MOUNTAIN-SICKNESS AND THE PHYSIOLOGICAL PROBLEMS OF HIGH ALTITUDE MOUNTAINEERING

By C. B. M. WARREN

It has long been known that people may be overcome by unpleasant symptoms on going rapidly to a great altitude. The malady is called mountain-sickness. The early travellers when they used this term referred to a condition which was often acute in onset and affected only those who made rapid ascents before they had got used to the heights. Since the advent of Himalayan mountaineering it has become apparent that a more insidious condition may overtake the climber at altitudes over 21,000 ft., even though he has acclimatised to such a degree that he is no longer in danger of falling a victim to the form of mountain-sickness known to the early travellers in the Alps. Both these conditions are due primarily to lack of oxygen in the atmosphere at great altitudes and should be termed *anoxia*. In the event of a mountaineer remaining up at an altitude greater than 21,000 ft. for any length of time it is found that he fails to acclimatise completely and a state of high altitude *deterioration* sets in.

Mountain-Sickness

A person suffering from mountain-sickness complains of a variety of symptoms, the commoner of which are difficulty with the breathing, giddiness, headache, dislike of the light and nausea which may end with vomiting. These symptoms rarely come on until an altitude of at least 10,000 ft. has been reached. Mountain-sickness can affect people even when at rest, as witness Barcroft's description of the state of the passengers in a train in the Andes; but on the whole it is more likely to attack those who have made an ascent on foot, thus expending muscular energy. Although acute, the symptoms may be delayed in onset, not making an appearance until 8 to 10 hrs. after exposure, by which time the climber may have descended from the heights. During the 1936 Mount Everest Expedition one of the climbers, soon after reaching Tangu (12,800 ft.), made an ascent of a mountain near the bungalow at that place before he was acclimatised. Throughout the climb he felt perfectly well, but some hours after he had descended to the bungalow he was overcome by severe headache, nausea and vomiting; symptoms typical of mountain-sickness.

During the Mount Everest expeditions mountain-sickness only occurs at the beginning of the journey to the mountain. The early marches bring the climbers steeply and rapidly from the plains of

India on to the high Tibetan plateau, and involve an ascent of 16,000 ft. within the first 70 miles. Later on the route to the mountain runs for some 200 miles across comparatively level country, but all the time at altitudes greater than 13,000 ft. After about ten days spent marching across the Tibetan plateau most of the discomforts occasioned by the altitude have gone.

There is no doubt that mountain-sickness is due, in great measure, to lack of oxygen in the rarified atmosphere at high altitudes; but to what extent other factors play a part in bringing on an attack is still largely a matter of speculation. Probably lack of training and severe exercise are important in this respect, but climatic changes may also play a part. For instance mountaineers have often remarked that under certain conditions of wind and temperature they are more disabled, and on the slopes of Mount Everest 'glacier lassitude' has often been experienced whilst ascending the central trough of the East Rongbuk Glacier.

A person ill with acute mountain-sickness is found, when examined carefully, to be breathing rather more rapidly and perhaps more deeply than usual. Often the respirations are periodic in character: the so-called 'Cheyne-Stokes' breathing. His lips, ears and finger-tips are cyanosed and look blue, but in other respects no abnormalities are found. The pulse rate is variable; sometimes it may be increased a little, but quite often it is abnormally slow. In the case of a member of the 1935 Mount Everest Expedition who was acutely ill with mountain sickness at 12,800 ft. the pulse rate was only 60 beats a minute. The heart when examined by the usual clinical methods appears to be normal.

A person who has had time to acclimatise does not usually suffer from mountain-sickness as described above, but on going higher than the altitude to which he is acclimatised he feels the effects of oxygen-lack in other ways.

In these circumstances the symptoms usually appear at altitudes above 21,000 ft., and remain present to a variable degree however long the climber remains at that altitude. Lassitude and a sense of muscular weakness are the most prominent features of the condition. At Camp III on Mount Everest I found that I always wanted to sit down and do nothing. I can only compare the feeling to that sense of weakness which is experienced on first getting up after a long illness. This lassitude together with a feeling of giddiness was often particularly noticeable on getting up in the mornings. Starting out for the day's climb always required a considerable mental effort, but once one had got going the lassitude seemed to wear off to some extent. Although the condition improved after a short period spent at Camp III, in my own case at any rate it never disappeared completely. When climbing on the N. Col the muscles tired more rapidly than at lower altitudes.

There was always a very distinct disinclination for serious mental work above 21,000 ft., whilst at extremely high altitudes such as 26,000 ft. a diminution in the acuity of vision has been reported. Often no visual disturbance is noticed at the time, but on descending to lower levels again a surprising increase in the brilliance of coloured objects is appreciated.

Sleep is often disturbed above 21,000 ft. This may to some extent be due to the altered respirations, for Cheyne-Stokes breathing is of frequent occurrence during sleep. At rest there is no very obvious alteration in the depth or frequency of the respirations, though in one individual they tended to be periodic even when he was sitting about in camp; and no difficulty is felt. On exertion a very marked increase in frequency takes place, which is out of all proportion to the amount of exercise taken, and dyspnoea may be a very prominent symptom.

Once acclimatisation has taken place there is no increase in the frequency of the pulse at rest below about 20,000 ft. But at altitudes greater than this it is always increased. On exertion the increase in frequency of the pulse is out of proportion to the work done. I have never myself observed a dilated heart on Everest, but they have been reported by Greene and others. On one occasion I have observed an irregularity in the heart's rhythm known as extra systoles.

Loss of appetite is a troublesome consequence of life above 20,000 ft. Climbers on Everest often fail to realise how little they are eating until made to write down the estimated quantities of the various things taken at each meal. Only then is it realised how inadequate their diet has been. Loss of weight follows, the weight lost being quickly regained on descending to lower altitudes such as 16,000 ft.

The Carriage of Oxygen in the Blood and its Function

Atmospheric air contains approximately 20 per cent. of oxygen, the remaining 80 per cent. being composed almost entirely of the inert gas nitrogen. Each of these gases exerts a pressure, and the pressure which it exerts depends upon two factors: the barometric pressure and the percentage composition of the mixture of the gases. When a man goes to a high altitude he has to breathe an atmosphere which contains less oxygen than there is at sea-level, though the proportion of oxygen to nitrogen remains the same: that is, oxygen still forms 20 per cent. of the atmospheric air breathed. What has altered is the barometric pressure, so that the pressure exerted by each of the gases composing the atmosphere has altered also.

At sea-level the average barometric pressure is 760 mm. of mercury. The partial pressure exerted by oxygen in the air at this level then is $\frac{20}{100} \times 760$, or about 150 mm. of mercury.

At 30,000 ft. the barometric pressure would be about 250 mm. of mercury, or about a third of the pressure at sea-level. The partial pressure of oxygen in the air at that altitude then would be $\frac{20}{100} \times 250$, or about 50 mm. of mercury.

Now the composition of the air in the alveoli or furthest spaces of the lungs is not the same as that of the breathed atmospheric air, because in that situation the breathed air is diluted with the waste gas carbon ·ide which is diffusing from the lungs; it is also saturated with ·pour at body temperature. By analysis alveolar air is found to contain about 14 per cent. of oxygen under normal resting conditions; and the pressure of aqueous vapour at body temperature is 47 mm. of mercury. From these data the partial pressure of oxygen in alveolar air at sea-level can be calculated and is $\frac{14}{100} \times 760 - 47$, or about 100 mm. of mercury.

TABLE OF OXYGEN PRESSURES AT DIFFERENT ALTITUDES

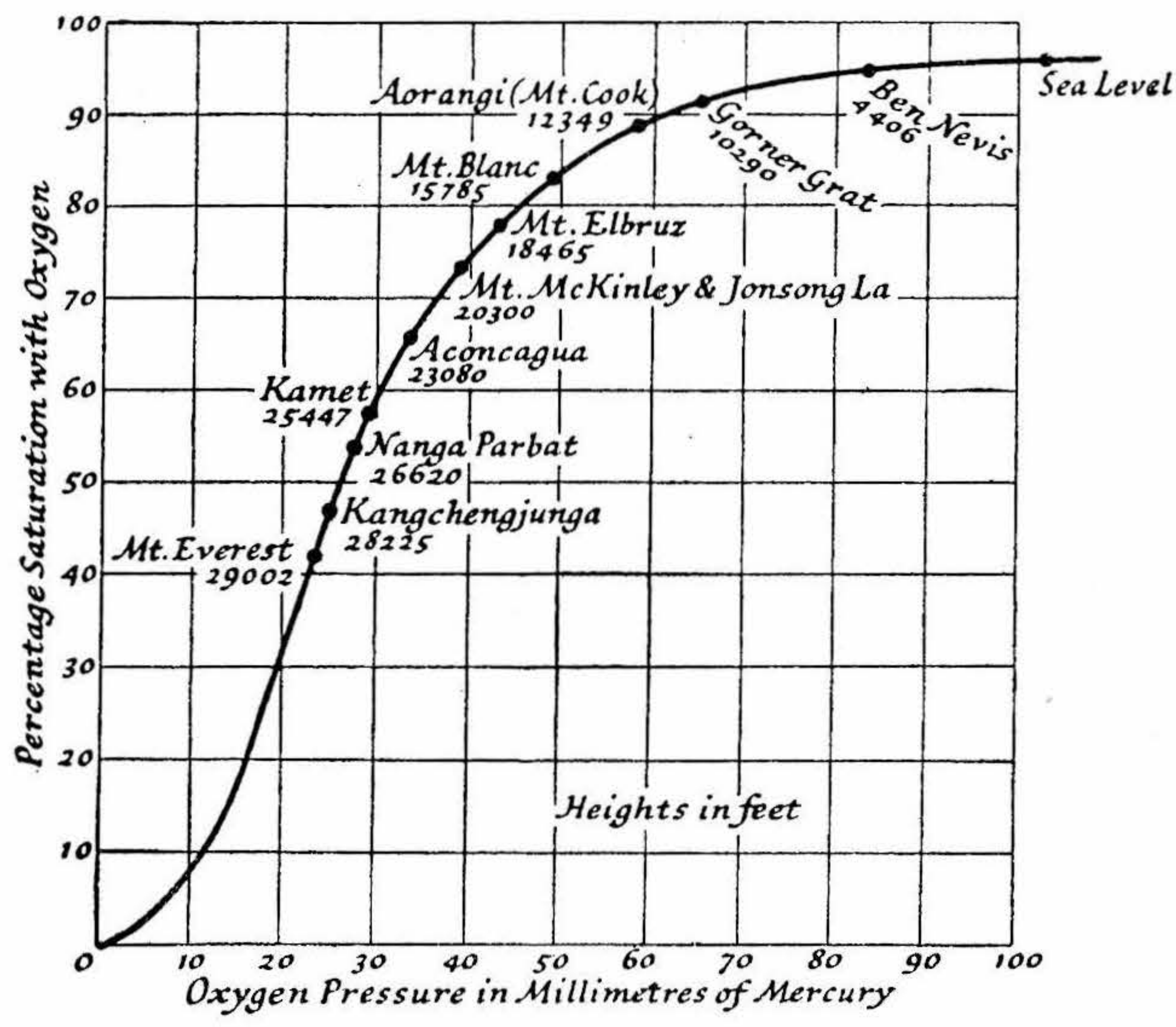
Altitude.	Barometric [1] Pressure.	Partial Pressure O_2 Air.	Partial Pressure [2] O_2 Alveolar Air.
Sea-level.	760 mm.	150 mm.	100 mm.
10,000	530 ,,	106 ,,	68 ,,
14,000	460 ,,	92 ,,	58 ,,
16,000	430 ,,	86 ,,	54 ,,
20,000	370 ,,	74 ,,	45 ,,
22,000	340 ,,	68 ,,	40 ,,
30,000	250 ,,	50 ,,	28 ,,

Oxygen passes from the air in the lungs into the blood which is circulating through those organs as a result of the pressure exerted by the gas, and the amount which is taken up depends upon this pressure. In persons breathing air at sea-level the arterial blood when it leaves the lungs contains about 20 c.c. of oxygen per 100 c.c. of blood. This represents about 95 per cent. of its total oxygen-carrying capacity, i.e. it is 95 per cent. saturated. The tension of oxygen in the alveolar air as we have seen is about 106 mm. of mercury, and that in the blood leaving the lungs is a little lower, namely 100 mm. of mercury. These values are summarized in the table which follows.

Situation.	O_2 Tension. Mm. Hg.[3]
Inspired air . .	159
Alveolar air . .	106
Arterial blood .	100
Venous blood .	40
Tissue spaces .	20–40

[1] Approximate values taken from the curve showing relation of barometric pressure to height as calculated from the formula of Zuntz, Loewi, Müller, and Caspari. (See *Respiration*, 2nd edn., facing p. 324: Haldane and Priestley.)
[2] Compare with values obtained on Mt. Everest: Greene, *Journal of Physiology*, 1934, vol. 82, p. 481; Warren, *op. cit.*, 1939, vol. 96.
[3] *Oxygen and Carbon Dioxide Therapy*, 1934, p. 9: Argyll Campbe'' E. P. Poulton.

If the partial pressure of oxygen in the breathed air is reduced, as it is at high altitudes (and in low-pressure chambers at sea-level), then less of it is taken up by the blood, which leaves the lungs less fully saturated with the gas and so has less to deliver to the body tissues. Enough oxygen must be supplied to the tissues if their life and functions are to be maintained. It is lack of oxygen to the tissues which gives rise to the symptoms of mountain-sickness and which calls forth the adjustments in the body known as acclimatisation. Argyll Campbell has shown that not only is the *amount* of oxygen transported to the tissues of importance but also the *tension* of the gas in the blood which reaches the tissues. When the partial pressure of oxygen in the breathed air falls below about 106 mm. mercury, corresponding to an



altitude of about 10,000 ft. the tension of the gas in the tissues begins to fall. His experiments were performed upon animals (mostly rabbits), but perhaps it is significant that 10,000 ft. is about the altitude at which noticeable symptoms may appear in man unless he has acclimatised.

Most of the oxygen taken up by the blood is combined with the pigment haemoglobin which is present in the red corpuscles, this haemoglobin becoming converted into oxyhaemoglobin. A much smaller quantity goes into simple solution in the plasma or fluid fraction of the blood.

Blood, when exposed to air containing oxygen at a known partial pressure such as might obtain in the alveoli of the lungs, takes up oxygen and becomes partly saturated with the gas. If the partial pressure to which it is exposed is increased it will become more fully saturated; but if it is reduced the saturation will become less complete. A curve can be constructed which will show the relationship between partial pressure of oxygen and the percentage saturation of the blood. This is known as the Dissociation Curve of Oxyhaemoglobin in Blood. On such a curve Dr. Kellas has plotted the alveolar oxygen tensions calculated for altitudes corresponding to a number of well-known mountains.

The curve (on p. 275) shows that up to about 10,000 ft. the blood remains almost fully (90 to 95 per cent.) saturated with oxygen, but at about 15,000 ft. the percentage saturation is beginning to fall. By the time 20,000 ft. is reached the curve is steepening rapidly and with every 1000 ft. rise above this altitude there is an increasingly rapid fall in the percentage saturation. At a height corresponding to the summit of Mt. Everest the degree of saturation is only about 40 per cent. From a consideration of this curve it seems clear that the difficulties in ascending above 20,000 ft. will increase considerably although acclimatisation may modify them to a certain extent; an observation which is borne out by the accounts of all those who have come back from the higher camps on Mt. Everest. Thus, although the climbers have already struggled to 28,000 ft. on the mountain, there is no reason to suppose that because they have done so they are bound to be able to climb the last 1000 ft. without using oxygen, for above that altitude the further fall in percentage saturation will be very considerable.

Acclimatisation

What is the sequence of events in the process of acclimatisation, and how do they affect the functions of the body at high altitudes?

With the fall of oxygen tension in the alveolar air the respiratory centre in the brain stem at first becomes more sensitive to the carbon dioxide present in the blood and respiration is stimulated. The breathing becomes deeper and more rapid. Dyspnoea, or difficulty with the breathing is felt, even when at rest. Later on dyspnoea is felt only on exertion, and at that period it may have a different explanation. Christie suggests that dyspnoea in these circumstances is cardiac in origin, and is brought about reflexly. With exercise the heart works harder, the return of venous blood to the organ is increased and the blood vessels in the lungs become congested and stretched. This stretching sets up impulses which travel in the vagus nerve to the respiratory centre and modify its activity.

Increased ventilation of the lungs causes the tension of carbon dioxide in the alveolar air to fall; in other words carbon dioxide is washed out from the lungs, its place being taken by more air, and the alveolar oxygen tension rises. But with the loss of carbon dioxide the chemical stimulus to breathing has gone, so the respirations die down until the carbon dioxide level in the blood has once more built up to its former level. This cycle is repeated and there is a tendency for the breathing to become periodic, the so-called Cheyne-Stokes breathing which has so often been observed at high altitudes.

As a result of hyperventilation and the washing out of carbon dioxide from the lungs and blood, the blood tends to become more alkaline. After a short time this alkalosis is compensated for by loss of alkali in the urine. In this way the kidneys are able to restore the reaction of the blood to its original level and the deep breathing can be maintained.

In order that more oxygen may be carried to the tissues in a given time the output of the heart increases. This increase in the minute volume of blood leaving the heart for the tissues probably plays an important part in helping to maintain their nutrition.

In addition to the above-mentioned mechanisms there is the one whereby the number of red corpuscles is increased in the blood. At first this increase is probably brought about by contraction of the spleen. When this organ contracts red cells are squeezed out from its meshes into the general circulation as water is squeezed from a sponge. Obviously the number of red cells in the circulation can quickly be increased by such means. At a later stage, however, there is actually increased formation of red cells by the bone marrow, which is stimulated into greater activity by lack of oxygen. Running parallel with the increase in the blood count is an increase in the haemoglobin or oxygen-carrying pigment of the blood. These changes in the blood take place slowly over a comparatively long period ; they also take a considerable time to return to normal on coming down to sea-level again. So far no evidence has been produced to support the view that alterations in the blood count and haemoglobin are related to changes in the volume of the blood.

Date.	Place.	Altitude.	Blood Count.	Haemoglobin. Per Cent.
14-3-36	Gangtok	6,000	4,710,000	93
25-3-36	Lachen	8,800	4,950,000	96
29-3-36	Tangu	12,800	4,885,000	96
6-4-36	Kampa Dzöng	15,000	5,110,000	99
11-4-36	Tengkye Dzöng	13,800	5,420,000	105
21-4-36	Shekkor Dzöng	14,000	5,850,000	116
5-5-36	Camp I.	17,700	6,090,000	120
15-5-36	Camp III.	21,200	6,550,000	129
16-6-36	Base camp	16,600	6,800,000	134
27-6-36	Tenkye Dzöng	13,800	6,710,000	129
22-7-36	Bombay	Sea-level	6,770,000	134
17-8-36	London	Sea-level	6,550,000	129

Blood count and haemoglobin percentage of one member of the 1936 Mount Everest Expedition.[4]

(Normal blood-count = 5,000,000 per mm.[3] Normal haemoglobin = 100 per cent.)

[4] C. B. M. Warren, *G.J.*, xc. p. 126, 1937.

To summarise: Argyll Campbell states that—'The main factor in rapid acclimatisation to lowered oxygen pressure in the air is the ability of the vital organs (heart, respiratory organs, medulla) to withstand a surrounding low oxygen tension in their immediate environment and to maintain their normal supply of oxygen. The main factors controlling oxygen *tension* in the tissues are the oxygen pressure in the air in the lungs and the haemoglobin, or in other words the oxygen content of the blood. There is no evidence that acclimatisation raises the tissue oxygen tension to anywhere near normal again, . . . increase of haemoglobin which occurs at a later stage is a factor in the later stages of acclimatisation, probably relieving the vital organs in their efforts to supply the necessary oxygen.'

Deterioration

Something must now be said about the deterioration in the physical condition of the climbers which is alleged to set in above a certain altitude. As a result of experiments with animals which were kept at low oxygen pressures for a long time, Argyll Campbell came to the conclusion that it was useless to attempt to acclimatise to altitudes greater than 21,000 ft. by staying for prolonged periods at the higher camps on Mt. Everest. Above this altitude his animals eventually died, and when examined were found to have dilated hearts and fatty degeneration of all their organs. He utters the following warning: 'Great care is necessary that the climbers do not expose themselves for unduly long periods to oxygen below 10 per cent. (20,000 ft.); animal experiments indicate that there is a time limit for safety, beyond which recovery becomes impossible.' '. . . the risk is great from oxygen want alone, without the added dangers from cold and exhausting climbing.'

It is possible to argue, of course, that these results with animals need not necessarily have any bearing upon what happens in the human organism under similar circumstances. But it is interesting to note that after the 1933 expedition it was decided that in future the climbers ought not to stay in the camps above Camp III (21,200 ft.) for longer than is absolutely necessary.

The evidence which suggests that a similar deterioration to that seen in Campbell's animals is taking place in the climbers on Everest is: their loss of appetite with attendant loss of weight, which is rapidly regained on going to lower levels; and the increase in their basal pulse rates which is always present above 20,000 ft. and seems to indicate that the heart must be overworking even when the body is at complete rest. It is obvious that the power of acclimatising to a strange environment must have a limit, and in the light of such evidence as we have it looks as though this limit, in the case of high altitude acclimatisation, is in the region of 21,000 ft. Beyond that altitude the body must work outside its reserves.

Acute Oxygen Lack

It is interesting to consider what happens when the partial pressure of oxygen in the breathed air falls suddenly beyond certain limits. Symptoms which are directly attributable to the reduced pressure are met with. For instance, if an airman goes rapidly to a great altitude he loses consciousness without warning. The same thing happens if he is put into a closed chamber at sea-level from which the air is rapidly exhausted. In 1875 Tissandier and his companions made their famous ascent in a balloon from Paris. At 26,500 ft. Tissandier lost consciousness. He recovered to find the balloon descending, but his two companions were dead. The same kind of experience befell Glaisher and Coxwell during a balloon ascent. At 29,000 ft. Glaisher was completely paralysed and Coxwell only retained the movement of his head. He was able to seize the valve rope with his teeth and so stopped the ascent of the balloon. It has been suggested that such an accident might happen on Everest, but I do not think it is likely when we consider what happens if the oxygen pressure is reduced more slowly. With a more gradual onset of oxygen-lack the train of symptoms is as follows. The intellect and senses become dulled without the subject being aware of what is happening. Visual acuity is diminished and sensation impaired. The experiences of Haldane and Kellas in a low pressure chamber are instructive. Haldane at the time insisted that the pressure be kept low, but could remember nothing of this later. At a pressure of 356 mm. of mercury he picked up a mirror to look at his lips. For a long time he peered at the back of the mirror. The subject may be in danger and not realize it; or he may realise his danger and yet be incapable of deciding upon a line of action that would put him in safety. Eventually there is paralysis of the arms and legs, and ultimately loss of consciousness. On the extreme heights of Everest the climber is likely to be brought to a standstill by the fatigue in his muscles (or by actual paralysis) before losing consciousness. But if he had to exert himself unduly as in the effort of overcoming a very difficult step, he might increase his oxygen consumption to such an extent that he would lose consciousness. In any case he would be exposed to the risks due to mental impairment, such as failure to realise the danger of his position and carelessness in his movements on difficult ground. Apart from the fact that it may not be possible to reach such an altitude as 29,002 ft. without using oxygen, I think that the dangers consequent upon mental impairment form the strongest argument in favour of its use on the last lap to the summit.

Physiological Aids to High Altitude Mountaineering

It has been suggested that the administration of acid salts, such as ammonium chloride, might assist acclimatisation during the early stages. There is said to be a tendency towards an alkalosis at that period as a result of overbreathing. The salt is administered with the idea of counteracting such a tendency. Greene tried the method on Kamet without very convincing results. In most cases the salt was not tolerated. In any case the remedy could only be a temporary measure ; it would be valueless at a later stage when, if anything, there is a tendency towards acidosis.

As the result of two rough experiments conducted in the course of the 1936 Mount Everest Expedition I found that the hydrochloric acid, which normally should be secreted by the stomach on taking a meal, was not apparently secreted at 21,000 ft. Because of this discovery I administered dilute hydrochloric acid as a cocktail before meals to several of the party. The acid was pleasant to take, and some of us imagined that our appetites were improved by it, but the results again were not very convincing. It might be given a trial on future occasions.

It has been suggested that extract of thyroid gland should be given with the idea of increasing the metabolic rate and thus the oxygen consumption of the tissues. In animal experiments Campbell found that ' excessive thyroid feeding caused a marked increase in consumption of food and a marked loss of weight, but the oxygen tension in the tissues remained unaltered.' There seems to be singularly little point in stimulating oxygen consumption when already there is difficulty in supplying enough oxygen to the tissues because of the low tension of that gas in the lungs. I can see nothing to recommend the method.

The most obvious way of overcoming the physiological difficulties encountered at very high altitudes is to make the climber breathe oxygen. This brings us to a consideration of how best this gas may be administered.

The Administration of Oxygen for High Altitude Mountaineering

Whatever kind of apparatus is used for this purpose the object is to increase the partial pressure of oxygen in the alveolar spaces of the lungs. This object can be achieved in one of two ways : either by giving the climber a mixture of air and oxygen to breathe, or by making him breathe pure oxygen from a circuit which is completely cut off from all access with the outside air. With this latter arrangement some means must be provided for absorbing the waste gas carbon dioxide which will be exhaled into the closed circuit.

With the open type of apparatus the outside air is breathed from a bag to which oxygen is added from a cylinder of the gas at a fixed rate. When an arrangement such as this is used the partial pressure of oxygen in the bag will depend upon the rate at which the gas is allowed to flow into it. It will also depend upon the degree to which the oxygen is diluted by the air entering the bag. Now once the reduction valve on the oxygen cylinder has been set, the rate at which the gas flows into the bag remains constant. But whenever the ventilation of the lungs increases, as it does with exercise, a greater volume of air will be drawn into the bag which will dilute the mixture there, and the partial pressure of oxygen will fall. Furthermore, much oxygen will be wasted because it will be exhaled from the dead spaces of the lungs into the outside atmosphere at the end of each breath. A further disadvantage with such an apparatus is that moisture and heat will be lost from the body in the breath, because the climber has to exhale into the outside air in order to get rid of the carbon dioxide he has generated in his body.

In order to be able to calculate a suitable rate of oxygen flow for this kind of apparatus several factors have to be taken into consideration. When working out the rate of flow for an apparatus to be used on Mount Everest in 1938 we consulted Dr. Douglas at Oxford. We started with the assumption that the climbers would be able to acclimatise to at least 20,000 ft. Then we calculated how much oxygen would be required to put up the partial pressure in the bag from 50 mm. of mercury (29,000 ft.) to 75 mm. of mercury (20,000 ft.). In other words we aimed to bring the climbers down from the top of Mount Everest to an altitude of 20,000 ft. Before making the calculation we had to decide what would be the maximum ventilation of the lungs under conditions of severe physical strain such as would be encountered when climbing. Dr. Douglas thought the pulmonary ventilation might be as great as 60 litres per minute when doing hard work, as opposed to 17 litres per minute when at rest. These figures are probably on the generous side. But for safety we chose the higher of the two figures and based our calculation on that. The result worked out at 2 litres of oxygen per minute, as measured under sea-level conditions. With an open apparatus of this kind weighing 25 lb., two cylinders of Vibrac steel, each holding 500 litres of oxygen, could be carried. The supply then would be 1000 litres, and this flowing at the rate of 2 litres per minute would last about 8 hours.

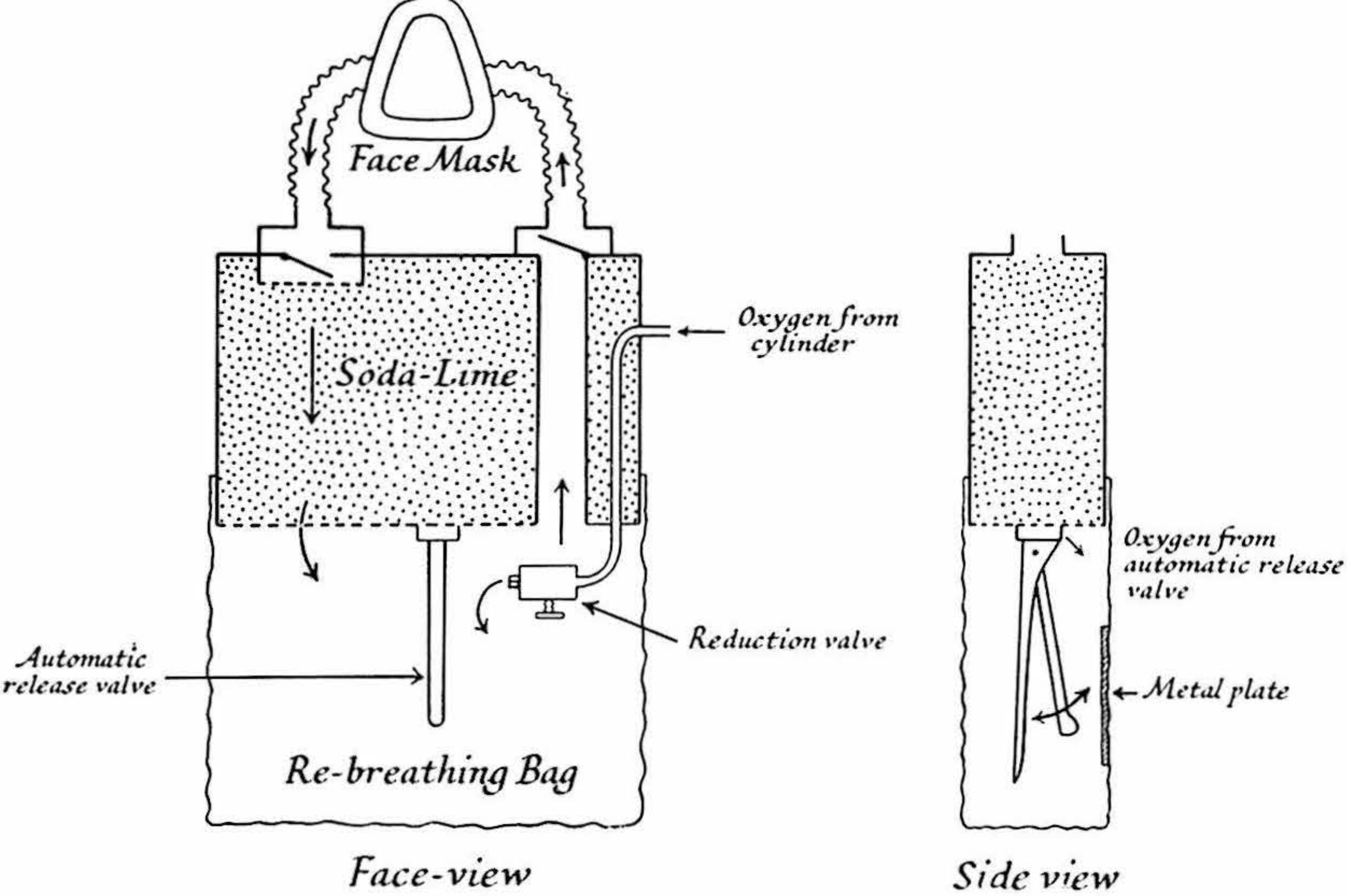
With the more recent closed type of apparatus instead of breathing air to which oxygen is added the climber breathes oxygen only, and the carbon dioxide in his expired breath is all absorbed by passing it through a canister containing soda lime. The breathing circuit therefore is completely enclosed so that nothing is exhaled into the outside air. With an arrangement such as this the pressure of oxygen breathed is the same as that exerted by the external atmosphere upon the outer surface of the bag, namely 250 mm. of mercury at 30,000 ft.; a pressure which is well above the partial pressure of oxygen in the atmosphere at sea-level. A climber wearing this respirator on the top of Mount Everest would then be brought down to sea-level conditions as far as the oxygen he was getting was concerned. Other advantages of this particular arrangement are that no oxygen is wasted, and practically no heat and moisture are lost from the body in the expired breath.

In order to be able to determine what should be the rate of flow of oxygen for the closed circuit type of apparatus we must know the rate at which the body uses up oxygen under various conditions of work. This is approximately ½ litre per minute at rest, and 2 litres or more per minute when taking fairly hard exercise, as can be seen from the figures obtained by Zuntz on Monte Rosa.

—	Oxygen per Minute.
	cc.
Sea-level, at rest, fasting	233
Monte Rosa, at rest, fasting	260
Monte Rosa, ascending glacier . . .	1329

On the respirator which was taken to Mount Everest the main reduction valve was adjusted to deliver oxygen at a fixed rate of ½ litre per minute; that is, enough was allowed to flow to provide for the bodily consumption when at rest. But by means of an automatic by-pass valve, which came into operation whenever the re-breathing bag began to get empty, a greater supply of oxygen was obtainable at any given moment as when undertaking strenuous climbing. With a closed apparatus of this type weighing approximately 35 lb. one cylinder of Vibrac steel, holding 750 litres of oxygen, could be carried. The 35 lb. weight was made up of the cylinder which weighed 12 lb., the charge of soda lime which weighed 10 lb., and duralumin frame, soda lime canister, valves, and harness which comprised the remainder. If we allow that the average rate of consumption of oxygen when climbing on Mount Everest would be about 2 litres per minute, then the supply would last about 6 hours. In practice this really does appear to be about the average rate of consumption when climbing over moderately steep ground and then descending over the same ground again. On the average it was found that about twice as much oxygen was used up when climbing as when descending; so a climber would be safe to continue ascending until the cylinder was two-thirds empty, then he would have to descend at once.

On theoretical grounds the re-breathing type of oxygen respirator has much to recommend it: thus, no oxygen is wasted with it, heat and moisture are not lost, and with it the climber is breathing oxygen at the same pressure as that of the external atmosphere (namely 250 mm. of mercury at 30,000 ft.). Although similar respirators have been used with success for rescue work in coal mines for some years now, and have stood up to rough handling well, on Everest they suffer from several disadvantages. In the first place they have to be constructed of much lighter materials, and this necessarily entails some loss of rigidity which is a serious fault when they have to be exposed to rough handling, as they are bound to be in the course of such an expedition. Again, much extra weight has to be carried in the form of soda lime. And finally, all the mechanical complications introduced by the inclusion of so many valves in the circuit are a very real disadvantage when working under trying conditions such as prevail at the higher



RE-BREATHING TYPE OF OXYGEN APPARATUS.
Reproduced by the courtesy of the Editor, *Geographical Journal*.

camps on Mount Everest. In a previous article in this Journal [5] Lloyd has already mentioned the mechanical difficulties we encountered when using the apparatus on the last expedition.

Other criticisms which have been levelled at this method of giving oxygen are: that there is no advantage in bringing the climber down to sea-level conditions, for such a change may actually do harm; that soda lime absorbs moisture, so there will be much loss of moisture from the body; and that nobody could tolerate wearing a mask over their face at 28,000 ft. These criticisms can to some extent be refuted. In the first place no harm does accrue in practice as a result of breathing pure oxygen for a few hours on end, nor does it interfere with such acclimatisation as has already been gained. We know that the blood count, which is one of the most important indications of acclimatisation, remains elevated for weeks and not days after a climber has returned to sea-level; a few hours spent at sea-level therefore is hardly likely to do much harm. Then, with regard to the moisture which it is suggested would be absorbed by the soda lime, most of the patent carbon dioxide absorbing materials which are so frequently used nowadays in anæsthetic apparatus and in oxygen tents are not particularly hygroscopic. From the practical point of view this property of the soda lime can probably be disregarded. And finally, with regard to the question whether a mask could be tolerated over the face at 28,000 ft., this is to some extent a personal matter; the question of altitude does not enter into the argument with this particular apparatus because the climber who is wearing it would not be suffering from the breathlessness of high altitudes, he would be as at sea-level. The mask could even be an advantage since it would protect the face against the wind and other elements.

In spite of these arguments in defence of the closed circuit type of oxygen respirator, it would seem that its theoretical advantages are outweighed by the disadvantages of its greater weight and greater complexity when compared with the open variety. So as things stand at present the simpler open type of oxygen apparatus is the more suitable of the two for use on Mount Everest. In spite of this, however, it does seem to be desirable to continue making experiments with both designs.

With regard to the future, no startling changes in design are to be expected. It is always possible that some entirely new principle in the administration of oxygen may be developed such as the use of the liquid gas, or of gas generated from some chemical substance which the climber carries, but this is very unlikely. For the moment we must content ourselves with minor alterations and improvements in design on the existing types of apparatus. In this respect the most hopeful lines of investigation would seem to be: to discover whether any lighter cylinders are obtainable; to find a really comfortable face mask or mouth piece; to inquire into the possibility of charging the existing cylinders at a greater pressure. At present all these lines are being followed up, and a certain amount of progress has already been made.

[5] *A.J.* 51. 85 *sqq.*