

In this second edition, therefore, new facts and developments in the realm of bodily stabilization have been incorporated, in order to bring the exposition up to date; and also a new chapter has been added, on the effects of age on homeostatic mechanisms.

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INTRODUCTION

I

OUR bodies are made of extraordinarily unstable material. Pulses of energy, so minute that very delicate methods are required to measure them, course along our nerves. On reaching muscles they find there a substance so delicately sensitive to slight disturbance that, like an explosive touched off by a fuse, it may discharge in a powerful movement. Our sense organs are responsive to almost incredibly minute stimulations. Only recently have men been able to make apparatus which could even approach the sensitiveness of our organs of hearing. The sensory surface in the nose is affected by vanillin, 1 part by weight in 10,000,000 parts of air, and by mercaptan $1/23,000,000$ of a milligram in a liter (approximately a quart) of air. And as for sight, there is evidence that the eye is sensitive to $5/1,000,000,000,000$ erg, an amount of energy, according to Bayliss, which is $1/3,000$ that required to affect the most rapid photograph plate.

The instability of bodily structure is shown also by its quick change when conditions are altered. For example, we are all aware of the sudden stoppage of action in parts of the brain, accompanied by fainting and loss of consciousness, that occurs when there is a momentary check in the blood flow through its vessels. We know that if the blood supply to the brain wholly ceases for so short a time

as seven or eight minutes certain cells which are necessary for intelligent action are so seriously damaged that they do not recover. Indeed, the high degree of instability of the matter of which we are composed explains why drowning, gas poisoning, or electric shock promptly brings on death. Examination of the body after such an accident may reveal no perceptible injury that would adequately explain the total disappearance of all the usual activities. Pathetic hope may rise that this apparently normal and natural form could be stirred to life again. But there are subtle changes in the readily mutable stuff of the human organism which prevent, in these conditions, any return of vital processes.

When we consider the extreme instability of our bodily structure, its readiness for disturbance by the slightest application of external forces and the rapid onset of its decomposition as soon as favoring circumstances are withdrawn, its persistence through many decades seems almost miraculous. The wonder increases when we realize that the system is open, engaging in free exchange with the outer world, and that the structure itself is not permanent but is being continuously broken down by the wear and tear of action, and as continuously built up again by processes of repair.

II

The ability of living beings to maintain their own constancy has long impressed biologists. The idea that disease is cured by natural powers, by a *vis medicatrix naturae*, an idea which was held by Hippocrates (460-377 B. C.),

implies the existence of agencies which are ready to operate correctively when the normal state of the organism is upset. More precise references to self-regulatory arrangements are found in the writings of modern physiologists. Thus the German physiologist, Pflüger, recognized the natural adjustments which lead toward the maintenance of a steady state of organisms when (1877) he laid down the dictum, "The cause of every need of a living being is also the cause of the satisfaction of the need." Similarly, the Belgian physiologist, Léon Fredericq, in 1885, declared, "The living being is an agency of such sort that each disturbing influence induces by itself the calling forth of compensatory activity to neutralize or repair the disturbance. The higher in the scale of living beings, the more numerous, the more perfect and the more complicated do these regulatory agencies become. They tend to free the organism completely from the unfavorable influences and changes occurring in the environment." Again, in 1900, the French physiologist, Charles Richet, emphasized the remarkable fact. "The living being is stable," he wrote. "It must be so in order not to be destroyed, dissolved or disintegrated by the colossal forces, often adverse, which surround it. By an apparent contradiction it maintains its stability only if it is excitable and capable of modifying itself according to external stimuli and adjusting its response to the stimulation. In a sense it is stable because it is modifiable—the slight instability is the necessary condition for the true stability of the organism."

Here, then, is a striking phenomenon. Organisms, composed of material which is characterized by the ut-

most inconstancy and unsteadiness, have somehow learned the methods of maintaining constancy and keeping steady in the presence of conditions which might reasonably be expected to prove profoundly disturbing. For a short time men may be exposed to dry heat at 115 to 128 degrees Centigrade (239 to 261 degrees Fahrenheit) without an increase of their body temperature above normal. On the other hand arctic mammals, when exposed to cold as low as 35 degrees Centigrade below freezing (31 degrees below zero Fahrenheit) do not manifest any noteworthy fall of body temperature. Furthermore, in regions where the air is extremely dry the inhabitants have little difficulty in retaining their body fluids. And in these days of high ventures in mountain climbing and in airplanes human beings may be surrounded by a greatly reduced pressure of oxygen in the air without showing serious effects of oxygen want.

Resistance to changes which might be induced by external circumstances is not the only evidence of adaptive stabilizing arrangements. There is also resistance to disturbances from within. For example, the heat produced in maximal muscular effort, continued for twenty minutes, would be so great that, if it were not promptly dissipated, it would cause some of the albuminous substances of the body to become stiff, like a hard-boiled egg. Again, continuous and extreme muscular exertion is accompanied by the production of so much lactic acid (the acid of sour milk) in the working muscles that within a short period it would neutralize all the alkali contained in the blood, if other agencies did not appear and prevent that disaster. In short, well-equipped organisms—for instance, mammalian forms—may be confronted by dangerous conditions in the outer

world and by equally dangerous possibilities within the body, and yet they continue to live and carry on their functions with relatively little disturbance.

III

The statement was made above that somehow the unstable stuff of which we are composed had learned the trick of maintaining stability. As we shall see, the use of the word "learned" is not unwarranted. The perfection of the process of holding a stable state in spite of extensive shifts of outer circumstance is not a special gift bestowed upon the highest organisms but is the consequence of a gradual evolution. In the eons of time during which animals have developed on the earth probably many ways of protecting against the forces of the environment have been tried. Organisms have had large and varied experience in testing different devices for preserving stability in the face of agencies which are potent to upset and destroy it. As the construction of these organisms has become more and more complex and more and more sensitively poised, the need for more efficient stabilizing arrangements has become more imperative. Lower animals, which have not yet achieved the degree of control of stabilization seen in the more highly evolved forms, are limited in their activities and handicapped in the struggle for existence. Thus the frog, as a representative amphibian, has not acquired the means of preventing free evaporation of water from his body, nor has he an effective regulation of his temperature. In consequence he soon dries up if he leaves his home pool, and when cold weather comes he must sink to its muddy bottom

and spend the winter in sluggish numbness. The reptiles, slightly more highly evolved, have developed protection against rapid loss of water and are therefore not confined in their movements to the neighborhood of pools and streams; indeed, they may be found as inhabitants of arid deserts. But they, like the amphibians, are "cold-blooded" animals, that is, they have approximately the temperature of their surroundings, and therefore during the winter months they must surrender their active existence. Only among the higher vertebrates, the birds and mammals, has there been acquired that freedom from the limitations imposed by cold that permits activity even though the rigors of winter may be severe.

The constant conditions which are maintained in the body might be termed *equilibria*. That word, however, has come to have fairly exact meaning as applied to relatively simple physico-chemical states, in closed systems, where known forces are balanced. The coördinated physiological processes which maintain most of the steady states in the organism are so complex and so peculiar to living beings—involving, as they may, the brain and nerves, the heart, lungs, kidneys and spleen, all working coöperatively—that I have suggested a special designation for these states, *homeostasis*. The word does not imply something set and immobile, a stagnation. It means a condition—a condition which may vary, but which is relatively constant.

It seems not impossible that the means employed by the more highly evolved animals for preserving uniform and stable their internal economy (i.e., for preserving homeostasis) may present some general principles for the establishment, regulation and control of steady states, that

would be suggestive for other kinds of organization—even social and industrial—which suffer from distressing perturbations. Perhaps a comparative study would show that every complex organization must have more or less effective self-righting adjustments in order to prevent a check on its functions or a rapid disintegration of its parts when it is subjected to stress. And it may be that an examination of the self-righting methods employed in the more complex living beings may offer hints for improving and perfecting the methods which still operate inefficiently and unsatisfactorily. At present these suggestions are necessarily vague and indefinite. They are offered here in order that the reader, as he continues into the concrete and detailed account of the modes of assuring steady states in our bodies, may be aware of the possibly useful nature of the examples which they offer.

IV

In the chapters which follow I propose to consider, first, what may be regarded as the fundamental condition of stability, then the various physiological arrangements which serve to restore the normal state when it has been disturbed, and finally, the narrowing limits of adaptation imposed by age. While considering these arrangements we shall gradually become acquainted with the general devices which are employed to regulate and control the numerous processes and the supplies of material required for our natural activities. We shall see that the nervous system is divisible into two main parts, the one acting outwardly and affecting the world about us, and the other acting in-

wardly and helping to preserve a constant and steady condition in the organism itself. I shall strive to describe the physiological agencies and events in terms which will be clear to anyone who has had a simple training in biology and in general science.

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1

THE FLUID MATRIX OF THE BODY

I

WE ORDINARILY speak of ourselves as air-inhabiting animals. A little reflection will disclose, however, the interesting fact that we are separated from the air which surrounds us by a layer of dead or inert material. The skin has an outer covering of dry and horny scales (which may, of course, at times be wet with sweat), and the surfaces of the eyes and the inner parts of the nose and the mouth are bathed in a salty water. All of us that is *alive*, the vast multitudes of minute living elements or cells which compose our muscles, glands, brain, nerves and other parts, reside within this surface coat of non-living stuff. And, except their sides where they are contiguous one with another, the cells are in contact with *fluid*. The living elements of the body, therefore, are water inhabitants, or inhabitants of water which has been modified by the addition of salt and thickened by an albuminous or colloid material. In order to understand the significance of this watery environment or fluid matrix, we must inquire into the services it performs and how it performs them.

To the simple organisms which may be found attached to the rocks of the bed of a stream the flowing water brings