E. P.	20.3	7.7	—	683	66
	A. P.	20.1	7.5	—	670	68
fore quarter	E. P.	20.0	8.0	—	690	66
	A. P.	15.1	6.0	—	517	88
hind quarter	E. P.	20.7	8.3	—	715	64
	A. P.	16.2	6.6	—	534	85
side	E. P.	20.2	8.1	—	697	65
	A. P.	15.6	6.3	—	539	84
Vegetable soup, canned		2.9	—	.5	62	735
Walnuts, California	E. P.	18.4	64.4	13.0	3182	14
	A. P.	4.9	17.3	3.5	859	53
black	E. P.	27.6	56.3	11.7	3001	15
	A. P.	7.2	14.6	3.0	780	59
Watermelons	E. P.	.4	.2	6.7	136	332
	A. P.	.2	.1	2.7	57	800
Wheat, cracked		11.1	1.7	75.5	1635	28
Whitefish	E. P.	22.9	6.5	—	680	67
	A. P.	10.6	3.0	—	315	144
Zwiebach		9.8	9.9	73.5	1915	24

TABLE II

Ash Constituents of Foods in Percentage of the Edible Portion

(Compiled from various sources)

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Almonds	.30	.35	.20	.03	.87	.005	.135	.002
Apples	.014	.014	.15	.02	.03	.004	.005	.0003
Apricots	.018	.018	.28	.06	.06	.003		
Asparagus	.04	.02	.20	.01	.09	.04	.04	.0010
Bananas	.01	.04	.50	.02	.055	.20	.013	.0006
Barley, pearled	.025	.10	.35	.04	.46	.02		.0013
whole	.06	.22	.50	.06	.95	.02	.14	.004
Beans, dried	.22	.25	1.40	.26	1.14	.03	.22	.0070
lima, dried	.10	.31	2.1	.33	.77	.025	.16	.0070
lima, fresh	.04	.11	.7	.12	.27	.009	.06	.0025
string	.075	.043	.28	.03	.12		.04	.0016
Beef (*see* Meat)								
Beer	.007	.010	.059	.059	.089	.014		
Beets	.03	.033	.45	.10	.09	.04	.015	.0006
Blackberries	.08	.035	.20		.08		.01	
Blueberries	.045	.015	.05		.02			
Bread, white	.03	.03	.10		.20		.12	.0009
whole wheat	.04	.08	.27		.4			.0015
Breadfruit	.12	.01	.28	.04	.16	.10		
Buckwheat flour	.02	.08	.16	.04	.40	.01		
Butter	.02	.001	.02		.03			
Buttermilk	.15	.026	.18	.08	.22	.10		
Cabbage	.068	.026	.45	.05	.09	.03	.07	.0011
Cocoa	.14	.48	1.0	.05	1.1	.04		.0024
Capers	.17	.04	.25	.07	.14	.27		
Caraway seed	.9	.4	1.3	.3	1.2	.15		
Carrots	.077	.034	.35	.13	.10	.036	.022	.0008
Cauliflower	.17	.02	.27	.10	.14	.05	.085	
Caviar	.19		.13	1.2	.4	1.8		

TABLE II, *continued*

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Celery	.10	.04	.37	.11	.10	.17	.025	.0005
Cheese, hard	1.1	.06	.2	1.	1.45	1.		
Cottage cheese	.3	.015			.5			
Cherries	.03	.027	.26	.03	.07	.01		.0005
Cherry juice	.025	.02	.15	.02	.03	.004	.006	
Chestnuts	.04	.08	.50	.05	.20	.01	.068	.001
Chicory	.05	.03	.27	.11	.00	.06		
Chives	.20	.05	.33	.04	.20	.04		
Chocolate	.14	.48			.90			
Citron	.17	.03	.25	.02	.08	.01		
Cocoanut pulp	.09	.10	.77	.10	.38	.25		
Codfish (*see* Fish)								
Coffee	.25	.42	2.3	.08	.054	.04		
Corn, sweet, dried	.03	.20	.5	.2	.8	.05	.16	.0029
sweet, fresh	.008	.055	.137	.05	.22	.014	.044	.0008
Corn meal	.015	.13	.17	.03	.3		.116	.0011
Crackers, soda	.028	.017	.12		.23		.12	.0015
Cranberries	.024	.011	.09	.013	.03		.008	.0006
Cream	.14	.02	.15	.06	.18	.1	.03	.0002
Cucumbers	.022	.015	.17	.015	.08	.03	.022	
Currants, fresh	.05	.04	.25	.02	.10	.01	.01	.0005
Zante	.14	.08	1.0	.1	.3	.06		
Currant juice	.03	.02	.2		.05			
Dandelion greens								.0027
Dates	.10				.12			.003
Eggs	.093	.015	.165	.2	.37	.10	.19	.003
Egg white	.015	.015	.19	.21	.03	.15	.196	.0001
Egg yolk	.2	.02	.13	.1	1.0	.1	.157	.0085
Endive	.14	.02	.45	.15	.10		.03	
Figs, fresh	.074	.036	.365	.016	.082	.014		.0008
dried	.299	.145	1.478	.064	.332	.056		.0032
Fish,[1] cod	.015	.03	.40	.13	.4	.24		.0004

---

[1] Average fish flesh is calculated to contain *per 100 grams protein* .15 CaO, .2 MgO, 2.5 P_2O_5, .004 Fe.

TABLE II, *continued*

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
haddock	.03	.04	.40	.13	.4	.24	.22	
halibut	.013				.4			.0003
herring	.08	.05			.55		.23	
herring roe	.012	.06						
pike	.05	.05	.4	.15	.48	.04	.22	
salmon	.011	.05	.32	.17	.42	.28		.0015
Flaxseed	.27	.42	1.04	.06	1.30		.17	
Flour (*see* under wheat, buckwheat, etc.)								
Gooseberries	.05	.02	.21	.03	.65	.01		
Grapefruit	.03	.02	.17		.04	.01		.0004
Grapes	.024	.014	.25	.03	.12	.01	.024	.0013
Grape juice (and must)	.021	.016	.20	.01	.04	.01		
Guava	.02	.013	.46		.07	.05		
Haddock (*see* Fish)								
Halibut (*see* Fish)								
Hazelnuts								.004
Honey	.005	.03	.5		.04	.03		.0010
Horseradish	.13	.065	.56	.08	.1	.02	.18	
Huckleberries	.035	.025			.07			.0011
Infants' foods[1]								
Lamb (*see* Meats)								
Leeks	.08	.02	.24	.11	.15	.03	.08	
Lemons	.05	.01	.21	.01	.02	.01	.012	.0006
Lemon juice	.033	.01	.17	.01	.025	.01		
Lemon, sweet	.04	.01	.53		.10	.01		
Lentils	.12	.05	.75	.25	.66	.08		.0086
Lettuce	.05	.01	.42	.04	.09	.06	.014	.001

---

[1] Ash analyses, more or less complete, of a number of proprietary foods are given in König's *Chemie der Nahrungs- und Genüssmittel*, 4th ed.

TABLE II, *continued*

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Limes	.08	.02	.42		.08	.04		
Mamey	.02	.02	.42		.06	.14		
Mango	.03	.01	.28		.04	.02		
Maple sap	.17	.06	.25	.01	.06			
Meat,[1] beef, lean	.011	.04	.42	.09	.50	.05	.20	.0038
veal, lean	.016	.045	.46	.12	.50	.07	.23	
ox tongue	.028	.02	.56	.06	.60			
chicken	.015	.06	.56	.13	.58	.06	.216	
pork, lean	.012	.046	.34	.13	.45	.05	.20	
ham	.032	.04						
rabbit's flesh	.026	.05	.48	.07	.58	.05	.20	
frog's flesh	.027	.04	.37	.07	.43	.04	.16	
Meat extracts[2]								
Meat sauces[2]								
Milk, cow's	.168	.019	.171	.068	.215	.12	.033	.00024
Molasses	.9	.3	1.7	.3	.2	.2		
Mushrooms	.024	.026	.46	.04	.24	.02	.03	
Muskmelons	.024	.020	.283	.082	.035	.041	.014	.0003
Mustard	.689	.430	.917	.076	1.729	.016	1.230	
Mutton (*see* Meat)								
Oatmeal	.13	.212	.458	.109	.872	.035	.215	.0036
Olives	.17	.01	1.8	.17	.03	.01		.0029
Onions	.06	.03	.23	.02	.12	.02	.06	.0005
Oranges	.06	.02	.22	.01	.05	.01	.013	.0003
Orange juice	.05	.02	.22	.01	.03	.01		
Paprika	.32	.27	2.5	.24	.78	.15		
Parsnips	.09	.07	.70	.01	.19	.03		
Peaches	.01	.02	.25	.02	.047	.01	.01	.0003

---

[1] Average meat is calculated to contain *per 100 grams protein* .075 CaO, .2 MgO, 2.0 K_2O, .4 Na_2O, 2.3 P_2O_5, .2 Cl, .9 S, .015 Fe.

[2] See König's *Chemie der menschlichen Nahrungs- und Genüssmittel*, 4th ed.

TABLE II, *continued*

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Peanuts	.10	.28	.85	.07	.90	.04	.243	.0020
Pears	.021	.019	.16	.03	.06			.0003
Peas, dried	.14	.24	1.06	.16	.91	.04	.23	.0056
fresh (calc. from dried)	.04	.07	.30	.04	.26	.01	.06	.0016
cow peas, dried	.18	.21	1.01	.40	1.00	.02		
Persimmons	.03	.015	.35	.02	.05	.01		
Pie, mince	.04	.04			.2			
squash	.03	.02			.15			
Pineapple	.02	.02	.38	.02	.06	.05		.0005
juice					.02	.05	.007	
Plums	.025	.02	.25	.03	.055	.01		.0005
Pork (*see* Meat)								
Potatoes	.016	.036	.53	.025	.140	.03	.03	.0013
sweet	.025	.02	.47	.06	.09	.12		.0005
Prunes, dried	.06	.08	1.2	.1	.25	.01	.03	.0029
Pumpkins	.03	.015	.08	.08	.11	.01	.02	
Quince juice			.18		.035			
Radishes	.05	.02	.17	.11	.09	.05	.05	.0006
Raisins	.08	.15	1.0	.19	.29	.07	.06	.005
Raspberries	.07	.04	.21		.12			
Raspberry juice	.03	.03	.17	.01	.03	.01	.007	
Rhubarb	.06	.02	.39	.03	.07	.035		
Rice	.012	.045	.084	.028	.203	.05	.105	.0009
Rutabagas	.1	.03	.48	.11	.13			
Rye	.07	.22	.60	.04	.81	.02	.17	.004
Rye flour	.018	.13	.60	.03	.80			
Rye bran	.25	1.1	1.9	.1	3.4			
Salsify					.12		.04	
Sapato	.04	.02	.22		.02	.09	.01	
Soup, canned vegetable	.025	.02	.18		.11			
Spinach	.09	.08	.94	.20	.13	.02	.041	.0032

TABLE II, *continued*

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Squash	.02	.01	.05	.05	.08	.01	.026	.0008
Strawberries . .	.05	.03	.18	.07	.064	.01		.0009
Tamarinds . . .	.01	.03			.15	.01	.01	
Tomatoes . . .	.020	.017	.35	.01	.059	.03	.02	.0004
Tomato juice . .	.01	.017	.35	.02	.034	.05		
Turnips	.089	.028	.40	.08	.117	.04	.07	.0005
Turnip tops . .	.48	.05	.37	.11	.11	.17	.07	
Vanilla (bean) . .	1.0	.5	.85	.35	.6	.03		
Veal (*see* Meat)								
Vinegar	.02	.02	.25		.05			
Walnuts	.108	.237	.44	.03	.77	.01	.195	.0021
Water chestnuts .	.12	.25	.77	.03	.79	.01		
Water cress . .	.26	.05			.07			
Watermelon . .	.02	.02	.09	.01	.02	.01		
Wheat, entire grain	.061	.213	.519	.068	.902	.08	.17	.0053
Wheat flour . .	.025	.027	.146	.04	.20	.07	.17	.0015
low grade . .	.04	.07	.23		.37			
Wheat bran . .	.14	.84	1.5	.07	3.0		.26	
Whortleberries .	.037	.024	.21	.03	.06			
Wine	.012	.019	.100	.018	.036	.01		

TABLE III

ASH CONSTITUENTS OF FOODS IN GRAMS PER 100 CALORIES OF EDIBLE FOOD MATERIAL

(Estimated from preceding tables)

FOOD	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Almonds	.046	.053	.030	.004	.132	.001	.020	.0003
Apples	.022	.022	.237	.03	.05	.006	.008	.0005
Apricots	.031	.031	.485	.10	.10	.005	.01	
Asparagus	.17	.09	.88	.04	.39	.17	.17	.0043
Bananas	.01	.04	.50	.02	.055	.20	.013	.0006
Barley flour, patent					.083		.031	.00028
Barley, pearled	.007	.028	.097	.011	.127	.005		.00036
Beans, dried	.063	.072	.401	.074	.326	.008	.063	.0020
lima	.028	.087	.59	.092	.219	.007	.045	.00195
string	.177	.102	.663	.070	.284		.10	.0038
Beets	.06	.071	.965	.21	.19	.08	.032	.0013
Blackberries	.13	.059	.33		.13		.02	
Blueberries	.060	.020	.07		.03			
Bread, white	.011	.011	.04		.075		.05	.0003
"whole wheat"	.016	.032	.109		.16			.0006
graham	.019				.19			.0013
Buckwheat flour	.006	.022	.045	.011	.114	.003		
Butter	.003	.0001	.003		.004			
Buttermilk	.415	.072	.495	.22	.61	.275		
Cabbage	.214	.081	1.425	.16	.28	.09	.22	.0035
Cacao (cocoa)[1]	.027	.095	.20	.010	.22	.008		.0005
Carrots	.168	.074	.765	.28	.22	.078	.048	.0016
Cauliflower	.55	.06	.88	.32	.45	.16	.277	
Celery	.54	.22	2.00	.60	.54	.9	.13	.0027
Cheese, hard	.25	.014	.05	.2	.329	.2		
Cottage cheese	.3	.013			.4			
Cherries	.04	.034	.32	.04	.09	.01		

---

[1] General average of samples of beans, nibs, and powdered sample.

TABLE III, *continued*

FOOD	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Chestnuts	.017	.034	.21	.02	.08	.004	.028	.0004
Chocolate	.02	.08			.14			
Citron	.052	.009	.076	.006	.024	.003		
Coconut pulp	.015	.016	.129	.011	.063	.042		
Corn, green	.008	.053	.134	.05	.21	.014	.042	.00075
Corn meal	.004	.036	.05	.01	.08		.032	.0003
Crackers, soda	.006	.004	.028		.054		.028	.00035
Cranberries	.051	.023	.19	.027	.06		.017	.0013
Cream	.07	.01	.07	.03	.10	.05	.01	.0001
Cucumbers	.12	.09	1.0	.09	.45	.2	.12	
Currants, fresh	.09	.07	.43	.03	.17	.02	.02	.0009
Zante	.04	.02	.3	.03	.09	.02		
Dates	.03				.03			.001
Eggs	.06	.009	.108	.1	.24	.06	.12	.0019
Egg white	.028	.028	.355	.395	.05	.28	.370	.0002
Egg yolk	.05	.005	.035	.03	.27	.03	.043	.0023
Figs	.089	.043	.442	.019	.099	.017		.0010
Fish, cod	.021	.04	.57	.18	.6	.34		.0006
haddock	.04	.05	.55	.18	.5	.33	.30	
halibut	.010				.3			.0002
herring	.05	.03			.38		.16	
pike	.06	.06	.5	.19	.60	.05	.27	
salmon	.005	.02	.15	.08	.20	.13		.0007
Grapes	.024	.014	.25	.03	.12	.01	.024	.0013
Grape juice and must	.021	.016	.20	.01	.04	.01		
Honey	.001	.01	.13		.01	.01		.0003
Horseradish	.26	.129	.111	.16	.2	.04	.35	
Huckleberries	.046	.033			.09			.0014
Leeks	.24	.06	.73	.33	.45	.09	.24	
Lemons	.12	.02	.46	.02	.04	.02	.027	.0013
Lemon juice	.083	.03	.43	.03	.063	.03		
Lentils	.03	.01	.21	.07	.18	.02		.0024

TABLE III, *continued*

Food	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Lettuce	.26	.05	2.1	.2	.47	.3	.07	.005
Maple sap	.06	.02	.09	.003	.02			
Meats, bacon	.001	.003			.04			.0002
beef, lean	.009	.03	.35	.08	.42	.04	.17	.0032
veal, lean	.012	.033	.34	.09	.37	.05	.17	
chicken	.007	.03	.24	.06	.25	.02	.08	
ham	.005	.014			.18			.0011
frog's flesh	.042	.06	.57	.11	.67	.06	.25	
Milk, cow's	.239	.027	.243	.097	.303	.17	.047	.00034
Molasses	.3	.1	.6	.1	.1	.1		
Mushrooms	.053	.057	1.01	.09	.53	.04	.06	
Oatmeal	.03	.052	.113	.027	.216	.009	.053	.0009
Olives	.06	.003	.6	.06	.01	.003		.0009
Onions	.12	.06	.46	.04	.24	.04	.12	.0011
Oranges	.11	.04	.42	.02	.09	.02	.025	.0006
Orange juice	.12	.05	.51	.02	.07	.02		
Parsnips	.14	.11	1.07	.02	.29	.05		
Peaches	.02	.05	.60	.05	.113	.02	.02	.0007
Peanuts	.018	.049	.152	.012	.160	.007	.043	.00035
Pears	.032	.029	.25	.05	.09			.0005
Peas, dried	.04	.07	.29	.04	.25	.01	.06	.0015
fresh	.032	.054	.29	.01	.24	.01	.06	.0016
Cowpeas	.05	.06	.29	.11	.29	.006		
Persimmons	.02	.011	.25	.01	.04	.01		
Pie, mince	.01	.01			.1			
squash	.02	.01			.08			
Pineapple	.04	.04	.87	.04	.14	.11		.0011
Plums	.029	.02	.029	.03	.064	.01		.0006
Potatoes	.019	.042	.63	.030	.166	.04	.04	.0015
sweet	.020	.02	.37	.05	.08	.10		.0004
Prunes, dried	.02	.03	.4	.03	.08	.003	.01	.0009
Pumpkins	.11	.057	.30	.30	.42	.038	.08	
Radishes	.17	.07	.57	.37	.30	.17	.17	.0020

TABLE III, *continued*

FOOD	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	S	Fe
Raisins	.02	.04	.3	.05	.08	.02	.02	.001
Raspberries	.11	.06	.335		.18			
Raspberry juice	.08	.08	.45	.03	.08	.03	.019	
Rhubarb	.26	.09	1.69	.13	.30	.151		
Rice	.003	.013	.023	.008	.057	.01	.029	.0003
Rutabagas	.2	.07	1.16	.26	.31			
Rye flour	.005	.04	.17	.01	.22			
Soup (canned vegetable)	.18	.15	1.3		.8			
Spinach	.37	.33	3.905	.83	.54	.08	.170	.0133
Squash	.04	.02	.11	.11	.17	.02	.055	.0017
Strawberries	.13	.08	.45	.18	.162	.03		.0023
Tomatoes	.087	.074	1.52	.04	.257	.13	.09	.0017
Turnips	.222	.070	1.00	.20	.292	.10	.17	.0013
Turnip tops	1.00	.10	.77	.23	.23	.35	.14	
Walnuts	.015	.033	.061	.004	.108	.001	.027	.00029
Watermelon	.06	.06	.29	.03	.06	.03		
Wheat flour	.007	.007	.040	.01	.05	.02	.05	.0004
low grade	.01	.02	.006		.10			
Whortleberries	.043	.028	.24	.03	.07		.02	

INDEX

A LIST OF WORKS ON CHEMISTRY

Published by The Macmillan Company

KAHLENBERG. **Outlines of Chemistry.** A textbook for college students. By Louis Kahlenberg, Ph.D., Professor of Chemistry and Director of the Course in Chemistry in the University of Wisconsin. Published in New York, 1909. *Cloth, 8vo, 548 pages, $2.60 net*

STODDARD. **Introduction to General Chemistry.** By John T. Stoddard, Professor of Chemistry at Smith College, Northampton, Mass. New York, 1910. *Cloth, 12mo, 432 pages, $1.60 net*

GOOCH & WALKER. **Outlines of Inorganic Chemistry.** By Frank Austin Gooch, Professor of Chemistry in Yale University, and Claude Frederic Walker, teacher of Chemistry in the High School of Commerce of New York City. *Cloth, 514 pages, $1.75 net*

JONES. **Principles of Inorganic Chemistry.** By Harry C. Jones, Professor of Physical Chemistry in the Johns Hopkins University. New York. Third Edition, 1906. *Cloth, 521 pages, $3.00 net*

JONES. **Elements of Inorganic Chemistry.** By Harry C. Jones, Professor of Physical Chemistry in the Johns Hopkins University. New York, 1903. Second Edition, 1904. Reprinted, 1908.
Cloth, 12mo, 343 pages, $1.25 net

OSTWALD. **The Principles of Inorganic Chemistry.** By Wilhelm Ostwald. Translated with the author's sanction by Alexander Findlay, M.A., Ph.D., D.Sc. London, 1902. Third Edition, 1908.
Cloth, 8vo, 801 pages, $6.00 net

ROSCOE & HARDEN. **An Inorganic Chemistry for Advanced Students.** By Sir Henry E. Roscoe, F.R.S., and Arthur Harden. London.
Cloth, 8vo, $1.00 net

ROSCOE & SCHORLEMMER. **A Treatise on Chemistry.** By Sir H. E. Roscoe, F.R.S., and C. Schorlemmer, F.R.S. Vol. I — The Non-Metallic Elements. London, 1877. Third Edition, 1905.
Cloth, 8vo, 931 pages, $5.00 net

Vol. II — The Metals. London, 1878. Third Edition, 1897. Fourth Edition, 1907. *Cloth, 8vo, 1436 pages, $7.50 net*

Vol. III. Preparing.

ROSCOE. **Lessons in Elementary Chemistry, Inorganic and Organic.** By Sir Henry E. Roscoe, D.C.L., L.L.D., F.R.S. London, 1902. Latest reprint, 1907. *Cloth, 12mo, 523 pages, $1.25 net*

DOBBIN & WALKER. **Chemical Theory for Beginners.** By Leonard Dobbin, Ph.D., and James Walker, Ph.D., D.Sc. London, 1892. Fifth Edition, 1906. *Cloth, 16mo, 240 pages, $ .70 net*

A LIST OF WORKS ON CHEMISTRY—*Continued*

RAMSAY. **Experimental Proofs of Chemical Theory for Beginners.** By WILLIAM RAMSAY, Ph.D., LL.D., Sc.D., F.R.S. London, 1884. Second Edition, 1893. Reprinted, 1900, 1908. *Cloth, 18mo, 143 pages, $ .60 net*

LENGFELD. **Inorganic Chemical Preparations.** By FELIX LENGFELD, Assistant Professor of Inorganic Chemistry in the University of Chicago. New York, 1899. Reprinted, 1905. *Cloth, 12mo, 57 pages, $ .60 net*

BENEDICT. **Chemical Lecture Experiments.** By FRANCIS GANO BENEDICT, Ph.D. New York, 1901. *Cloth, 12mo, 436 pages, $2.00 net*

PERKIN & LEAN. **Introduction to the Study of Chemistry.** By W. H. PERKIN, Lr., Ph.D., F.R.S., and BEVAN LEAN, D.Sc., B.A. London, 1896. Seventh reprint, 1906. *Cloth, 12mo, 334 pages, $ .75 net*

NERNST. **Theoretical Chemistry from the Standpoint of Avogadro's Rule and Thermodynamics.** By Prof. WALTER NERNST, Ph.D., of the University of Göttingen. Revised in accordance with the fourth German edition. London, 1895. Second English edition, 1904.
Cloth, 8vo, 771 pages, $ 4.50 net

OSTWALD. **The Scientific Foundations of Analytical Chemistry.** Treated in an elementary manner. By WILHELM OSTWALD. Translated with the author's sanction by George M. Gowan. London, 1895. Third Edition, 1908. *Cloth, 12mo, 247 pages, $2.00 net*

CHESNEAU. **Theoretical Principles of the Methods of Analytical Chemistry, based upon Chemical Reactions.** By M. G. CHESNEAU, Ingenieur en chef des Mines: Professeur d'analyse minérale à l'école nationale des Mines. Authorized translation by A. T. Lincoln, Ph.D., Assistant Professor of Chemistry, Rensselaer Polytechnic Institute, and D. H. Carnahan, Ph.D., Associate Professor of Romance Languages, University of Illinois. New York, 1910. *Cloth, 8vo, 184 pages, $1.75 net*

JONES. **Practical Inorganic Chemistry for Advanced Students.** By CHAPMAN JONES, F.I.C., F.C.S., etc. London, 1898. Latest reprint, 1906.
Cloth, 12mo, 239 pages, $ .60 net

BASKERVILLE & CURTMAN. **Qualitative Chemical Analysis.** By Professor CHARLES BASKERVILLE and Dr. L. J. CURTMAN, College of the City of New York. New York, 1910. *Cloth, 8vo, 200 pages, $1.40 net*

NOYES. **A Detailed Course of Qualitative Chemical Analysis of Inorganic Substances.** With Explanatory Notes by Arthur A. Noyes, Ph.D. New York, 1899. *Cloth, 8vo, 89 pages, $1.25 net*

MORGAN. **Qualitative Analysis.** As a laboratory basis for the study of general inorganic chemistry. By WILLIAM CONGER MORGAN, Ph.D., Assistant Professor of Chemistry in the University of California. New York, 1906. Reprinted, 1907. *Cloth, 8vo, 351 pages, $1.90 net*

HILLYER. **Laboratory Manual.** Experiments to illustrate the elementary principles of chemistry. By H. W. HILLYER, Ph.D., Assistant Professor of Organic Chemistry in the University of Wisconsin. New York, 1900.
Cloth, 8vo, 200 pages, $ .90 net

A List of Works on Chemistry—*Continued*

ABEGG & HERZ. **Practical Chemistry.** An experimental introduction to laboratory practice and qualitative analysis from a physiochemical standpoint. By R. Abegg and W. Herz. Translated by H. T. Calvert, B.Sc. London, 1901. *Cloth, 12mo, 118 pages, $1.50 net*

TALBOT. **An Introductory Course of Quantitative Chemical Analysis.** With explanatory notes and stoichiometrical problems. By H. P. Talbot, Ph.D. New York, 1908. Fifth Edition. Rewritten and revised. *Cloth, 8vo, 176 pages, $1.50 net*

BAILEY. **Elements of Quantitative Analysis.** By G. H. Bailey, D.Sc., Ph.D. London, 1905. *Cloth, 12mo, 246 pages, $1.00 net*

LINCOLN & WALTON. **Exercises in Elementary Quantitative Chemical Analysis for Students of Agriculture.** By Azariah Thomas Lincoln, Ph.D., Assistant Professor of Chemistry, University of Illinois, and James Henri Walton, Jr., Ph.D., Assistant Professor of Chemistry, University of Wisconsin. New York, 1907. Third reprint, 1910. *Cloth, 8vo, 218 pages, $1.50 net*

MILLER. **The Calculations of Analytical Chemistry.** By Edmund H. Miller, Ph.D., Professor of Analytical Chemistry in Columbia University. New York. Third Edition, 1906. *Cloth, 8vo, 201 pages, $1.50 net*

WADDELL. **Arithmetic of Chemistry.** Being a simple treatment of the subject of chemical calculations. By John Waddell, B.Sc., Ph.D., D.Sc. New York, 1899. Fifth reprint, 1907. *Cloth, 12mo, 133 pages, $ .90 net*

LUPTON. **Chemical Arithmetic, with Twelve Hundred Examples.** By Sydney Lupton, M.S., F.C.S. London, 1882. Second Edition, 1886. Sixth reprint, 1907. *Cloth, 16mo, 171 pages, $ 1.10 net*

GUTTMAN. **Percentage Tables for Elementary Analysis.** By Leo F. Guttman, Ph.D. London, 1904. *Cloth, 8vo, 43 pages, $1.10 net*

THORPE. **A Series of Chemical Problems, with Key for Use in Colleges and Schools.** By F. E. Thorpe, LL.D., F.R.S. Revised and enlarged by W. Tate, Assoc. N.S.S., F.C.S. London, 1877. Second Edition, 1891. Latest reprint, 1907. *Cloth, 16mo, 139 pages, $ .65 net*

HEMPEL. **Methods of Gas Analysis.** By Dr. Walter Hempel. Translated from the third German edition and considerably enlarged by L. M. Dennis, Professor of Analytical and Inorganic Chemistry. New York, 1902. Latest reprint, 1910. *Cloth, 12mo, 487 pages, $2.25 net*

WADE. **Introduction to the Study of Organic Chemistry.** A theoretical and practical textbook for students in the universities and technical schools. By John Wade, D.Sc. London, 1897. Second Edition, 1905. *Cloth, 12mo, 646 pages, $1.75 net*

PUBLISHED BY

THE MACMILLAN COMPANY

64-66 Fifth Avenue, New York

A List of Works on Chemistry—*Continued*

GATTERMAN. **The Practical Methods of Organic Chemistry.** By Ludwig Gatterman, Ph.D. Translated by William B. Schober, Ph.D. Authorized translation. The second American from the fourth German edition. New York, 1896, 1901. Sixth reprint, 1910.
Cloth, 8vo, 350 pages, $1.60 net

SHERMAN. **Methods of Organic Analysis.** By Henry C. Sherman, Ph.D., Adjunct Professor of Analytical Chemistry in Columbia University. New York, 1905. *Cloth, 8vo, 245 pages, $1.75 net*

COHEN. **Theoretical Organic Chemistry.** By Julius B. Cohen, Ph.D., B.Sc. London, 1902. Latest reprint, 1907.
Cloth, 12mo, 578 pages, $1.50 net

COHEN. **Practical Organic Chemistry for Advanced Students.** By Julius B. Cohen, Ph.D., B.Sc. London, 1900. Second Edition, 1908.
Cloth, 12mo, 456 pages, $ .80 net

LASSAR-COHEN. **A Laboratory Manual of Organic Chemistry.** A compendium of laboratory methods for the use of chemists, physicians, and pharmacists. By Dr. Lassar-Cohen. Translated, with the author's sanction, from the second German edition, by Alexander Smith, B.Sc., Ph.D. London, 1895. Reprinted, 1896. *Cloth, 8vo, 403 pages, $2.25 net*

LACHMAN. **The Spirit of Organic Chemistry.** An introduction to the current literature of the subject. By Arthur Lachman, Professor of Chemistry in the University of Oregon. With an introduction by Paul C. Greer, M.D., Ph.D., Professor of General Chemistry in the University of Michigan. New York, 1899. Second reprint, 1909.
Cloth, 12mo, 229 pages, $1.50 net

MANN. **Chemistry of the Proteids.** By Gustav Mann, M.D., B.Sc., University Demonstrator of Physiology, Oxford. London, 1906.
Cloth, 8vo, 606 pages, $3.75 net

LE BLANC. **A Textbook of Electro-Chemistry.** By Max Le Blanc, Professor in the University of Leipzig. Translated from the fourth enlarged German edition, by Willis R. Whitney, Ph.D., Director of the Research Laboratory of the General Electric Company, and John W. Brown, Ph.D., Director of the Research and Battery Laboratory of the National Carbon Company. New York, 1907. Reprinted, 1910.
Cloth, 8vo, 335 pages, $2.60 net

BLOUNT. **Practical Electro-Chemistry.** By Bertram Blount, F.L.C., Assoc. Inst. C.E. London, 1901. Second Edition. Revised, 1906.
Cloth, 8vo, 394 pages, $3.25 net

NEUMANN. **The Theory and Practice of Electrolytic Methods of Analysis.** By Dr. Bernhard Neumann. Translated by John B. C. Kerslaw, F.I.C. London, 1878. *Cloth, 8vo, 254 pages, $3.00 net*

A List of Works on Chemistry—*Continued*

TALBOT & BLANCHARD. **The Electrolytic Dissociation Theory with Some of its Applications.** An elementary treatise for the use of students of chemistry. By Henry P. Talbot, Ph.D., Professor of Inorganic and Analytical Chemistry, and Arthur A. Blanchard, Ph.D., Instructor in Inorganic Chemistry at the Massachusetts Institute of Technology. Second Edition. New York, 1907. *Cloth, 85 pages, $1.25 net*

JONES. **The Theory of Electrolytic Dissociation and Some of its Applications.** By Harry C. Jones, Professor of Physical Chemistry in the Johns Hopkins University. New York, 1900. Third Edition, 1906.
Cloth, 8vo, 289 pages, $1.60 net

JONES. **Introduction to Physical Chemistry.** By H. C. Jones, Professor of Physical Chemistry in the Johns Hopkins University. New York, 1910.
Cloth, 12mo, 279 pages, $1.60 net

JONES. **The Elements of Physical Chemistry.** By H. C. Jones, Professor in the Johns Hopkins University. Fourth Edition. Revised and enlarged. New York, 1909. *Cloth, 8vo, 650 pages, $4.00 net*

WALKER. **Introduction to Physical Chemistry.** By James Walker, D.Sc., Ph.D., F.R.S., Professor of Chemistry in the University of Edinburgh. London, 1899. Fifth Edition, 1909. Reprinted, 1910.
Cloth, 8vo, 389 pages, $3.25 net

REYCHLER. **Outlines of Physical Chemistry.** By A. Reychler, Professor of Chemistry in the University of Brussels. Translated from the French, with the author's permission, by John McCrae, Ph.D. London. Second Edition, 1904. *Cloth, 12mo, 268 pages, $1.00 net*

BOYNTON. **Applications of the Kinetic Theory to Gases, Vapors, Pure Liquids, and the Theory of Solutions.** By William Pingry Boynton, Ph.D., Assistant Professor of Physics in the University of Oregon. New York, 1904. *Cloth, 12mo, 288 pages, $1.60 net*

THOMSON. **Application of Dynamics to Physics and Chemistry.** By Sir J. J. Thomson, F.R.S. London, 1888. *Cloth, 8vo, 312 pages, $1.90 net*

HARDIN. **The Rise and Development of the Liquefaction of Gases.** By Willett L. Hardin, Ph.D. New York. Latest reprint, 1905.
Cloth, 12mo, 250 pages, $1.50 net

TRAVERS. **The Experimental Study of Gases.** By Dr. Morris W. Travers, Assistant Professor of Chemistry, University College, London. With Introduction by Sir W. Ramsay. London, 1901.
Cloth, 8vo, 323 pages, $3.25 net

RAMSAY. **The Gases of the Atmosphere; The History of their Discovery.** By Sir William Ramsay, K.C.B., F.R.S. London, 1896. Third Edition, 1905. *Cloth, 12mo, 296 pages, $2.00 net*

FLEISCHER. **A System of Volumetric Analysis.** By Dr. Emil Fleischer. Translated, with notes and additions, from the second German edition, by M. M. Pattison Muir, F.R.S.E., Owens College, Manchester. London. *Cloth, 12mo, 277 pages, $2.00 net*

ROSCOE. **Spectrum Analysis.** By Sir HENRY E. ROSCOE, F.R.S. Revised by the author and A. Schuster, F.R.S. London.
Cloth, 8vo, colored plates, $6.00 net

LANDAUER. **Blowpipe Analysis.** By J. LANDAUER. Authorized English edition by James Taylor. London, 1879. Third Edition, 1901.
Cloth, 12mo, 173 pages, $1.10 net

GETMAN. **The Elements of Blowpipe Analysis.** By FREDERICK HUTTON GETMAN, F.C.S. New York, 1899. *Cloth, 12mo, 77 pages, $ .60 net*

BEHRENS. **A Manual of Microchemical Analysis.** By Professor H. BEHRENS. With an introductory chapter by Professor John W. Judd, F.R.S. London, 1894. *Cloth, 12mo, 246 pages, $1.50 net*

ELSDEN. **Principles of Chemical Geology.** A review of the application of the equilibrium theory to geological problems. By JAMES VINCENT ELSDEN, D.Sc., F.G.S. London, 1910. *Cloth, 8vo, 222 pages, $1.60 net*

TUTTON. **Crystalline Structure and Chemical Constitution.** By A. E. H. TUTTON, D.Sc., M.A., F.R.S., etc. Vice President of the Mineralogical Society, etc. London, 1910. *Cloth, 8vo, 204 pages, $1.60 net*

MIERS. **Mineralogy: An Introduction to the Scientific Study of Minerals.** By H. A. MIERS, D.Sc., M.A., F.R.S., Professor of Mineralogy at Oxford. London, 1902.
Cloth, 8vo, 584 pages, with 2 colored plates and 716 illustrations, $8.00 net

THORP. **Outlines of Industrial Chemistry.** A textbook for students. By FRANK HALL THORP, Ph.D. Second Edition, revised and enlarged, and including a chapter on Metallurgy, by Charles D. Demond, S.B. New York, 1905. Latest reprint, 1908. *Cloth, 8vo, 618 pages, $3.75 net*

SCHNABEL. **Handbook of Metallurgy.** By Dr. CARL SCHNABEL, Konigl. Preuss. Bergrath. Professor of Metallurgy. Translated by Henry Louis, M.A., A.R.S.M., F.I.C., etc. Second Edition. London, 1907.
Cloth, 8vo, 2 vols., pages 1123 and 867, per vol., $6.50 net

BAILEY. **A Textbook of Sanitary and Applied Chemistry of Water, Air, and Food.** By E. H. S. BAILEY, Ph.D., Professor of Chemistry. University of Kansas. New York, 1907. Reprinted 1908, 1910.
Cloth, 12mo, 345 pages, $1.40 net

SNYDER. **The Chemistry of Plant and Animal Life.** By HARRY SNYDER, B.S., Professor of Agricultural Chemistry, University of Minnesota. New York, 1903. Fifth reprint, 1910. *Cloth, 12mo, 406 pages, $1.25 net*

ARRHENIUS. **Immuno-Chemistry.** The application of the principles of physical chemistry to the study of the biological antibodies. By SVANTE ARRHENIUS. New York, 1907. *Cloth, 12mo, 309 pages, $1.60 net*

SNYDER. **Dairy Chemistry.** By HARRY SNYDER, B.S., Professor of Agricultural Chemistry, University of Minnesota. New York, 1905. Reprinted, 1907. *Cloth, 12mo, 190 pages, $1.00 net*

A List of Works on Chemistry—*Continued*

BARTHEL. **Methods used in the Examination of Milk and Dairy Products.** By Dr. Chr. Barthel, Stockholm. Translation by W. Goodwin, M.Sc., Ph.D. London, 1910. *Cloth, 8vo, 260 pages, $1.90 net*

SNYDER. **Human Foods and their Nutritive Value.** By Harry Snyder, B.S., Professor of Agricultural Chemistry, University of Minnesota, and Chemist of the Minnesota Experiment Station. New York, 1909. *Cloth, 12mo, 362 pages, $1.25 net*

ROLFE. **The Polariscope in the Chemical Laboratory.** An introduction to polarimetry and related methods. By George William Rolfe, A.M., Instructor in Sugar Analysis in the Massachusetts Institute of Technology. New York, 1905. *Cloth, 12mo, 320 pages, $1.90 net*

YOUNG. **Fractional Distillation.** By Sidney Young, D.Sc., F.R.S., Professor of Chemistry in University College, Bristol. London, 1903. *Cloth, 12mo, 284 pages, $2.60 net*

MELDOLA. **The Chemistry of Photography.** By Raphael Meldola, F.R.S., etc. London, 1899. Latest reprint, 1901. *Cloth, 12mo, 382 pages, $2.00 net*

DERR. **Photography for Students of Physics and Chemistry.** By Louis Derr, M.A., S.B., Associate Professor of Physics in the Massachusetts Institute of Technology. New York, 1906. Reprinted, 1909. *Cloth, 12mo, 247 pages, $1.40 net*

FRAPS. **Principles of Dyeing.** By G. S. Fraps, Ph.D., Assistant Professor of Chemistry, North Carolina College of Agriculture and Mechanic Arts. New York, 1903. *Cloth, 12mo, 270 pages, $1.60 net*

SCHULTZ & JULIUS. **A Systematic Survey of the Organic Colouring Matters.** Founded on the German of Drs. G. Schultz and P. Julius. Revised throughout and greatly enlarged by Arthur G. Green, F.I.C., F.C.S. London. *Cloth, 8vo, 290 pages, $7.00 net*

LEWKOWITSCH. **Chemical Technology and Analysis of Oils, Fats, and Waxes.** By Dr. J. Lewkowitsch, M.A., F.I.C., Consulting Chemist to the city and guilds of London Institute. Fourth Edition. Entirely rewritten and enlarged. 3 vols. London, 1909. *Cloth, 8vo, Vol. I 542 pages, Vol. II 812 pages, Vol. III 406 pages, $15.00 net*

LEWKOWITSCH. **Laboratory Companion to Fats and Oils Industries.** By Dr. J. Lewkowitsch, M.A., F.I.C. London, 1909. *Cloth, 8vo, 197 pages, $1.90 net*

GUTTMAN. **The Manufacture of Explosives.** A theoretical and practical treatise on the history, the physical and chemical properties, and the manufacture of explosives. By Oscar Guttman, Assoc. M. Inst. C.E., F.I.C. In two volumes. London, 1895. *Cloth, 8vo, Vol. I 348 pages, Vol. II 444 pages, the set $9.00 net*

A LIST OF WORKS ON CHEMISTRY—*Continued*

GUTTMAN. **The Manufacture of Explosives.** Twenty Years' Progress. Four Cantor Lectures delivered at the Royal Society of Arts in November and December, 1908. By OSCAR GUTTMAN, member of Inst. of Civil Engineers, etc. London, 1908. *Cloth, 8vo, 84 pages, $1.10 net*

VON MEYER. **A History of Chemistry from Earliest Times to the Present Day.** Being also an introduction to the study of the science. By ERNST VON MEYER, Ph.D. Translated with the author's sanction by George McGowan, Ph.D. Third English edition, with various additions and alterations. London. First Edition, 1891. Third Edition, 1906. *Cloth, 8vo, 691 pages, $4.25 net*

THORPE. **Essays in Historical Chemistry.** By T. E. THORPE, C.B., LL.D., F.R.S., Principal of the Government Laboratory, London. London, 1902. *Cloth, 8vo, 582 pages, $4.00 net*

THORPE. **Humphrey Davy, Poet and Philosopher.** By T. E. THORPE, LL.D., F.R.S. New York, 1896. *Cloth, 12mo, 240 pages, $1.25 net*

SHENSTONE. **Justice von Liebig: His Life and Work (1803-1873).** By W. . SHENSTONE, F.I.C., Lecturer on Chemistry in Clifton College. London, 1895. *Cloth, 12mo, 219 pages, $1.25 net*

ROSCOE. **John Dalton, and the Rise of Modern Chemistry.** By Sir HENRY E. ROSCOE, D.C.L., LL.D., F.R.S. London, 1895. *Cloth, 12mo, 212 pages, $1.25 net*

ROSCOE & HARDEN. **A New View of the Origin of Dalton's Atomic Theory.** A contribution to chemical history. Together with letters and documents concerning the life and labors of John Dalton, published from manuscript in the possession of the Literary and Philosophical Society of Manchester. By Sir HENRY E. ROSCOE, F.R.S., and ARTHUR HARDEN. London. *Cloth, 8vo, $1.90 net*

JONES. **An Introduction to the Science and Practice of Qualitative Chemical Analysis.** Inorganic. By CHAPMAN JONES, F.I.C., F.C.S., etc. London, 1898. Reprinted, 1906. *Cloth, 12mo, 213 pages, $ .60 net*

PUBLISHED BY

THE MACMILLAN COMPANY

64-66 Fifth Avenue, New York