SEVENTH EDITION

A Text in Applied Physiology

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PREFACE TO THE SEVENTH EDITION

According to a reliable and conservative estimate some half billion words are published annually on medical subjects in the journals of English-speaking countries alone. Much of the mass of scientific writing turned out by the laboratories and clinics comes within the scope of this book, at least for review. With each succeeding revision we became increasingly conscious of the hopelessness of trying to cover so great an expanse of medical literature. Even those whose interests are largely confined to one or another special field are inundated and complain that they often find it hard to keep their heads above the swelling tide. We ourselves now marvel at the intrepid not to say reckless spirit in which this book was conceived and its first edition written. Though we are not abject in our apology we fully realize and regret the insufficiency of the last revision. There was a disconcerting gap between its text and the more recent advances in physiology and related branches of scientific medicine, which made us acutely aware of the necessity of calling upon others for help. This we have done and our colleagues have responded magnificently and most generously to our appeal. We have been extremely fortunate in gathering together for this edition a galaxy of contributors, each of whom is outstanding in the field which his contribution covers. We believe that this, the seventh, is the most comprehensive and authoritative edition since the inception of the book twenty-five years ago. We wish to extend our most cordial thanks to our colleagues for this happy outcome which the excellence of their contributions has brought about.

The names of the contributors are listed alphabetically on page ix.

The section on Circulation, Chapters 14 through 28, has been rewritten, mainly by Dr. Donald E. Gregg and his associates.

Chapters 1 to 13, on the Physiology of the Blood, and those numbered 44 to 49 and 51 to 55, all inclusive, have been revised or rewritten by members of the staff of the Department of Physiology, and of the Banting and Best Department of Medical Research, University of Toronto. Professor C. H. Best has exercised general supervision over these chapters.

More specific reference to the contributions of the several authors will be found in the Table of Contents.

PREFACE TO FIRST EDITION

Physiology is a science in its own right and the laboratory worker who pursues his researches quite detached from medical problems need offer no apology for his academic outlook. Indeed some of the most valuable contributions to medical science have been the outcome of laboratory studies whose applications could not have been foreseen. Nevertheless, we feel that the teacher of physiology in a medical school owes it to his students, whose ultimate interest it must be conceded is in the diagnosis and treatment of disease, to emphasize those aspects of the subject which will throw light upon disorders of function. The physiologist can in this way play a part in giving the student and practitioner a vantage point from which he may gain a rational view of pathological processes.

We have endeavored to write a book which will serve to link the laboratory and the clinic, and which will therefore promote continuity of physiological teaching throughout the pre-clinical and clinical years of the under-graduate course. It is also hoped that when the principles underlying diseased states are pointed out to the medical student, and he is shown how a knowledge of such principles aids in the interpretation of symptoms or in directing treatment, he will take a keener interest in physiological studies. When such studies are restricted to the classical aspects of the subject, apparently remote from clinical application, the student is likely to regard them only as a task which his teachers in their inscrutable wisdom have condemned him to perform. Too often he gains the idea, from such a course, that physiology is of very limited utility and comes to believe that, having once passed into the clinical years, most of what he has "crammed" for examination purposes may be forgotten without detriment to his more purely medical studies. Unfortunately, he does not always realize at this stage in his education how great has been the part which physiological discoveries have played in the progress of medicine, and that the practice of today has evolved from the "theories" of yesterday.

Many physiological problems can be approached only through animal experimentation. Advances in many fields, most notably in those of carbohydrate metabolism, nutrition, and endocrinology, bear witness to the fertility of this method of research. On the other hand, many problems can be elucidated only by observations upon man, and physiology has gained much from clinical research. The normal human subject as an experimental animal possesses unique advantages for many types of investigation; and in disease, nature produces abnormalities of structure and function which the physiological laboratory can imitate only in the crudest way. Within recent years the clinical physiologist, fully realizing these advantages and the opportunities afforded by the hospital wards, has contributed very largely to physiological knowledge. In many instances, clinical research has not only revealed the true nature of the underlying process in disease, but has cast a light into some dark corner of physiology as well; several examples of clinical investigation which have pointed the way to the physiologist could be cited. In the last century, knowledge of the processes of disease was sought mainly in studies of morbid *anatomy*; biochemistry was in its infancy and many of the procedures now commonly employed for the investigation of the human subject had not been devised. Today, the student of scientific medicine is directing his attention more and more to the study of morbid *physiology* in his efforts to solve clinical problems. This newer outlook has borne fruit in many fields. It has had the beneficent result of drawing the clinic and the physiological and biochemical laboratories onto common ground from which it has often been possible to launch a joint attack upon disease. We feel that this modern trend in the field of research should be reflected in the teaching of medical students, and have therefore given greater prominence to clinical aspects of the subject than is usual in physiological texts.

In order to understand the function of an organ it is usually essential to have a knowledge of its structure. For this reason we have followed the plan of preceding the account of the physiology of a part by a short description of its morphology and, in many instances, of its nerve and blood supply. The architecture and functions of the central nervous system are so intimately related that some space has been devoted to a description of the more important fiber tracts and grey masses of the cerebrum, cerebellum and spinal cord.

We wish to thank our colleagues in physiology, biochemistry and anatomy whom we have drawn upon on so many occasions for information and advice; without their generous help the undertaking would have been an almost impossible one. We are also deeply grateful for the unstinted assistance which we have received from our friends on the clinical staff, several of whom have read parts of the text in manuscript or in proof. We wish especially to acknowledge our indebtedness to Professor A. M. Wynne, who has written the section on the oxidizing systems of living cells, to Dr. J. K. W. Ferguson for his collaboration in the preparation of Chapter 33, and to Professor C. B. Weld and Dr. E. T. Waters whose stimulating criticisms and sound counsel have been invaluable.

Finally, we wish to thank our secretaries, Miss Mabel Cory and Miss Dudley Martin, who have spent so many tedious hours in preparing the manuscript for the press, in checking the references and in compiling the index.

C. H. B.
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October 15, 1936

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THE PHYSIOLOGICAL BASIS OF MEDICAL PRACTICE

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SECTION ONE
The Blood and Lymph

1

THE PHYSIOLOGICAL PROPERTIES, PHYSICAL CHARACTERS AND COMPOSITION

Outline of the Functions of Blood

In animals whose bodies are composed of many cells (Metazoa) the blood serves those purposes, which for unicellular organisms (Protozoa) are carried out by the fluid medium, the salt or fresh water, which surrounds them and bathes their surfaces. For example, an organism such as the amoeba acquires oxygen by diffusion directly from the environment into the interior of the cell. Similarly the carbon dioxide diffuses outwards. The processes of nutrition and the excretion of the products of the cell's metabolism are accomplished in a manner equally simple. Food is taken in through the cell membrane either in solution or as particulate matter, and waste products pass into the surrounding medium. Other requirements of this organism, such as the maintenance of an optimum temperature and the proper degree of moisture, are dependent on the immediate (internal) environment, the *milieu interne* of Claude Bernard.

The elemental needs of each cell in a multicellular individual from the most primitive type to the highest vertebrate are the same as for the unicellular organism; yet in the evolution of the higher forms the cells composing their bodies have become farther and farther removed from immediate contact with the outside world. Myriads of cells have become packed together, and the deeper ones could not possibly satisfy their needs after the direct and simple fashion of the unicellular forms. The more primitive multicellular types overcame the difficulty by the development of canal systems which opened to the exterior and through which the ocean waters flowed freely in and out, bringing oxygen and aliment to the more deeply lying cells and bearing carbon dioxide and other excretory products away. This, the first attempt at a circulation, was an open one. As higher forms evolved the circulation became closed and the waters of the environment no longer flowed and ebbed through the body. No longer could the interchange of the respiratory gases and the absorption of nutriment be carried out in this direct and simple way. Yet the vessels of this closed circulatory system were filled with a fluid which took the place of and fulfilled the duties of the watery environment of the more primitive types. The blood and other body fluids may be looked upon as that environment which has become enclosed within the bodies of the higher forms, and has undergone certain modifications in its composition to meet the requirements of the more specialized cells which it bathes.

The similarity between the compositions of sea water and blood which has been stressed by the researches of Macallum lends support to these views on the evolution of the blood.[1] This brief account will also serve as an introduction to a consideration of the functions of the body fluids, since their duties are to satisfy in the same way as did their prototype, the requirements of the individual cells.

[1] Sea water of today differs from blood serum in having a total salt concentration of about 3 per cent, a much higher concentration of magnesium and a lower concentration of potassium. But Macallum points out that the sea water of the geological period when the ancestors of mammalian forms adapted themselves to a terrestrial life was probably closely similar in its inorganic composition to blood serum.

1. Respiratory. The transport of oxygen from the air in the lungs to the tissues, and of carbon dioxide from the tissues to the lungs.

2. Nutritive. The conveyance of food materials, glucose, amino acids and fats from the alimentary canal to the tissues.

3. Excretory. The removal of waste products of metabolism, e.g., urea, uric acid, creatinine, etc.

4. The maintenance of the water content of the tissues. Though the blood itself is contained within vascular channels, a constant interchange of fluid through the vessel walls takes place. This fluid which has left the blood vessels and come into direct contact with the tissue cells is known as the tissue or interstitial fluid. It closely resembles the blood plasma in chemical composition, and is identical with lymph. Through the medium of the transuded fluid the final stage in the transportation of oxygen and food materials to the tissues and the first stage in the journey of CO_2 and waste products from the tissues are made.

5. To regulate body temperature. The body owes its ability to regulate its temperature (ch. 52) largely to the water of the blood and tissue fluids. Water possesses three qualities which fit it preeminently to fulfil this purpose.

a. The specific heat[2] of water is considerably higher than that of any other liquid or solid. On account of this great heat storage power of water, sudden changes of body temperature are avoided and even a cold-blooded animal such as the frog has, due to this purely physical quality, some ability to maintain a relatively constant body temperature against transient fluctuations in environmental temperature. A man of average weight develops 3000 Calories in 24 hours. This amount of heat is capable of raising the temperature of his tissues (which are largely water) only about 32°C. Heat elimination (radiation, etc.) is able to keep pace with heat production and the body temperature varies but slightly within normal limits. But it has been pointed out by L. J. Henderson that if the tissues had the low heat storage capacity (spec. heat) of most substances, an amount of heat equal to 3000 Calories would raise the temperature of the tissues and fluids of the body by from 100° to 150°C.

b. High conductivity. The thermal conductivity of water is greater than that of any other ordinary liquid. The advantage of this in the dissipation of heat from deeply situated regions of the body is obvious.

c. High latent heat of evaporation. More heat is required for the vaporization of water than for that of an equivalent amount of any other liquid. One cubic centimeter of water requires about 0.6 Calories for its vaporization. This figure is 50 per cent higher than that of water's closest competitor. Fluid is being constantly lost from the body through evaporation from the lungs and skin. A large amount of heat is lost in the process.

These physical properties of water which make it ideal as a heat regulating medium are enhanced by other purely *physiological factors.* The mobility of the blood and the readiness with which it may be quickly redistributed in the body, combined with the unique physical properties of the fluid itself, render it so highly efficient as a regulator of body temperature. The blood may in a moment be brought from deeper to superficial regions and spread out in fine vessels over a broad area just beneath the skin, and in this way will greatly increase the radiation of heat. At another instant, in order that heat may be conserved, the fluid is drained from the surface areas and collected in the deeper parts of the body—internal organs, muscles, etc.

6. Protective and regulatory. The blood and lymph contain certain chemical substances of a complex nature, antitoxins, lysins, and other antibodies, which are the basis of the body's defense against injurious agents of various kinds. The circulating fluids are also the vehicle by which the hormones of the different ductless glands are brought into direct contact with the cells of the tissues.

The Composition of Blood

The blood is a highly complex fluid in which solid elements are suspended—the *corpuscles or blood cells.* Its specific gravity varies between individuals from 1.050 to 1.060 and its viscosity from 5 to 6 times that of water. If blood is centrifuged before it has had time to clot, or if clotting is prevented by special means (ch. 12), the solid elements are thrown down and separated from the fluid portion. The latter is called the *plasma* and contains *proteins,* as well as many organic and inorganic substances in solution—nutritive and excretory materials, antibodies and hormones, and other substances of an unknown or imperfectly known chemical constitution. The specific gravity of plasma is normally around 1.027 but varies with its concentration in protein. The cells constitute about 46 per cent of the volume of human blood, the plasma 54 per cent. Small variations above or below these values are commonly encountered.

The specific gravity of a small sample of blood or of plasma may be measured by the method of Phillips, Van Slyke and associates. A series of small bottles is set up containing copper sulfate solutions varying by small equal increments (0.004) in specific gravity. A drop of blood or plasma is allowed to fall gently from the tip of a

[2] The specific heat of a substance is defined as the number of calories required to raise 1 gram of the substance 1°C.