FURTHER OBSERVATIONS AND RESEARCHES ON FLEUSS'S SYSTEM OF DIVING AND LIVING IN IRRESPIRABLE ATMOSPHERES[1]

YOU will find in NATURE, vol. xxi. p. 62, the experiments I made in relation to the process of living under water by means of the Fleuss apparatus. I there related what I had observed after Mr. Fleuss had been under water at a very low temperature for the period of an hour. A few days later I made another observation on a different plan. I filled the large diving bell at the Polytechnic with carbonic acid gas, displacing every portion of air. I then let the bell go down ten inches under the water, so as to put the gas under pressure, and all the while I kept a stream of gas pouring into the bell, and causing a constant bubbling of gas out of the mouth of it into the water. This done, Mr. Fleuss put on his dress and helmet and entered the bell. He sat in it over the water for the period of twenty minutes, the pressure and constant stream of gas being maintained. At the end of twenty minutes I signalled to him to come out, and had the bell brought round to the side of the tank. He returned into the air quite unaffected. His pulse, which was beating at 72° in the minute when he went in, was at 68° when he came out, and quite steady. His temperature in the mouth, which was at 98·2° F. when he went in, was at 97·5° when he came out, and in a few minutes was at its natural standard. He said he had felt no oppression whatever, and would have remained an hour in the gas if I had allowed him.

While the diving-bell was still charged with a large volume of carbonic acid gas I got Mr. Fleuss to go into it again, and then volatised into the bell vapour of amyl hydride until I had made an utterly irrespirable atmosphere from that vapour alone. In this way I formed an atmosphere which closely resembled the atmosphere of the mine charged with choke-damp, except that the vapour I used is more determinate in its narcotising action than choke-damp. In this mixed atmosphere, in which a man unprotected would have been absolutely unconscious in less than a minute, Mr. Fleuss remained for twenty minutes. At that time he came out of the bell in the most perfect condition, in a word, altogether unaffected.

The principle of the Fleuss system is very simple. Within the helmet, which is of the usual shape of a diver's helmet, there is a space equal to a quarter of a cubic foot inclosed in metal. This space is charged with oxygen under pressure, the compression giving a supply of the gas sufficient to last for a period of five hours if necessary. As a rule Mr. Fleuss charges for three hours under a pressure of about eight atmospheres. This is his supply of vital air. In the cuirass, which is the next part of the apparatus to be described, he has two metal cases, one in front, the other at the back. These cases are filled with small pellets of porous india-rubber charged with caustic soda. Over this surface of soda he can exhale his breath with perfect freedom, and at the lower part of each case he has a small trough under a perforated bottom, in which the water of the breath, condensed in passing, is caught. Lastly, he has a double-valved mouthpiece, made almost exactly after the plan of the late Dr. Sibson's chloroform mouthpiece, to which is attached a large elastic artificial trachea, or windpipe.

These are the effective parts of the apparatus. The other parts, common to the diver's dress, are the waterproof jacket and leggings and weighted boots.

In preparing for his work Mr. Fleuss proceeds as you will see (for he will go step by step through the process of assuming his dress). He first charges his helmet with oxygen. He does this from one of Orchard's compressed oxygen bottles, measuring the pressure by a pressure-gauge. This ready, he puts on the cuirass and the waterproof dress. Then he ties firmly over his mouth and nostrils the double-valved mouthpiece, and connects the free end of the artificial windpipe with a tube leading into the soda-chamber in front of the cuirass. Finally he assumes the helmet, and when that is on and closed he is complete.

The mode in which he lives in this closed dress is as follows :—By a valvular opening he lets into the helmet from the compressed store of oxygen a stream of oxygen, which diffuses into the space between the helmet and cuirass and his body—his breathing- or air-space. When he inhales through the mouthpiece he draws in the oxygen through the two side valves into his lungs. When he exhales, those valves close, and so his exhaled breath passes through the tube and over the soda in the soda-chambers, and down the chamber in front along a connecting tube into the lower part of the chamber at the back ; then, ascending through that chamber, it escapes *in part* into the helmet by a tube from the back chamber near the shoulder. In its passage through these two chambers all the carbonic acid of the breath is fixed by the soda, and most of the water is condensed in the troughs. The return oxygen and the nitrogen of the expired breath passes over free and enters the helmet, where it meets and admixes, by diffusion, with the oxygen which is admitted from the oxygen reservoir.

Thus there is constantly being made within the dress a fresh supply of air for respiration, while the product of respiration and of animal combustion—carbonic acid—which would be dangerous if it were not removed, is removed and fixed by the soda.

Mr. Fleuss relies on two practical indications for supply of the oxygen from the reservoir. If he feels any undue pressure on the drums of his ears he knows that there is too much oxygen in the helmet. If he feels any sense of suffocation he knows that the oxygen is deficient. In the first instance he stops the entrance of oxygen for a short time ; in the second case he lets in a further supply.

It must be admitted that this plan is not one that ensures a due admixture of oxygen and of nitrogen according to the atmospheric formula, and there can be no doubt that he is always breathing, while in his dress, an excess of oxygen. This fact opens up the question once more of pure oxygen as a supporter of natural life.

In my experiments on this subject reported to the British Association for the Advancement of Science in 1860, I showed that oxygen supplied in steady current from a fresh source, and not breathed many times over again, would support life readily enough for long periods of time—extending in one experiment to three weeks—at a medium temperature ; but that at a low temperature, 35° F., it became negative, so that animals went to sleep in it and became cold ; while at a high temperature, 75°, they became heated in it, underwent rapid wasting, and ate voraciously.

In another paper, published in 1869, I tried to prove that the use of nitrogen in the atmosphere is not to act as a mere diluent and economiser, but as an equaliser of the temperature, and so to make the combination of oxygen with the blood and the tissues equable in the different regions of the globe.

Mr. Fleuss's experiments are in entire accord with these views. He can live, with oxygen in excess, for long periods in medium temperatures. In a cold temperature his own heat goes down several degrees below the standard. In a high temperature he would become overheated. But between a range of 35° F. on the one side and 75° F. on the other he is, in my opinion, safe in his closed oxygenated chamber. Whether he can descend to the same depths as other divers—say to 86 feet—and remain there, has to be proved. Theoretically, he ought to be able to do so, but in this field of inquiry he must

[1] Abstracted from lecture delivered to the Society of Arts on Thursday, May 8.

win his spurs. The lowest depth to which he has descended is 25 feet. He has walked under water a distance of four hundred yards in a straight line.

Some improvements may be made in the arrangements. He might be supplied with a feeding-apparatus, and so remain under water several hours longer than he has done. At present he finds from two to three hours no difficulty.

The experiments I have made with the apparatus indicate that the dress and apparatus may be used for entering wells, burning houses, and mines that are charged with suffocating gases. In the mine the dress would be invaluable, and if a telephonic connection could be set up between the man in the dress and the outside world—an adaptation I believe to be quite possible—a remarkably useful advance would be made.

I will now ask Mr. Fleuss to make one experiment which will be a visible exposition of the perfection of his apparatus as he stands equipped in it. The directors of the Royal Institution have been so good as to lend me the glass chamber in which Prof. Tyndall experimented when he was demonstrating the mask he invented for breathing in an atmosphere charged with dense fumes of smoke. This chamber I have had charged with carbonic acid, so that it has in it an irrespirable atmosphere. In it, as you will see, a candle cannot be lighted, and a taper will be extinguished. Mr. Fleuss will go into the chamber, sit down in it, and wait there until the current of carbonic acid which is being admitted forms an absolute atmosphere of the gas to above the level of the top of his helmet, and there he will remain, if we like, until the supply of oxygen in the helmet is exhausted.

The next step onward will be to construct a small closed canoe, in which the apparatus can be fitted on a larger scale, and in which men, or those who are in the canoe, can rise or sink in the water and be propelled under the water. This is a certain extension of the system now under our consideration, and when it is completed, my idea that the next greatest geographical discoveries will be made on the floors of the great oceans may not be so far wide of the mark as was once supposed.

B. W. RICHARDSON

THE AURORA BOREALIS[1]

OUR experiments on the electric discharge, which have been already published in the *Phil. Trans.* and the *Proceedings* of the Royal Society, enable us to state with some degree of probability the height of the aurora borealis when its display is of maximum brilliancy, and also the height at which this phenomenon could not occur on account of the great tenuity of the atmosphere.

In Part III. of our electric researches, *Phil. Trans.*, Part I. vol. 171, we have shown that the least resistance to the discharge in hydrogen is at a pressure of 0·642 millim., 845 **M**; after this degree of exhaustion has been reached a further reduction of pressure rapidly increases the resistance. When the exhaustion has reached 0·002 millim., 3 **M**, the discharge only just passes with a potential of 11,000 chloride of silver cells (11,330 volts); at the highest exhaust we have been able to obtain (and which we believe has not been surpassed), namely, 0·000055 millim., 0·066 **M**, not only did 11,000 cells fail to produce a discharge, but even a 1-inch spark from an induction-coil could not do so.

Although we have not experimentally determined the pressure of least resistance for air, we have ascertained that while the discharge occurs in hydrogen at atmospheric pressure between disks 0·22 inch distant, they require to be approached to 0·13 inch to allow the discharge to take place in air. We may therefore assume that the pressure of least resistance for air is

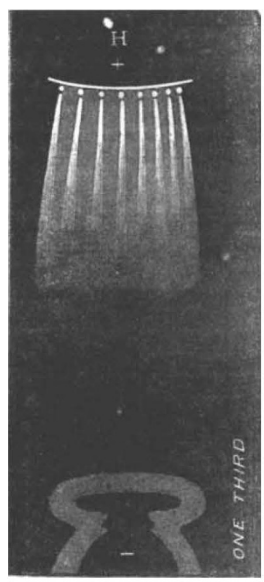
$$\frac{0{\cdot}642 \times 13}{22} = 0{\cdot}379 \text{ millim., } 498{\cdot}6 \ \mathbf{M}.$$

At a height of 37·67 miles above the sea level, the atmosphere would have this pressure (neglecting change of temperature), and therefore the display at this elevation would be of maximum brilliancy and would be visible at a distance of 585 miles.

The greatest exhaust that we have produced, 0·000055 millim., 0·066 **M**, corresponds to a height of 81·47 miles, and as 11,000 cells failed to produce a discharge in hydrogen at this low pressure, it may be assumed that at this height the discharge would be considerably less brilliant, especially in air, than that at 37·67 miles, the height of maximum brilliancy.

At a height of 124·15 miles the pressure would be only 0·00000001 millim., 0·00001 **M**, and it is scarcely probable that an electric discharge would occur with any potential conceivable at such a height.

The colour of the discharge varies greatly with the tenuity of air or other gas with the same potential. Thus in air at a pressure of 62 millim., 81579 **M**, the discharge has the carmine tint which is so frequently observed in the display of the aurora; this corresponds to an altitude 12·4 miles, and would be visible at a distance 336 miles. At a pressure of 1·5 millims., 1974 **M**, corresponding to a height of 30·86 miles, the discharge becomes salmon-coloured, having completely lost the carmine tint. At a pressure of 0·8 millim., corresponding to 33·96 miles, the tint of the discharge is of a paler salmon colour, and as the exhaust is carried further it becomes a pale milky white. The roseate and salmon-coloured tints are always in the vicinity of the positive source of the electric current, the positive luminosity fades away gradually, and frequently becomes almost invisible at some distance from its source; as, for instance, in the hydrogen discharge at a pressure of 2·3 millims., 3027 **M**, shown in the accompanying figure, H, which resembles in some



respects the phenomena of the aurora. The discharge at the negative terminal in air is always of a violet hue, and this tint in the aurora indicates a proximity to the negative source.

The following table, with the exception of pressure

[1] "On the Height of the Aurora Borealis." Paper read at the Royal Society. By Warren De La Rue, M.A., D.C.L., F.R.S., and Hugo W. Müller, Ph.D., F.R.S.