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Helium and Oxygen in Deep Diving

The first to suggest the possibilities and advantages of the use of helium and oxygen in place of ordinary atmospheric air was the eminent American physicist and chemist Elihu Thomson.

Owing to its lower solubility, particularly in fat and brain, and its greater diffusivity, it was hoped that helium in place of nitrogen would enable deep sea divers to work at greater depths and render them less liable to compressed air illness after working at such depths, and that the decompression times could be reduced. After considerable experiment, however, these hopes were not wholly realized. While it was proved that divers using helium mixed with the correct percentage of oxygen were enabled to work at greater depths, it was not found safe to reduce the decompression times from those used for diving on normal air. But in course of investigations, the American scientists made a very important and valuable discovery. They found that, whereas the nitrogen content of atmospheric air breathed above a certain pressure caused nitrogen narcosis, the substitution of helium for nitrogen resulted in complete immunity from this condition, and kept the diver at great depths clear-headed and mentally alert throughout his task.

Helium being a great conductor of heat, the diver would become very cold were his suit not electrically heated or other efficient means of warmth provided.

All the original experimental work on breathing of helium-oxygen mixtures in deep-sea diving was carried out by American scientists, including Sayer, Yant, Behnke and Yarborough—to whom also is due the credit for the development of their highly specialized system of diving until it is now standard practice in the United States Navy. A few experiments were carried out a few years before the last war by the British Admiralty in collaboration with Siebe, Gorman & Co. Ltd., and the firm's associates, Sir Leonard Hill, F.R.S., Captain G. C. C. Damant, C.B.E., R.N. (retired) and others, but they were on a very small scale, owing to the limited supply of helium available.

Helium (He), an inert gas, colourless, odourless, non-toxic and non-explosive, next to hydrogen the lightest gas known, was first discovered as a terrestrial element in 1895 by Sir William Ramsay. It belongs to the group of rare gases known as argon, neon, xenon and krypton. By Dewar's method, Ramsay estimated the amount in the atmosphere as one part in 250,000 by volume, while W. Watson, using Claude's method, gave the volume as one part in 185,000.

According to Jeans, the proportion of helium in the atmosphere is much greater at considerable altitudes, and at a height of 500 miles the atmosphere is made up of helium and hydrogen.

Helium is found in measurable quantities in minerals containing the radio-active elements thorium and uranium, e.g. samarskite, monazite, thioriomite, etc., which have been generating helium for hundreds of thousands of years. When heated, the material gives off large quantities of hydrogen that would normally mask the helium emitted, but the introduction of activated charcoal immediately absorbs the hydrogen and leaves the helium in a pure state

Helium is also found in gases evolved from mineral springs and in natural gas. Comparatively small quantities have been produced from certain springs in France. England's sole source is the spring at Bath, but the percentage of helium from this is negligible. Certain Canadian gas fields produce helium, but so far they have not yielded this gas in paying quantities. The world's chief sources of supply are the natural gas fields of the United States.

The use of helium for filling balloons and airships is, of course, well known. The weight of 1,000 cubic feet of helium under normal atmospheric conditions is 11 lb., and that of air under the same conditions about 75 lb. The buoyant effect or "lift" is, therefore, about 64 lb. pei 1,000 cubic feet.

The author is very greatly indebted to the United States Navy Department for kind permission to reproduce the following extracts and the helium-oxygen tables employed in the United States Diving Department, and records his grateful thanks.

"(a) *The breathing of helium when mixed with the proper amount of oxygen is harmless.*

(b) *Helium is absorbed and given off more rapidly in solution in the body tissues than is nitrogen.*

(c) *Some tissues will not absorb as large an amount of helium as they will nitrogen. For example, fat tissue will contain about seven times more nitrogen than lean muscle, but only about three times more helium.*

(d) *As helium is absorbed more rapidly than nitrogen, some tissues may take up more helium during a given exposure to pressure. Helium will also leave the tissues faster. Both phases promote the formation of bubbles which can cause bends. While the ratio of the pressure of the gas within the diver's body to the external pressure can be 2·0 or 2·25 to 1 safely with nitrogen, this ratio is about 1·7 to 1 with helium. Therefore, this lower safe ratio of pressures with helium requires the first decompression stop to be deeper than with nitrogen. Accordingly it is desired to emphasize that a diver can contract bends when using oxygen-helium mixtures as readily as with normal air, and that decompression in accordance with the tables herein is essential.*

(e) *Oxygen and helium must be mixed in proper proportions to suit the depth of the particular dive involved. The oxygen and helium should be obtained in separate cylinders and mixed on board as required. Oxygen concentration must be kept within the safe limits of about 2½ atmospheres absolute pressure of pure oxygen. During decompression, the diver can be shifted to pure oxygen at 60 feet to hasten helium elimination from his body.*

(f) *Apparently, divers are more mentally alert when breathing oxygen-helium mixtures under pressure than when breathing normal air. The sense of depth commonly experienced when breathing the latter is much reduced. Also they work considerably harder and for longer periods, although this latter condition may be due to some extent to the better ventilation of the helmet with its resultant improved oxygen supply and decrease of carbon-dioxide.*

(g) *The advantages of using oxygen-helium mixtures in lieu of normal air are applicable mainly to diving in depths in excess of 150 feet. For the shallower depths, the time saved in decompression and improved physiological reactions are not commensurate with the elaborate special equipment which has to be provided. Consequently, this equipment is furnished only to submarine rescue vessels and to such submarine tenders that have facilities for carrying out deep submarine rescue and salvage operations.*

(h) *Helium conducts heat much more rapidly than air. When diving with oxygen-helium mixtures, the heat is transferred from the diver's body so rapidly that special provision must be made to keep him from becoming chilled. Specially-designed electrically-heated underwear developed for this purpose contributes to his comfort when worn in water of less than 60° F.*

(i) *When using oxygen-helium mixtures for diving, it is necessary that an adequate recirculating system be provided in order to recover and conserve the helium. An efficient purifier for removing the CO_2 ordinarily generated in the helmet is essential as a part of this system. In the Navy's work this is accomplished by modification of the conventional helmets.*

Decompression. The characteristics of decompression with oxygen-helium mixtures are different from those of air. With the former, a larger volume of gas is concentrated in the faster saturating parts of the body, and the rapid diffusion of gas from one part of the body to another on reduction of pressure requires the keeping of the body at high pressures for a longer time during the primary period of decompression. Also the normal procedure for decompression after an oxygen-helium dive is to have the diver breathe pure oxygen beginning at the 60-foot stop. Since pure oxygen should not be used at depths greater than 60 feet, the decompression must be made on oxygen-helium mixtures up to that point. In case of necessity, however, the diver can be decompressed on oxygen-helium mixture throughout, or shifted to compressed air, subject to separate and*

* See note at end of Chapter

distinct procedure for use in these two cases. In shifting to compressed air, however, it has been found that the human body cannot stand a direct change from helium to nitrogen at depths beyond six atmospheres' pressure without discomfort unless the air is supplied gradually at an increase in volume of about 3 per cent per minute. In actual practice, gradual shift from helium to air is accomplished through use of the recirculation system for 20 minutes of decompression time. The oxygen-helium decompression tables which follow are accordingly different from those used for ordinary compressed air diving. The tables are somewhat complicated, but at this time further simplification has been impracticable due to the many factors and conditions affecting the decompression.

To prevent initial formation of bubbles in the diver's body under different conditions of exposure to helium under pressure, the proper rate of ascent must be observed up to the first decompression stop. The rate of ascent varies with the depth of the dive and its duration. The approved procedure for decompression with oxygen-helium mixtures is as follows:

(*a*) *Take percentage of oxygen breathed by divers and the depth. Based on these factors, obtain proper rate of ascent from Table I.*

(*b*) *Take depth of dive and percentage of oxygen used by diver. Based on these factors, find from Table II the partial pressure of helium in tissues most completely saturated.*

(*c*) *Take time of dive from beginning of descent to beginning of ascent.*

(*d*) *With partial pressure obtained from Table II and time of dive, find depth and time for decompression stops in Table III.*

(*e*) *Bring diver to first stop at rate of ascent prescribed in Table I. When diver reaches 60-foot stop, shift him to pure oxygen and order him to "ventilate" to remove helium from his hose and dress. This will require about 25 cubic feet of pure oxygen. After ventilating, order diver to "circulate". The change in the sound of the diver's voice over the telephone, due to the change in the density of the gas he is breathing, is an excellent indication of the effectiveness of the ventilation. Continue the supply of pure oxygen to the end of the decompression.*

In case it becomes necessary to recompress a diver for bends after he has inhaled pure oxygen during his decompression, oxygen should be administered with care. Under such conditions the diver may exhibit abnormal susceptibility to oxygen poisoning.

In deciding the oxygen concentration of the oxygen-helium mixture to be used for divers, care should be exercised to insure that the maximum concentration does not exceed 2½ atmospheres (absolute) of pure oxygen at the depths of the dive, and that the minimum in all cases is sufficient to insure enough oxygen to meet the diver's requirements under all conditions of descent, work on the bottom, and ascent. A minimum of 15 per cent has been the practice in training.

UNITED STATES NAVY TABLES FOR DIVING WITH HELIUM-OXYGEN

TABLE I. *Rate of ascent in feet per minute*

Depth	Oxygen per cent								
	10	15	20	25	30	35	40	45	50
50	10	10	20	20	30	30	40	50	75
100	10	20	30	40	50	75	—	—	—
150	10	30	40	50	75	—	—	—	—
200	10	40	50	75	—	—	—	—	—
250	20	50	75	—	—	—	—	—	—
300	20	50	75	—	—	—	—	—	—
350	30	75	—	—	—	—	—	—	—
400	30	75	—			Rate, feet per minute			—
450	40	75	—	—	—	—	—	—	—
500	40	75	—	—	—	—	—	—	—
550	50	75	—	—	—	—	—	—	—
600	50	75	—	—	—	—	—	—	—

NOTE. 75 feet per minute is the maximum practical rate

TABLE II. *Helium-oxygen—table of partial pressures—40 to 600 feet*

Depth	Percentage of oxygen used												
	13	15	17	19	21	23	25	30	35	40	45	50	55
40	65	64	62	61	59	58	56	—	—	—	—	—	—
50	74	72	71	69	68	66	64	60	56	—	—	—	—
60	83	81	79	78	76	74	72	67	63	58	53	—	—
70	92	90	88	86	84	82	80	75	69	64	59	54	—
80	101	99	96	94	92	90	87	82	76	71	65	59	53
90	110	107	105	103	100	98	95	89	83	77	71	65	58
100	119	116	113	111	108	105	103	96	90	83	76	70	63
110	128	124	121	119	116	113	110	103	97	89	82	75	67
120	136	133	130	127	124	121	118	110	103	95	87	80	72
130	145	142	139	135	132	129	126	118	109	101	93	85	—
140	154	151	147	144	140	137	133	125	116	107	99		
150	163	159	156	152	148	145	141	132	123	114	104		
160	172	168	164	160	157	153	149	139	129	120			
170	181	177	173	169	165	160	156	146	136	126			
180	190	186	181	177	173	169	164	154	143				
190	199	194	190	185	181	176	172	161	150				
200	208	203	198	194	189	184	180	168	156				
210	216	212	207	202	197	192	187	175					
220	225	220	215	210	205	200	195	183					
230	234	229	224	219	213	208	203	190					
240	243	238	232	227	222	216	211	197					
250	252	247	241	235	230	224	218						
260	261	255	249	243	237	231	225						
270	270	264	258	252	246	240	233						
280	280	273	267	260	253	247	241						
290	288	281	275	268	262	255	249						
300	297	290	283	277	270	263	257						
310	306	299	292	285	278	271							
320	314	307	300	293	286	279							
330	323	316	309	302	294	287							
340	332	325	317	310	303	295							
350	341	334	326	318	311	303							
360	350	343	335	327	319								
370	359	351	343	335	327								
380	368	359	351	343	334								
390	377	368	360	351									
400	386	377	368	359									
410	395	386	377	368									
420	403	394	385	376									
430	412	403	394	385									
440	421	412	403										
450	430	420	410										
460	439	429	419										
470	448	438	428										
480	457	447	437										
490	466	456	446										
500	475	465											
510	484	473											
520	493	482											
530	502	492											
540	511	500											
550	520	509											
560	529	518											
570	538	527											
580	548												
590	557												
600	566												

1. *Obtain partial pressure from Table II.*
2. *Time of dive is from time diver starts down until beginning of ascent.*
3. *When diver reaches 60-foot stop, or 50-foot stop when first stop is at 50 feet, shift to pure oxygen and have diver "ventilate" with 25 cubic feet of pure oxygen to remove helium from dress and hose. Finish decompression with diver breathing pure oxygen.*

TABLE III. *Decompression tables*

Partial pressure (feet)	Time of dive in minutes	Stops, 50 feet	Time to first stop	Total time	Partial pressure (feet)	Time of dive in minutes	Stops, 50 feet	Time to first stop	Total time
60	10	0	2	2	110	10	6	2	8
	20	0	2	2		20	21	2	23
	30	0	2	2		30	32	2	34
	40	0	2	2		40	41	2	43
	60	4	1	5		60	57	2	59
	80	7	1	8		80	69	2	71
	100	10	1	11		100	76	2	78
	120	12	1	13		120	81	2	83
70	10	0	2	2		140	84	2	86
	20	5	1	6		160	85	2	87
	30	8	1	9		180	86	2	88
	40	10	1	11		200	87	2	89
	60	15	1	16	120	10	8	2	10
	80	21	1	22		20	27	2	29
	100	26	1	27		30	38	2	40
	120	29	1	30		40	48	2	50
	140	31	1	32		60	65	2	67
	160	32	1	33		80	78	2	80
80	10	4	1	5		100	86	2	88
	20	9	1	10		120	91	2	93
	30	14	1	15		140	94	2	96
	40	18	1	19		160	95	2	97
	60	26	1	27		180	97	2	99
	80	34	1	35		200	98	2	100
	100	42	1	43	130	10	9	2	11
	120	46	1	47		20	31	2	33
	140	48	1	49		30	44	2	46
	160	49	1	50		40	56	2	58
90	10	5	2	7		60	75	2	77
	20	13	2	15		80	88	2	90
	30	19	2	21		100	95	2	97
	40	25	2	27		120	100	2	102
	60	36	2	38		140	103	2	105
	80	46	2	48		160	105	2	107
	100	55	2	57		180	106	2	108
	120	59	2	61		200	107	2	109
	140	61	2	63		220	108	2	110
	160	62	2	64	140	10	10	2	12
	180	63	2	65		20	34	2	36
100	10	6	2	8		30	50	2	52
	20	17	2	19		40	63	2	65
	30	26	2	28		60	83	2	85
	40	33	2	35		80	96	2	98
	60	46	2	48		100	104	2	106
	80	57	2	59		120	109	2	111
	100	65	2	67		140	111	2	113
	120	70	2	72		160	113	2	115
	140	73	2	75		180	115	2	117
	160	74	2	76		200	116	2	118
	180	75	2	77		220	117	2	119
	200	76	2	78					

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in minutes	Stops (minutes)				Time to first stop	Total time
		80 feet	70 feet	60 feet	50 feet		
150	10	—	—	—	10	3	13
	20	—	—	—	36	3	39
	30	—	—	—	56	3	59
	40	—	—	10	61	3	74
	60	—	—	10	81	3	94
	80	—	—	10	94	3	107
	100	—	—	10	101	3	114
	120	—	—	10	106	3	119
	140	—	—	10	109	3	122
	160	—	—	10	111	3	124
	180	—	—	10	113	3	126
	200	—	—	10	114	3	127
	220	—	—	10	114	3	127
	240	—	—	10	115	3	128
160	10	—	—	—	21	3	24
	20	—	—	10	34	3	47
	30	—	—	10	54	3	67
	40	—	—	10	69	3	82
	60	—	—	10	91	3	104
	80	—	—	10	102	3	115
	100	—	—	10	108	3	121
	120	—	—	10	113	3	126
	140	—	—	10	115	3	128
	160	—	—	10	116	3	129
	180	—	—	10	117	3	130
	200	—	—	12	117	3	132
	220	—	—	14	117	3	134
	240	—	—	15	117	3	135
170	10	—	—	10	16	3	29
	20	—	—	10	38	3	51
	30	—	—	10	61	3	74
	40	—	—	10	75	3	88
	60	—	7	10	94	3	114
	80	—	7	10	106	3	126
	100	—	7	10	113	3	133
	120	—	7	10	117	3	137
	140	—	8	13	117	3	141
	160	—	10	14	117	3	144
	180	—	12	15	117	3	147
	200	—	13	15	117	3	148
	220	—	14	15	117	3	149
	240	—	15	15	117	3	150
180	10	—	7	10	19	3	39
	20	—	7	10	43	3	63
	30	—	7	10	64	3	84
	40	—	7	10	80	3	100
	60	—	7	10	101	3	121
	80	—	9	10	110	3	132
	100	7	5	12	117	3	144
	120	7	9	13	117	3	149
	140	7	11	14	117	3	152
	160	7	14	15	117	3	156
	180	7	17	15	117	3	159
	200	7	19	15	117	3	161
	220	7	21	15	117	3	163
	240	7	23	15	117	3	165

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in minutes	Stops (minutes)						Time to first stop	Total time
		100 feet	90 feet	80 feet	70 feet	60 feet	50 feet		
190	10	—	—	—	7	10	21	4	42
	20	—	—	—	7	10	49	4	70
	30	—	—	—	7	10	70	4	91
	40	—	—	7	0	10	87	4	108
	60	—	—	7	5	10	103	4	129
	80	—	—	7	9	10	115	4	145
	100	—	—	7	13	11	117	4	152
	120	—	—	7	17	13	117	4	158
	140	—	—	9	19	14	117	4	163
	160	—	—	11	20	15	117	4	167
	180	—	—	13	21	15	117	4	170
	200	—	—	14	22	15	117	4	172
	220	—	—	15	23	15	117	4	174
	240	—	—	16	23	15	117	4	175
200	10	—	—	—	7	10	24	4	45
	20	—	—	7	0	10	55	4	76
	30	—	—	7	0	10	74	4	95
	40	—	—	7	4	10	91	4	116
	60	—	—	7	9	10	109	4	139
	80	—	7	3	13	12	115	4	154
	100	—	7	6	16	14	117	4	164
	120	—	7	8	20	15	117	4	171
	140	—	7	11	21	15	117	4	175
	160	—	7	15	23	15	117	4	181
	180	—	7	17	23	15	117	4	183
	200	—	7	18	23	15	117	4	184
	220	—	7	20	23	15	117	4	186
	240	—	8	20	23	15	117	4	187
210	10	—	—	7	0	10	27	4	48
	20	—	—	7	0	10	57	4	78
	30	—	7	0	3	10	79	4	103
	40	—	7	0	7	10	94	4	122
	60	—	7	4	10	10	110	4	145
	80	—	7	8	14	12	117	4	162
	100	—	7	12	17	14	117	4	171
	120	—	8	15	21	15	117	4	180
	140	—	10	17	21	15	117	4	184
	160	—	12	17	22	15	117	4	187
	180	—	14	18	22	15	117	4	190
	200	—	16	18	23	15	117	4	192
	220	—	17	19	23	15	117	4	194
	240	—	18	20	23	15	117	4	196
220	10	—	—	7	0	10	29	4	50
	20	—	7	0	1	10	62	4	84
	30	—	7	0	6	10	84	4	111
	40	—	7	3	9	10	98	4	131
	60	7	0	9	11	11	113	4	155
	80	7	3	11	15	13	117	4	170
	100	7	6	14	17	15	117	4	180
	120	7	8	18	23	15	117	4	192
	140	7	11	18	23	15	117	4	195
	160	7	14	19	23	15	117	4	199
	180	7	15	20	23	15	117	4	201
	200	7	16	20	23	15	117	4	202
	220	8	17	20	23	15	117	4	204
	240	9	19	20	23	15	117	4	207

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in minutes	Stops (minutes) 120 feet	110 feet	100 feet	90 feet	80 feet	70 feet	60 feet	50 feet	Time to first stop	Total time
230	10	—	—	—	—	7	0	10	31	4	52
	20	—	—	—	7	0	3	10	66	4	90
	30	—	—	—	7	2	4	10	87	4	116
	40	—	—	7	0	6	9	10	102	4	138
	60	—	—	7	4	9	12	11	114	4	161
	80	—	—	7	8	12	17	14	117	4	183
	100	—	—	7	12	15	20	15	117	4	194
	120	—	—	8	14	19	23	15	117	4	204
	140	—	—	10	16	20	23	15	117	4	209
	160	—	7	6	18	20	23	15	117	4	214
	180	—	7	7	19	20	23	15	117	4	216
	200	—	7	9	19	20	23	15	117	4	218
	220	—	7	11	19	20	23	15	117	4	220
	240	—	7	13	19	20	23	15	117	4	222
240	10	—	—	—	7	0	0	10	35	4	56
	20	—	—	7	0	1	4	10	71	4	97
	30	—	—	7	0	5	7	10	90	4	123
	40	—	7	0	3	7	9	10	103	4	143
	60	—	7	0	8	10	14	11	115	4	169
	80	—	7	3	10	14	18	14	117	4	187
	100	—	7	6	12	17	23	15	117	4	201
	120	—	7	7	16	19	23	15	117	4	208
	140	—	7	11	16	20	23	15	117	4	213
	160	—	7	13	19	20	23	15	117	4	218
	180	—	8	15	19	20	23	15	117	4	221
	200	—	8	17	19	20	23	15	117	4	223
	220	—	9	17	19	20	23	15	117	4	224
	240	—	11	17	19	20	23	15	117	4	226
250	10	—	—	7	0	0	1	10	38	4	60
	20	—	—	7	0	1	6	10	73	4	101
	30	—	7	0	4	6	6	10	95	4	132
	40	—	7	0	5	8	9	10	106	4	149
	60	—	7	4	8	11	14	12	117	4	177
	80	—	7	7	11	16	18	15	117	4	195
	100	—	7	10	14	19	23	15	117	4	209
	120	7	3	12	17	19	23	15	117	4	217
	140	7	4	15	18	19	23	15	117	4	222
	160	7	7	16	19	19	23	15	117	4	227
	180	7	9	17	19	20	23	15	117	4	231
	200	7	11	17	19	20	23	15	117	4	233
	220	7	12	17	19	20	23	15	117	4	234
	240	7	13	17	19	20	23	15	117	4	235
260	10	—	—	7	0	0	2	10	41	4	64
	20	—	7	0	0	3	7	10	77	4	105
	30	—	7	0	4	6	8	10	97	4	136
	40	—	7	2	5	9	9	10	109	4	155
	60	7	0	7	9	12	16	13	116	4	184
	80	7	3	9	13	15	21	15	117	4	204
	100	7	6	11	14	19	23	15	117	4	216
	120	7	8	13	19	20	23	15	117	4	226
	140	7	11	15	19	20	23	15	117	4	231
	160	8	13	17	19	20	23	15	117	4	236
	180	9	14	17	19	20	23	15	117	4	238
	200	10	16	17	19	20	23	15	117	4	241
	220	11	16	17	19	20	23	15	117	4	242
	240	13	16	17	19	20	23	15	117	4	244

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in minutes	Stops (minutes)											Time to first stop	Total time
		150 feet	140 feet	130 feet	120 feet	110 feet	100 feet	90 feet	80 feet	70 feet	60 feet	50 feet		
270	[1] 10	—	—	—	—	7	0	0	0	4	10	44	4	70
	20	—	—	—	—	7	0	2	4	6	10	80	4	113
	30	—	—	—	7	0	2	5	6	9	10	100	4	143
	40	—	—	—	7	0	3	8	9	10	10	110	4	161
	60	—	—	—	7	3	7	10	14	16	13	117	4	191
	80	—	—	—	7	6	10	13	17	23	15	117	4	212
	100	—	—	7	2	9	13	16	20	23	15	117	4	226
	120	—	—	7	4	11	14	19	20	23	15	117	4	234
	140	—	—	7	5	14	15	19	20	23	15	117	4	239
	160	—	—	7	7	15	17	19	20	23	15	117	4	244
	180	—	—	7	9	16	17	19	20	23	15	117	4	247
	200	—	—	7	11	16	17	19	20	23	15	117	4	249
	220	—	—	7	13	16	17	19	20	23	15	117	4	251
	240	—	—	7	15	16	17	19	20	23	15	117	4	253
280	[1] 10	—	—	—	—	7	0	0	1	3	10	47	4	73
	20	—	—	—	7	0	0	2	6	6	10	84	4	119
	30	—	—	—	7	0	3	6	6	9	10	104	4	149
	40	—	—	7	0	2	5	8	8	12	11	113	4	170
	60	—	—	7	0	6	8	10	14	18	14	116	4	197
	80	—	—	7	3	8	11	14	17	23	15	117	4	219
	100	—	—	7	5	11	13	16	20	23	15	117	4	231
	120	—	—	7	8	12	16	19	20	23	15	117	4	241
	140	—	—	7	10	16	17	19	20	23	15	117	4	248
	160	—	—	8	13	16	17	19	20	23	15	117	4	252
	180	—	—	9	14	16	17	19	20	23	15	117	4	254
	200	—	—	10	15	16	17	19	20	23	15	117	4	256
	220	—	—	12	15	16	17	19	20	23	15	117	4	258
	240	—	—	14	15	16	17	19	20	23	15	117	4	260
290	[1] 10	—	—	—	—	7	0	0	2	3	10	49	4	76
	20	—	—	—	7	0	0	4	6	7	10	86	4	124
	30	—	—	7	0	1	5	5	9	9	10	105	4	155
	40	—	—	7	0	4	6	8	9	12	11	114	4	175
	60	—	—	7	4	6	8	12	15	18	14	117	4	205
	80	—	7	0	7	9	11	15	17	23	15	117	4	225
	100	—	7	2	9	11	15	17	20	23	15	117	4	240
	120	—	7	4	11	13	16	19	20	23	15	117	4	249
	140	—	7	5	13	16	17	19	20	23	15	117	4	256
	160	—	7	8	14	16	17	19	20	23	15	117	4	260
	180	—	7	10	15	16	17	19	20	23	15	117	4	263
	200	—	7	12	15	16	17	19	20	23	15	117	4	265
	220	—	7	13	15	16	17	19	20	23	15	117	4	266
	240	—	7	14	15	16	17	19	20	23	15	117	4	267
300	[1] 10	—	—	—	7	0	0	0	3	3	10	52	5	81
	20	—	—	7	0	0	1	6	6	6	10	91	5	133
	30	—	—	7	0	2	5	5	9	9	10	106	5	158
	40	—	—	7	0	5	7	8	11	13	12	111	5	179
	60	—	7	0	6	7	9	12	15	20	15	117	5	213
	80	—	7	2	8	10	12	16	19	23	15	117	5	234
	100	—	7	5	10	12	15	19	20	23	15	117	5	248
	120	—	7	8	11	16	17	19	20	23	15	117	5	258
	140	—	8	9	14	16	17	19	20	23	15	117	5	263
	160	—	8	13	15	16	17	19	20	23	15	117	5	268
	180	7	3	13	15	16	17	19	20	23	15	117	5	270
	200	7	5	14	15	16	17	19	20	23	15	117	5	273
	220	7	6	14	15	16	17	19	20	23	15	117	5	274
	240	7	9	14	15	16	17	19	20	23	15	117	5	277

[1] Take 1 extra minute from first stop to next stop.

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in minutes	Stops (minutes) 170 feet	160 feet	150 feet	140 feet	130 feet	120 feet	110 feet	100 feet	90 feet	80 feet	70 feet	60 feet	50 feet	Time to first stop	Total time
310	[1] 10	—	—	—	—	—	7	0	0	1	3	3	10	54	5	84
	20	—	—	—	—	7	0	0	3	5	6	6	10	93	5	135
	30	—	—	—	7	0	0	5	5	7	8	9	10	109	5	165
	40	—	—	—	7	0	3	5	8	8	11	13	11	115	5	186
	60	—	—	—	7	3	6	7	10	12	17	20	15	117	5	219
	80	—	—	7	0	6	9	11	12	16	19	23	15	117	5	240
	100	—	—	7	1	9	10	14	17	19	20	23	15	117	5	256
	120	—	—	7	4	11	12	14	17	19	20	23	15	117	5	263
	140	—	—	7	5	12	15	16	17	19	20	23	15	117	5	270
	160	—	—	7	8	14	15	16	17	19	20	23	15	117	5	275
	180	—	—	7	10	14	15	16	17	19	20	23	15	117	5	277
	200	—	—	7	12	14	15	16	17	19	20	23	15	117	5	279
	220	—	—	8	13	14	15	16	17	19	20	23	15	117	5	281
	240	—	—	9	13	14	15	16	17	19	20	23	15	117	5	282
320	[1] 10	—	—	—	—	7	0	0	0	2	3	3	10	57	5	88
	[1] 20	—	—	—	7	0	0	1	4	5	6	7	10	94	5	140
	30	—	—	—	7	0	2	4	5	7	8	11	10	110	5	169
	40	—	—	7	0	1	4	6	7	8	12	15	12	117	5	194
	60	—	—	7	0	5	6	9	11	13	17	20	15	117	5	225
	80	—	—	7	3	7	9	11	13	17	20	23	15	117	5	247
	100	—	—	7	5	9	11	13	17	19	20	23	15	117	5	261
	120	—	—	7	7	12	13	16	17	19	20	23	15	117	5	271
	140	—	7	2	9	12	15	16	17	19	20	23	15	117	5	277
	160	—	7	3	11	14	15	16	17	19	20	23	15	117	5	282
	180	—	7	5	11	14	15	16	17	19	20	23	15	117	5	284
	200	—	7	6	13	14	15	16	17	19	20	23	15	117	5	287
	220	—	7	7	13	14	15	16	17	19	20	23	15	117	5	288
	240	—	7	9	13	14	15	16	17	19	20	23	15	117	5	290
330	[1] 10	—	—	—	—	7	0	0	0	3	3	3	10	60	5	92
	20	—	—	—	7	0	0	2	5	5	6	8	10	96	5	144
	30	—	—	7	0	0	4	4	6	7	9	11	11	112	5	176
	40	—	—	7	0	4	4	6	7	9	12	16	14	114	5	198
	60	—	7	0	2	6	8	9	11	14	17	23	15	117	5	234
	80	—	7	0	6	8	8	13	14	19	20	23	15	117	5	255
	100	—	7	2	7	10	13	16	17	19	20	23	15	117	5	271
	120	—	7	4	9	12	13	16	17	19	20	23	15	117	5	277
	140	—	7	6	11	13	15	16	17	19	20	23	15	117	5	282
	160	—	7	8	13	14	15	16	17	19	20	23	15	117	5	287
	180	—	7	10	13	14	15	16	17	19	20	23	15	117	5	289
	200	—	7	12	13	14	15	16	17	19	20	23	15	117	5	291
	220	—	9	12	13	14	15	16	17	19	20	23	15	117	5	293
	240	—	10	12	13	14	15	16	17	19	20	23	15	117	5	294
340	[1] 10	—	—	—	7	0	0	0	1	3	3	4	10	64	5	98
	[1] 20	—	—	7	0	0	1	3	4	6	5	10	10	98	5	150
	30	—	—	7	0	1	4	5	6	8	8	13	11	113	5	181
	40	—	7	0	1	4	5	7	7	10	12	17	13	117	5	205
	60	—	7	0	5	6	8	9	11	15	19	23	15	117	5	240
	80	—	7	2	7	8	10	13	15	19	20	23	15	117	5	261
	100	—	7	5	9	9	13	16	17	19	20	23	15	117	5	275
	120	7	1	7	10	13	15	16	17	19	20	23	15	117	5	285
	140	7	2	9	12	14	15	16	17	19	20	23	15	117	5	291
	160	7	4	10	13	14	15	16	17	19	20	23	15	117	5	295
	180	7	5	12	13	14	15	16	17	19	20	23	15	117	5	298
	200	7	6	12	13	14	15	16	17	19	20	23	15	117	5	299
	220	7	8	12	13	14	15	16	17	19	20	23	15	117	5	301
	240	7	10	12	13	14	15	16	17	19	20	23	15	117	5	303

[1] Take 1 extra minute from first stop to next stop.

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in minutes	Stops (minutes)															Time to first stop	Total time
		190 feet	180 feet	170 feet	160 feet	150 feet	140 feet	130 feet	120 feet	110 feet	100 feet	90 feet	80 feet	70 feet	60 feet	50 feet		
350	[1] 10	—	—	—	—	—	7	0	0	0	2	3	3	4	10	67	5	102
	[1] 20	—	—	—	—	7	0	0	1	4	5	7	8	9	10	99	5	156
	30	—	—	—	7	0	0	3	5	5	6	8	9	13	10	115	5	186
	40	—	—	—	7	0	2	4	6	7	8	10	13	16	14	117	5	209
	60	—	—	7	0	3	5	6	9	10	13	16	18	19	15	117	5	243
	80	—	—	7	0	7	7	8	11	13	15	19	20	23	15	117	5	267
	100	—	—	7	2	8	8	12	13	16	17	19	20	23	15	117	5	282
	120	—	—	7	4	9	11	13	15	16	17	19	20	23	15	117	5	291
	140	—	—	7	6	11	13	14	15	16	17	19	20	23	15	117	5	298
	160	—	—	7	9	11	13	14	15	16	17	19	20	23	15	117	5	301
	180	—	—	8	9	12	13	14	15	16	17	19	20	23	15	117	5	303
	200	—	—	8	11	12	13	14	15	16	17	19	20	23	15	117	5	305
	220	—	—	10	11	12	13	14	15	16	17	19	20	23	15	117	5	307
	240	—	—	11	11	12	13	14	15	16	17	19	20	23	15	117	5	308
360	[1] 10	—	—	—	—	7	0	0	0	1	2	3	3	5	10	69	5	106
	[1] 20	—	—	—	7	0	0	0	3	4	5	5	7	9	10	102	5	158
	30	—	—	—	7	0	1	4	4	5	7	8	11	13	11	114	5	190
	40	—	—	7	0	1	3	5	6	7	8	11	14	17	15	117	5	216
	60	—	—	7	0	5	5	8	8	11	12	16	19	23	15	117	5	251
	80	—	—	7	2	7	7	10	11	13	17	19	20	23	15	117	5	273
	100	—	7	0	6	8	9	11	15	16	17	19	20	23	15	117	5	288
	120	—	7	1	7	9	12	14	15	16	17	19	20	23	15	117	5	297
	140	—	7	3	9	11	13	14	15	16	17	19	20	23	15	117	5	304
	160	—	7	4	10	12	13	14	15	16	17	19	20	23	15	117	5	307
	180	—	7	5	11	12	13	14	15	16	17	19	20	23	15	117	5	309
	200	—	7	7	11	12	13	14	15	16	17	19	20	23	15	117	5	311
	220	—	7	9	11	12	13	14	15	16	17	19	20	23	15	117	5	313
	240	—	7	10	11	12	13	14	15	16	17	19	20	23	15	117	5	314
370	[1] 10	—	—	—	—	7	0	0	0	1	2	2	3	7	10	69	5	106
	[1] 20	—	—	—	7	0	0	1	3	4	5	5	8	10	10	104	5	162
	30	—	—	7	0	0	3	3	5	6	7	8	11	12	14	117	5	198
	40	—	—	7	0	2	4	5	7	7	9	10	14	19	15	117	5	221
	60	—	—	7	2	5	6	7	9	11	14	16	19	23	15	117	5	256
	80	—	7	0	6	6	8	11	12	14	16	19	20	23	15	117	5	279
	100	—	7	2	7	8	11	13	13	16	17	19	20	23	15	117	5	293
	120	—	7	4	8	10	12	14	15	16	17	19	20	23	15	117	5	302
	140	7	0	7	9	12	13	14	15	16	17	19	20	23	15	117	5	309
	160	7	0	9	10	12	13	14	15	16	17	19	20	23	15	117	5	312
	180	7	2	9	11	12	13	14	15	16	17	19	20	23	15	117	5	315
	200	7	3	10	11	12	13	14	15	16	17	19	20	23	15	117	5	317
	220	7	5	10	11	12	13	14	15	16	17	19	20	23	15	117	5	319
	240	7	7	10	11	12	13	14	15	16	17	19	20	23	15	117	5	321
380	[1] 10	—	—	—	7	0	0	0	0	2	3	3	3	7	10	72	5	113
	[1] 20	—	—	7	0	0	0	2	4	4	5	5	8	10	10	105	5	166
	[1] 30	—	7	0	0	1	3	4	4	7	7	8	11	16	11	117	5	202
	40	—	7	0	0	4	4	5	6	8	10	11	14	20	15	117	5	226
	60	—	7	0	4	5	7	8	9	11	13	17	20	23	15	117	5	261
	80	7	0	3	6	7	9	10	12	15	17	19	20	23	15	117	5	285
	100	7	0	6	7	9	10	14	15	16	17	19	20	23	15	117	5	300
	120	7	1	7	9	11	13	14	15	16	17	19	20	23	15	117	5	309
	140	7	2	9	11	12	13	14	15	16	17	19	20	23	15	117	5	315
	160	7	4	10	11	12	13	14	15	16	17	19	20	23	15	117	5	318
	180	7	5	10	11	12	13	14	15	16	17	19	20	23	15	117	5	319
	200	7	7	10	11	12	13	14	15	16	17	19	20	23	15	117	5	321
	220	7	9	10	11	12	13	14	15	16	17	19	20	23	15	117	5	323
	240	8	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	325

[1] Take 1 extra minute from first stop to next stop.

TABLE III. *Decompression tables*—continued

Partial pressure (feet)	Time of dive in mins.	Stops (minutes)																	Time to first stop	Total time
		210 feet	200 feet	190 feet	180 feet	170 feet	160 feet	150 feet	140 feet	130 feet	120 feet	110 feet	100 feet	90 feet	80 feet	70 feet	60 feet	50 feet		
390	[1] 10	—	—	—	—	—	7	0	0	0	0	2	3	3	4	7	10	74	5	116
	[1] 20	—	—	—	—	7	0	0	1	2	4	5	5	5	9	9	10	109	5	172
	30	—	—	—	7	0	0	2	4	5	6	7	8	10	12	12	12	116	5	206
	40	—	—	—	7	0	2	3	5	6	6	8	9	13	14	21	15	117	5	231
	60	—	—	7	0	2	5	5	8	8	9	11	15	17	20	23	15	117	5	268
	80	—	—	7	0	5	7	8	9	11	12	16	17	19	20	23	15	117	5	292
	100	—	—	7	2	7	8	9	11	14	15	16	17	19	20	23	15	117	5	307
	120	—	—	7	5	8	9	11	13	14	15	16	17	19	20	23	15	117	5	316
	140	—	7	0	7	10	10	12	13	14	15	16	17	19	20	23	15	117	5	322
	160	—	7	1	9	10	11	12	13	14	15	16	17	19	20	23	15	117	5	325
	180	—	7	3	9	10	11	12	13	14	15	16	17	19	20	23	15	117	5	327
	200	—	7	5	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	329
	220	—	7	7	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	331
	240	—	7	8	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	332
400	[1] 10	—	—	—	—	—	7	0	0	0	1	2	3	3	6	9	10	74	5	121
	[1] 20	—	—	—	7	0	0	0	1	4	4	4	5	8	8	10	10	109	5	176
	[1] 30	—	—	7	0	0	0	4	4	4	5	7	7	10	11	15	13	117	5	209
	40	—	—	7	0	1	4	5	6	6	6	7	10	11	16	18	15	117	5	234
	60	—	7	0	0	5	5	6	7	8	11	13	14	17	20	23	15	117	5	273
	80	—	7	0	3	6	6	8	10	12	12	15	17	19	20	23	15	117	5	295
	100	—	7	0	6	7	8	10	13	14	15	16	17	19	20	23	15	117	5	312
	120	—	7	2	6	9	11	12	13	14	15	16	17	19	20	23	15	117	5	321
	140	—	7	2	8	10	11	12	13	14	15	16	17	19	20	23	15	117	5	324
	160	—	7	3	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	327
	180	—	7	5	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	329
	200	—	7	7	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	331
	220	—	7	9	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	333
	240	7	1	9	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	334
410	[1] 10	—	—	—	—	7	0	0	0	0	2	2	3	3	6	9	10	78	5	126
	[1] 20	—	—	—	7	0	0	0	2	4	4	4	5	7	9	11	10	110	5	179
	30	—	—	7	0	0	2	3	4	4	5	7	8	12	15	15	12	117	5	216
	40	—	—	7	0	2	3	4	6	6	6	9	11	13	16	20	15	117	5	240
	60	—	7	0	2	5	5	6	7	10	10	13	15	19	20	23	15	117	5	279
	80	—	7	0	5	6	8	8	9	12	15	16	17	19	20	23	15	117	5	302
	100	—	7	3	6	7	8	11	13	14	15	16	17	19	20	23	15	117	5	316
	120	7	0	5	7	10	10	12	13	14	15	16	17	19	20	23	15	117	5	325
	140	7	0	7	9	10	11	12	13	14	15	16	17	19	20	23	15	117	5	330
	160	7	2	8	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	334
	180	7	3	9	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	336
	200	7	5	9	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	338
	220	7	7	9	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	340
	240	7	8	9	10	10	11	12	13	14	15	16	17	19	20	23	15	117	5	341

[1] Take 1 extra minute from first stop to next stop.

Alternative decompressions for emergencies. *In an emergency it may be that oxygen cannot be used for decompression, owing to failure of oxygen supply, or possibly to symptoms of oxygen poisoning. Either air or helium-oxygen mixtures may be used. Emergency tables for using helium-oxygen mixtures may be calculated for the particular dive being made. In order to have a table that may be available immediately, the decompression provided in regular tables should be given up to the 60-foot stop, and from that point on, Table IV should be used (using same helium-oxygen mixture that was used on the dive).*

TABLE IV

60 feet	50 feet	40 feet	30 feet	20 feet	10 feet
23 minutes	26 minutes	30 minutes	35 minutes	42 minutes	55 minutes

In emergencies when it is not possible to use helium-oxygen mixtures or oxygen during decompression, it may become necessary to use air. Decompression for each case can be calculated. However, since the emergency may occur at any point from the bottom to the last stop, it is impractical to attempt to cover all of the possibilities in tables. Therefore, a table (Table V) for maximum saturation is provided and this table may be used for any emergency. When it is possible to do so, the air should be administered or furnished through the recirculator for the first twenty minutes of these tables. Otherwise the diver may experience uncomfortable symptoms, dizziness, weakness, loss of consciousness, etc., as a result of a sudden shift to air.

The tables are provided for each 50 feet and the table selected should be one next higher than the actual depth, unless the depth is at an even 50-foot figure.

TABLE V

Stops (feet)	Depth (feet) up to—								
	100 feet	150 feet	200 feet	250 feet	300 feet	350 feet	400 feet	450 feet	500 feet
230	—	—	—	—	—	—	—	—	9
220	—	—	—	—	—	—	—	—	9
210	—	—	—	—	—	—	—	6	10
200	—	—	—	—	—	—	—	10	10
190	—	—	—	—	—	—	3	11	11
180	—	—	—	—	—	—	11	11	11
170	—	—	—	—	—	—	12	12	12
160	—	—	—	—	—	9	12	12	12
150	—	—	—	—	—	13	13	13	13
140	—	—	—	—	4	13	14	14	14
130	—	—	—	—	14	15	15	15	15
120	—	—	—	—	16	16	16	16	16
110	—	—	—	13	16	17	17	17	17
100	—	—	—	18	18	18	18	18	18
90	—	—	7	19	19	20	20	20	20
80	—	—	22	22	22	22	22	22	22
70	—	—	24	24	24	24	24	24	24
60	—	22	26	26	26	27	27	27	27
50	—	30	30	30	30	30	30	30	30
40	14	35	35	35	35	35	35	35	35
30	42	42	42	42	42	42	42	42	42
20	52	52	52	52	52	52	52	52	52
10	68	68	68	68	68	68	68	68	68

SURFACE DECOMPRESSION. *Many occasions may arise where it is desirable or necessary to bring the diver aboard as quickly as possible. When a diver is removed from the water before his decompression has been completed (except after blowing up) the following procedure should be followed:*

1. (a) Decompress diver in the water in accordance with the regular helium-oxygen tables until the diver has reached the 50-foot stop. (The diver is shifted to oxygen at 60 feet and remains there for the time called for in the regular tables.)

(b) Keep the diver (on oxygen) at 50 feet for the same time that he spent at 60 feet.

(c) Upon completion of his stop at 50 feet, bring the diver to the surface (at the rate of 50 feet per minute), remove helmet, belt and shoes, and then place him in the recompression chamber as quickly as possible.

(d) Recompress diver in the recompression chamber to 50 feet. If the diver can clear his ears, he should start breathing oxygen on his way down; otherwise as soon as he reaches 50 feet he should start breathing oxygen. The tender should assist diver to remove the diving suit and underwear while pressure is being applied. The total elapsed time, from 50 feet in the water until the diver is at 50 feet in the chamber breathing oxygen, should not exceed three to four minutes.

(e) Keep the diver at 50 feet (on oxygen) in the recompression chamber for the time required for the 50-foot stop, as given in the normal helium-oxygen decompression tables.

(*f*) *When bringing the diver out of the recompression chamber, reduce the pressure at the rate of 10 feet per minute (that is, take five minutes to bring him to the surface from 50 feet).*

2. (*a*) *In case the first stop in the table used is 50 feet, bring the diver to 50 feet and shift him to oxygen.*

   (*b*) *After he has been breathing oxygen for ten minutes at 50 feet, bring him to the surface and carry out the same procedure for recompression as described in paragraphs 1 (c), (d), (e) and (f) above.*

Recompression chamber should be equipped with oxygen supply system, and oxygen masks provided for use in the chamber.

Decompression in this manner has been successful for exposures of one hour at 250 feet, 20 minutes at 300 feet, and 10 minutes at 350 and 440 feet.

Decompression procedure following "blow up" by diver using helium.

1. *Bring diver aboard and remove helmet, belt and shoes as quickly as possible and place in recompression chamber.*
2. *Recompress to point of relief of symptom (or recovery) plus 15 lbs. If no symptoms have developed, recompression to 75 lbs.*
3. *Maintain maximum pressure a minimum of 30 minutes after symptoms have been relieved. If no symptoms have developed, maintain pressure of 75 lbs. for 30 minutes.*
4. *Decompress according to Table V, selecting the next higher table than the actual depth (pressure) used in preceding paragraph, unless the depth (pressure) is at an even 50-foot figure as tabulated in Table V. For example, if pressure (depth) used is 175 feet, use the 200-foot table.*
5. *Complete the decompression from the 60-foot level (stop) to breathing pure oxygen for 90 minutes as follows:*
   (*a*) *At 60 feet for time as indicated in air treatment table (22 minutes if 150-foot table is used).*
   (*b*) *At 50 feet for 68 minutes.*
   (*c*) *From 50 feet to surface in 15 minutes with oxygen mask in place.*
6. *Surface slowly after 90 minutes oxygen breathing period, maintaining the oxygen mask until surface is reached.*

MIXING OXYGEN AND HELIUM

Quality. *Impurities are detrimental to proper decompression. Requisitions should bear a notation that the helium must be at least 97·5 per cent pure, the impurities, if any, to be nitrogen, and that both gas and flask are to be free of oil or oil vapour as the gas is to be mixed with oxygen. The oxygen must be at least 99·44 per cent pure, the impurities, if any, to be nitrogen and water vapour.*

Splitting helium flasks. *Helium fittings are made up with a left-hand thread and special fittings are utilized when using the cylinders. Because of the high pressure in the flasks when received, it is desirable to "bleed" fully charged flasks into empty ones before mixing the oxygen. Connect an empty helium flask to a full one (about 1,800 lbs. per square inch) with the T-fitting provided with two left-hand threaded nuts. Open the stop valve on the full flask and read the pressure on the gauge on the T-fitting. Open the valve on empty flask and allow the pressure to equalize. The gauge reading should then be half its original value.*

Mixing helium and oxygen. *In order to add oxygen to the helium, a fully-charged oxygen flask is "bled" into the helium flask containing helium at the reduced pressure mentioned above. This requires a T-fitting provided at one end with a right-hand threaded nut, and at the other with a left-hand threaded nut.*

Using the T-fitting, connect a split helium flask (about 900 lbs. per square inch) to a full oxygen flask (about 1,800 lbs. per square inch). Open the stop valve on the helium flask, read the pressure on the gauge on the T-connection, then close the valve again. Open the stop valve on the oxygen flask and read the gauge.

Compute the pressures which each flask will contain when enough oxygen has flowed into the helium flask to give the desired percentage, as follows:

Divide helium pressure in flask by percentage of helium desired in mixture. This will be pressure corresponding to 1 per cent of pressure of the mixture. To find pressure in helium flask after mixing, multiply by 100. To obtain drop in pressure in oxygen flask, multiply by percentage of oxygen desired.

Example:

Helium flask pressure 800 lbs. per square inch.

Oxygen flask pressure 1,400 lbs. per square inch, 20 per cent oxygen, 80 per cent helium mixture desired.

$$\text{Pressure of 1 per cent mixture} = \frac{800}{80} = 10 \text{ lbs. per square inch.}$$

Pressure of mixture in helium flask $= 100 \times 10 = 1{,}000$ *lbs. per square inch.*

Pressure drop in oxygen flask $= 20 \times 10 = 200$ *lbs. per square inch.*

Experience has shown that if the oxygen is allowed to enter the helium flask rapidly, more accurate results are obtained.

The helium flask will heat up and the oxygen flask will become cold due to their respective pressure changes (Charles' Law).

If the flow between the two flasks is stopped under these conditions, and the temperatures of the two flasks allowed to equalize again, the pressure in the oxygen flask will have increased slightly and that in the helium flask will have dropped (Charles' Law also). No way of controlling the temperature of the gases during mixing has been devised, so this temperature effect must be compensated for by running over a slight excess oxygen pressure, or by adjusting the pressures two or three times at intervals after the flasks have been allowed to return to approximately the same temperature. The technique depends entirely on judgment developed by experience.

After the gases are mixed, they must be allowed to set for two or three days to permit the oxygen and helium to diffuse through each other. Before using the mixture, draw a sample from each flask and determine the oxygen percentage by chemical analysis. Mark each flask with chalk to show gas it contains. Serial numbers of all flasks and the analysis of the contents of each should be recorded on a form for that purpose.

Each flask of oxy-helium mixture must be checked accurately for oxygen percentage before being used. The carbon dioxide percentage is determined at the same time and is of importance to the diver. Samples of the gas are collected in the sampling bottles, the carbon dioxide measured by absorbing it in the apparatus, then the oxygen percentage determined in the same way. The remaining gas is assumed to be helium with not more than 3 to 4 per cent nitrogen, provided the helium and oxygen mixed were of required purity (97·5 per cent and 99 per cent respectively).

Samples of air and exhaled breath may be analysed for practice.

Flasks of oxy-helium mixture used for diving should have an oxygen content within 2 per cent of the percentage desired, and have not more than 0·03 per cent carbon dioxide. Flasks are placed in the manifold so that the average of the flasks in each bank is as close as possible to the oxygen percentage to be used.

Helium flows through orifices faster than oxygen, and will penetrate openings through which oxygen cannot pass. When the gases are mixed and are not used for some time, the proportions may change, due to loss of helium. For this reason gas analysis should be made just before the mixture is to be used.

***Haldane-Henderson gas analysis apparatus.** The Haldane-Henderson apparatus shown in Fig. 138 is very accurate and will give percentages of oxygen and carbon dioxide to within 0·01 per cent in the laboratory with an experienced technician. The gas burette is calibrated to 0·001 cc. and the cost of a burette alone is equal to more than one-third of the value of the entire outfit.*

***Assembling apparatus.** For good results the apparatus should be mounted. The equipment is shipped disassembled. It should be mounted on the wooden stand as illustrated in Fig. 138, thus avoiding strains on glass tubing. The stand should be attached permanently to a table. The fluorescent lamp is mounted behind the panel of the stand to provide illumination through the ground glass windows in the panel. Vibration, motion of the equipment, poor lighting, temperature variations, and other inaccuracies will introduce errors in reading the scales. Attempts have not been made to use the apparatus on board ship, so the probable limits of error under such conditions are not known, but they may be large.*

The stirring tube may be connected to a source of compressed air instead of to the rubber bulb.

All joints should be made up glass-to-glass, using sulphur free rubber tubing. Lubricate and seal stopcocks with a minimum amount of Lubriseal. Stopcocks must be kept clean.

* The late Professor J. S. Haldane of Oxford University and Professor Yandell Henderson of Yale University

Reagents. The carbon dioxide absorbent is potassium hydroxide (KOH), 10 per cent. It must be entirely clear and free of precipitate.

The oxygen absorbent is potassium pyrogallol. It is prepared as follows:

Add 200 cc. of water to 300 grams of potassium hydroxide sticks (not purified by alcohol). Place solution in a bottle with a greased stopper. To each 100 cc. of the solution add 15 grams of pyrogallic acid (Merck).

Both reagents must be kept from contact with the air to prevent their absorbing carbon dioxide and oxygen, thus losing their strength. Both are very caustic. The potassium pyrogallol should be kept in a bottle with a greased stopper.

Preparation for use. Fill water jacket with water to just above enlarged portions of thermobarometer tube, and attach rubber tube full of mercury, and clamps for levelling. This can be done by attaching mercury levelling bulb to thermobarometer, running mercury up the tube and drawing water required through the thermobarometer outlet to the KOH reservoir by lowering the mercury level. Then put clamps on the rubber tubing leading to the levelling bulb and cut tubing.

Set four-way cock to connect burette to carbon dioxide absorption chamber. Run mercury to near top of burette by elevating levelling bulb. Pour KOH solution into its reservoir. Draw solution up into the carbon dioxide absorbing chamber by lowering mercury level in burette.

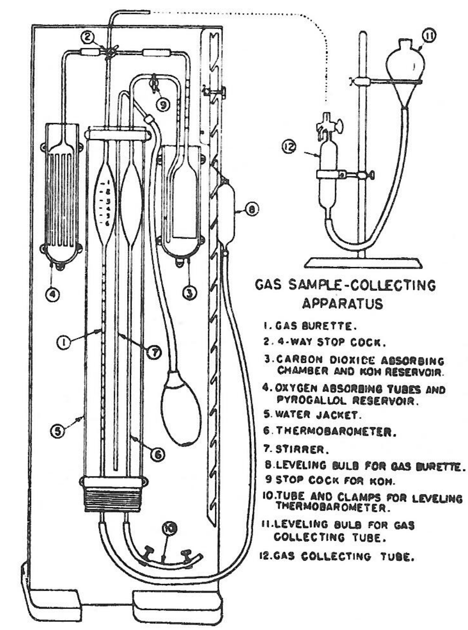

Fig. 138

Haldane-Henderson gas analysis apparatus

Shift four-way cock to connect burette to oxygen absorbing chamber. Again run mercury to near top of burette. Pour potassium pyrogallol solution into its reservoir and draw it up into the oxygen absorbing chamber by lowering mercury in burette. Pour some liquid petrolatum into pyrogallol reservoir to protect the solution from the air.

Adjust level of KOH in the thermobarometer connection to the KOH reservoir to one of the marks on this glass tube by means of the levelling tube and clamp on the bottom of the thermobarometer. Next, adjust the level of the liquid in the glass tube to the carbon dioxide absorbing chamber to one of the marks on this tube by changing the mercury level in the burette. It may be necessary to repeat these operations if the liquid in the thermobarometer connection moves appreciably off its mark.

All carbon dioxide and oxygen must be removed from the apparatus, leaving only inert gas in it. This is done by analysing at least two samples of atmospheric air, which also checks the accuracy of the set-up. The clearing process and the check analysis must be repeated whenever the apparatus stands unused for any length of time.

Sealing of gas samples. Gas samples must be sealed with mercury. They are taken with the gas sampling tubes shown in Fig. 138.

Open sample tube stopcock and fill tube and cock with mercury from the levelling bulb, then close cock. Gas must be allowed to escape from a high pressure container through a regulator, or a needle valve, to reduce the pressure. Permit gas to flow through regulator and connecting tube to gas sample tube for a minute to expel air. Open the stopcock, rinsing the sample tube by running mercury up and down, then trap a sample by closing stopcock.

At least two complete analyses should be run on each sample to insure that results are correct.

Analysis of sample. Connect gas sample bottle to apparatus. Open four-way cock to sample connection. Elevate burette levelling bulb to run mercury to sample bottle stopcock, expelling previous sample, then open sample bottle stopcock. Run mercury up and down in burette two or *three times to rinse, then draw in sample by running it down to just above the 10 cc. mark, allowing for pressure of sample. Shift cock clockwise to connect burette to carbon dioxide absorbing chamber and make first reading of burette* quickly. *Run mercury in burette up and down with levelling bulb a few times to absorb the carbon dioxide. Return level of KOH in absorbing chamber tube to its previous mark by adjusting height of mercury in burette. Read burette again. The carbon dioxide content in per cent of volume is:*

$$\frac{\textit{Difference between burette reading}}{\textit{First burette reading}} \times 100$$

Turn four-way cock clockwise to connect burette to oxygen absorption chamber. Run level of pyrogallol up and down in the chamber a few times to absorb oxygen. Return pyrogallol level to original mark on absorption chamber tube, then shift four-way cock counter-clockwise to connect burette to carbon dioxide absorption chamber again.

The gas sample is washed in the KOH solution again, then in the pyrogallol. Adjust the level of the liquid each time in the absorbing chamber used before shifting the stopcock.

At the conclusion of the second washing with pyrogallol, shift back to the carbon dioxide absorbing chamber, adjust level of KOH solution, and read burette. Repeat washings until burette scale reading remains constant within 0·04. This is the third burette reading.

The oxygen content of the sample in per cent of volume is:

$$\frac{\textit{Difference between second and third readings}}{\textit{First reading}} \times 100$$

Precautions during and after operations. *Keep the fluorescent lamp turned off except while actually taking reading. The heat from the lamp will cause temperature changes and errors.*

By careful manipulation and practice, bubbles of gas and drops of liquid can be kept out of the apparatus.

If either of the solutions is run over into the burette, they must be drained out and the burette washed out with 1 per cent solution of sulphuric acid.

The length of time required to complete the absorption processes is a measure of the strength of the reagents.

When potassium pyrogallol becomes old and thick, it may clog the small tubes in the oxygen absorption chamber, causing errors due to bubbles and slowing the reaction.

When a test on a sample is finished, leave the levels of the liquids in the connecting tubes at their reference marks to save time. The level of KOH in the thermobarometer connection to the KOH reservoir should not vary more than a perceptible extent during a test.

Once a sample has been taken into the apparatus the blue end of the four-way stopcock handle must not be moved through the upper half of its arc until the analysis is finished.

Bubble air through water jacket with stirrer every three to five minutes to keep it at same temperature throughout. Do not agitate water enough to make it splash on burette and thermobarometer tubes.

Keep the apparatus and the mercury clean to prevent introduction of errors.

When apparatus is to be left unattended for a time, open stopcock on thermobarometer connection to KOH reservoir to avoid having liquids run over.

Consult standard reference works and text books on analytical chemistry for details of technique."

Note—As described in Chapter 7 the deeper divers of the British Navy, on completion of their task below, normally return to the surface in the Davis Submersible Decompression Chamber and complete their decompression therein, being supplied with oxygen at the 60-foot stage of their ascent. United States Navy deep divers, however, still normally decompress entirely under water, standing on a platform slung from the diving vessel (See page 236). At the 60-foot stage in their case, the oxy-helium mixture which they have been breathing during work is replaced by oxygen, the oxy-helium in their air pipe and dress being washed out with about 25 cubic feet of oxygen.