26, at the age of five years;
20, between fifteen and twenty years;
19, between twenty and twenty-five years;
16, about the thirtieth year;
18, between thirty and fifty years.

The influence of sex is not marked in very young children. There is no difference between males and females at birth; but in young women, the respirations are a little less frequent than in young men of the same age.

The various physiological conditions which have been noted as affecting the pulse have a corresponding influence on respiration. In sleep the number of respiratory acts is diminished by about twenty per cent. (Quetelet). Muscular effort accelerates the respiratory movements *pari passu* with the movements of the heart.

*Relations of Inspiration and Expiration to each other—Respiratory Sounds.*—In ordinary respiration, inspiration is produced by the action of muscles, and expiration, by the passive reaction of the lungs and of the elastic walls of the thorax. The inspiratory and expiratory acts do not immediately follow each other. Beginning with inspiration, it is found that this act maintains about the same intensity throughout. There is then a very brief interval, when expiration follows, which has its maximum of intensity at the beginning of the act and gradually dies away. Between the acts of expiration and inspiration is an interval, which is somewhat longer than the interval between inspiration and expiration.

The duration of expiration is generally somewhat longer than that of inspiration, although the two acts may be nearly, or in some instances, quite equal. After five to eight ordinary respiratory acts, an effort generally occurs which is rather more profound than usual, by which the air in the lungs is more thoroughly changed. The temporary arrest of the acts of respiration in violent muscular efforts, in straining, in parturition etc., is sufficiently familiar.

Ordinarily respiration is not accompanied by any sound which can be heard without applying the ear directly, or by the intervention of a stethoscope, to the chest, except when the mouth is closed and breathing is carried on exclusively through the nasal passages, when a soft, breezy sound accompanies both acts. If the mouth be opened sufficiently to admit the free passage of air, no sound is to be heard in health. In sleep the respirations are more profound; and if the mouth be closed the sound is rather more intense.

Snoring, which sometimes accompanies the respiratory acts during sleep, occurs when the air passes through both the mouth and the nose. It is more marked in inspiration, sometimes accompanying both acts, and sometimes it is not heard in expiration. It is not necessary to describe the characters of a sound so familiar. Snoring is an idiosyncrasy in many individuals, although those who do not snore habitually may do so when the system is unusually exhausted and relaxed. It occurs only when the mouth is open, and the sound is produced by vibration and a sort of flapping of the velum



pendulum palati, between the two currents of air from the mouth and nose, together with a vibration in the column of air itself.

Applying the stethoscope over the larynx or trachea, a sound is heard, of a distinctly and purely tubular character, accompanying both acts of respiration. In inspiration, according to the late Dr. Austin Flint, "it attains its maximum of intensity quickly after the development of the sound and maintains the same intensity to the close of the act, when the sound abruptly ends, as if suddenly cut off." After a brief interval, the sound of expiration follows. This is also tubular in quality. It soon attains its maximum of intensity, but unlike the sound of inspiration, it gradually dies away and is lost imperceptibly. It is seen that these phenomena correspond with the nature of the two acts of respiration.

Sounds approximating in character to the foregoing are heard over the bronchial tubes before they penetrate the lungs.

Over the substance of the lungs, a sound may be heard entirely different in its character from that heard over the larynx, trachea or bronchial tubes. In inspiration the sound is much less intense than over the trachea and has a breezy, expansive, or what is called in auscultation, a vesicular character. It is much lower in pitch than the tracheal sound. It is continuous and rather increases in intensity from its beginning to its termination, ending abruptly, like the tracheal inspiratory sound. The sound is produced in part by the movement of air in the small bronchial tubes, but chiefly by the expansion of the air-cells of the lungs. It is followed, without an interval, by the sound of expiration, which is shorter—one-fifth or one-fourth as long—lower in pitch and much less intense. A sound is not always heard in expiration.

The variations in the intensity of the respiratory sounds in different individuals are very considerable. As a rule they are more intense in young persons; which has given rise to the term puerile respiration, when the sounds are exaggerated in parts of the lung, in certain cases of disease. The sounds are generally more intense in females than in males, particularly in the upper regions of the thorax.

It is difficult by any description or comparison to convey an accurate idea of the character of the sounds heard over the lungs and air-passages, and it is unnecessary to make the attempt, when they can be so easily studied in the living subject.

*Coughing, Sneezing, Sighing, Yawning, Laughing, Sobbing and Hiccough.*—These peculiar acts demand a few words of explanation. Coughing and sneezing are generally involuntary acts, produced by irritation in the air-tubes or nasal passages, although coughing is often voluntary. In both of these acts, there is first a deep inspiration followed by a convulsive action of the expiratory muscles, by which the air is violently expelled with a characteristic sound, in the one case by the mouth, and in the other by the mouth and nares. Foreign bodies lodged in the air-passages are frequently expelled in violent fits of coughing. In hypersecretion of the bronchial mucous membrane, the accumulated mucus is carried by the act of coughing either to the mouth or well into the larynx, when it may be expelled by the act of exspui-

tion. When either of these acts is the result of irritation from a foreign substance or from secretions, it may be modified or partly smothered by the will, but is not completely under control. The sensibility of the mucous membrane at the summit of the air-passages usually protects them from the entrance of foreign matters, both liquid and solid; for the slightest impression received by the membrane gives rise to a violent and involuntary cough, by which the offending substance is removed. The glottis, also, is spasmodically contracted.

In sighing, a prolonged and deep inspiration is followed by a rapid and generally an audible expiration. This occurs, as a general rule, once in five to eight respiratory acts, for the purpose of changing the air in the lungs more completely, and it is due to an exaggeration of the cause which gives rise to the ordinary acts of respiration. When due to depressing emotions, it has the same cause; for at such times respiration is less efficiently performed. Yawning is an analogous process, but it differs from sighing in the fact that it is involuntary and can not be produced by an effort of the will. It is characterized by a wide opening of the mouth and a very profound inspiration. Yawning is generally assumed to be an evidence of fatigue, but it often occurs from a sort of contagion. When not the result of imitation, it has the same exciting cause as sighing—deficient oxygenation of the blood—and it is followed by a sense of satisfaction, which shows that it meets some decided want on the part of the system.

Laughing and sobbing, although expressing opposite conditions, are produced by very nearly the same action. The characteristic sounds accompanying these acts are the result of short, rapid and convulsive movements of the diaphragm, attended with contractions of the muscles of the face, which produce the expressions characteristic of hilarity or grief. Although to a certain extent under the control of the will, these acts are mainly involuntary. Violent and convulsive laughter may be excited in many individuals by titillation of certain portions of the surface of the body. Laughter and sometimes sobbing, like yawning, may be the result of involuntary imitation.

Hiccough is a peculiar modification of the act of inspiration, to which it is exclusively confined. It is produced by a sudden, convulsive and entirely involuntary contraction of the diaphragm, accompanied by a spasmodic constriction of the glottis. The contraction of the diaphragm is more extensive than in laughing and sobbing and occurs only once every four or five respiratory acts.

## Capacity of the Lungs, and the Quantity of Air changed in the Respiratory Acts.

The volume of air ordinarily contained in the lungs is about two hundred cubic inches (3,277 c.c.); but it is evident, from the simple experiment of opening the chest, when the elastic lungs collapse and expel a certain quantity of air which can not be removed while the lungs are *in situ*, that a part of the gaseous contents of these organs necessarily remains after the most complete and forcible expiration. After an ordinary act there is a certain



quantity of air in the lungs which can be expelled by a forced expiration. In ordinary respiration a comparatively small volume of air is introduced with inspiration, and a nearly equal quantity is expelled by the succeeding expiration. By the extreme action of all the inspiratory muscles in a forced inspiration, a supplemental quantity of air may be introduced into the lungs, which then contain much more than they ever do in ordinary respiration. For convenience of description, physiologists have adopted the following names, which are applied to these various volumes of air:

1. *Residual Air;* that which is not and can not be expelled by a forced expiration.

2. *Reserve Air;* that which remains after an ordinary expiration, deducting the residual air.

3. *Tidal, or Ordinary Breathing Air;* that which is changed by the ordinary acts of inspiration and expiration.

4. *Complemental Air;* the excess over the ordinary breathing air, which may be introduced by a forcible inspiration.

In measuring the air changed in ordinary breathing, it has been found that the acts of respiration are so easily influenced and it is so difficult to experiment on any individual without his knowledge, that the results of many good observers are not to be relied upon. This is one of the most important of the questions under consideration. The difficulties in the way of estimating with accuracy the residual, reserve or complemental volumes, will readily suggest themselves. The observations on these points which may be taken as the most definite and exact are those of Herbst and of Hutchinson. Those of the last-named observer are very elaborate and were made on a large number of subjects of both sexes and of all ages and occupations. They are generally accepted by physiologists, as the most extended and accurate.

*Residual Air.*—Perhaps there is not one of the questions under consideration more difficult to answer definitely than that of the quantity of air which remains in the lungs after a forced expiration; but it fortunately is not one of any great practical importance. The residual air remains in the lungs as a physical necessity. The lungs in health are always in contact with the walls of the thorax; and when this cavity is reduced to its smallest dimensions, it is impossible that any more air should be expelled. The volume which thus remains has been variously estimated. The residual volume has been estimated at about one hundred cubic inches (1,639 c.c.), but the quantity varies very considerably in different individuals (Hutchinson). Taking everything into consideration, it may be assumed that this estimate is as nearly correct as any.

*Reserve Air.*—This name is given to the volume of air which may be expelled and changed by a voluntary effort, but which remains in the lungs, added to the residual air, after an ordinary act of expiration. It may be estimated, without any reference to the residual air, by forcibly expelling air from the lungs, after an ordinary expiration. The average volume, according to Hutchinson, is one hundred cubic inches (1,639 c.c.).

More or less of the reserve air is changed whenever there is a necessity for a more complete renovation of the contents of the lungs than ordinary. It is encroached upon in the unusually profound inspiration and expiration which occur once in every five to eight acts. It is used in certain prolonged vocal efforts, in blowing etc. Added to the residual air, it constitutes the minimum capacity of the lungs in ordinary respiration. As it is continually receiving watery vapor and carbon dioxide, it is always more or less vitiated, and when reënforced by the breathing air, which enters with inspiration, is continually in circulation, in obedience to the law of the diffusion of gases. Those who are in the habit of arresting respiration for a time, learn to change the reserve air as completely as possible by several forcible acts and then fill the lungs with fresh air. In this way they are enabled to suspend the respiratory acts for two or three minutes without inconvenience. The introduction of fresh air with each inspiration, and the constant diffusion which is going on and by which the proper quantity of oxygen finds its way to the air-cells, give, in ordinary breathing, a composition to the air in the deepest portions of the lungs which insures a constant aëration of the blood.

*Tidal, or Ordinary Breathing Air.*—The volume of air which is changed in the ordinary acts of respiration is subject to certain physiological variations; and the respiratory movements, as regards their extent, are so easily influenced, that great care is necessary to avoid error in estimating the volume of ordinary breathing air. As a mean of the results obtained by Herbst and by Hutchinson, the average volume of breathing air, in a man of ordinary stature, is twenty cubic inches (327·7 c.c.). According to Hutchinson, in perfect repose, when the respiratory movements are hardly perceptible, not more than seven to twelve cubic inches (114·7 to 196·6 c.c.) are changed; while, under excitement, the volume may be increased to seventy-seven cubic inches (1,261·8 c.c.). The breathing volume progressively increases in proportion to the stature of the individual, and bears no definite relation to the apparent capacity of the chest (Herbst).

*Complemental Air.*—The thorax may be so enlarged by an extreme voluntary inspiratory effort as to contain a quantity of air much larger than after an ordinary inspiration. The additional volume of air thus taken in may be estimated by measuring all the air which can be expelled from the lungs after the most profound inspiration, and deducting the sum of the reserve air and breathing air. This quantity has been found by Hutchinson to vary in different individuals, bearing a close relation to stature. The mean complemental volume is one hundred and ten cubic inches (1,802·9 c. c.).

The complemental air is drawn upon whenever an effort is made which requires a temporary arrest of respiration. Brief and violent muscular exertion is generally preceded by a profound inspiration. In sleep, as the volume of breathing air is somewhat increased, the complemental air is encroached upon. A part or the whole of the complemental air is also used in certain vocal efforts, in blowing, in yawning, in the deep inspiration which precedes sneezing, in straining etc.



*Extreme Breathing Capacity.*—By the extreme breathing capacity is meant the volume of air which can be expelled from the lungs by the most forcible expiration after the most profound inspiration. This has been called by Hutchinson, the vital capacity, as signifying "the volume of air which can be displaced by living movements." Its volume is equal to the sum of the reserve air, the breathing air and the complemental air, and it represents the extreme capacity of the chest, less the residual air. Its physiological importance is due to the fact that it can readily be determined by an appropriate apparatus, the spirometer, and comparisons can thus be made between different individuals, both healthy and diseased. The number of observations on this point made by Hutchinson amounts in all to a little less than five thousand.

The extreme breathing capacity in health is subject to variations which have been shown to bear a very close relation to the stature of the individual. Hutchinson begins with the proposition that in a man of medium height (five feet eight inches, or 170·2 centimetres), it is equal to two hundred and thirty cubic inches (3,768·6 c. c.).

The most striking result of the experiments of Hutchinson, with regard to the modifications of the vital capacity, is that it bears a definite relation to stature, without being affected in a very marked degree by weight or by the circumference of the chest. This is especially remarkable, as it is well known that height does not depend so much upon the length of the body as upon the length of the lower extremities. He ascertained that for every inch ($\frac{1}{4}$ centimetre) in height, between five and six feet (152·4 and 182·9 centimetres), the extreme breathing capacity is increased by eight cubic inches (131·1 c. c.).

Age has an influence, though less marked than stature, upon the extreme breathing capacity. As the result of 4,800 observations on males, it was ascertained that the volume increases with age up to the thirtieth year, and progressively decreases, with tolerable regularity, from the thirtieth to the sixtieth year. These figures, though necessarily subject to certain individual variations, may be taken as a basis for examinations of the extreme breathing capacity in disease.

*Relations in Volume of the Expired to the Inspired Air.*—A certain proportion of the inspired air is lost in respiration, so that the air expired is always a little less in volume than that which is taken into the lungs. The loss was put by Davy at $\frac{1}{10}$, and by Cuvier at $\frac{1}{50}$ of the volume of air introduced. Observations on this point, to be exact, must include a considerable number of respiratory acts; and from the difficulty of continuing respiration in a perfectly regular and normal manner when the attention is directed to the respiratory movements, the most accurate results may probably be obtained from experiments on the lower animals. Despretz caused six young rabbits to respire for two hours in a confined space containing 2,990 cubic inches (49,000 c. c.) of air, and ascertained that the volume had diminished by sixty-one cubic inches (1,000 c. c.), or a little more than one-fiftieth. Adopting the approximations of Davy and Cuvier, applied to the human subject, as

nearly correct, it may be assumed that in the lungs, $\frac{1}{10}$ to $\frac{1}{50}$ of the inspired air is lost.

*Diffusion of Air in the Lungs.*—When it is remembered that with each inspiration, but about twenty cubic inches (327·7 c. c.) of fresh air are introduced, sufficient only to fill the trachea and larger bronchial tubes, it is evident that some forces must act by which this fresh air finds its way into the air-cells, and the vitiated air is brought into the larger tubes, to be expelled with the succeeding expiration.

The interchange between the fresh air in the upper portions of the respiratory apparatus and the air in the deeper parts of the lungs is constantly going on by simple diffusion aided by the active currents or impulses produced by the alternate movements of the chest. In the respiratory apparatus, at the end of an inspiration, the atmospheric air, composed of a mixture of oxygen and nitrogen, is introduced into the tubes with a considerable impetus and is brought into contact with the gas in the lungs, which is heavier, as it contains a certain quantity of carbon dioxide. Diffusion then takes place, aided by the elastic lungs, which are gradually forcing the gaseous contents out of the cells, until a certain portion of the air loaded with carbon dioxide finds its way to the larger tubes, to be thrown off in expiration, its place being supplied by the fresh air.

In obedience to the law established by Graham, that the diffusibility of gases is inversely proportionate to the square root of their densities, the penetration of atmospheric air, which is the lighter gas, to the deep portions of the lungs would take place with greater rapidity than the ascent of the air charged with carbon dioxide; so that eighty-one parts of carbon dioxide should be replaced by ninety-five parts of oxygen. It is found, indeed, that the volume of carbon dioxide exhaled is always less than the volume of oxygen absorbed. This diffusion is constantly going on, so that the air in the pulmonary vesicles, where the interchange of gases with the blood takes place, maintains a nearly uniform composition. The process of aëration of the blood, therefore, has little of that intermittent character which attends the muscular movements of respiration, which would occur if the entire gaseous contents of the lungs were changed with each respiratory act.

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## CHAPTER V.

### *CHANGES WHICH THE AIR AND THE BLOOD UNDERGO IN RESPIRATION.*

Composition of the air—Consumption of oxygen—Exhalation of carbon dioxide—Relations between the quantity of oxygen consumed and the quantity of carbon dioxide exhaled—Sources of carbon dioxide in the expired air—Exhalation of watery vapor—Exhalation of ammonia—Exhalation of organic matter—Exhalation of nitrogen—Changes of the blood in respiration (hæmatosis)—Difference in color between arterial and venous blood—Comparison of the gases in venous and arterial blood—Analysis of the blood for gases—Nitrogen of the blood—Condition of the gases in the blood—Relations of respiration to nutrition etc.—The respiratory sense—Sense of suffocation—Respiratory efforts before birth—Cutaneous respiration—Breathing in a confined space—Asphyxia.

From the allusions already made to the general process of respiration, it is apparent that before the discovery of the nature of the gases which compose the air and those which are exhaled from the lungs, it was impossible for physiologists to have any correct ideas of the nature of this important function. It is also evident that no definite knowledge of the processes of respiration could exist prior to the discovery of the circulation of the blood.

The discovery of the properties of oxygen and carbon dioxide were simply isolated facts and failed to develop any definite idea of the changes of the air and blood in respiration. The application of these facts was made by Lavoisier, whose observations mark the beginning of an accurate knowledge of the physiology of respiration. With the balance, Lavoisier showed the nature of the oxides of the metals; he discovered that carbon dioxide is formed by a union of carbon and oxygen; and noting the consumption of oxygen and the production of carbon dioxide in respiration, he advanced, for the first time, the view that the one was concerned in the production of the other. Although, as would naturally be expected, the doctrines of Lavoisier have been modified with the advances in science, he developed facts which have served as the starting-point of definite knowledge on this subject.

*Composition of the Air.*—Pure atmospheric air is a mechanical mixture of 79·19 parts of nitrogen with 20·81 parts of oxygen (Dumas and Boussingault). It contains, in addition, a very small quantity of carbon dioxide, about one part in two thousand. The air is never free from moisture, which is very variable in quantity, being generally more abundant at a high than at a low temperature. Floating in the atmosphere, are large numbers of minute organic bodies; and various odorous and other gaseous matters sometimes are present as accidental constituents.

In considering the processes of respiration, it is not necessary to take account of any of the constituents of the atmosphere except oxygen and nitrogen, the others being either inconstant or existing in excessively minute quantity. It is necessary to the regular performance of respiration, that the air should contain about four parts of nitrogen to one of oxygen, and have about the density which exists on the general surface of the globe. When the density is very much increased, as in mines, respiration is more or less disturbed. By exposure to a rarefied atmosphere, as in the ascent of high mountains or in aërial voyages, respiration may be very seriously interfered with, from the fact that less oxygen than usual is presented to the respiratory