

4 DEC 1944

RESTRICTED

(FOR OFFICIAL USE ONLY)

Not to be communicated to anyone outside H.M. Service

ADMIRALTY FLEET ORDER

DIVING—EFFECTS OF BREATHING OXYGEN UNDER PRESSURE

ADMIRALTY, S.W.1,
24th August, 1944.

The following Order having been approved by My Lords Commissioners of the Admiralty is hereby promulgated for information and guidance and necessary action.

By Command of Their Lordships,

H. V. Markham

To all Commanders-in-Chief, Flag Officers, Senior Naval Officers, Captains and Commanding Officers of H.M. Ships, Vessels and C.O. Craft (see A.F.O. 3758/44), Superintendents or Officers in Charge of H.M. Naval Establishments, and Admiralty Overseers concerned.

NOTE:—The scale of distribution is shown in the Admiralty Fleet Order Volume, 1941, Instructions, paragraph 10.

HEAD OF "P" BRANCH

4565.—Diving—Effects of Breathing Oxygen under Pressure

(G. 010637/44.—24 Aug. 1944.)

Diving—Effects of Breathing Oxygen under Pressure.—The effects of breathing oxygen under pressure have recently been the subject of considerable investigation and experiments. The following information is promulgated as a guide to Diving Officers and instructors, and represents the results obtained from actual dives carried out by the Admiralty Experimental Diving Unit. When oxygen is breathed under pressure for too long a time or at too great a pressure, undesirable symptoms may occur. These symptoms are referred to hereafter as "oxygen illness."

2. *Principal Findings of the Experiments.*

- (i) That danger of oxygen illness exists at any time when the depth of the diver exceeds 33 ft. of sea water.
- (ii) The time at a given depth before symptoms appear varies greatly between individuals.
- (iii) A given individual may vary greatly from day to day for no apparent reason.

3. *Special Warning.*—From the above it will be seen that previously accepted figures for safe times on oxygen (see B.R. 241 (40) "Handbook of D.S.E.A.", p. 24) are misleading and should not be used as a guide to oxygen diving. A depth of 5½ fathoms is never to be exceeded in normal diving when breathing pure oxygen. In time of war, however, or in cases of exceptional emergency, it may be that the advantages to be gained as a result of the dive may be such that some risk to the diver must be accepted. The instructions which follow are for guidance in such cases and if studied and followed should reduce such risks to the minimum. Should it be decided that depths greater than 5½ fathoms are to be exceeded, only divers experienced in oxygen diving should be employed.

4. *Difference between diving under water and breathing Oxygen in a Chamber of Compressed Air.*—It has been demonstrated that when breathing oxygen under water (in the "Wet") the symptoms of oxygen illness appear sooner than when oxygen is breathed from an apparatus whilst in a compressed air chamber (in the "Dry").

Depth and time limitations given herein should not therefore be taken as affecting the times for oxygen decompression given in Table III of B.R. 155/43—"Diving Manual," which remain unaffected. Watch should always be kept, however, for the man who is unusually sensitive to oxygen, and if symptoms appear at the higher pressures, oxygen breathing must be delayed until the pressure can be reduced and decompression correspondingly prolonged.

Conversely, it must not be assumed that because such times are possible in the decompression chamber, they can be used as a guide for under-water work, since quite clearly they cannot.

No definite relation can be given between "Wet" and "Dry" times, but the "Wet" may well be as little as one quarter of the "Dry".

5. *Effects on the Body and Symptoms.*—The actual cause of oxygen illness, i.e., what happens inside the body, has not yet been sufficiently determined to allow of any simple explanation. The Diving Officer must accept the fact that it does exist and constitutes a very real menace to the diver.

The symptoms are varied, and those experienced during the trials are given below in the order in which they most frequently occur. They may usually be expected to give some warning before the final stage of convulsions and unconsciousness is reached, but it must be emphasized that *no definite warning period can be laid down.*

While some divers have shown that it is possible even to lose the symptoms altogether and carry on, others have lost consciousness without any warning at all.

The rule, therefore, must be that if any diver breathing oxygen experiences any of the symptoms shown below, he must be brought to the surface immediately.

Symptoms.—(1) *Lip Twitching.*—Starting with a slight twitch of the upper lip it increases in severity, at decreasing intervals, until it becomes an uncontrollable movement of the whole mouth. Convulsions will follow almost immediately on this last stage unless the diver is surfaced.

(2) *Loss of Control of Lips.*—As opposed to definite twitching of the lips, some divers have experienced difficulty in retaining the mouthpiece just before convulsing. This is easily detected from the surface since it leads to loss of oxygen past the lip-seal and consequently bubbles appear on the surface. The diver should be called up if this is observed to be happening continuously, though it must be remembered that if the diver is not working, excess oxygen from the reducer will probably escape past his lips in a thin steady trickle of bubbles. It is when this trickle suddenly increases and stays increased that the diver may be considered to be in danger.

(3) *Vertigo (Dizziness).*—If the diver feels dizzy underwater, it is a definite warning. In cold water, particularly if the head is not enclosed, a slight dizziness may be felt on entering the water, which should not be confused with oxygen illness.

(4) *Nausea.*—A feeling of sickness. Here again some people may feel slightly sick if not accustomed to wearing oxygen apparatus.

With both nausea and vertigo, the depth should be the deciding factor. If the diver is below 33 ft. they should be regarded as warning symptoms, otherwise they should be ignored, so far as oxygen illness is concerned.

(5) *Unpleasant Sensations concerning Breathing.*—The onset of oxygen illness may be heralded by strange sensations concerning breathing. The diver may feel that he is getting too much or too little oxygen, he may feel "his breath coming in waves," or even be under the false impression that his apparatus is flooded.

Cases have occurred of divers' diaphragms going into a state of contraction preventing him taking a full breath. This is extremely unpleasant and a dangerous symptom, though it is not very common.

Again, while such sensations may be due to defective apparatus, or inexperience of the diver, they should not be ignored when the diver is at dangerous depths.

(6) *Twitching of Parts other than Lips.*—Sometimes other parts than the lips will develop a warning twitch. Usually the affected part is under uncomfortable strain due to ill-fitting apparatus or undue exertion of the muscles. For example:—

- (a) A diver wearing tight D.S.E.A. goggles had violent twitching of the upper face and top of his head.
- (b) A diver struggling with a difficult job at 46 ft. had severe twitching of one leg, which he ignored, and very soon afterwards he had violent convulsions.

(7) *Sensations of Abnormality.*—Divers on oxygen have also experienced drowsiness, numbness, exhaustion, confusion and general malaise.

(8) *Visual Disturbances and Acoustic Hallucinations.*—Such troubles as dazzle, loss of vision (temporary) and hearing imaginary noises, such as bands playing, have occasionally occurred.

(9) *Tingling of Fingers and Toes.*—This symptom, frequently described as a common one, has been met with only once during the present series of experiments.

(Note.—In case it may be thought by some that experimental conditions are misleading, it should be noted that most of the above symptoms have been reproduced in actual diving operations in open water.)

6. *Alleviation of Symptoms.*—Generally speaking, if the pressure under which the diver is working is reduced, the symptoms will tend to disappear, but it has been found that convulsions may occur even after the diver has been brought out of the water and is breathing atmospheric air.

A technique has been tried out experimentally with some success which, should it be absolutely necessary, will enable a diver to prolong his total time at depths where the danger of oxygen illness exists. This consists of bringing a diver up to a depth of 10 ft. or less at given intervals, while continuing to breathe oxygen. On completion of this "rest" he may return to the bottom and continue his work for a further period. As the depth increases, the length of stay on the bottom is of course decreased, while the rest period must be increased. This technique should allow a diver to complete at least 4 periods on the bottom without the risk of oxygen illness.

Should a diver, however, get symptoms during this procedure, he must come to the surface, since it has been found that he cannot get rid of them by coming shallow once they have started. The periods on the bottom should be carefully timed in accordance with the following table, and should not be exceeded:—

Depth	Time of each period	
	at maximum depth	Time at 10 ft. or less
50 ft.	15 minutes	30 seconds
60 ft.	10 minutes	2 minutes
70 ft.	7 minutes	5 minutes

7. *Acute Stages of Oxygen Illness.*—The convulsions experienced in the acute stage of oxygen illness are very similar to an epileptic fit. If breathing oxygen under these conditions is continued, the results will be fatal.

8. *Treatment.*—A diver having convulsions should be brought to the surface at once and put on air-breathing, and his head got clear of any dress or apparatus he is wearing. He should be treated like an epileptic patient and the usual precautions against choking, etc., taken. The convulsions will last only a few minutes, when the diver will appear to go into a deep and stertorous sleep. He should be kept warm and allowed to sleep this off and very little serious after effects will be felt. There may be headache, vomiting, and loss of memory, all of which should disappear in 48 hours. In view of the loss of memory, which is sometimes acute immediately after recovering consciousness, the patient should be escorted to sick bay and kept under observation for at least 24 hours. He should have a minimum of 72 hours stand-off from diving.

There is no danger of any permanent injury being sustained from oxygen illness.

9. *The effect of Work done by the Diver.*—The effect of work on oxygen tolerance has not been investigated in detail. It is, however, sufficiently obvious that oxygen tolerance is greatly reduced by hard work.

10. *The effect of Water Temperature on Oxygen Illness.*—No significant change was found in human subjects over a range of 49° F. to 88° F. It is unlikely that any marked effects will be found until the body temperature of the diver is appreciably altered.

11. *Variation in Resistance to Oxygen Illness.*—It is extremely important that diving officers should appreciate the significance of the two facts stated in paragraph 2 (ii) and (iii) above. The fact that individual divers vary greatly in their resistance and that a given diver varies from day to day means that it is not possible to draw up a table or curve giving safe times on oxygen at various depths below 33 ft. Also, although certain divers are permanently more resistant than others, it must not be assumed that because a diver "gets away" with a deep dive one day, he can necessarily repeat the performance again.

As an illustration, 100 operational divers were "tested" for oxygen tolerance on a single dive to 50 ft. for 30 minutes; 50 per cent. convulsed or had symptoms, and the party was consequently graded accordingly. Subsequent experience, however, showed that this grading was quite erroneous and misleading.

12. *Graph showing probable Danger of Oxygen Illness.*—The attached graph, A.F.O. Diagram No. 263/44, shows the probable percentage of a group of divers who will be more or less severely affected by oxygen under pressure at various times and depths. Put in another way, it shows the chances of a given diver being able to remain safely at a given depth for a given time. Thus officers in charge of a diving operation can judge for themselves whether the object to be achieved from the dive justifies the risk to the diver. The figures given are for dives without hard work, and due allowances must be made for a reduction in tolerance if hard work is anticipated. Depths are taken from surface to the diver's chest and assume normal sea densities.

13. *To Use the Graph.*—The curves represent the depth, the time is shown along the bottom and the probable percentage eliminated by marked symptoms is shown vertically. Follow the curve up till it cuts the vertical line representing the maximum time the diver will have to spend on the bottom, then the horizontal line will give the chances of the diver being affected. To allow for the possibility of the onset of symptoms after the pressure has been reduced (see first sub-paragraph of paragraph 6 above) the estimated time for the ascent should count as time on the bottom.

Should a diver, however, get symptoms during this procedure, he must come to the surface, since it has been found that he cannot get rid of them by coming shallow once they have started. The periods on the bottom should be carefully timed in accordance with the following table, and should not be exceeded:—

Depth	Time of each period at maximum depth	Time at 10 ft. or less
50 ft.	15 minutes	30 seconds
60 ft.	10 minutes	2 minutes
70 ft.	7 minutes	5 minutes

7. *Acute Stages of Oxygen Illness.*—The convulsions experienced in the acute stage of oxygen illness are very similar to an epileptic fit. If breathing oxygen under these conditions is continued, the results will be fatal.

8. *Treatment.*—A diver having convulsions should be brought to the surface at once and put on air-breathing, and his head got clear of any dress or apparatus he is wearing. He should be treated like an epileptic patient and the usual precautions against choking, etc., taken. The convulsions will last only a few minutes, when the diver will appear to go into a deep and stertorous sleep. He should be kept warm and allowed to sleep this off and very little serious after effects will be felt. There may be headache, vomiting, and loss of memory, all of which should disappear in 48 hours. In view of the loss of memory, which is sometimes acute immediately after recovering consciousness, the patient should be escorted to sick bay and kept under observation for at least 24 hours. He should have a minimum of 72 hours stand-off from diving.

There is no danger of any permanent injury being sustained from oxygen illness.

9. *The effect of Work done by the Diver.*—The effect of work on oxygen tolerance has not been investigated in detail. It is, however, sufficiently obvious that oxygen tolerance is greatly reduced by hard work.

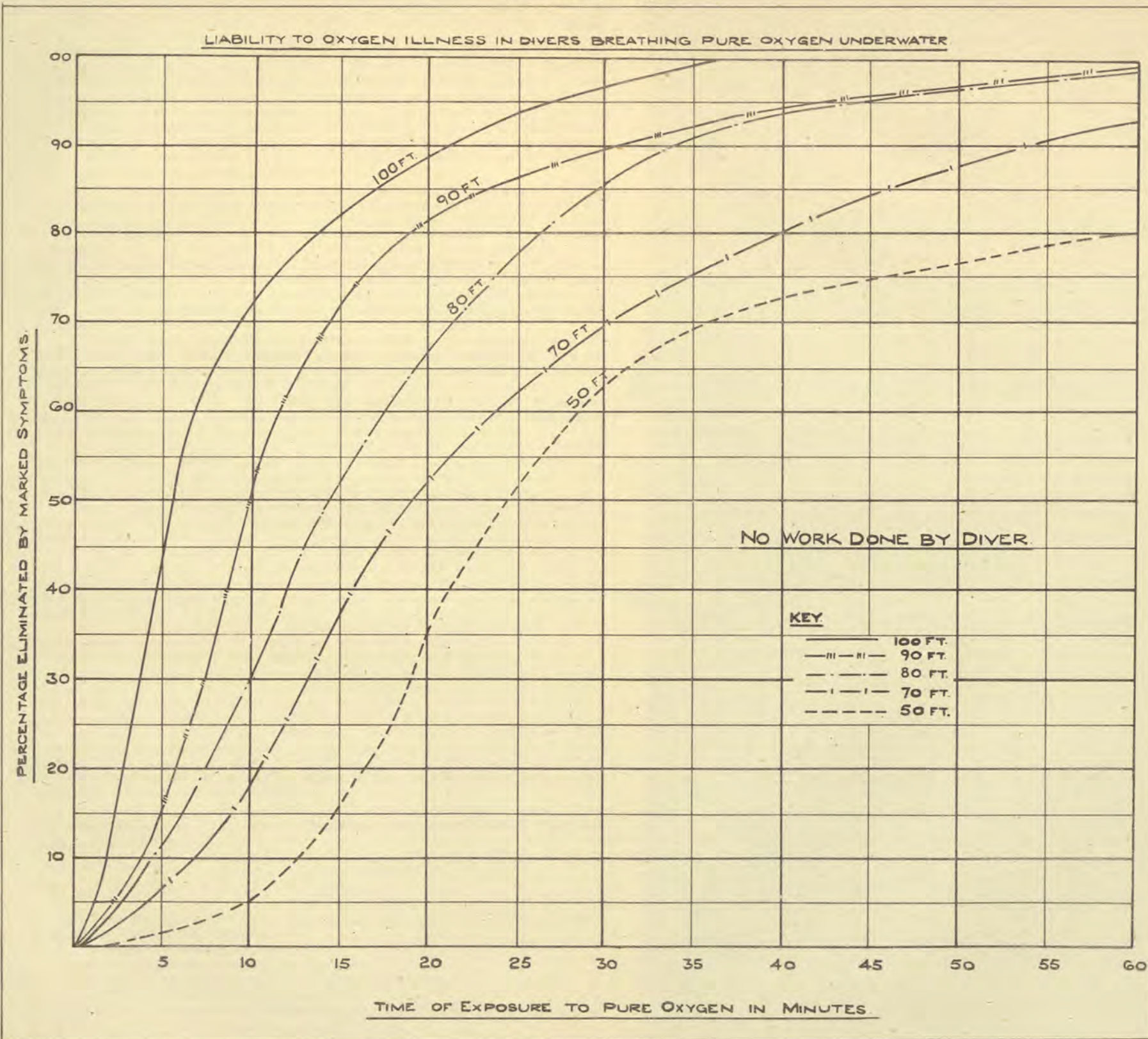
10. *The effect of Water Temperature on Oxygen Illness.*—No significant change was found in human subjects over a range of 49° F. to 88° F. It is unlikely that any marked effects will be found until the body temperature of the diver is appreciably altered.

11. *Variation in Resistance to Oxygen Illness.*—It is extremely important that diving officers should appreciate the significance of the two facts stated in paragraph 2 (ii) and (iii) above. The fact that individual divers vary greatly in their resistance and that a given diver varies from day to day means that it is not possible to draw up a table or curve giving safe times on oxygen at various depths below 33 ft. Also, although certain divers are permanently more resistant than others, it must not be assumed that because a diver "gets away" with a deep dive one day, he can necessarily repeat the performance again.

As an illustration, 100 operational divers were "tested" for oxygen tolerance on a single dive to 50 ft. for 30 minutes; 50 per cent. convulsed or had symptoms, and the party was consequently graded accordingly. Subsequent experience, however, showed that this grading was quite erroneous and misleading.

12. *Graph showing probable Danger of Oxygen Illness.*—The attached graph, A.F.O. Diagram No. 263/44, shows the probable percentage of a group of divers who will be more or less severely affected by oxygen under pressure at various times and depths. Put in another way, it shows the chances of a given diver being able to remain safely at a given depth for a given time. Thus officers in charge of a diving operation can judge for themselves whether the object to be achieved from the dive justifies the risk to the diver. The figures given are for dives without hard work, and due allowances must be made for a reduction in tolerance if hard work is anticipated. Depths are taken from surface to the diver's chest and assume normal sea densities.

13. *To Use the Graph.*—The curves represent the depth, the time is shown along the bottom and the probable percentage eliminated by marked symptoms is shown vertically. Follow the curve up till it cuts the vertical line representing the maximum time the diver will have to spend on the bottom, then the horizontal line will give the chances of the diver being affected. To allow for the possibility of the onset of symptoms after the pressure has been reduced (see first sub-paragraph of paragraph 6 above) the estimated time for the ascent should count as time on the bottom.



Example.—A certain job at 50 ft. is estimated to take 25 minutes from the time the diver is on the bottom to the time he reaches surface again. The 50-ft. curve cuts the 25 minute line at 52 per cent., i.e. there is slightly less than a "50-50 chance" of it being a safe dive. Obviously, if it is only a question of retrieving some article lost overboard, it is hardly worth it. If, however, it is a vital examination or repair, or a question of saving other people's lives, the risk could well be taken.

It will be seen that the 90 and 100-ft. curves give very little chance of immunity for more than a few minutes at most, and oxygen diving should not be used for such depths except in extreme circumstances.

14. *Sensitivity to Oxygen Illness.*—In spite of the variations encountered during the experiments, it has been possible after considerable experience to assess the experimental divers as "weak" or "tough" oxygen divers. There is no apparent guide as to whether a diver is going to prove one or the other; physical fitness, athleticism, smoking and ingestion of alcohol all appear to have no regular effect, nor do the height, weight, or age. All that can be said is that some men will consistently show symptoms at depths shallower than normal, and at shorter times. It might be possible to work out a routine of selection if divers could be made available for long enough periods, but this is obviously impossible, and in addition there is a risk of shaking a diver's "nerve" during the selection period.

If during training, especially for special work where oxygen diving is a primary consideration, such men do manifest themselves, serious consideration must be given to discharging them as unfit for the work. It is unlikely that they will cure themselves "when they get used to it".

15. *Instruction.*—When instructing new divers, some mention of oxygen illness is unavoidable. Great care should, however, be taken not to over-emphasize or to give the impression that oxygen diving is dangerous.

If proper precautions are taken, as outlined above, oxygen diving is not only safe and harmless, but in view of the compactness of the gear, the speed with which a diver can be got ready, and his comparative mobility when under water, it can and has proved itself immensely valuable for certain types of work.

The recent experiments have shown that the alleged possibility of lung damage or pneumonia after prolonged oxygen breathing is non-existent for dives of five or six hours at shallow depths.

It has also been demonstrated that carbon dioxide accumulations of a degree which may be expected in properly designed and correctly functioning apparatus, do not affect oxygen illness. Oxygen tolerance is not affected until the percentage of carbon dioxide in the inspired air approaches 3 per cent., and this should not normally occur.

The present wide extension of oxygen diving has given rise to some cases of divers being incapacitated at depths less than 33-ft. where oxygen illness can definitely be ruled out. In these cases the symptoms are altogether different, the diver usually experiencing something similar to an ordinary faint or even only a mental black-out or confusion, from which he rapidly recovers. Such incidents are usually associated with hard work by inexperienced divers and are probably due to inefficient ventilation of the whole breathing system, possibly accentuated by "dead-space" or resistance to breathing. The subject is a complicated one, and is being fully investigated, but in the meantime divers, particularly those without much experience, should be cautioned against sudden spasms of violent activity under water, and should be warned to keep their breathing at a steady controlled rate throughout the dive.

16. *Reports.*—All information that can be collected is of great assistance to the experimental work. Any cases of divers being incapacitated whilst breathing oxygen should be reported direct to:—

The Chairman,
Admiralty Diving Committee,
H.M.S. "Dolphin",
c/o G.P.O., London.

Such reports, apart from giving a general description of the occurrence, should particularly include the following:—

- (1) Depth and time at that depth.
- (2) Diver's previous training or experience.
- (3) Type of apparatus and any defects found therein.
- (4) Whether work was being done or not.
- (5) Diver's own account of his feelings and, when possible, a medical report.

(B.R. 241/40, B.R. 155/43.)

Example.—A certain job at 50 ft. is estimated to take 25 minutes from the time the diver is on the bottom to the time he reaches water again. The 25-min. curve will be 22 minutes less at 33 per cent, i.e. there is slightly less than a "closed" or "at least a safe" diver. Obviously, it is only a question of retaining some extra gas overboard, it is hardly worth it. However, it is a vital question of oxygen, or a question of having other gas in the tank could well be retained. It will be seen that the 50 and 100-ft. curves are very little above or below the for more than a few minutes at most, and oxygen diving should not be used for such depths except in extreme circumstances.

14. *Continuing Oxygen Dives*.—In spite of the variations encountered during the experiments, it has been possible after considerable experience to make the experimental dives as "work" or "rough" oxygen dives. There is no agreement as to whether a diver is going to prove one or the other; physical fitness, altitude, training and location of alcohol all appear to have an equal effect, but the height, weight, or age. All that can be said is that someone will necessarily show symptoms at depths shallower than normal, and at shorter times. It might be possible to work out a routine of selection if divers could be made available for long enough periods, but this is obviously impossible, and in addition there is a risk of spoiling a diver's "nerve" during the selection period. It is during training, especially for special work where oxygen diving is a primary consideration, that one should remember that the diver's nervous system must be given to discharging itself as well for the work. It is naturally the case that the diver will "forget" when they get used to it.

15. *Accidents*.—When instructing new divers, some mention of oxygen dives is inevitable. Great care should, however, be taken not to over-emphasize or to give the impression that oxygen diving is dangerous.

If proper precautions are taken, as outlined above, oxygen diving is not only safe and pleasant, but in view of the compactness of the gear, the speed with which a diver can be got ready, and his comparative mobility when under water, it can and has proved itself immensely valuable for certain types of work.

The recent experiments have shown that the alleged possibility of lung damage or pneumonia after prolonged oxygen breathing is non-existent for dives of two to six hours at shallow depths.

It has also been demonstrated that carbon dioxide accumulations of a degree which may be expected in properly designed and correctly functioning apparatus do not affect oxygen fitness. Oxygen tolerance is not affected until the percentage of carbon dioxide in the inspired air approaches 3 per cent, and this should not normally occur.

The present wide extension of oxygen diving has given rise to some cases of divers being incapacitated at depths less than 33-ft. where oxygen fitness can definitely be ruled out. In these cases the symptoms are altogether different, they usually experience something similar to an ordinary faint or even only mental blackouts or confusion, from which he rapidly recovers. Such incidents are familiarly associated with hard work by experienced divers and are probably due to insufficient ventilation of the whole respiratory system, possibly accentuated by "head-space" or resistance to breathing. The subject is a complicated one and is being fully investigated, but in the meantime divers, particularly those without much experience, should be cautioned against sudden spasms of violent activity under water, and should be warned to keep their breathing as a steady controlled rate throughout the dive.

16. *Records*.—All information that can be collected is of great assistance to the experimental work. Any cases of divers being incapacitated whilst breathing oxygen should be reported back to:

The Chairman,
Admiralty Diving Committee,
H.M.S. "Dolphin",
c/o G.P.O., London.

Such records should give a general description of the circumstances, should particularly include the following:—

- (1) Depth and time at that depth.
- (2) Diver's previous training or experience.
- (3) Type of apparatus and any defects found therein.
- (4) Whether work was being done or not.
- (5) Diver's own account of his feelings and, where possible, a medical report.