SCIENCE

FRIDAY, MAY 9, 1919

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MSS. intended for publication and books, etc., intended for review should be sent to The Editor of Science, Garrison-on-Hudson, N. Y.

THE PHYSIOLOGY OF THE AVIATOR[1]

DOUBTLESS you have all read the delightful historical accounts by the late Admiral Mahan of the great naval battles of the eighteenth century, when France and England struggled for the mastery of the sea. You will recall the stress laid on the weather gauge, or windward position. If the wind blew from the eastward, as does the "northeast trade" among the Caribbean Islands where a great part of the struggle occurred, whichever admiral was able so to maneuver as to be to the east of his enemy obtained a great, and often a decisive, advantage. He could choose the time and mode of attack, while his antagonist was compelled to remain on the defensive, unable either to force the fighting or to escape it.

In modern naval warfare the position of the sun in relation to the enemy's fleet affects the accuracy of aim. The speed of the ships is of importance equalling that of their gunfire. But there is no element of position which quite corresponds to that of the weather gauge for a fleet under sail.

In the battles of the ships of the air, however, there is again a condition which corresponds quite closely to the tactical advantage of maneuvering between the wind and the enemy. In this case it is not a direction in the plane of the horizon, except so far as light is important; but it is the direction at right angles, vertical to this plane. It is the upper position—the advantage obtained by him who can climb above his enemy, and, choosing the moment

[1] Address before the Harvey Society, New York City, March 22, 1919.

of attack, can swoop down upon him from above.

With this as one of the fundamental conditions of aerial warfare, it was inevitable that in the development of the battle plane there should be the utmost effort to produce machines of continually greater speed and, its correlative, climbing power. Likewise in the air, the greatest practicable altitude has meant for the flying man at once an advantage over his enemy and a reduction of his own chance of being hit by anti-aircraft fire from the enemy's guns on the ground.

Accordingly, from the comparatively low altitude at which the aerial fighting of the first year of the war usually occurred, the struggle rose, as more and more powerful airplanes were constructed by both sides, until at the end of the war it was quite common for battle planes to ascend to altitudes of 15,000 to 18,000 feet—three miles up, higher than the summits of the Rocky Mountains or the Alps.

Along with this development there occurred with increasing frequency among the aviators a condition of so-called "air-staleness." It is a condition closely similar to, perhaps identical with, the "overtraining" or staleness, the physical and nervous impairment of athletes in a football team or college crew. In the last year of the war this condition had become so common that, as reported to us by some observers, the majority of the more experienced aviators in the British service were incapacitated to ascend to the necessary altitude, and many could no longer fly at all. It was to make good this most serious military deficiency that the enlistment and training of aviators was undertaken by the American Air Service on the enormous scale that it was. It was for the purpose of testing our airmen initially, and of keeping tab on their physical condition thereafter, that the work at the Mineola laboratory, of which probably you have heard, was undertaken.

It is work which lies in a field of physiology in which before the war not half a dozen men in America, and not many more in Europe, were interested, and for them it was a field of what is called "pure" science. To-day it promises contributions of practical value not only to aviation, but to problems in medicine, climatology, athletics and hygiene.

We will turn then to the problem of the aviator and the methods of human engineering which have been developed for its solution. But first, it will be advisable to review briefly what is known concerning the immediate effects of low barometric pressure and the functional readjustments involved in acclimatization to elevated regions; that is, life at great altitudes.

Paul Bert,[2] the brilliant French physiologist, was the first to demonstrate, in 1878, that the effects of lowered barometric pressure or altitude are wholly dependent on the decreased pressure of oxygen. He carried out experiments upon men and animals both with artificial gas mixtures and reduced barometric pressure in a steel chamber.

He showed that in pure oxygen at 21 per cent. of atmospheric pressure life goes on in practically the same manner as in air, which contains 21 per cent. of oxygen, at the ordinary pressure. So also the breathing of an artificial gas mixture containing only 10.5 per cent. of oxygen has the same untoward effects at sea level that breathing pure air has at an altitude of about 20,000 feet, where the barometer is reduced by one half.

These considerations are fundamental for the differentiation of the disorders in-

[2] Paul Bert, "La Pression Barometrique," Paris, 1878.

duced by rarefied air—so-called mountain sickness—from the conditions resulting from work in compressed air—so-called caisson disease. It is clear that it is from the former, and not at all from the latter, that aviators suffer; but, as the two disorders are sometimes confused, a few words regarding the latter are in place here.

Caisson disease—known also as the "bends," "diver's palsy," and by other names—depends upon the fact that, under the high pressure necessary for diving, tunneling, and other work below water, the the nitrogen of the air dissolves in the blood and in the other fluids and tissues of the body in amounts proportional to the pressure. This in itself does no harm, and has in fact no effect upon the body, until the subject comes out of the pressure lock or caisson, or rises from the depth of the sea where he has been working. Then the nitrogen which has been dissolved begins to diffuse out of the body. This also does no harm and has no effect unless the pressure under which the man has been working is so high, and the lowering of the external pressure is so rapid, that the dissolved nitrogen separates in the form of bubbles. Such bubbles may form in the blood, in the synovial fluid of the joints, and even in the brain. They induce intense pain, and even paralysis and death. In order that bubbles may be formed it is essential, however, that the pressure with which the tissues are in equilibrium should have been lowered considerably more than half its absolute amount in a few seconds.

In the present state of the art of flying it is scarcely possible for an aviator to rise to a height of more than 20,000 feet, where the barometer would be less than half of that at sea level, in a period sufficiently short to allow bubbles of nitrogen to form in this way. The disorders from which aviators suffer are, therefore, of a different class from those to which workers in compressed air are exposed.

When the study of the effects of lowered barometric pressure was begun, it was supposed that the circulation might be primarily disturbed. The blood in the arteries of a healthy man is under such a pressure that, if a glass tube were inserted vertically into one of the arteries of his neck, and the blood were allowed to flow up the tube, the column of blood would come to rest at a height of 4 or 5 feet above his heart, corresponding to pressures of 120 to 150 mm. mercury. Knowing that the air pressure is reduced at great altitudes, some of the earlier writers made the mistake of supposing that such a column of blood would rise higher, and the blood vessels would be under a greater strain, and more likely to burst therefore, at a great altitude that at sea level. That which they looked for they found. One writer has left a lurid description of how, while crossing a pass in the Andes, he got off his mule and walked for a time to rest the animal. On the least exertion his breathing became oppressed, "his eyes bulged and his lips burst." The odd part of this is that in reality the blood vessels are under no greater strain at a high altitude that at sea level. When the air pressure upon the exterior of the body and in the lungs is reduced, a part of the gas —at least the nitrogen dissolved in the blood—rapidly diffuses out through the lungs, so that the gas pressure within and without the blood vessels are again equal just as at sea level. The idea is still prevalent that hemorrhages occur under low barometric pressures. However, among thousands of people whom I had an opportunity to observe on Pike's Peak during a five weeks stay at the summit, I saw not a single nose bleed, except one which was caused by the forcible application of a hard object to the organ in question.

The only direct effects of changes of pressure are those which are felt in the ears, and occasionally in the sinuses connected with the nose. The ear drums are connected with the throat and contain air at the prevailing pressure. If the pressure is lowered this air expands, and forces its way out through the Eustachian tubes into the throat. If the outside pressure is increased, it sometimes happens, particularly when the subject has a cold and the Eustachian tubes are inflamed, that air does not pass readily into the middle ear. Accordingly the tympanic membranes are forced inward by the pressure; and this may cause acute pain. Workers in compressed air are accustomed, while going "into the air," *i. e.*, into pressure, to hold their noses and blow at frequent intervals as a means for expanding the ear drums. Aviators even during very rapid descents are generally relieved by merely swallowing.

To sum up all that has been said thus far, the influence of low barometric pressure is not mechanical but chemical. Life is often compared to a flame; but there are marked differences, depending upon the peculiar affinity of the blood for oxygen. A man may breathe quite comfortably in an atmosphere in which a candle is extinguished. The candle will burn with only slightly diminished brightness at an altitude at which a man collapses. The candle is affected by the proportions of oxygen and nitrogen. The living organism depends solely upon the absolute amount of oxygen—its so-called partial pressure.

Unlike the flame, a man may become acclimatized to a change of atmosphere in the course of a few days or weeks. He is thus adjusted to the mean barometric pressure under which he lives. Every healthy person is so adjusted, New Yorkers to a mean barometric pressure of 760 mm. no less than the inhabitants of Denver or Cripple Creek to their altitudes. Even your tall buildings could probably be shown to exert a slight climatic effect upon the tenants of the upper stories. The study of the processes involved in such acclimatization affords us one of the most promising means of analyzing some of the fundamental problems of life. In fact, is not the gaseous interchange of protoplasm, the carbon and oxygen metabolism of the cell, the central fact of life? Is not the mode of regulation of the interior environment of the body—the constants of the "humours"—the prime problem of the "vegetative" side of physiology.

Among the ill effects of lack of oxygen we may distinguish three more or less distinct conditions. They are comparable, in terms of more common disorders, to acute disease in contrast with chronic conditions of various degrees. Thus any one suddenly exposed to acute deprivation of oxygen, as is the balloonist or the aviator in very lofty ascents, shows one set of symptoms. If the exposure is less acute, as in the case of one taking up residence on a high mountain, the effects develop gradually; he passes through the stages of mountain sickness, a condition much like sea sickness, to a state of acclimatization and renewed health. If however the ascent or the flight is for only two or three hours, a period too short for any degree of acclimatization to develop, and this strain on the oxygen-needing organs is repeated daily, as is the case with the aviator of the upper air, the condition of "air staleness" is likely sooner or later to result. It is the effect of repeated slight oxygen deficiency on an individual who does not become acclimatized. It is, I believe, closely related to those effects of repeated over-exertion and oxygen shortage which appear in the over-trained athlete.

The classic description of collapse from oxygen deficiency is that written by Tissandier,[3] the sole survivor of a fatal balloon ascent in 1875.

I now come to the fateful moments when we were overcome by the terrible action of reduced pressure. At 7,000 meters (Bar. 320 mm.) we were all below in the car. . . . Torpor had seized me. My hands were cold and I wished to put on my fur gloves; but without my being aware of it, the action of taking them from my pocket required an effort which I was unable to make. At this height I wrote, nevertheless, in my notebook almost mechanically, and reproduce literally the following words, though I have no very clear recollection of writing them. They are written very illegibly by a hand rendered very shaky by the cold. My hands are frozen. I am well. We are well. Haze on the horizon, with small rounded cirrus. We are raising. Crocé is panting. We breathe oxygen. Sivel shuts his eyes. Croce also shuts his eyes. I empty aspirator. 1.20 P.M.,–11°, Bar. 320. Sivel is dozing. 1.25–11°, Bar. = 300. Sivel throws ballast. Sivel throws ballast. (The last words are scarcely legible.) . . . I had taken care to keep absolutely still, without suspecting that I had already perhaps lost the use of my limbs. At about 7,500 meters (Bar. 300 mm.) the condition of torpor which comes over one is extraordinary. Body and mind become feebler little by little, gradually and insensibly. There is no suffering. On the contrary one feels an inward joy. There is no thought of the dangerous position; one rises and is glad to be rising. The vertigo of high altitudes is not an empty word; but so far as I can judge from my own impressions this vertigo appears at the last moment, and immediately precedes extinction, sudden, unexpected and irresistible. . . . I soon felt myself so weak that I could not even turn my head to look at my companions. I wished to take hold of the oxygen tube, but found that I could not move my arms. My mind was still clear, however, and I watched the aneroid with my eyes fixed on the needle, which soon pointed to 290 mm. and then to 280. I wished to call out that we were now at 8,000 meters; but my tongue was paralyzed. All at once I shut my eyes and fell down powerless, and lost all further memory. It was about 1.30.

[3] Quoted from Paul Bert, *op. cit.*, p. 1061.

In this ascent the balloon continued to rise until a minimum pressure, registered automatically, of 263 mm. was reached. When Tissandier recovered consciousness Sivel and Crocé-Spinelli were dead. They were all provided with oxygen, ready to breath; but all were paralyzed before they could raise the tubes to their lips. Tissandier's notes are characteristic of the mental condition when oxygen-want is becoming dangerous.

In marked contrast to this condition is that of men who, gradually ascending into the mountains, day by day become acclimatized without realizing that any change has occurred. The record for the greatest altitude attained by mountaineers is held by the Duke of Abruzzi and his party in the Himalayas. They reached an altitude of 24,000 feet, where the atmospheric pressure is only two fifths of that at sea level, or practically the same as that at which Tissandier's companions lost consciousness. At this tremendous altitude the Duke and his Swiss guides were not only free from discomfort, but were able to perform the exertion of cutting steps in ice and climbing. Dr. Filippi, the physician who accompanied them, in discussing this matter says that the fact of their immunity admits of but one interpretation:

Rarefaction of the air under ordinary conditions of the high mountains to the limits reached by man at the present day (307 mm.) does not produce mountain sickness.[4]

In this statement, however, he is certainly mistaken, for the observations of others show conclusively that the sudden exposure of unacclimatized men to an altitude considerably less than that reached by this party would either produce collapse like that of Tissandier's companions, or if long

[4] Quoted from Douglas, Haldane, Henderson and Schneider, "Physiological Observations on Pikes Peak," *Phil. Trans.*, 1913, B. 203, p. 310.

continued would result in mountain sickness. The latter effect especially is one which was the subject of careful study by an expedition of which I was a member, and which during the summer of 1911 spent five weeks at the summit of Pike's Peak, Colorado, altitude, 14,100 feet, Bar. 450 mm. We were there enabled to make observations upon hundreds of tourists who ascended the Peak, and who were acclimatized at most to the altitude of Colorado Springs or Manitou at the foot of the mountain. We saw a number of cases of collapse—fainting—from oxygen deficiency as shown by the striking cyanosis.

In the majority of cases, however, tourists who spent no more than the regulation half hour at the summit of the Peak, and then descended, experienced no acute ill effects. Headache and some degree of nausea were common even among these persons, however—often developing slowly for some hours after their descent. On the other hand, among persons who remained over night, and were thus exposed for several hours to deficiency of oxygen, the classic symptoms of mountain sickness occurred; and few escaped. Their second day at the summit was marked usually by extreme discomfort—headache, nausea, vomiting, dizziness and extraordinary instability of temper—symptoms which were strikingly exacerbated by even the smallest use of alcohol.

Our immediate party passed through these conditions and after two or three days, or in one case nearly a week, re-attained practically normal health. A definite functional readjustment had occurred. To illustrate and emphasize the nature of this readjustment I will quote a recent experiment[5] of my friend the leader of the Pike's Peak expedition, Dr. J. S. Haldane.

He has equipped his laboratory at Oxford with a small lead-lined chamber in which a man can be hermetically closed. The carbonic acid which he exhales is continually absorbed by alkali, so that no accumulation occurs, while the oxygen is progressively decreased by the breathing of the man himself. Dr. Haldane found that after a day or two in this chamber he had reduced the oxygen to an extent comparable to Pike's Peak. At the same time there had evidently occurred in himself a gradual process of adjustment, for he felt quite well. At this stage he invited another person to come into the chamber with him, and he had the satisfaction of observing the immediate development of blueness and the other symptoms of oxygen collapse in his companion.

Evidently acclimatization is a very real phenomenon and of the utmost importance to any one exposed to a lowered tension of oxygen.

As we observed it in ourselves during our stay on Pike's Peak acclimatization consists in three chief alterations: (1) increased number of red corpuscles in the blood; (2) some change in the lungs or blood (Haldane considers it the secretion of oxygen inward by the pulmonary tissue) which aids the absorption of oxygen, and (3) a lowering of the CO_2 in the alveolar air of the lungs. This lowering of the CO_2 in the lungs is bound up with increased volume of breathing. It is the concomitant of a decreased alkaline reserve in the blood just as in nephritis and diabetes. Acclimatization in this respect consists therefore in the development of a condition which would nowadays be called acidosis.

All of these changes are of a quantitative character. Miss FitzGerald[6] has supplemented the results obtained on Pike's Peak by an extensive series of careful observa-

[5] Personal communication.

[6] FitzGerald, M. P., *Phil. Trans.*, 1913, B. 203, p. 351, and *Proc. Royal Soc.*, 1914, B. 88, 248.

tions on the inhabitants of towns of closely graded altitude from sea level up to that of the highest inhabited place in our western country. She has thus shown that the mean hemoglobin and the mean alveolar CO_2 of the inhabitants of any town are functions of the mean barometric pressure of the place.

I shall not discuss pulmonary oxygen secretion now, because the problem is still extremely obscure; nor the increased production of red blood corpuscles, which is a slow process requiring weeks for completion, and playing no considerable part in the matter particularly before us.

We will fix our attention upon the fact that both the alveolar CO_2 of the pulmonary air and the alkaline reserve of the blood are reduced in accurate adjustment to any altitude, or oxygen tension, to which a man is subjected for a few days or even a few hours. This functional readjustment is, I believe, of great significance in relation to aviation, since it involves a larger volume of breathing per unit mass CO_2 eliminated: it thus compensates in part for the rarefaction of the air.

But how is it brought about? And why are the changes of breathing gradual, when the changes of altitude and oxygen tension are abrupt? The answer lies in part at least in the mode of development, and the nature of that acidosis of altitude to which I have referred. It is scarcely necessary to remind you that, as L. J. Henderson has shown, the balance of acids and bases in the blood, its C_H, depends upon the maintenance of a certain ratio between the dissolved carbonic acid, H_2CO_3 and sodium bicarbonate, $NaHCO_3$, or as Van Slyke terms it, the alkaline reserve. On the basis of this conception the prevalent view of acidosis is that, when acids other than carbonic are produced in the body, the bicarbonate is in part neutralized. The alkaline reserve is thus lowered, and the carbonic acid of the blood being now in relative excess, an increased volume of breathing is caused as an effort at compensation.

Recent investigations[7] by Dr. H. W. Haggard and myself show that an exactly opposite process is likewise possible. We find that whenever respiration is excited to more than ordinary activity, and the carbonic acid of the blood is thus reduced below the normal amount, a compensatory fall of the alkaline reserve occurs. The body is evidently endowed with the ability to keep the ratio of H_2CO_3 to $NaHCO_3$ normal, not only by eliminating CO_2 when the alkali is neutralized, but also by the passage of sodium out of the blood into the tissue fluid (or by some equivalent process) to reduce the alkaline reserve. A loss of CO_2 during over-active breathing is thus balanced. If it were not balanced a state of alkalosis would occur, which would inhibit and induce a fatal apnoea.

It is really in this way I believe that some of those conditions arise which nowadays are called "acidosis." If so they are not truly acidosis, or rather the process producing them is not acidosis, although the resultant condition gives some of the most characteristic tests of this condition. It is on the contrary a state, or rather a process, which Mosso was the first to recognize, although obscurely, and which he termed "acapnia" an excessive elimination of CO_2. Recent papers[8] from my laboratory have shown that a sudden and acute acapnia induces profound functional disturbances, including circulatory failure.

It is one of the well-known facts in physi-

[7] Henderson and Haggard, *Jour. Biol. Chem.*, 1918, 33, pp. 333, 345, 355, 365.

[8] Henderson and Harvey, *Amer. Jour. Physiol.*, 1918, 46, p. 533, and Henderson, Prince and Haggard, *Jour. Pharmac. Exper. Therap.*, 1918, 11, p. 189.

ology that deficiency of oxygen, or anoxemia, causes an "acidosis." Recent and as yet unpublished work of Dr. Haggard and myself indicates that the process involved is almost diametrically the opposite of that which has heretofore been supposed to occur, and that the result is not a true acidosis. Under low oxygen, instead of the blood becoming at first more acid with a compensatory blowing off of CO_2, what actually occurs is that, as the first step, the anoxemia induces excessive breathing. This lowers the CO_2 of the blood, rendering it abnormally alkaline; and alkali passes out of the blood to compensate what would otherwise be a condition of alkalosis.

We regard the current explanation, based on the production of lactic acid, as needing reversal.

The application of this idea to the changes of breathing and of the blood alkali in acclimatization clears up some of the points which heretofore have been obscure. Thus on Pike's Peak we saw that persons whose breathing under the stimulant of oxygen deficiency increased quickly to the amount normal for the altitude suffered correspondingly little, while those whose respiratory center was relatively insensitive to this influence suffered severely. The one type readily developed the acapnia and in consequence the pseudo-acidosis which the altitude requires. The other did not.

Here let me pause a moment to bring these conceptions into some degree of harmony with fundamental doctrines regarding respiration. For more than a century, in fact ever since the days of Lavoisier, the argument has been active whether our breathing is controlled by oxygen need or by the output of CO_2. For the past thirty years, and especially during the last ten or twelve, the theory of regulation by CO_2, or in its later form by C , has held the field. Indeed it is established now—almost beyond the possibility of contradiction, it would seem—that during any brief period of time, and under conditions to which the individual is accustomed, the amount of CO_2 produced in the tissues of the body, through its influence on the C_H of the blood, is the factor controlling the volume of air breathed. Its effects are immediate.

But when we view the matter more broadly it is clear that this is by no means the whole story. The oxygen tension of the air is the influence which determines just how sensitive the respiratory center is to excitement by CO_2. But the effects of any change of oxygen tension are slow in developing, requiring in some persons, as we saw on Pike's Peak, hours to begin and several days to become complete. In fact there are many perfectly healthy persons who, if caused to breathe progressively lowered tensions of oxygen down to 6 or 7 per cent. in the course of half an hour, feel nothing. Their breathing shows no considerable augmentation. They simply lose consciousness, and if left alone they would die, without any apparent effort on the part of respiration to compensate for the deficiency of oxygen. In such persons the stimulant of oxygen deficiency exerts only a slowly developing influence upon the sensitiveness of the respiratory center to the stimulus of CO_2. They can become acclimatized to great altitude only at the cost of prolonged mountain sickness. Evidently they are not suited to be aviators.

In very sensitive subjects, on the contrary, the period of readjustment is much shorter. It is a matter not of days but of hours, and the functional alterations begin to develop almost immediately even under slight oxygen deficiency. The upper air is for those men whose organization readily responds with vigorous compensatory reacgen.

With this inadequate sketch of present scientific knowledge regarding life at great altitudes as a background, we may turn to the application of this knowledge to the problems of human engineering in the aviation service of our army during the war. In September, 1917, I was appointed chairman of the Medical Research Board of the Air Service and was asked to lay out a plan for the development of a method of testing the ability of aviators to withstand altitude.

You will readily guess the line along which one would attack such a problem. It consisted in the development of an apparatus from which the man under test breathes air of a progressively falling tension of oxygen. The particular form which we use is called a rebreathing apparatus. It consists of a steel tank holding about 100 liters of air, connected with a small spirometer to record the breathing, and a cartridge containing alkali to absorb the CO_2 which the subject exhales. Breathing the air in this apparatus through a mouthpiece and rubber tubing the subject consumes the oxygen which it contains, and thus produced for himself the progressively lower and lower tensions of oxygen which are the physiological equivalent of altitude. To control and test the accuracy of the results with the rebreathing apparatus we installed in our laboratory at Mineola a steel chamber, in which six or eight men together can sit comfortably, and from which the air can be exhausted by a power driven pump down to any desired barometric pressure.

Such apparatus was however only the beginning. The practical problem was to determine the functional changes—pulse rate, arterial pressure, heart sounds, muscular coordination and psychic condition occurring in the good, the average and the poor candidates for the air service, and then to systematize and introduce these standards on a very large scale at the flying fields in this country and in France.

That this program was successfully carried through, and was approaching completion when the armistice was signed, was due chiefly on the scientific side to the brilliant work of my colleagues Majors E. C. Schneider, J. L. Whitney, Knight Dunlap and Captain H. F. Pierce, and on the administrative side to the splendid cooperation of Colonel W. H. Wilmer and Lieutenant Colonel E. G. Seibert.

We have recently published a group of papers,[9] brief but fairly comprehensive in their technical details, and I shall not now repeat what has there been said, but shall confine myself to a few salient points. One of these is a final and striking demonstration of our main thesis. Schneider and Whitney went into the steel chamber and the air was pumped out of it until the barometer stood at only 180 mm., 23 per cent. of the pressure outside: the equivalent of an altitude of 35,000 feet. Throughout the test they were supplied with oxygen from a cylinder through tubes and mouthpieces. They experienced no discomfort except from flatus: the gases of the stomach and intestine of course expanded nearly five fold.

In comparison with this observation is to be placed the recent record ascent by Captain Lang and Lieutenant Blowes in England to a height of 30,500 feet. They were supplied with oxygen apparatus; but a defect developed in the tube supplying Lieutenant Blowes and he lost consciousness. Captain Lang seems to have suffered only from cold.

From this it might appear that the

[9] Y. Henderson, E. G. Seibert, E. C. Schneider, J. L. Whitney, K. Dunlap, W. H. Wilmer, C. Berens, E. R. Lewis and S. Paton, *Journal American Medical Association*, 1918, Vol. 71, pp. 1382–1400.

simplest way to solve the problem of lofty ascents would be by means of oxygen apparatus. The Germans evidently made use of such apparatus, for it was found in the wreck of one of the German planes shot down over London. The British also had such apparatus, but it was difficult to manufacture, wasteful in operation, and in other respects left much to be desired. In fact the devising of such apparatus and its adaptation to the peculiar requirements of the human wearer are a problem which can be solved only by the close cooperation of a physiologist and a mechanical engineer. Mr. W. E. Gibbs, of the Bureau of Mines, with whom I had cooperated in developing mine rescue oxygen apparatus, took up this problem and produced a device which should prove valuable. Unfortunately the common tendency to favor ideas and apparatus coming to us from Europe operated against the adoption of the better American device.

It is doubtful however whether any apparatus of this sort will ever quite take the place of physical vigor and capacity to resist oxygen deficiency on the part of the aviator himself. Imagine him, when fighting for his life above the clouds, handicapped by goggles over his eyes, wireless telephone receivers on his ears, a combined telephone transmitter and oxygen inhaler over his mouth, and a padded helmet on his head!

The importance of determining the aviator's inherent power of resistance to oxygen deficiency, if he is to be even for a few moments without an oxygen inhaler, is demonstrated by the results of the routine examinations made with the rebreathing apparatus in the laboratory. These results show that 15 to 20 per cent. of all the men who pass an ordinary medical examination are unfit to ascend to the altitudes now required of every military aviator. On the other hand these tests pick out a small group of 5 to 10 per cent. who, without apparent immediate physical deterioration, withstand oxygen deficiency corresponding to altitudes of 20,000 feet or more.

It is particularly interesting to note that when the rebreathing test is pushed beyond the limit that the man can endure, be it the equivalent of only 10,000 or 25,000, two different physiological types with all gradations between them are revealed. The fainting type collapses from circulatory failure and requires an hour or two to recover. Often the heart appears distinctly dilated. The other and better type, on the contrary, goes to the equivalent of a tremendous altitude on the rebreathing apparatus and loses consciousness, becoming glassy-eyed and more or less rigid, but without fainting. When normal air is administered such men quickly recover.

Perhaps I ought to say at least a few words regarding the other aspects of the work at Mineola: for example the valuable psychological investigations and the controversy over the rotation tests, which has figured so largely in our medical journals of late. It seemed best, however, to confine myself this evening to my own special field. Nevertheless I can not suppress a public expression here of my sympathy for the brave and able scientific men in the psychological group at Mineola, who insisted on investigating the validity of the rotation tests. I am sure that you will feel as I do, when I tell you that they were threatened with punishmnet for insubordination when they refused to recognize that a regulation of the army, which prescribes the duration of nystagmus after the rotation test, necessarily makes this a physiological fact.

I would gladly devote a few minutes also to pointing out some of the lessons to be drawn from the rather unusually good opportunities which fell to my lot to observe the mingling of science and militarism. The chief lesson can be put in a single phrase: They do not mix. The War Gas Investigations, which formed the nucleus on which the Chemical Warfare Service finally developed, and the Medical Aviation Investigations, of which I have spoken this evening, were both successful largely because at first they were developed under civilian control, under that splendid scientific arm of the government, the Bureau of Mines and its able director. It is a wise provision of our government by which the Secretary and Assistant Secretaries of War are always civilians. It would also be wise for the general staff in any future war to keep scientific men on a scientific status instead of practically forcing them into uniform.

We all hope that we are done with war, and with soldiers—at least for a generation. We can, however, derive certain broad lessons applicable to the conditions of peace from the experiences and intense activities of war, when almost unlimited funds were obtainable for research and the experiences ordinarily scattered over years were crowded into a few months. One of these lessons is that scientific men need to develop the capacity to become the heads of large enterprises without ceasing to be scientific, without degenerating, as is too often the case, into the super-clerk, who seems to be the American ideal of the high executive official. It is not enough for the scientific man to become the expert adviser to the unscientific administrator. If the latter has the responsibility he will use his power as he, and not as the scientific man, sees fit. To this rule I have known only one splendid exception.

For the most part among us the great prizes go to the man who works up through clerical rather than through expert lines. We must find some way to change this. The path of science must lead to the top, and at the top must still be science. To achieve this ideal, the scientist must show generosity toward colleagues and subordinates, an enthusiastic recognition of their merit and an abnegation of self-aggrandizement, no less than skill in plan and energy in execution. It is essential also that he should develop methods for conserving time and strength by assigning clerical work to clerks instead of becoming a clerk himself, in order that he may keep mind and desk clear for the really important things.

The Chemical Warfare Service was a success largely because the chief of the Research Division followed these principles as the spontaneous promptings of science and patriotism.[10] Medical research in aviation was productive just so long as it pursued a similar course.

He who charts this course, so that others may follow it through the pathless seas of the future, will make a great contribution to science, education, government, and indeed to nearly every phase of trained activity in America.

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YALE UNIVERSITY

A NEW DEPOSIT OF URANIUM ORE[1]

HITHERTO the known deposits of radium-uranium ore of commercial importance in the United States have been confined to the carnotite fields of Colorado and Utah, and to a much smaller extent to the pitchblende of Gilpin county, Colorado. In the spring of 1918, a new uranium deposit was discovered at Lusk, Wyo., which is hundreds of miles from any other known fields, and which has proved to be the first isolated deposit of uranium ore to produce commercial quantities. The deposit at Lusk has now proved itself by the

[10] *Cf.* G. A. Burrell, *Journal of Industrial and Engineering Chemistry*, 1918, Vol. II., p. 93.

[1] Published with the permission of the director of the U. S. Bureau of Mines.