The influence of high altitudes in mountaineering / by Malcolm L. Hepburn.

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With the Author's Compliments.

THE INFLUENCE OF HIGH ALTITUDES IN MOUNTAINEERING.

The Influence of High Altitudes in Mountaineering.

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(Read before the Alpine Club, April 2, 1901.)

THERE is nothing more humiliating to the feelings than to try to assume the position of being an authority on any particular subject, be it scientific or otherwise. I can hardly describe the sensations nor show in how many various ways they can be brought about, but I would invite those who are not familiar with them to try the experiment of working in any way they please at some special subject, preferably one about which they fondly hope little is known and few people have written.

Under these circumstances you can readily understand that when our Secretary asked me to read a paper on the influence of high altitudes in mountaineering, I consented to do so with some degree of reluctance. Two other reasons made me hesitate. One is, that, having no personal experience or physiological discoveries to place before you this evening, there are many here far better fitted than I am to unravel this complex problem; and I feel, in this age of original

scientific research, I owe you an apology for this omission, though it is not from want of desire but from force of circumstances. You are able to appreciate, better than any other audience, the difficulties of personal investigation in this particular branch of science, for in the present state of our knowledge it would necessitate, on the one hand, climbing above 17,000 ft. with several cumbersome physiological instruments and also a supply of oxygen, or, on the other hand, performing laboratory experiments on human beings. I have ascertained that there is no apparatus for such experiments in England; and Professor von Liebig, of Munich, who has one, and to whom I wrote, is unable for certain reasons to undertake the experiment I proposed, and I have not had the opportunity of an interview. My other reason is that I feared a physiological dissertation and discussion might prove rather wearisome to the majority of members, but my fears were partially allayed on reading some observations by an eminent physiologist from which I gathered that some of the effects of diminished atmospheric pressure might serve to account for several hitherto unexplained phenomena observed by many climbers at inconsiderable altitudes.

For example, on his authority, I understand that the flea is an animal peculiarly susceptible to the influence of diminution of pressure, exhibiting increased vitality beyond reasonable expectation. I regret to say that I have no evidence with which to refute this important observation.

Again, the abuse of things in general which is an occasional weakness of some climbers when encountering difficulties at high altitudes is due, on the authority of the same physiologist, to the special conditions under which these sufferers (?) find themselves. This is consoling, but I look in vain through his work for some similar explanation for the use of abusive expressions at sea-level; though I do find that they are more commonly met with in cyclists.

Yet once more; those of us who are disposed to judge, with undue harshness, our noisy but more fortunate companions, when we are trying to snatch a few hours' sleep before the morning start, must remember that snoring is always louder than usual under reduction of pressure, owing to the sound being conveyed more readily through the less dense atmosphere.

However, I do not propose to study the influence of diminished atmospheric pressure on all animals from the flea upwards, highly interesting as this would prove, as we have already enough before us.

As far as one may judge from the literature of the last few months, it seems a little difficult, at the beginning of a century, to avoid entering into an elaborate historical sketch of every subject under the sun; but I will spare you this also, and merely remark that so-called mountain-sickness was first described three hundred years ago, and that a large amount of work has been done bearing directly and indirectly on our subject, more especially by foreign physiologists, which only needs putting together to be of great value to us in mountain exploration. This I am attempting to do in the present paper.

I now propose to describe briefly the symptoms complained of by mountaineers; and, for purposes of convenience, I will divide them into three classes:

1. Those of explorers at the end of the eighteenth and beginning of the nineteenth century.
2. Those in the middle of last century.
3. Those within the last twenty or thirty years.

Of the earlier accounts we may regard Bougner, De Saussure, and Humboldt as the types.

De Saussure describes symptoms occurring at from 10,000 ft. to 14,000 ft., and these are his words: 'Faintness, accompanied generally by vomiting, indescribable uneasiness, anxiety, thirst, no appetite, tendency to sleep.'

And he adds: 'This kind of fatigue is absolutely irresistible. . . . When I attempted to force myself, my legs gave out; I felt the approach of a fainting fit associated with violent palpitations; . . . my eyes grew dim. . . . The second peculiarity of this kind of fatigue is that one feels a complete restoration of the strength from the mere cessation of motion.'

Humboldt is responsible for the following symptoms at 17,300 ft.: 'One after another we all began to feel indisposed, and experienced a feeling of nausea, accompanied by giddiness, which was far more distressing than the difficulty in breathing. . . . Blood exuded from the lips and gums, and the eyes became bloodshot. . . .' On another peak, though bleeding did not occur, he says: 'I was seized with such violent pain in the stomach and overpowering giddiness that I sank upon the ground in a state of insensibility, in which condition I was found by my companions. . . .'

There were several papers written in the middle of last century by many observers, both English and foreign, and out of these I have selected Dr. Speer's in the 'Association Medical Journal' for 1853, as this gives the greatest variety

of symptoms, most of which are common to the other accounts. They are:

Somnolence, dizziness, vertigo, confusion of ideas, fulness in the head, headache, ringing in the ears, throbbing of carotids, palpitation, constriction of the chest, dyspnœa, syncopal tendency, occasional oozing of blood from mucous surfaces, increased rapidity of the pulse, anorexia, nausea and vomiting, thirst, loss of appetite, febrile tongue, muscular pains, sense of extreme debility in lower limbs, general prostration of strength.

These symptoms are said to occur at 9,000 ft., and at 10,000 ft. to be more marked.

I ought to mention in this class the opinion of the Italian physiologist, Angelo Mosso, for, although recorded at a later date, his views coincide more with the writers of this period; and without quoting largely from his exhaustive work I can best indicate his opinion by the following passages, which are constantly occurring.

He says (p. 144): 'Many people show symptoms of mountain-sickness at these inconsid-rable heights (Little St. Bernard, 2,513 m). Some stop from time to time during the last part of the climb and arrive panting. They are unable to eat . . . and have a feverish feeling'

'Dr. Courten, of Zermatt, told me of a lady who had had an attack of mountain-sickness on the Riffelalp, and of another who had suffered on the Gornergrat. He examined these ladies, but found no defect of the heart in either of them.'

He takes De Saussure's account as one of his types, and also quotes Tscudi's experiences in Peru, which are 'indisposition, such as I never felt before . . . increased discomfort at every step . . . had to stop to draw breath without being able to find sufficient air to relieve me . . . an oppression . . . palpitation . . . breathing short and broken . . . lips chapped, little blood-vessels of the eyelid burst . . . senses became inert,' &c. He also mentions Professor Kronecker's experiences on the Zermatt Breithorn: 'All felt well when they remained motionless and at their ease . . . pulse more rapid . . . the most important and most appreciable symptom was the pernicious influence of the slightest movement . . . palpitation of heart . . . and oppression in breathing.' On Monte Rosa Mosso says there were several of the party who suffered from nausea and vomiting, violent headache, physical prostration, with loss of appetite and sleep. He also says, 'Cold predisposes to mountain-sickness and aggravates its

phenomena.' 'When the snow is deep and soft, so that one sinks into it up to the knees, travellers suffer more from mountain-sickness.' Again (on p. 232): 'This convinced me that mountain-sickness may appear in all at not very great altitudes.'

The descriptions given by those in the third class are well known to most of us, and therefore I need not here do more than extract from their writings their leading symptoms.

Mr. Whymper in the Andes suffered from acute symptoms at an altitude of 16,664 ft. without any previous exertion. They appeared quite suddenly, and were as follows: Accelerated respiration with spasmodic gulps, accelerated action of the heart, general malaise, and incapacity for exertion, intense headache, rise of temperature. These more acute symptoms pass off after a certain time, leaving general feeling of lassitude and disinclination for exertion, accelerated respiration and accelerated action of the heart, with tired feeling in the lower limbs on the slightest movement.

Sir W. Martin Conway, in the Himalayas, mentions his experiences in many passages in his book, from which we gather the following prominent symptoms: Feeling of discomfort, headache in all members of the party, accelerated heart's action, accelerated respiration, disinclination for exertion. These appeared at about 17,000 ft. At 23,000 ft., he says: 'We ceased to pant for breath the moment the need for exertion was withdrawn, and a delicious lassitude and sense of forgetfulness of past labour supervened on our overwrought frames. . . . All felt weak and ill, like men just lifted from beds of sickness.'

Mr. Douglas Freshfield mentions his symptoms in the Caucasus and Himalayas, which can be best described by quoting from a private note in answer to my inquiries as to his experiences. He says: 'Lassitude is the only distinct effect in my own case, *not* increased with height over 15,000 ft., varying on different days and sometimes absent altogether.'

Mr. E. A. FitzGerald describes symptoms which generally took the form of disinclination for exertion. At 16,000 ft., after a hard day's work up a slope of loose stones, he says he suffered acutely from nausea, inability to catch his breath, dry throat, unpleasant feelings of choking . . . difficulty in breathing at night. After remaining several days over a fortnight at altitudes ranging from 18,700 ft. to 23,000 ft. he suffered from the following symptoms during a climb: Incapacity for exertion, accelerated respiration, accelerated

action of the heart, nausea and giddiness. But on this occasion it was very cold, and the party had not partaken of proper nourishment.

The Duke of Abruzzi in his ascent of Mt. St. Elias says that six out of ten in the party were more or less acutely affected. Legs felt as heavy as lead, there was difficulty in breathing and a sense of suffocation, palpitation, throbbing of the temples, and headaches. He draws attention to the fact that it was a slow and monotonous climb, and says: 'It seems to me that the attacks of mountain-sickness experienced by our party were chiefly caused by our long and difficult marches over snow and ice, and weeks of over-fatigue and discomfort we had gone through.'

Mr. and Mrs. Bullock Workman, in the Himalayas, say: 'We both felt quite fit at the summit (19,000 ft.), experiencing no ill-effects from the rarefied air beyond mild headaches, and at once losing breath on sudden exertion.' Zurbriggen was perfectly well.

On reviewing these various descriptions we notice at once that although within the last twenty years or more the number of climbers at increasingly high altitudes is considerably augmented, yet the number of symptoms described by them as inevitable has materially diminished; and, moreover, it is an important point to learn from the more recent accounts that although it often happened that all members of the party were affected at about the same altitude, this was not necessarily the case, and frequently large numbers of individuals were entirely unaffected by the diminished atmospheric pressure. You will also observe the absence of such symptoms as hæmorrhage from nose and mouth, and vomiting.

We can, without much difficulty, reduce the symptoms which we may call unavoidable to the following:

1. General lassitude and tired feeling in the extremities, especially the legs, with disinclination for the slightest exertion when at rest.

These symptoms are aggravated when in motion with the addition of—

2. Increased respiration, accelerated heart's action, feeling of oppression in the chest, sometimes headache, nausea and vomiting.

The crux of the whole matter lies in the question: Are all symptoms as above described by all classes of observers to be regarded as mountain-sickness, irrespective of conditions, altitude, or individuality? If this interpretation of the

complaint be allowed to remain, it complicates interminably the study of the subject, and places an unjustifiable responsibility on the mountains, which I venture to suggest is, to say the least, unscientific. For instance, to say that an individual who partakes of some indigestible food and suffers accordingly is afflicted with indigestion at sea-level, and mountain-sickness if it occurs during climbing, appears to me not only unreasonable but absurd.

Now the first point in treatment is to make an accurate diagnosis, if possible, without which all treatment is empirical and liable to failure; and, in my opinion, it is the non-recognition of this fact which has led to so many conflicting statements met with in connection with Alpine physiology, notably in such a work as Mosso's 'Life of Man in the High Alps;' but in whatever light we regard Professor Mosso's book, and however much we may differ from him in his conclusions, one is bound to acknowledge that it is an admirable record of most painstaking observations under exceptionally difficult circumstances.

The method of approaching any case is much the same in all branches of medicine and surgery.

1. The history and symptoms from the patient's point of view.
2. Our own observations, and the physical signs.
3. Diagnosis from other diseases presenting similar symptoms (or, at any rate, the same leading symptoms).
4. Pathology, or physiological cause.
5. Finally, prognosis and treatment.

The most difficult cases to diagnose are those which possess no specific symptom or symptoms marking them out at once as distinct from any other, or where they present one or more symptoms common to several diseases.

All medical men are aware that there are many cases which always present the same leading symptoms, such as, for example, meningitis, tumour of the brain, and renal disease; or, again, the different varieties of coma; and I could mention several others; and it is only by studying carefully other collateral evidence as to history, conditions, further symptoms or the absence of them, that one is enabled to arrive at a satisfactory diagnosis, and often this is an impossibility even though furnished with these additional data.

The symptoms associated together in a case of so-called mountain-sickness strike us at once as being of a most ordinary type, and ones which are continually arising in connection with many diseases at sea-level; and the more

diseases there are presenting the leading symptoms of this complaint, the greater will be our difficulty in diagnosis, and the more trouble we must take in weighing minutely all collateral evidence.

Physical and mental fatigue, anæmia, neurasthenia, febriculæ, dilated heart, commencing degeneration of circulatory apparatus, are some of the cases which produce exactly the same symptoms as those we have before us for discussion; and it is, therefore, at once evident that we must, if possible, eliminate any of these conditions which from the nature of things is likely to appear and create complications.

Even the very earliest writers, over a hundred years ago, recognised the possibility of fatigue complicating the symptoms of mountain-sickness, and many observers of later years have drawn attention to the same difficulty.

The greatest amount of work a man *can* do is to raise his body-weight through a definite number of feet; and this fact, together with the various groups of muscles brought into play on mountaineering expeditions, lends itself peculiarly to the development of this particular form of complaint.

It is a matter of common medical knowledge that the symptoms complained of in anæmia, senile change, or any pathological defect, such as dilated heart, are at sea-level aggravated by excessive exertion, and often by the least movement, producing, as we say, a condition of fatigue; and on this account rest is the recognised form of treatment adopted in such cases.

We need, therefore, only concern ourselves with fatigue in the healthy subject.

Dr. Pavy, in an interesting paper in the 'Lancet,' 1876, on 'The Effect of Prolonged Muscular Exercise on the System,' describes experiments performed on Perkins and Weston, and Perkins having walked 65½ miles in 29 hrs., at the rate of 4½ miles an hour, with two short halts of half an hour each, was obliged to give in, suffering from fatigue, which showed itself in the following way: a tired feeling in the limbs; rapid, feeble, and irregular pulse; general malaise; rise of temperature; vomiting.

I have read numerous other papers on this subject, describing symptoms and entering into their pathology; notably by Professor Clifford Allbutt, Messrs. Roy and Adami, Mosso, Tissie, Dr. Haig, Dr. Hutchison, and others; but I would draw your attention to one mentioned in Mosso's book (p. 78), where Janetti, a soldier in the Professor's party, walked 36 kilometres in 10 hrs. 22 min., taking 3 hrs. halt

in the middle, with a weight of 22 kilogrammes. Here the symptoms noted were: palpitation, loss of blood-pressure, feeling of lassitude, finally fainting.

Another author on fatigue, Salvioli, in his 'Influence de la Fatigue sur la Digestion stomacale,' speaks of the effect of fatigue on the digestive fluids; and demonstrates that their power is, under the circumstances, greatly diminished, but that they quickly recover after a short rest.

Although it is a matter of doubt, and the authors of articles on fatigue often hold exactly opposite opinions as to the cause, I notice that they all agree in their accounts of the symptoms themselves. Fatigue may be produced in two ways:

1. Directly; either by (*a*) excessive mental exertion, or (*b*) excessive bodily exertion.

2. Indirectly; by depriving the tissues of proper nutriment, and so allowing metabolism (wear and tear) to proceed without adequate compensation. This may again act in two different ways: (*a*) by not supplying digestible food in a suitable form; (*b*) by the organs, principally the stomach, not being strong enough to deal with the food supplied to it.

The symptoms of fatigue are much the same in any case, whether they are the result of direct or indirect causes, and I have observed that in nearly all accounts nausea and vomiting are included. This constitutes an important point, of which there are very few, in the diagnosis between this condition and what we may call true mountain-sickness. On comparing the cases of fatigue with those of mountain-sickness as described by many of the earlier writers, one is at once struck with the similarity; and, in fact, so much so, that one is forced to admit that there is very little collateral evidence, if any, to enable us to make a clear diagnosis between the two. It is true they occur on the mountain-side, but at a height where the oxygen of the air is amply sufficient for the needs of the tissues, both at rest and under active exertion, and where the mechanical effect of reduction of pressure can be clearly proved not to produce its influence even when rapidly applied, as shown by aëronaut and laboratory experiments; and moreover under circumstances which, in almost every instance which I have looked into, specially predispose towards the development of fatigue. And again, can we accept without question the constantly recurring statement that mountain-sickness, acknowledged by nearly every writer to be due in some way to diminished atmospheric pressure, should show itself at moderate altitudes and disappear entirely several

thousand feet higher up on the same day? On these grounds I have come to the conclusion that the symptoms complained of below a certain height are due to fatigue alone, caused in some of the ways above mentioned; and I am still audacious enough to assert that I see no reason to regard any of the symptoms described by mountaineers below a given height (that height at present undetermined, but certainly not lower than 16,500 ft.) as applying to mountain-sickness.

But assuming for the present that the symptoms appearing above this height may be the result of some condition of the atmosphere due to reduction of pressure, what modifications of the ordinary atmosphere do we find at higher altitudes likely to account for their development?

There are two results to be obtained from reduction of atmospheric pressure—one is the mechanical effect produced by diminishing the ordinary pressure on the body of 15 lbs. to the square inch, and the other is the chemical effect on the blood of the change in density of a unit volume of the atmosphere.

Both these changes may produce different effects, according as they are applied rapidly or gradually. In order to appreciate the results on the human subject of any change relative to the mechanical pressure of the atmosphere, we must consider why it is we do not feel the normal pressure of 15 lbs. to the square inch. The answer is because the pressure is equal and opposite in every direction, and owing to the ordinary permeability of the tissues this is exerted inside as well as outside the body; and time has not only acclimatised us to that pressure, but also the physiological mechanism is so arranged as to work without hindrance between these two forces which it has learnt to disregard.

It must be at once apparent that if the tissues can resist and work at a pressure exerted against them of 15 lbs. to the square inch, they could equally well perform their functions under a pressure of nothing to the square inch, given a sufficient time for acclimatisation. Whether there is a limit to the powers of resistance of the tissues as regards augmentation of pressure I have not yet satisfactorily determined, but in all probability there is such a limit. The difficulty, however, in deciding this point is that if the pressure be increased beyond a certain amount (according to experiments on animals by M. Paul Bert) the chemical effect asserts itself before the mechanical, and produces death by interference with the metabolism of the tissues and the giving off of carbonic acid.

When I speak of the chemical result of reduction of pressure I refer principally to the diminution of oxygen (per unit volume), since this is the main element in the atmosphere upon which the tissues of the human body depend for reconstruction after metabolism.

It is not out of place at this stage to bring to your notice other methods of studying the effect of reduction of pressure on the human subject. These are three in number:

1. In cases of compressed-air illness or caisson-disease.
2. Aëronaut experiments.
3. Laboratory experiments, conducted under bell-jars, from which the air is exhausted by some mechanical means;

and it is not surprising that investigators on the subject of mountain-sickness should turn their attention to these cases in the hope of finding a way out of their difficulties, since these methods are easier of access and more adapted for experiment than the mountains.

The first class comprise those cases of illness occurring in men who have been working in the caissons at a greatly increased pressure (often $3\frac{1}{2}$ to 4 atmospheres), and who are allowed too quickly to return to the normal pressure of the atmosphere, and the symptoms which result from it have been the subject of a good deal of discussion by various writers. Dr. Snell, the medical officer in connection with the Blackwall Tunnel, has given an excellent epitome of most of the writings and theories up to the time of the publication of his book four years ago. There is practically a unanimous agreement regarding the symptoms, the difference being more a matter of degree than of kind; and they are as follows: Sudden pain occurring in some part of the body, generally one of the joints, the knee being the commonest; giddiness, sometimes amounting to a definite form of vertigo; often paralysis of lower limbs; paralysis of bladder and rectum; and occasionally coma and death.

The symptoms always occur *after* the men have gained the ordinary atmospheric pressure, usually within half an hour of their arrival at the surface, and never while they are *in* the caissons. The milder cases clear up in a few days, the majority in from three to twelve; but some last for several weeks, the longest with recovery being five or six weeks.

If, *immediately* on the appearance of the symptoms, the patient be subjected to recompression, improvement takes place rapidly, and if decompression be repeated more slowly than before the symptoms do not as a rule recur.

Although there is not such complete accord with regard to

the cause of the complaint, yet from the *post-mortem* examinations on men and animals, and from experimental work, there is a decided leaning in the majority of accounts towards one particular theory, and that is that it is due to the liberation of gas dissolved in the blood and lymph under mechanical increase of pressure, which finds its way into the intercellular spaces; this causes minute emboli (obstructions in blood-vessels), which may constitute a serious hindrance to the circulation in various parts of the body, producing different effects according to the position and consistence of the organ in which such obstruction occurs. It only requires a further stage in this mechanical influence on the tissues to imagine the formation of hemorrhages, which is indeed said to occur, and has been found *post-mortem*.

We have several records of balloon ascents during the last hundred years, and the symptoms complained of by aëronauts are of the following type: Giddiness and fulness in the head; nausea; accelerated respiration and heart's action; dimness of vision; powerlessness to perform any voluntary movement; sometimes eyes and lips full of blood, followed by coma and death.

It is to be observed that, as a rule, no pain is complained of as in caisson-disease, but the symptoms are more marked the more rapidly the balloon ascends, and show themselves usually about 21,000 ft. to 25,000 ft. The reduction of pressure in aëronaut experiments is necessarily of an extremely rapid nature up to a certain height, and there is reason to believe that when symptoms occur they are due to the combination of the mechanical and chemical effect. Inhalation of oxygen produced a marked improvement on all occasions when it was used, enabling aeronauts to reach an altitude of 27,000 ft. and upwards in comparative comfort.

In the well-known fatal balloon accident in 1875, the two aëronauts who died were found in the car with their mouths full of blood, and with a certain amount of oxygen still remaining in the bag, at a height of only 22,750 ft., thus suggesting that the mechanical effect of reduction of pressure was the cause of death.

The symptom that stands out as specially belonging to aëronauts, and equally characteristic of laboratory experiments, is the powerlessness to perform any voluntary movement, although the conception of volition is still unimpaired; and the remarkable point about this pseudo-paralysis is that, in the case of Mr. Glaisher in 1862, this symptom improved higher up, and the desired movement was accomplished.

This unmistakably gives us the pathology. Dr. Marcet, a member of this Club, has demonstrated that the supply of an adequate amount of oxygen to the motor centres of the brain is of more importance than the supply of that gas to the muscles themselves; and the sudden deprivation of oxygen occurring under these conditions prevents the initial stimulation from the motor area.

The symptoms recorded in laboratory experiments are much the same as in the case of aëronauts, though of a milder type; and it is probable that here we have less of the mechanical effect than the chemical, though I am still inclined to think that, as such experiments have hitherto been performed, the reduction of pressure is too rapid to entirely eliminate the mechanical influence. In M. Paul Bert's and Signor Mosso's experiments the whole period was seldom longer than three or four hours, and often much less; but when symptoms do begin to show themselves, inhalation of oxygen has produced decided improvement, though not in every case. In one or two instances, however, it was a complete success, and enabled the experimenters to sustain pressures as low as we shall ever require.

In 1895 I pointed out that the conditions under which symptoms show themselves in these three classes of cases are totally different from those of mountaineers; and since that time many other writers have made the same observation, so that some—*e.g.* Loëwy and von Schrötter—have marked the distinction by speaking of 'air-rarefication' and 'air of the heights' (mountains).

In the first place, there is no element of fatigue to eliminate; in the second place, reduction of pressure has been performed rapidly, the longest period being two or three hours, so that probably an insufficient time has been allowed for acclimatisation to the mechanical change of pressure; in the third place, the time during which subjects remain at the reduced pressure is generally very short, often only a few minutes—a time during which most people could exist without much discomfort; in the fourth place, the low temperature of the air is a factor to be considered on the mountains and in aëronaut experiments, but is absent in the laboratory; and I would draw your attention to the results of inhalation of oxygen, which were sometimes disappointing and only partially relieved the symptoms; and this is likely to be the case if the effects are partly due to the mechanical reduction of pressure and partly to diminished supply of oxygen.

Under these circumstances it is difficult to see how such

experiments will help us, except indirectly, in discovering the cause of mountain-sickness; and it is, I think, partly because investigators attempt to account for all the symptoms resulting from any kind of reduction of pressure by adopting one common theory, that there is so much difference of opinion, and that the subject has assumed such a complicated aspect.

The question of acclimatisation to changes of pressure is an interesting one, and one that requires our careful consideration.

Mr. Whymper was the first to attach importance to this part of the subject in mountaineering, and conducted his investigations in the Andes with this special object in view. Acclimatisation may be studied in its relation to the passage from the ordinary atmosphere to a higher pressure and the reverse process, and also from the ordinary atmosphere to a lower pressure and the reverse process; and these two conditions may be further dealt with according to their mechanical or chemical influence, or both.

We have an opportunity of studying the purely mechanical effect apart from the chemical in cases of compressed-air illness, since there is plenty of oxygen in the inspired air for the needs of the tissues in whatever position the men find themselves.

The whole study of compressed-air illness turns on the question of acclimatisation, and the point to decide is what length of time is necessary in passing from one pressure to another. In reviewing a series of cases one notices several facts which are full of interest. First, the longer the men remain in the caissons the more liable they are to suffer from the complaint, and the more serious the symptoms, when they return to the ordinary pressure, unless the 'lock-out' period be correspondingly lengthened; secondly, the men who attend the 'lock-out' mechanism, and are therefore continually passing from one pressure to another without remaining long in any, never suffer from the disease at all; thirdly, they never suffer while *in* the caissons, however long they stay, but only on returning to the ordinary atmospheric pressure. It has been found that eight hours is about the time that the men can work comfortably and return to the ordinary atmosphere, with a 'lock-out' period of ten to fifteen minutes, free from the fear of development of symptoms.

From these facts we may fairly deduce the following conclusions:

1. That the mechanical acclimatisation to a higher pressure of about three atmospheres is not complete in eight hours.

2. That the mechanical and physical acclimatisation from a higher to a lower pressure is probably of a comparatively

short duration. This receives support also from aëronaut and laboratory experiments (*vide* Paul Bert's work).

3. That although acclimatisation takes place more slowly from a lower to a higher pressure, there are no symptoms attending it. We have again an analogous state of affairs in aëronaut and laboratory experiments where the return from a greatly reduced pressure to that of the ordinary atmosphere is performed very rapidly without being marked by any particular symptoms.

In applying these principles to mountaineering, which essentially belongs to the gradual type of reduction of pressure, we are obviously well acclimatised to the ordinary atmosphere; we then proceed, by adopting a 'lock-out' system extending over a period of hours, and often days, to pass gradually to a lower pressure. Guided by the points and conclusions I have just now dwelt upon, one is led to believe that not only is it possible for the functions of the body to work without hindrance in the absence of atmospheric pressure (provided the necessary amount of oxygen be supplied), but that what we have called the 'lock-out' period is amply sufficient for the acclimatisation of the mechanical effect of the difference in pressure. It occurred to me that, in order to test this point satisfactorily, any experiments performed at sea-level must conform to the type of gradual reduction of pressure found in mountaineering. As far as I can make out from records of laboratory work, no one up to the present has attempted to prolong their experiments over several hours; and to this end I made inquiries regarding bell-jars, &c., but with the disappointing results mentioned at the beginning of my paper.

Largely supported by my observations on acclimatisation, I take it that, in all probability, we have only the chemical side of the question to discuss; but before entering into this part of the subject, I will briefly summarise the various theories already put forward.

One of the earliest theories was that of De Saussure, which was expressed by him in the following words: 'Relaxation of the vessels, which arises from a diminution in the compressing power of the air.' This obviously only accounts for a very small part of the symptoms, and that not a very important one.

M. Brachet, another of the earlier writers, explains some of the symptoms by saying that 'during the act of locomotion those muscles which are contracting remove the oxygen of the blood which traverses them more rapidly than those

which are at rest; hence the necessity for an accelerated respiration.' This is reasonable as far as it goes, but it only accounts for one special symptom.

Dr. Speer, whose account of symptoms we have already mentioned, based his opinion on the following hypothesis which he established as a fact: 'In an ordinary state of health there exists in the intestines a certain quantity of gas, intended to counteract the pressure of the external atmosphere upon the parietes of the abdomen.' He therefore concludes, 'These symptoms may be referred to a three-fold source—viz. a gradually increasing congestion of the deeper portions of the circulatory apparatus, increased venosity of the blood, and loss of equilibrium between the pressure of the external air and that of the gases existing within the intestines.' This mechanical theory assumes that the gases within the intestines are a constant quantity which would not otherwise be able to counteract the normal uniform pressure of the air without our feeling discomfort.

M. Paul Bert's opinion, expressed in 1878, was that diminution of oxygen per unit volume accounts for all symptoms produced in any case of reduction of pressure, based upon numerous experiments performed in the laboratory on animals and on human subjects, together with several balloon ascents. It would take far too long to enter even superficially into M. Bert's great work, but the evidence he brings forward substantiates to a great extent the truth of his theory, though he persistently refuses to acknowledge the mechanical effect of diminished pressure.

Mr. Whymper, in his 'Great Andes of the Equator,' entered minutely into his own symptoms as far as his physiological knowledge was able to guide him, and he is to be congratulated on the admirable way he handles the subject in many parts of his book, considering the disadvantages under which he worked. After describing the symptoms, he says: 'The whole of these, doubtless, were due to diminution of pressure; but the transitory ones, presumably, were produced by some cause which was itself temporary. There are strong grounds for believing that they are due to the expansion (under diminution of external pressure) of gaseous matter within the body, which seeks to be liberated, and causes an internal pressure that strongly affects the blood-vessels. While equilibrium was being restored between the internal and external pressure, "the indescribable feeling of illness" gradually disappeared and headache died away; and it may be reasonably expected that these acute troubles can

be escaped by taking pains to avoid abrupt diminution of pressure. From the permanent effects there is no escape,' &c.

His opinion evidently is that his acute symptoms were caused by the mechanical effect of diminution of pressure, and the chronic symptoms by reduction in volume of oxygen inspired.

It seems to me that the reduction of pressure in his case was too gradual to produce such a sudden evolution of gas in the body; for in caisson-disease the longest 'lock-out' period is three-quarters of an hour, and in the majority of cases ten minutes is considered sufficient to prevent the appearance of symptoms which are generally acknowledged to be due to sudden dissociation of gas from the blood.

Professor Clifford Allbutt at one time attached particular importance to dilatation of the heart as a cause of the symptoms, but in his book on Medicine published in the last few years he is inclined to think rather less of it, regarding it as a result of fatigue, and not a cause of mountain-sickness.

Mr. Clinton Dent considers 'the effect of diminished pressure on the portion of spinal cord concerned with the nutrition of the lower limbs is a far more important matter than the effects of pressure on internal organs.' He says in an article on 'Influence of Science on Mountaineering,' in February, 1895, 'The circulation in the portion of the spinal cord, or marrow, immediately concerned with the innervation of the lower limbs becomes greatly disturbed. The partial loss of power in the lower limbs is brought about in this wise: The blood collects and stagnates in this portion.' I gather from this that he concludes that a sort of hypostatic congestion of this part of the cord takes place, which accounts for the symptoms. This is therefore a mechanical explanation, but one somewhat difficult to verify.

Professor Roy, on Sir W. Martin Conway's symptoms, says: 'So far as the symptoms are concerned we need, therefore, be in no difficulty regarding the nature of mountain-sickness. It is asphyxia. The important feature in the asphyxia of mountain-sickness is the reduction in the amount of oxygen supplied to the tissues, but the same effect is produced if, with a limited supply of oxygen to the system, there be from any cause an increased demand for it by the tissues.'

Had the term 'anæmia' been substituted for 'asphyxia,' I think it would have been more intelligible, since the latter suggests somewhat more alarming symptoms than one ordinarily meets with.

Several observers, Viault, Schaumann and Rosanquist, Lawrinovitsch, and others, claim to have found changes in

the quantity of hæmoglobin at high altitudes, and in this way account for the appearance and subsequent disappearance of the symptoms; but there are as many equally positive on the other side. The true explanation of these apparently conflicting observations will be referred to later on.

Angelo Mosso considers the fact that there is less carbonic acid in the blood at high altitudes accounts for the appearance of the symptoms, and he maintains that the experiments he has performed have demonstrated this conclusively. As regards this theory, called by him 'Acapnia,' Dr. A. Loëwy has found that 'it is not borne out by his own experience in the laboratory or in mountain-climbing.' The actual diminution of carbonic acid in the blood at high altitudes may or may not be true, and a point upon which there is great difference of opinion, the tension of that gas in the blood being a very variable quantity under any circumstances; but, be that as it may, it requires an effort to believe that a gas which is undoubtedly of an excretory nature can be of such vital importance to human life.

Professor G. von Liebig's theory is based upon the mechanical effect of reduction of pressure on the lungs themselves, producing a more contracted state of these organs, and so stagnation of the venous circulation through them. This necessarily leads to accelerated respiration.

Dr. A. Loëwy considers that anæmia of the brain wil adequately account for the symptoms.

Von Schrötter, 1899, discusses the subject from a chemical point of view, and contributes an interesting article dealing with it much in the same way as I am doing to-night; but he enters into details which time prevents my touching on.

He recognises mountain-sickness as possible in the Alps. He says, 'Height as such is no criterion, but on the whole mountain-sickness appears to set in latest (*i.e.* at greatest height) in the Himalayas, earlier in the Andes, and earliest in the Alps. Thus:

Himalayas: 4,900 to 5,200 m.

Andes: At 5,100 m.

Alps: Mountain-sickness can occur at 3,000 m., declares itself strongly at 3,500 m., and spares nobody at 4,000 m.

'It cannot be doubted that many of the cases ascribed to mountain-sickness under a level of 4,000 m. are in reality not attributable thereto. The symptoms may naturally be produced by physical over-exertion in an unwonted environment, or as a consequence of unfavourable conditions of nutriment,' &c.

Then he says: 'The fact that oxygen consumption is greater in the high levels, and that exertion is inseparably bound up with oxygen consumption, makes it apparent that fatigue will declare itself sooner at high levels than on the flat.'

It is impossible to enter into and discuss all the theories expressed, but these are sufficient for our present purpose, and you will notice there is a great variety of opinion.

I think I am right, however, in stating that all those who have written on the subject regard fatigue or any physical defect as predisposing towards mountain-sickness, and not a distinct form of complaint likely to arise as a complication.

I hope you have been able to follow me in my endeavour to focus my remarks up to what I consider the only part which diminished atmospheric pressure plays in the study of mountain-sickness—viz. the relation of the deficiency of oxygen to the blood both from the view of pulmonary absorption and acclimatisation; and I trust you will pardon me if I enter briefly into the physiology of respiration to enable you to understand the rest of the paper.

The mechanism of respiration may be described shortly as follows:

By rhythmical expansion and contraction of the chest, air charged with oxygen is taken into the lungs through the air-passages, and air charged with carbonic acid is given out. This action is automatic under control of a nerve centre in the brain, but at the same time is capable of alteration by means of volition. The automatic action is partly dependent upon the amount of oxygen in the blood flowing through this centre, and partly due to nerve action exercised through the terminal branches of the pneumogastric nerve in the air-cells, which are so arranged that when expiration has arrived at a certain point it exercises a stimulus to the ends of the nerves which is conducted to the brain, subsequently producing an inspiration. The oxygen of the air, which is the only gas contained in it that we appear to want, on arriving in the air-cells finds it way into the blood in the vessels surrounding them, and combining with the red blood corpuscles enters the circulation, and so is carried to the various tissues of the body, muscles, &c., and there stored up for future use; and no oxygen can be extracted from the tissues when they have once got hold of it. At the same time carbonic acid, which the tissues are ready to give up as a result of their metabolism, is brought away by the blood to the lungs, where this gas is given up to the air in the

alveoli (air-cells) and is expired. The oxygen is held in the blood partly by following the ordinary law of solution of gases in liquids, and partly by loose chemical combination with the hæmoglobin, while on the other hand carbonic acid is held in the blood partly by some chemical combination (at present imperfectly understood), but chiefly by solution, following the ordinary law. It is probable, therefore, that, subject to certain modifications into which it is not necessary for me to enter here, the carbonic acid in the blood would be more influenced by reduction of pressure than the oxygen, and this is generally found to be the case (see Mermod (1878) and Marcet's works).

The difficulty of determining whether the symptoms complained of by mountaineers above a certain height really constitute mountain-sickness, in addition to the complication of fatigue, is threefold. One is, that it does not yet appear to have been determined at what height the oxygen of the air becomes insufficient for human life.

It has long been an old-established physiological fact that, when blood is exposed to a gradually decreasing percentage of oxygen, the blood corpuscles at first only give off a small proportion of the oxygen they contain, but that when the percentage has reached 10 per cent. in the inspired air there is a sudden dissociation of the gas in large quantity.

Setschenow, of St. Petersburg, in 1880 demonstrated that when the atmospheric pressure is reduced to about one-third of the normal, corresponding to an altitude of 28,800 ft. to 29,500 ft., the variations in the chemical absorption of oxygen by the blood is quite insignificant even at the temperature of the body. Very trustworthy experiments were also performed by Geppert and Fränkel in 1883 at Berlin, by which they reached the conclusion that the blood of a living dog at half that of the normal pressure, corresponding to 380 mm. of mercury, showed on the average a slight diminution in the proportion of oxygen, but this was not so great as to be beyond compensation by an augumented respiratory activity. And, again, Hüfner, in 1890, proved that the chemical relation of the oxygen in the blood only began to alter at a pressure of 238 mm. equal to 9,345 m., corresponding to an altitude of 30,607 ft. It is also an acknowledged fact that the relative power of absorption of oxygen by the blood increases as the pressure is reduced; that is to say, as long as there is any oxygen at all remaining in the pulmonary alveoli, the corpuscles of the blood, by means of their selective power, will still take up oxygen and attempt, as far as

possible, to supply the needs of the tissues, the amount of that gas absorbed being dependent, not upon the chemical interchange through the lungs, but upon the demands of the various tissues themselves. Hence we may conceive of a condition of things when the blood will continue to take up oxygen until there is none left in the alveoli; and we are given to understand that the limit of the atmosphere (presumably where there is no oxygen) is 40 miles above sea level, corresponding to a height of 237,600 ft., which I dare not say is beyond the ambition of the Alpine Club, but where it would not be becoming to pursue physiological investigations as to our feelings when our time comes to arrive at that altitude.

I mention these points in order to show that nature has allowed us a very wide margin in which our respiratory mechanism can do its work satisfactorily to the tissues during rest, and this margin is again further widened by some recent physiological facts which have come to light. And this constitutes our second difficulty—viz. that it is not yet decided what the average amount of oxygen is that the tissues need, nor the minimum quantity they can exist on at rest; but we do know that by training the corpuscles can be made to carry a considerably smaller amount of oxygen without any apparent discomfort to the individual. Drs. Haldane and Smith have during the last few years made some important experiments with reference to the oxygen capacity of different corpuscles and different layers of corpuscles, and also the varying capacity of different individuals. From these physiologists we learn that there are distinct differences amounting sometimes to more than 20 per cent. in the specific oxygen capacity of the corpuscles. Many observers have also demonstrated that there is an actual increase of red blood corpuscles at high altitudes, especially in those who remain for some days or months at considerable heights. Others again claim to have proved the contrary, or affirm that the apparent increase is only relative, due to concentration of the plasma which is always present whenever the atmosphere contains less moisture than normal. It appears, however, from the most recent experimental work that there is actual increase of red blood-corpuscles and hæmoglobin, though relatively less of the latter.

And yet another difficulty is that of transporting oxygen to the requisite height, in order to have it at hand as a form of treatment when the symptoms manifest themselves. But, judging from the physiological facts into which we have

just entered, there is a likelihood of its not being necessary; and as it entails a most serious addition to our burdens we are naturally anxious to avoid this if possible.

In spite of these difficulties in connection with what we may call the oxygen theory of mountain-sickness, I am prepared to prove that lack of oxygen is quite sufficient to account for the symptoms usually experienced and described by mountaineers above a certain height; and if there is a form of complaint entirely apart from fatigue and all its indirect causes which we must call mountain-sickness I believe that M. Paul Bert's theory regarding its causation is the correct one.

The sudden evolution of oxygen which I have described as occurring at a certain point when a solution of hæmoglobin is exposed in the laboratory to gradually reduced pressure will account for the suddenness of the appearance of symptoms, as in Mr. Whymper's case, and also the observation made by several climbers that they suffer more at a certain height than above or below this level. The recovery of this symptom must be due to the acclimatisation of the tissues to a smaller amount of oxygen. Deficiency of oxygen in the blood will also account for the accelerated respiration by acting upon the respiratory centre in the medulla oblongata. An additional reason for accelerated respiration is the circulation of an extra amount of carbonic acid in the blood, together with certain unknown chemical products, as the result of muscular action.

The feeling of lassitude, especially in the lower limbs, is due to the fact that, although oxygen is not necessary for the manifestation of muscular energy in the muscles themselves, it is absolutely essential for the maintenance of their irritability, and, therefore, during the slightest exercise the muscles immediately demand more oxygen, which the blood is not able to supply.

The disinclination for exertion is due to the deficiency of oxygen carried to the motor areas in the cerebral cortex, which have been shown by the late Dr. Marcet to depend for their functions upon an adequate supply of oxygen, and where Professor A. Mosso, by a very pretty experiment, has demonstrated that the phenomenon of fatigue is first felt.

The headache can be explained by almost any theory, but in the present instance we account for it by saying that the blood, poor in oxygen, circulating through the vasomotor centre in the brain, raises the blood pressure, which, combined possibly with the effect produced by cold driving the blood more towards the internal organs, throws extra tension on the cerebral vessels.

The rise of temperature, though difficult of explanation, may also be accounted for by poorly oxygenated blood acting in some way on the heat-regulating centre in the pons, and so upsetting the balance; but it is not a constant symptom, or may frequently be so slight as to escape observation.

An additional piece of evidence in favour of the oxygen theory is the fact that cases of anæmia at sea-level complain of precisely the same symptoms as climbers at high altitudes.

Since working at this subject I have observed carefully cases of anæmia, and noted their symptoms. In all we hear of the lassitude and tired feeling in the legs, with disinclination for exertion while at rest; while in motion the helpless feeling of the lower extremities, the accelerated heart's action, the accelerated respiration with sense of weight and constriction at the chest. The headache is a variable symptom, as in mountain-sickness; nausea and vomiting are comparatively rare. I cannot say I have observed any rise of temperature.

The conditions which modify the symptoms, and the height at which they manifest themselves, act only in so far as they alter the amount of oxygen taken into the blood.

1. *Temperature of the Air.*—The influence of cold upon the system constitutes a special department by itself, and one I cannot enter into here. But the effect of lowered temperature on the air will be to increase its density, other things being equal. Therefore, if for any reason the temperature of the air on one mountain is not the same as on another at the same level, the symptoms will appear at a higher or lower level respectively. On referring to Sir Martin Conway's experiences it will be noticed that at certain heights he suffered no symptoms so long as the air was cool, but when the temperature rose, although he remained at the same height, they immediately made their appearance.

2. *Condition of Air, whether at rest or in motion.*—The improved condition in their symptoms when sufferers meet a strong current of air has been frequently observed by many climbers, and the reverse effect of stagnant air is also well known, and has been often described.

3. *The Shape and Condition of the Mountain.*—This may have a certain amount of influence over the development of the symptoms, according as one side of the mountain is colder or warmer than another, thus altering the constitution of a given volume of the atmosphere at any particular height.

4. *Hygrometry.*—Undoubtedly the diminution of aqueous vapour in the atmosphere at high altitudes does affect the body in some way, but it has more to do with the relation of

cold to the development of fatigue than with the chemistry of respiration.

5. *Time of Day.*—It has been more than once observed that the symptoms are more likely to manifest themselves during the night when lying down, and are, contrary to expectation, relieved on getting up and moving about. I can only throw out the following suggestion to account for this phenomenon—namely, that owing to the lowered vitality which is always present at night, aggravated also by the cold and deficiency of oxygen on the mountains, the carbonic acid accumulates in the blood and produces dyspnœa, which is immediately thrown off easily under the influence of muscular action.

6. *Individuality.*—(*a*) Rate and extent of metabolism. (*b*) Oxygen capacity of the red blood-corpuscles in different individuals. (*c*) Normal rate and depth of respiration.

The extent and rate of metabolism represents the needs of the various tissues for oxygen; and we are well aware of the difference in the powers of endurance of different individuals.

A previous ascent seems to establish a certain amount of acclimatisation to any subsequent attempt on the same mountain, even though in the meantime the climber may remain for several days at quite a moderate altitude.

There is evidently a growing feeling, both on theoretical and practical grounds, that the symptoms in which we are specially interested can be entirely avoided by proper care and forethought, and there is much to be said in favour of this view of the case. However this may be, the proper course for us to adopt is to pay special attention to the preventive treatment of fatigue; but in laying down the following rules for the guidance of future explorers I purposely avoid referring to any physiological or pathological defect, since I regard it as absolutely essential that those who undertake this sort of work should be possessed of perfectly healthy thoracic and abdominal organs.

Our main efforts should be directed towards the performance of the least possible work under the circumstances, and this may be best accomplished by attending to the five following rules:

(*a*) *A system of muscular training*, both before and during the expedition. This ought, I think, to be in the form of walking regular distances each day, and uphill if possible.

(*b*) *Method of walking*, and slow going, occupying several days, if necessary, in completing the ascent, so as to allow ample time for acclimatisation.

(*c*) *Avoidance of any Nerve Strain.*—At first sight this may appear to you a rather unnecessary point to dwell upon, but the concentration of the mind on a definite object for a length of time is a common and fertile source of fatigue. The more difficult our ascent the more concentration of brain power will be necessary, and therefore, from the point of view of success, the easier our peak is the better.

(*d*) *Food.*—This I consider a most important point, and one which has not received the attention it deserves. Pure nerve power and endurance will carry us through a great deal, and this necessarily varies with each individual, but we have no right to draw on our powers of physical endurance; and, although it sounds thrilling on paper to say that we have been going so many hours without food or halts, and enduring great hardships, I am convinced this is not the way to conquer the highest mountain in the world.

Our food must be of the simplest and lightest description and at the same time nourishing, so as to obtain the maximum amount of nutriment with the minimum amount of work for the digestive organs.

The meals must be small and frequent, never allowing more than four hours to elapse without taking something.

As regards particular kinds of food, it is difficult to lay down any hard-and-fast line—a great deal depends upon the easy and convenient portability of various articles of diet; but we may learn several hints to guide us in our selection from an article on the dietetic part of training by Dr. Clifford Allbutt in the September 1896 number of 'Travel,' or from any training list in use at the universities. Our food will differ according to whether we are actively engaged in or only training for the expedition; in the former case, fats, sugar, and farinaceous food, in addition to albuminous, are of the utmost importance, though the combination of all in one meal is not desirable.

(*e*) The last rule, and by far the most difficult to carry out, is *the inhalation of oxygen*. This gas seems not only necessary to counteract the atmospheric deficiency, but also to compensate for the special demands made upon it by the muscles in order to avoid fatigue. That oxygen would be beneficial under the circumstances there is very little doubt; but the practical question to be decided is whether it is absolutely necessary, since we would prefer to do without it if possible, owing to the difficulty of porterage. As yet I do not feel competent to give a positive answer one way or the other. If we had not to use our muscles to accomplish an ascent, I

think we have reason to believe that oxygen would not be necessary, as the margin is evidently wide enough to allow for the demands of the tissues during rest up to 30,000 ft. or higher, and, moreover, we can become acclimatised to a smaller amount than usual; but to ascend a mountain in a balloon or by railway are not methods which commend themselves to members of this Club.

The method of carrying oxygen requires careful consideration, but I think it must be in the form of the compressed gas in metal cylinders, preferably small ones.

Provided he have plenty of time, plenty of suitable food, and fine weather, I see nothing unavoidable in the condition of the atmosphere at high altitudes to prevent a man with healthy organs from ascending the highest point on the earth's surface.

It only remains for me to acknowledge my indebtedness to Mr. Victor G. Plarr, the librarian of the Royal College of Surgeons, and Mr. W. M. Rorison, for their valuable assistance in translation work, and for their efforts in obtaining for me much of the bibliography which would otherwise have been difficult to secure; also to Mr. Clinton Dent for kindly looking through the paper and giving me the benefit of his experience to condense it into readable form.