cause of these differences was studied very closely in the latter part of the last century, but it has lately been rendered clear by the researches of Helmholtz and of Koenig. In this connection it will be sufficient to indicate the results of the modern investigations very briefly. It will be seen in studying the physics of sound in connection with the sense of hearing, that nearly all sounds, even when produced by a single, vibrating body, are compound. Helmholtz, by means of his resonators, has succeeded in analyzing the apparently simple sounds into different component parts, and he has shown that the quality of such sounds may be modified by re-enforcing certain of the overtones, as they are called, such as the third, fifth or octave. For those who are familiar with the physics of sound, the explanation of the mechanism of the production of vowel-sounds will be readily comprehensible. The reader is referred, however, to the remarks upon overtones in another part of this work, under the head of audition, for a more thorough exposition of this subject. The different vowel-sounds may be emitted with the same pitch and intensity, but the sound in each is different on account of variations in the resonant cavities of the accessory vocal organs, especially the mouth. It has been ascertained experimentally that the overtones in each instance are different, as they are re-enforced by the vibrations of air in the accessory vocal organs, in some instances the third, in others, the fifth etc., being increased in intensity. This can hardly be better illustrated than by the following quotation from Tyndall, in which modern researches have been applied to the vowel-sounds of the English language:

"For the production of the sound *U* (*oo* in hoop), I must push my lips forward so as to make the cavity of the mouth as deep as possible, at the same time making the orifice of the mouth small. This arrangement corresponds to the deepest resonance of which the mouth is capable. The fundamental tone of the vocal chords is here re-enforced, while the higher tones are thrown into the shade. The *U* is rendered a little more perfect when a feeble third tone is added to the fundamental.

"The vowel *O* is pronounced when the mouth is so far opened that the fundamental tone is accompanied by its strong higher octave. A very feeble accompaniment of the third and fourth is advantageous, but not necessary.

"The vowel *A* derives its character from the third tone, to strengthen which by resonance the orifice of the mouth must be wider, and the volume of air within it smaller than in the last instance. The second tone ought to be added in moderate strength, whilst weak fourth and fifth tones may also be included with advantage.

"To produce *E* the fundamental tone must be weak, the second tone comparatively strong, the third very feeble, but the fourth, which is characteristic of this vowel, must be intense. A moderate fifth tone may be added. No essential change, however, occurs in the character of the sound when the third and fifth tones are omitted. In order to exalt the higher tones which characterize the vowel-sound *E*, the resonant cavity of the mouth must be small.

"In the production of the sound *ah!* the higher overtones come principally into play; the second tone may be entirely neglected; the third rendered very feebly; the higher tones, particularly the fifth and seventh, being added strongly.

"These examples sufficiently illustrate the subject of vowel-sounds. We may blend in various ways the elementary tints of the solar spectrum, producing innumerable composite colors by their admixture. Out of violet and red we produce purple, and out of yellow and blue we produce white. Thus also may elementary sounds be blended so as to produce all possible varieties of clang-tint. After having resolved the human voice into its constituent tones, Helmholtz was able to imitate these tones by tuning-forks, and, by combining them appropriately together, to produce the clang-tints of all the vowels."

Consonants.—Some of the consonants have no sound in themselves and serve merely to modify vowel-sounds. These are called mutes. They are *b*, *d*, *k*, *p*, *t*, and *c* and *g* hard. Their office in the formation of syllables is sufficiently apparent.

The consonants known as semi-vowels are *f*, *l*, *m*, *n*, *r*, *s*, and *c* and *g* soft. These have an imperfect sound of themselves, approaching in character the true vowel-sounds. Some of these, *l*, *m*, *n* and *r*, from the facility with which they flow into other sounds, are called liquids. Orthoepists have farther divided the consonants with reference to the mechanism of their pronunciation: *d*, *j*, *s*, *t*, *z*, and *g* soft, being pronounced with the tongue against the teeth, are called dentals; *d*, *g*, *j*, *k*, *l*, *n*, and *q* are called palatals; *b*, *p*, *f*, *v* and *m* are called labials; *m*, *n* and *ng* are called nasals; and *k*, *q*, and *c* and *g* hard are called gutturals. After the description already given of the voice, it is not necessary to discuss farther the mechanism of these simple acts of articulation.

For the easy and proper production of articulate sounds, absolute integrity of the mouth, teeth, lips, tongue and palate is required. All are acquainted with the modifications in articulation in persons in whom the nasal cavities resound unnaturally from imperfection of the palate; and the slight peculiarities observed after loss of the teeth and in harelip are sufficiently familiar. The tongue is generally regarded, also, as an important organ of speech, and this is the fact in the great majority of cases; but instances are on record in which distinct articulation has been preserved after complete destruction of this organ. These cases, however, are unusual, and they do not invalidate the great importance of the tongue in ordinary speech.

It is thus seen that speech consists essentially in a modification of the vocal sounds by the accessory organs, or by parts situated above the larynx; the latter being the true vocal instrument. While the peculiarities of pronunciation in different persons and the difficulty of acquiring foreign languages after the habits of speech have been formed show that the organs of articulation must perform their office with great accuracy, their movements are simple, and they vary with the peculiarities of different languages.

Whispering.—Articulate sounds may be produced by the action of the resonant cavities, the lips, teeth and tongue, in which the larynx takes no part.

This action occurs in whispering and it can not properly be called vocal. It is difficult to make any considerable variations in the pitch of a whisper, and articulation in this way may be produced in inspiration as well as in expiration, although the act in expiration is more natural and easy. The character of a whisper may be readily distinguished from that of the faintest audible sound involving vibration of the vocal chords. In aphonia from simple paralysis of the vocal muscles of the larynx, patients can articulate distinctly in whispering; but in cases of chronic bulbar paralysis (glosso-labio-laryngeal paralysis), speech is entirely lost.

The Phonograph.—In 1877, a remarkable invention was made in this country, by Mr. Thomas A. Edison, which possesses considerable physiological importance. Mr. Edison constructed a very simple instrument, called the phonograph, which will repeat, with a certain degree of accuracy, the peculiar characters of the human voice both in speaking and singing, as well as the pitch and quality of musical instruments. This demonstrates conclusively the fact that the qualities of vocal sounds depend upon the form of the sonorous vibrations. The following are the main features in the construction of this instrument: It consists of a cylinder of iron provided with very fine, shallow grooves in the form of an exceedingly close spiral. Upon the cylinder, a sheet of tin-foil is accurately fitted. Bearing upon the tin-foil, is a steel-point connected with a vibrating plate of mica or of thin iron. The vibrating plate is connected with a mouth-piece which receives the vibrations of the voice or of a musical instrument. The cylinder is turned with a crank, and at the same time, the plate is thrown into vibration by speaking into the mouth-piece. As the disk vibrates in consonance with the voice, the vibrations are marked by little indentations upon the tin-foil. When this has been done, the cylinder is moved back to the starting point and is turned again at the same rate as before. As the steel-point passes over the indentations in the tin-foil, the plate is thrown into vibration, and the sound of the voice is actually repeated, although much diminished in intensity and distinctness. The improvements that have lately been made in the phonograph do not involve any modifications in the principles of its construction.

CHAPTER XVI.

PHYSIOLOGICAL DIVISIONS, STRUCTURE AND GENERAL PROPERTIES OF THE NERVOUS SYSTEM.

Divisions and structure of the nervous tissue—Medullated nerve-fibres—Simple, or non-medullated nerve-fibres—Gelatinous nerve-fibres (fibres of Remak)—Accessory anatomical elements of the nerves—Termination of the nerves in the muscular tissue—Termination of the nerves in glands—Modes of termination of the sensory nerves—Corpuscles of Vater, or of Pacini—Tactile corpuscles—End-bulbs—Structure of the nerve-centres—Nerve-cells—Connection of the cells with the fibres and with each other—Accessory anatomical elements of the nerve-centres—Composition of the nervous substance—Degeneration and regeneration of the nerves—Motor and sensory nerves—Mode of action of the motor nerves—Associated movements—Mode of action of the sensory nerves—Physiological differences between motor and sensory nerve-fibres—Nervous excitability—Different means employed for exciting the nerves—Rapidity of nervous conduction—Personal equation—Action of electricity upon the nerves—Law of contraction—Induced muscular contraction—Electrotonus, anelectrotonus and catelectrotonus—Negative variation.

The nervous system is anatomically and physiologically distinct from all other systems and organs in the body. It receives impressions made upon the terminal branches of its sensory portion and it conveys stimulus to parts, determining and regulating their actions; but its physiological properties are inherent, and it gives to no tissue or organ its special excitability or the power of performing its particular office in the economy. The nervous system connects into a co-ordinated organism all parts of the body. It is the medium through which all impressions are received. It animates or regulates all movements, voluntary and involuntary. It regulates secretion, nutrition, calorification and all the processes of organic life.

In addition to its action as a medium of conduction and communication, the nervous system, in certain of its parts, is capable of receiving impressions and of generating a stimulating influence, or force, peculiar to itself. As there can be no physiological connection or co-ordination of different parts of the organism without nerves, there can be no unconscious reception of impressions giving rise to involuntary movements, no appreciation of impressions, general, as in ordinary sensation, or special, as in sight, smell, taste or hearing, no instinct, volition, thought or even knowledge of existence, without nerve-centres.

Divisions and Structure of the Nervous Tissue.

The nervous tissue presents two great divisions, each with distinct anatomical as well as physiological differences. One of these divisions is composed of fibres or tubes. This kind of nervous matter is incapable of generating a force or stimulus, and it serves only as a conductor. The other division is composed of cells, and this kind of nervous matter, while it may act as a conductor, is capable of generating the so-called nerve-force.

The nerve-fibres and cells are also divided into two great systems, as follows:

1. The cerebro-spinal system, composed of the brain and spinal cord with the nerves directly connected with these centres. This system is specially connected with the functions of relation, or of animal life. The centres pre-