ON THE EFFECTS PRODUCED IN THE
HUMAN SUBJECT

BY THE

ADMINISTRATION OF DEFINITE MIXTURES
OF NITROUS OXIDE AND AIR

AND OF

NITROUS OXIDE AND OXYGEN

BY

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I. INTRODUCTION.

The effects produced upon the human organism by the inhalation of nitrous oxide gas, either pure or mixed with certain percentages of air or of oxygen, are of considerable interest; for not only do they afford those of us who employ anæsthetics for surgical purposes much food for reflection and study, but by reason of the side-lights which they throw upon the subject of asphyxia they deserve attention from physiologists.

Whilst most observers who have had much clinical

experience in the administration of pure nitrous oxide agree in the main as to the phenomena produced, very divergent views have been and are still expressed as to the effects which attend the inhalation of this gas with different percentages of air or oxygen. It was this fact, indeed, which led me some years ago to commence the investigation which I now have the honour of placing before this Society. It seemed to me that there was need for greater accuracy; that our knowledge should be of such an order that it would enable us to state that when nitrous oxide is administered with certain small percentages of air or oxygen certain phenomena will arise; that when these percentages are increased certain other symptoms will make their appearance; that so far as the asphyxial accompaniments of an administration of nitrous oxide are concerned these will fail to assert themselves when this or that percentage of air or oxygen is present; and that so far as anæsthesia is concerned this will be most satisfactory with certain mixtures, and unsatisfactory or unattainable with others.

It is not difficult to understand the wide discrepancies of opinion which have existed concerning the influence which different percentages of air and of oxygen have in modifying the effects of pure nitrous oxide. In the first place, errors as to the precise compositions of the gaseous mixtures employed are very liable to arise, either because the nitrous oxide used is not pure or because the gasometer with which the administrations are conducted is incapable of accurately measuring the proportions of the constituent gases. In the next place, it is not an easy matter to wholly prevent the ingress of the surrounding atmospheric air during the administration. This is probably the most fruitful source of error. I do not exaggerate when I say that years of practice are necessary before absolute accuracy in adjusting the face-piece or mask can be obtained. Persons with hair about the lower part of the face are, for obvious reasons, unsuitable subjects in an investigation of this kind; and

in the case of lower animals it is perfectly clear that if the gases be administered by means of a face-piece or mask, fallacies must inevitably result. It must also be borne in mind that the valves of the apparatus employed should work in such a way that no air can be sucked back during their closure, otherwise dilution of the mixture employed will occur. Many of the inhalers formerly used, and even several of those employed at the present day for administering nitrous oxide gas, are quite unsuitable for accurate administrations. In the third place, care must be taken that the channels through which the patient inspires and expires are of sufficiently wide calibre, otherwise an asphyxial factor will be at once introduced, and the result thereby modified. In the fourth place, it is necessary, if we wish to obtain reliable and comparable results, to reproduce in each administration the main general circumstances which were present in other cases. Although it is true that we cannot, except rarely, obtain the same patient, we can, by employing the identical inhaler, method of administration, posture, looseness of dress, and general surroundings, secure such uniformity in our results that we are justified in making comparisons between the different percentages. From these considerations it will, I think, be clear that the possible sources of fallacy in administering gases and gaseous mixtures are very numerous; that if we wish to avoid them a close attention to numerous details is absolutely essential; and that unless they are avoided no reliance whatever can be placed upon the results obtained.

The present investigation was begun on December 3rd, 1894, at the Dental Hospital of London, Leicester Square, and was finished on January 26th, 1897.

II. THE GASES AND GASEOUS MIXTURES USED IN THE INVESTIGATION.

There were in all 231 administrations, which I have arranged in two Series. Series I consists of 226 cases; Series II of 5 cases.

The cases of Series I are comparable to one another, *i. e.* the general conditions in each case were the same, although the gases inhaled differed.

In Series II the cases were not comparable, *i. e.* the conditions under which the cases were conducted were dissimilar.

The following is a statement of the various gases administered in Series I and II.

SERIES I.				Cases.
Pure nitrous oxide	.	.	.	20
"	with	3 per cent. air	.	5
"	"	5	"	10
"	"	6	"	6
"	"	7	"	6
"	"	10	"	10
"	"	12	"	5
"	"	14	"	4
"	"	15	"	9
"	"	16	"	5
"	"	18	"	12
"	"	20	"	7
"	"	22	"	14
"	"	25	"	8
"	"	30	"	4
"	"	33 $\frac{1}{3}$	"	1
"	"	3	" oxygen	5
"	"	4	"	10
"	"	5	"	17

	Cases.
Pure nitrous oxide with 6 per cent. oxygen	11
„ „ 7 „	11
„ „ 8 „	18
„ „ 9 „	5
„ „ 10 „	10
„ „ 11 „	7
„ „ 13 „	2
„ „ 20 „	4
	<hr/>
	226

SERIES II.

Pure nitrous oxide	.	.	.	2
„	with 20 per cent. air	.	.	1
„	„ 5 „	oxygen	.	1
„	„ 10 „	„	„	1
				<hr/>
				5

III. THE APPARATUS EMPLOYED.

The gasometer which I used is here figured.

Its bell had a capacity of about 20 gallons, but, allowing for the “seal” (*i. e.* the layer of water necessary to prevent the escape of the gases when the bell was full), the working capacity proved to be exactly 18 gallons. The bell, which was 12 inches in diameter, was graduated by means of a painted scale into 100 equal divisions, so that any percentage of air or oxygen could be mixed with nitrous oxide. As the workable capacity of the bell was 18 gallons, each division of the scale represented $\frac{1}{10}$ gallon, and it was a simple matter to read off the scale to a tenth of each of these divisions. There were no counterbalancing weights, so that the mixed gases issued at slight pressure. The fulness of the inhaling bag, however, could be regulated at will by the tap between this bag and the gasometer. The

special stopcock through which the gases passed on their way from the inhaling bag to the face-piece was one which I have elsewhere described. It contains two accurately working flap valves, so that the patient's expirations escape into the surrounding air.

Before being used for any administration the bell of the gasometer was always "washed out" by a stream of pure nitrous oxide, in order to free it from all air. It was then filled to about one half with the anæsthetic gas; the proper percentage of air or oxygen was next introduced; and finally the bell was filled up by means of more nitrous oxide. This system was adopted in order to ensure the gases being thoroughly mixed. After waiting a minute or two the exit tube and inhaling bag were "washed out" by allowing some of the mixture to escape. The bag was then emptied, all stopcocks were turned off, and the first reading on the scale was taken.

IV. THE METHOD OF ADMINISTRATION; THE SYSTEM OF NOTE-TAKING; AND THE TERMS USED IN THE COURSE OF THE INVESTIGATION.

IN all the cases of Series I the patients were placed in exactly the same posture, all constricting clothing was unfastened, the same directions were given as to breathing, the same questions asked afterwards, and the same apparatus used. The face-piece having been applied with accuracy, each patient was allowed to take two or three breaths of air through the stopcock. Instructions were always given to "take long, deep breaths backwards and forwards through the mouth." When it was found that the face-piece fitted well, the mixture was turned on. The bag was kept as far as possible half distended. This was done by regulating the flow of the mixed gases from the gasometer by means of the tap of the exit tube. Each administration was conducted till distinct signs of

anæsthesia occurred. The face-piece was then removed and the operation begun. The note-taking was continued till anæsthesia was at an end. The patient then left the chair, and the note-taker made a further entry as to the patient's sensations and opinions. The final reading of the gasometer was now taken, after pressing back into the bell any of the mixture left in the bag. Any after effects were noted.

The special circumstances of the cases of Series II are referred to in a later part of the paper.

Throughout the investigation I had the services of two assistants; one to count aloud the bells of a metronome, the other to enter, on previously ruled forms, the various observations which I made during the progress of each administration. The metronome was set to ring its bell every three seconds, and as one assistant consecutively called out the number of bells the other entered the notes at the various stages of the administration or resulting anæsthesia.

In taking notes of the cases particular attention was paid to the following symptoms:

1. *Anoxæmic convulsion*.—Various terms, such as "epileptiform muscular twitching," "clonic muscular spasm," "jactitation," and "oscillation," have been used by authors to denote the peculiar phenomena so common when nitrous oxide is administered free from oxygen. But as everything in this inquiry goes to prove that these muscular phenomena are due to absence of oxygen, I have used the term anoxæmic convulsion as the most appropriate by which to designate the condition. Convulsive movements occurring during the operation have been disregarded in analysing the cases, as such movements may arise from intercurrent mechanical causes.

2. *Duskiness; lividity; cyanosis*.—Alterations in the patient's normal colour are exceedingly common, not only under nitrous oxide itself, but under various mixtures of this gas with air or oxygen. In estimating the alteration in colour under nitrous oxide and its mixtures, I have

disregarded lividity arising during the operation period, for during this period it may, like anoxæmic convulsion, depend upon other influences than want of oxygen in the gaseous mixtures used.

3. *Stertor*.—All grades of stertor, from mild and barely audible snoring, to coarse, loud, irregular, guttural sounds, were met with and recorded. As in the case of convulsion and cyanosis, I have disregarded stertor during operation, as this may possibly be dependent upon causes other than those under consideration.

4. *Retching movements*.

5. *Phonation*.—Under this term I have included all expiratory vocal sounds, from the slightest to the most intense (shrieking). In order to place the cases as far as possible upon the same footing, I only took cognizance of phonation during the inhalation, and during the thirty seconds immediately following it.

6. *Excitement and reflex movements*.—Under this heading I have included all muscular phenomena other than the purely voluntary and the epileptiform above referred to. Thus, we may meet with uncontrollable nervous movements; intoxication movements; tonic spasm; fine tremor; peculiar movements of the arms, legs, or body, occurring late in the administration of nitrous oxide and oxygen ("secondary rigidity"); and those strictly reflex movements dependent upon the operation. I have only taken into account the occurrence of such muscular phenomena during the inhalation and first thirty seconds after. In a few cases forcible restraint was needed to keep the patient in the chair.

7. *After effects*.—I was unfortunately only able to ascertain the immediate after effects in the large majority of cases, as most of the patients did not return to the hospital.

8. *Laboured or "catching" respiration*.

9. *Unpleasant dreams*.

10. *Duration of anæsthesia after inhalation*.—It is an exceedingly difficult matter to say in any given case at

what precise moment anæsthesia comes to an end after an inhalation of nitrous oxide, pure or diluted. This is more particularly so when the operation has been completed in the first few seconds after the removal of the inhaler. It therefore follows that the number of seconds given as the duration of the available anæsthesia in each case can only be regarded as approximately accurate. In estimating the duration of the resulting anæsthesia I found the best plan was to repeatedly ask each patient, whilst recovering from the effects of the anæsthetic mixture used, to open her eyes, and to take the moment at which conscious response to this request occurred as indicating the cessation of anæsthesia. I may say that by adopting this plan one is usually certain of being well within the mark, so far as the perception of pain is concerned ; for, as a general rule, there is, during the recovery from nitrous oxide anæsthesia, a distinctly analgesic borderland through which the patient passes after conscious response to questions has become possible (see p. 176). In several of the cases, either the patient's symptoms misled me, or, with the object of doing as much for the patient as possible, the operation was prolonged rather beyond the proper limit, and slight pain was felt. Deductions have, however, been made in these cases on the following system, it being held that the ideal to be aimed at is absolute unconsciousness, not merely of pain, but of any operative procedure whatsoever. Hence, whenever it was clear from the patient's statements that some pain was felt towards the end of the operation, or that consciousness was present without any pain being experienced, deductions were made for the erroneously estimated anæsthesia period. Two or three seconds were deducted when patients stated that they felt "something," but were unable to say precisely what they felt ; or when they knew something of the end of the operation without experiencing any pain ; or when they "thought" they felt something of the operation, but were not sure. See Cases 148, 62 a, 40, 122, 168,

146, 130, 133, 182, 121, 52, 18, 19, 97. Five seconds were deducted when slight pain was felt at the end of the operation, as in Cases 124, 33, 202, 95, 96, 206, 193, 5, 7, 22, 162, 103, 134, 42. Six or seven seconds were deducted when distinct pain was felt just at the end of the operation, as in Cases 84, 183, 8, 149, 76, 167, 99, 85, 91, 75, 78, 80. Ten, eleven, or twelve seconds were deducted when, from the patient's statements, and from a consideration of the operation performed, it seemed clear that an error to this extent had been made in estimating the anæsthesia. See Cases 156, 164, 77, and 48. In one case (Case 59) seven teeth were removed, but the patient declared that pain was experienced during the removal of the last three, so that the supposed anæsthesia of sixty seconds had to be reduced to thirty-six seconds. The following case will give a good example of the way in which the notes were recorded.

No. 169.	Date.—June 23rd, 1896.	Place.—Dental Hospital.
<p><i>Weather.</i>—Sultry morning. No direct sunlight.</p>		
Sex.—F.	Name.—Mrs. R. G—.	Age.—24.
<p><i>Description.</i>—A Russian Pole. Dark hair and eyes; thin; nervous.</p>		
<p><i>Anæsthetic used.</i>—Nitrous oxide with 22 per cent. of air.</p>		
<p><i>Operation performed.</i>—Two teeth extracted.</p>		<p><i>Operator.</i>—Mr. Cooper.</p>
		<p><i>Notes by Mr. Bellamy Gardner.</i></p>
<p><i>Patient's sensations and opinions.</i>—Thinks she remembers last tooth being removed, but is wrong as to its situation when questioned. Felt no pain. Dreamt she was talking to some one.</p>		
<p><i>Remarks.</i>—Metronome bell rings every three seconds. Some lassitude after administration. In this case the operation was purposely continued, and one tooth removed <i>after</i> patient had regained sense of hearing and power of responding to questions, but there was no pain and no distinct recollection of the removal of the tooth.</p> <p>NOTE.—Where no entries made, patient quite quiet, with good breathing and good colour.</p>		<p><i>Gasometer readings.</i>—</p> <p>Before ... 84·5</p> <p>After ... 32·0</p> <p>—</p> <p>52·5 divisions</p> <p>—</p> <p>4200</p> <p>525</p> <p>—</p> <p>9·450 gallons used.</p>
<p><i>Duration of inhalation.</i></p> <p>150 secs.</p>	<p><i>Duration of available anæsthesia.</i></p> <p>54 secs.</p>	<p><i>Gallons inhaled.</i></p> <p>9·45 gallons.</p>

INHALATION.			
Metronome bells.		Metronome bells.	
1		46	
2		47	
3		48	
4		49	
5		50	Administration discontinued.
6		51	
7	Responds when spoken to ("Can you hear me?").	52	
8		53	
9		54	
10	Breathing rather "held."	55	
11		56	
12			
13			
14	Responds when spoken to.	AVAILABLE ANÆSTHESIA	
15			
16	Do.		
17			
18			
19	Do.		
20			
21	Do.	1	Operation begun. Patient per- fectly tranquil.
22		2	
23	Do.	3	No reflex movement or noise.
24		4	
25		5	No conjunctival reflex. One tooth out.
26		6	
27		7	
28		8	
29	Goes on moving head although not asked whether she can hear.	9	No response when spoken to.
30		10	
31		11	Perfectly tranquil. Second tooth grasped.
32		12	
33		13	
34	Breathing regular; not very deep.	14	
35		15	Responds when spoken to. Ope- ration proceeding.
36		16	
37		17	Slight phonation during extrac- tion of tooth.
38	Colour unaltered.	18	Anæsthesia at an end.
39		19	
40	Pulse good and regular.	20	
41		21	
42		22	
43			
44			
45			

I have chosen Case 169, as it is an interesting one. It shows that deep and tranquil anæsthesia may be obtained by nitrous oxide even when as much as 22 per cent. of air is mixed with the anæsthetic gas. And it also shows that during recovery from anæsthesia a tooth may be painlessly removed *after* the sense of hearing and the power of making responses to questions have been regained. The sense of hearing and the faculty of understanding questions are late in disappearing during the inhalation of nitrous oxide gas, more especially when this gas is mixed with air, an analgesic state becoming established a considerable time before failure to hear and to respond is observed. During recovery from anæsthesia the exact reverse obtains, the power of hearing and of understanding questions returning before the perception of painful impressions is regained (see p. 172).

It would be impracticable to reproduce all the 231 cases *in extenso* as the foregoing, although they are of considerable interest in their entirety. I have been obliged, therefore, to condense them into the tables given on pp. 180—191.

V. THE PLAN BY WHICH IT WAS FOUND POSSIBLE TO NUMERICALLY EXPRESS THE UNSATISFACTORY OR OBJECTIONABLE PHENOMENA OF THE VARIOUS CASES.

It was not until I had spent a considerable time in analysing the various cases that I devised a plan by which I could compare them one with another irrespective of the gases inhaled; and the plan may thus be described. In certain of the cases an absolutely ideal state of anæsthesia was met with,—that is to say, the patients inhaled the gases administered to them without any discomfort, movement, or sound; they passed into deep sleep without any alteration in colour, and without any noisy or difficult breathing; an average dental operation was painlessly performed upon them without eliciting any phonated sounds or inconvenient reflex movements during the first thirty seconds after the

inhalation ; and consciousness was regained without discomfort or disagreeable after effects. Now such cases I have regarded as having no objectionable symptoms either from the point of view of the patient, the operator, or the administrator ; and I have assigned to them the value "0." In a large proportion of the cases, however, this ideal was not reached. In some it was nearly reached, and but for slight alteration in colour, or some other symptoms of minor importance, the cases were of the ideal type. I therefore assigned numbers, more or less arbitrarily fixed, to the various objectionable phenomena, and I found that I could by such a plan give a numerical expression to each and all of the objectionable phenomena met with in the various cases. The phenomena least objectionable had the fewest "bad marks ;" whilst those which greatly interfered with the comfort of the patient or the convenience of the operator, or which involved any risk to the patient which was absent in other cases, had more "bad marks" assigned to them. After a while I was able to draw up the following table, which will, I hope, explain itself after what I have just said.

Table showing the arbitrary numbers chosen for expressing the objectionable phenomena met with in each administration.

		Slight.	Moderate	Extreme.
Anoxæmic convulsion	—	20	35	50
Duskiness, or change of colour	—	10	20	30
Stertor	—	5	15	40
Retching movements at end of administration or early in anæsthesia period	—	20	35	45
Phonation	—	5	15	35
Excitement and reflex movements ...	—	0	20	40
Forcible restraint needed.....	65	—	—	—
After effects	—	5	15	35
Laboured or "catchy" respiration...	5	—	—	—
Unpleasant dreams	5	—	—	—
Anæsthesia after administration.....	Adults.	30 secs.	25 to 29	Under
		or over.	secs.	25 secs.
	Patients under 16 yrs.	0	10	20
		25 secs.	20 to 24	Under
		or over.	secs.	20 secs.

By this system it will be seen that such comparisons as the following may easily be made and numerically expressed.

(1) One group of cases conducted with a certain percentage of air or oxygen may be compared with another group conducted with a different percentage, the general result of the one group being expressed by one number, and that of the other group by another number (see p. 205).

(2) The patient remaining the same, the general result of administering on one occasion a particular mixture of gases may be compared with the general result on another occasion when a different mixture is employed.

(3) A certain symptom or objectionable phenomenon may be taken, and the extent to which it is met with in certain groups of cases may be readily expressed.

For example :

(1) Taking "0" as the value of the ideal cases at one end of the scale, and "200" as the value ("bad marks") of the unsatisfactory cases at the other and—the latter being cases in which failure to anæsthetise took place—and working with the various empirical values given in the above table, I find that whilst the average "bad marks" of an ordinary nitrous oxide administration may be expressed by the number 93·7, those of a mixture of 5 per cent. of oxygen with nitrous oxide amount only to 22·6 ; in other words, one system of anæsthetising is four times better than the other.

(2) I found that in the case of a patient anæsthetised on one occasion with a 5 per cent. of air mixture, and on another occasion with a 5 per cent. of oxygen mixture, the average objectionable phenomena in the air administration worked out at 115, whilst those in the oxygen administration only came to 15. Or, lastly—

(3) If we take the numbers 20, 35, and 50 to represent respectively slight, moderate, and extreme anoxæmic convulsion, we find that whilst the average degree of this convulsion in the pure nitrous oxide cases may be

expressed by the number 28·5, that in the 18 per cent. of air cases is but 19·1.

VI. THE CASES OF SERIES I.

(*Comparable cases.*)

For reasons already mentioned, the cases of Series I cannot be given *in extenso*. I have therefore analysed them in accordance with the plan just described, and have arranged them, under the various mixtures used, in the accompanying table.

No. of case.	Sex.	Age.	Inhalation (secs.).	Available anesthesia (secs.).	Gallons used.	Teeth or roots removed.	Arbitrary numerical expressions for objectionable phenomena.								Negative value of case as a whole.		
Average	...	...	55.9	30.3	4.5	1.6	28.5	12.5	17.	1.7	12.7	15.2	0.25	...	0.25	5.5	93.7
Pure Nitrous Oxide.																	
1	F.	19	69.	30.	5.01	3.	20.	20.	40.	...	15.	...	5.	...	5.	...	105.
2	F.	22	69.	30.	6.17	Nil	...	...	40.	...	35.	65.	...	...	...	...	140.
3	F.	24	60.	18.	3.60	1	...	...	15.	...	35.	40.	...	...	...	20.	110.
4	F.	15	48.	27.	5.86	1.	35.	20.	40.	...	...	40.	...	...	...	10.	145.
5	F.	39	60.	25.	5.63	3.	20.	20.	...	...	15.	...	...	...	...	10.	65.
6	F.	37	48.	33.	5.09	2.	35.	20.	15.	...	15.	20.	...	...	...	...	105.
7	F.	29	60.	31.	3.78	2.	...	...	40.	...	35.	40.	...	...	...	...	115.
8	F.	17	60.	26.	3.96	3.	50.	...	15.	...	...	...	...	...	...	10.	75.
9	F.	33	60.	27.	6.17	2.	...	...	15.	...	...	40.	...	...	...	10.	65.
18	F.	26	51.	33.	3.38	P	35.	20.	15.	...	15.	20.	...	...	...	...	105.
19	F.	18	42.	15.	4.19	1.	35.	10.	15.	...	...	...	...	...	...	20.	80.
71	M.	17	57.	33.	4.44	2.	35.	20.	15.	...	...	...	...	...	...	...	70.
73	F.	25	72.	30.	5.14	2.	...	20.	40.	...	5.	...	...	...	...	...	65.
74	F.	39	66.	36.	3.87	1.	50.	10.	5.	...	35.	...	...	...	...	...	100.
122	F.	21	60.	45.	4.24	Nil	35.	20.	...	...	15.	...	...	...	...	...	70.
123	F.	13	36.	27.	3.94	3.	50.	30.	15.	...	...	...	...	...	...	10.	105.
124	M.	17	60.	28.	5.23	1.	50.	10.	...	35.	...	20.	...	...	...	10.	125.
149	F.	19	33.	26.	3.90	2.	35.	30.	...	...	...	...	...	...	...	10.	75.
150	F.	27	42.	42.	5.18	2.	50.	...	...	...	...	...	...	...	...	...	85.
151	M.	20	66.	45.	5.63	1.	35.	...	15.	...	...	20.	...	...	...	...	70.

¹ Bag occasionally distended during inhalation.

3 per cent. Air.					
20	F.	22	60°	39°	4·28
21	F.	17	72°	27°	4·21
22	F.	24	57°	16°	3·43
23	F.	43	75°	33°	4·98
155	F.	35	84°	39°	8·03
Average	...	...	69·6	30·8	4·99
5 per cent Air.					
15	F.	13	60°	36°	3·42
16	F.	17	66°	48°	4·91
17	F.	24	63°	42°	5·36
46	M.	28	99°	42°	6·26
47	P	36	57°	33°	4·91
48	F.	32	57°	60°	4·17
97	F.	33	69°	24°	4·93
104	M.	24	87°	42°	5·49
105	M.	20	75°	39°	6·33
106	F.	23	60°	33°	4·86
Average	...	...	69·3	39·9	5·05
6 per cent. Air.					
24	F.	20	69°	36°	3·76
25	F.	14	45°	30°	4·41
26	F.	10	51°	30°	2·73
27	F.	21	63°	51°	4·91
159	F.	36	60°	33°	5·97
160	M.	15	69°	34°	6·64
Average	...	...	59·5	35·6	4·73

No. of case.	Sex.	Age.	Inhalation (secs.).	Available anaesthesia (secs.).	Gallons used.	Teeth or roots removed.	Arbitrary numerical expressions for objectionable phenomena.									Negative value of case as a whole.					
							Anæmic convulsion.	Change of colour.	Stertor.	Retching movements.	Phonation.	Excitement or reflex movements.	After-effects.	Laboured or "catchy" respiration.	Unpleasant dreams.		Short anaesthesia.				
7 per cent. Air.																					
28	F.	12	45.	30.	3.04	2.	35.	10.	40.	..	..	20.	..	..	..	..	105.				
29	F.	22	60.	30.	4.10	1.	35.	20.	15.	..	..	40.	..	..	..	..	110.				
30	M.	17	60.	36.	5.34	Nil	35.	10.	15.	..	..	20.	..	..	..	..	80.				
31	F.	30	72.	33.	5.32	1.	35.	10.	..	..	..	..	..	..	..	..	45.				
161	F.	21	60.	30.	5.07	2.	20.	40.	..	..	15.	..	..	..	..	..	75.				
162	M.	14	60.	46.	5.56	?	20.	10.	15.	..	..	..	..	..	..	..	45.				
Average	...	...	59.5	34.1	4.73	1.2	30.	16.6	14.1	..	2.5	13.3	..	..	..	..	76.6				
10 per cent. Air.																					
34	F.	33	75.	33.	6.24	6.	35.	20.	15.	..	..	..	..	..	..	..	70.				
35	F.	26	63.	21.	5.84	1.	35.	..	15.	..	15.	40.	..	..	5.	20.	130.				
36	F.	28	87.	36.	4.93	1.	20.	10.	15.	..	..	..	..	..	..	..	45.				
37	F.	20	63.	54.	5.22	3.	20.	..	15.	..	..	..	..	..	..	..	35.				
55	M.	29	81.	30.	5.88	5.	35.	10.	15.	..	35.	..	..	5.	..	..	100.				
56	F.	22	66.	30.	5.95	?	35.	..	..	..	..	..	..	..	..	..	35.				
100	F.	31	123.	48.	10.11	1.	35.	10.	..	..	..	..	..	..	..	..	45.				
101	F.	21	69.	18.	6.98	1.	35.	..	..	..	15.	20.	..	..	..	20.	90.				
102	F.	48	96.	39.	9.41	2.	..	10.	15.	..	15.	20.	..	..	..	..	60.				
103	F.	33	81.	46.	6.62	Nil	35.	20.	..	..	15.	20.	..	..	..	..	90.				
Average	...	...	80.4	35.5	6.71	2.2	28.5	8.	9.	..	9.5	10.	5.	..	5.	4.	70.				

[illegible]

No. of Case.	Sex.	Age.	Inhalation (secs.).	Available anæsthesia (secs.).	Gallons used.	Teeth or roots removed.	Arbitrary numerical expressions for objectionable phenomena.										Negative value of case as a whole.
							Anæmic convulsion.	Change of colour.	Stertor.	Retching movements.	Phonation.	Excitement or reflex movements.	After-effects.	Labour or "catchy" respiration.	Unpleasant dreams.	Short anæsthesia.	
16 per cent. Air.																	
43	F.	23	69.	45.	5.63	1.	35.	10.	15.	..	15.	..	5.	..	..	..	80.
44	F.	20	84.	48.	4.03	3.	20.	..	15.	..	..	..	5.	..	..	..	40.
45	F.	32	87.	45.	6.12	7.	20.	20.	15.	..	15.	..	..	..	..	..	70.
49	F.	30	129.	42.	8.53	4.	21.	20.	5.	..	..	20.	..	..	5.	..	70.
50	F.	25	114.	30.	9.10	2.	20.	20.	15.	..	15.	..	..	..	..	..	70.
Average		..	96.6	42.	6.6	3.4	23.	14.	13.	..	9.	4.	2.	..	1.	..	66.
18 per cent. Air.																	
83	F.	24	147.	30.	6.87	1.	20.	10.	..	..	..	..	..	..	..	..	30.
84	F.	22	90.	21.	4.59	2.	35.	10.	15.	..	35.	..	..	..	..	20.	115.
85	F.	20	84.	26.	?	3.	..	20.	20.	..	35.	..	..	..	..	10.	65.
87	F.	23	90.	30.	5.71	2.	20.	10.	5.	..	15.	40.	..	..	5.	..	95.
88	M.	14	102.	42.	6.62	2.	20.	10.	15.	..	..	..	..	..	..	..	45.
89	M.	31	141.	54.	10.31 ¹	3.	20.	10.	..	..	..	..	..	..	..	..	30.
90	F.	13	81.	39.	5.16	2.	20.	10.	..	..	..	..	..	..	..	..	30.
91	F.	29	69.	32.	6.42	3.	20.	10.	..	..	..	20.	..	..	..	..	50.
92	F.	49	87.	30.	8.82	4.	20.	10.	..	..	..	..	..	..	..	..	30.
93	F.	28	99.	27.	8.82	3.	..	..	15.	..	35.	40.	..	..	..	10.	100.
95	F.	28	111.	46.	7.77	5.	35.	10.	..	..	..	..	..	..	..	..	45.
96	F.	35	144.	25.	11.98	3.	20.	20.	5.	..	5.	20.	..	..	..	10.	80.
Average		..	103.7	33.5	7.2	2.7	19.1	10.8	4.5	..	10.4	10.	..	..	.4	4.1	59.5

[illegible]

¹ Bag occasionally distended during inhalation.

No. of case.	Sex.	Age.	Inhalation (secs.).	Available anæsthesia (secs.).	Gallons used.	Teeth or roots removed.	Arbitrary numerical expressions for objectionable phenomena.										Negative value of case as a whole.
							Anæmic convulsion.	Change of colour.	Stertor.	Retching movements.	Phonation.	Excitement or reflex movements.	After effects.	Labouring or "catchy" respiration.	Unpleasant dreams.	Short anæsthesia.	
25 per cent. Air.																	
65	F.	13	120	45	5.18	2	...	10	15	...	...	...	...	...	...	...	25
68	F.	28	102	39	9.99	3	35	10	15	...	...	...	...	...	...	...	65
69	F.	18	99	33	7.65	2	...	...	...	...	5	...	...	...	...	...	10
72	F.	8	93	27	4.24	2	20	10	5	...	65	...	...	...	...	...	60
75	M.	26	102	33	17.64 ¹	3	...	...	...	...	35	...	...	...	5	...	60
79	F.	22	138	36	17.64 ¹	4	20	10	...	...	35	...	...	...	...	...	65
80	F.	31	111	32	15.57 ¹	Nil	35	20	...	...	35	65	...	...	...	...	155
111	F.	26	126	about 51	10.63	2	20	...	...	...	...	...	5	...	...	...	25
Average	...	...	111.3	37	7.53	2.2	16.2	7.5	4.3	...	16.2	8.1	1.2	...	6	3.7	58.1
30 per cent. Air.																	
76	F.	24	129	32	12.0 ¹	5	...	10	...	...	...	...	15	...	...	...	25
77	F.	35	127	34	11.34 ¹	4	...	...	...	...	15	...	...	...	...	...	15
78	F.	28	141	14	17.64 ¹	2	...	10	...	...	35	40	...	...	...	20	105
171	F.	24	195	39	15.26	2	...	...	...	35	15	40	...	...	...	...	90
Average	...	...	148	29.7	...	3.2	0	5	...	8.7	16.2	20	3.7	...	...	5	58.7
33½ per cent. Air.																	
127	F.	35	279	Nil	17.64	?											200
3 per cent. Oxygen.																	
61	M.	29	72	?	9.10	Nil	35	10	15	...	...	...	...	...	...	...	60
62	M.	13	81	45	5.27	2	50	10	15	...	...	...	...	...	...	...	75
145	F.	32	120	45	8.76	?	20	20	...	...	15	...	...	...	...	...	55
146	F.	39	102	45	8.87	Nil	20	20	...	...	15	20	...	...	...	...	75
158	F.	33	108	51	8.64	6	...	10	...	...	...	...	...	...	...	...	10
Average	...	...	96.6	46.5	8.12	2	25	14	6	...	6	4	...	...	...	...	55

[illegible]

1 Bag occasionally distended during inhalation.

No. of case.	Sex.	Age.	Inhalation (secs.).	Available anesthesia (secs.).	Gallons used.	Teeth or roots removed.	Arbitrary numerical expressions for objectionable phenomena.								Negative value of case as a whole.		
							Anoxic convulsion.	Change of colour.	Stertor.	Retching movements.	Phonation.	Excitement or reflex movements.	After effects.	Laboured or "catchy" respiration.	Unpleasant dreams.	Short anesthesia.	
6 per cent. Oxygen.																	
129	F.	23	144	60	?	4	..	..	..	35	..	..	..	..	..	..	35
135	M.	25	162	45	8.10	2	..	10	..	..	..	20	..	..	..	..	10
136	F.	13	120	36	7.72	2	..	..	..	..	..	..	..	..	..	..	20
137	M.	17	126	51	9.75	1	..	10	..	..	..	..	..	..	..	..	10
138	F.	31	180	51	7.88	?	..	..	..	..	15	..	..	..	..	..	0
139	F.	26	99	33	7.83	5	..	..	..	..	..	..	..	..	..	..	15
140	M.	29	99	54	9.81	2	..	10	..	..	..	..	..	..	..	..	10
141	F.	23	108	36	7.88	1	..	20	15	..	15	..	..	..	..	..	50
142	F.	35	123	33	7.75	2	..	10	..	..	15	..	5	..	..	..	30
147	M.	28	135	36	8.28 ¹	1	..	20	5	..	..	40	5	..	..	..	70
148	F.	30	129	28	9.36	1	..	10	..	..	35	..	..	..	..	10	55
Average	...	...	129.5	42	8.67	2.1	..	8.1	1.8	3.1	7.2	5.4	.9	..	..	.9	27.7
7 per cent. Oxygen.																	
10	F.	14	135	42	7.25	4	..	..	15	..	15	20	..	..	..	..	50
11	F.	13	99	42	?	2	..	..	..	..	..	..	..	..	..	..	0
63	F.	26	144	57	7.97	3	..	10	5	..	15	..	..	..	..	..	30
64	F.	16	117	60	6.31	4	..	10	5	..	..	..	..	..	..	..	15
152	F.	25	147	63	10.78	4	..	10	..	..	..	..	..	..	5	..	15
153	M.	16	141	45	7.29	3	..	10	5	..	..	..	5	..	..	..	20
154	F.	36	87	45	8.10	5	..	..	..	..	..	..	..	..	..	..	0
172	F.	14	129	48	7.81	3	..	10	..	..	..	20	..	..	..	..	30
173	F.	15	141	51	8.26	2	..	..	..	..	..	..	..	..	..	..	0
174	F.	28	159	51	10.92	?	..	10	5	..	..	20	..	..	..	..	35
175	F.	23	162	48	10.8	?	..	..	..	..	..	..	..	..	..	..	0
Average	...	...	132.6	50.1	8.54	3.3	..	5.4	3.1	...	2.7	5.4	.45	..	.45	..	17.7

[illegible]

¹ Bag occasionally distended during inhalation.

No. of case.	Sex.	Age.	Inhalation (secs.).	Available anæsthesia (secs.).	Gallons used.	Teeth or roots removed.	Arbitrary numerical expressions for objectionable phenomena.									Negative value of case as a whole.
							Anæmic convulsion.	Change of colour.	Stertor.	Retching movements.	Phonation.	Excitement or reflex movements.	After effects.	Laboured or "catchy" respiration.	Unpleasant dreams.	
10 per cent. Oxygen.																
39	F.	33	138.	45.	10.27	7.	..	..	..	..	..	..	..	..	..	0.
116	F.	29	132.	63.	9.81	5.	..	..	..	..	..	..	..	..	..	15.
117	F.	35	123.	42.	7.83	5.	..	..	..	..	..	..	..	..	..	5.
118	F.	?	108.	57.	7.70	4.	..	..	..	..	15.	..	..	..	..	15.
121	F.	31	279.	54.	?	3.	..	..	..	..	..	..	..	..	..	0.
189	F.	19	174.	51.	?	0.	..	..	..	..	..	..	..	..	..	40.
193	F.	25	138.	37.	6.51	3.	..	..	..	..	..	..	..	..	..	40.
194	M.	12	114.	30.	4.87	3.	..	..	..	15.	..	..	..	..	..	70.
197	F.	31	168.	42.	7.48	1.	..	..	..	..	..	..	..	..	..	0.
198	F.	13	177.	33.	8.64 ¹	1.	..	..	..	..	5.	40.	..	..	..	45.
Average	..	..	155.1	45.4	7.78	3.3	..	1.	1.5	..	3.5	16.	5.	..	5.	23.
11 per cent. Oxygen.																
199	F.	43	183.	54.	10.65	5.	..	..	..	..	5.	..	5.	..	..	15.
200	F.	21	147.	33.	5.92	3.	..	..	..	..	..	20.	5.	..	..	25.
201	F.	18	192.	39.	8.13	1.	..	..	..	..	..	20.	..	..	..	20.
202	F.	37	255.	70.	9.03	6.	..	..	15.	..	15.	..	15.	..	..	45.
203	F.	11	171.	24.	4.51	?	..	..	..	..	5.	40.	15.	..	10.	105.
204	F.	21	126.	45.	13.39 ¹	3.	..	..	..	..	..	..	..	..	..	5.
205	F.	13	153.	36.	11.70 ¹	2.	..	..	..	..	..	..	15.	..	..	15.
Average	..	..	175.2	43.	7.64	3.3	..	..	2.1	5.	3.5	11.4	7.8	.7	1.4	32.8.

VII. A COMPARATIVE STUDY OF THE EFFECTS PRODUCED BY THE ADMINISTRATION OF THE DIFFERENT GASEOUS MIXTURES.

1. *The duration of inhalation which was found to be necessary for the production of anæsthesia for a short dental operation.*—In the accompanying chart the average duration in each group of cases is given. In every administration the inhalation was continued till, from the character of the breathing, the insensibility of the conjunctiva, or other conditions, it was clear that anæsthesia had been obtained.

CHART I.—*Showing average duration of inhalation necessary for the production of anæsthesia for a dental operation.*

It will be seen that the shortest average inhalation was recorded with pure nitrous oxide (55.9 secs.), which means that when this gas is administered without any oxygen asphyxial symptoms come on within a minute, and prevent the intake of more of the anæsthetic gas. In many cases the anoxæmic phenomena come about before anæsthesia is fully established. This is notably the case in persons with enlarged tonsils, post-nasal adenoid growths, or other obstructive affections of the

upper respiratory passages. It will be seen that as the proportion of air increases there is an increasing tendency, with one or two irregular fluctuations due to accidental circumstances, for the inhalation period to increase, till with 30 per cent. of air it reaches 148 secs. The same tendency is shown, and far more markedly, in the case of mixtures containing oxygen and no nitrogen. With 3 per cent. of oxygen the available inhalation period was 96·6 secs.; and with 20 per cent. of oxygen it was 223·5 secs.

2. *Average duration of anæsthesia after inhalation.*—In operations within and about the mouth, nose, or pharynx, the length of time during which a patient will

CHART II.—*Showing average duration of available anæsthesia after administration.*

remain anæsthetised after the removal of the face-piece becomes a matter of importance. The expression "available anæsthesia" is often employed to designate this after-insensibility. The most noticeable feature in the accompanying chart is that the available anæsthesia which results from the use of nitrous oxide mixed with

oxygen is very distinctly longer than that from nitrous oxide mixed with air.

It is true that in both sets of administrations the variations are considerable, being dependent upon other factors than the actual percentages of air or oxygen used. With pure nitrous oxide the average anæsthesia was 30·3 secs. In the air cases the shortest average anæsthesia was met with when employing 3 per cent. of air (30·8 secs.) and 30 per cent. of air (29·7 secs.), *i. e.* at the two extremes; the longest average anæsthesia being recorded with 14 per cent., 16 per cent., and 22 per cent. of air, the respective durations with these percentages being 40·5 secs., 42 secs., and 42·6 secs. With regard to the oxygen cases it will be seen that the lowest average anæsthesia (39·7) was very little below the highest (42·6) of the air cases. The best results, so far as a lengthy available anæsthesia is concerned, were met with when using 7 per cent. of oxygen, the average duration of anæsthesia after inhaling nitrous oxide mixed with this percentage of oxygen being 50·1 secs.

CHART III.—*Showing average quantity of gas or gases inhaled for the production of anæsthesia for a dental operation.*

3. *Average quantity of nitrous oxide or its mixtures needed to produce anæsthesia for a short dental operation.*—There is very little to be said concerning the accompanying chart, which, as one would expect, closely resembles that giving the duration of the inhalation. The slight want of correspondence between the two charts is probably owing to the occurrence of apnœic pauses in breathing in many of the cases.

4. *Anoxæmic convulsion during the inhalation or immediately after.*—This chart is, perhaps, the most interesting of the series, at all events from a physiological point of view. It clearly shows that the convulsive

CHART IV.—*Showing average degree of anoxæmic convulsion.*

Arbitrary Numerical Scale.—None = 0; slight = 20; moderate = 35; extreme = 50.

muscular phenomena with which we are so familiar when employing nitrous oxide free from oxygen are directly dependent upon the absence of this latter gas.

During the inhalation of nitrous oxide, either pure or

with percentages of air up to 25 or 30 per cent., or with oxygen up to 5 per cent., some degree of anoxæmic convulsion is very common. Roughly speaking, the more the mixture approaches to pure nitrous oxide—in other words, the greater the degree to which free oxygen is excluded—the greater will be the tendency for anoxæmic convulsion to arise; and conversely, the greater the proportion of oxygen mixed with nitrous oxide, either as air or as the pure gas, the less will that tendency become. When free oxygen is completely or almost completely absent the patient may be thrown into the most violent epileptiform state, the whole body participating in the attack. Some patients display an unusual susceptibility to this condition, whilst others may inhale large quantities of pure nitrous oxide before any convulsive phenomena appear. Anæmic subjects, alcoholic patients, and those with any pre-existing respiratory affection are more susceptible than others. By referring to the chart it will be seen that with the larger percentages of air and of oxygen the convulsive movements are but slightly marked. In some of these slighter cases the facial muscles seem to be chiefly affected by the convulsive seizure; in others the whole body may mildly oscillate, the convulsive spasm apparently chiefly affecting the trunk muscles; in others the arms, legs, and hands alone may twitch; whilst in a fourth group of cases the neck may be affected by barely perceptible clonic spasm, so that the head of the patient is felt by the administrator to move with fine rhythmic jerks in one or other direction. The anoxæmic convulsion of pure nitrous oxide becomes progressively attenuated and weakened, so to speak, as the proportion of oxygen mixed with the anæsthetic gas increases. It is curious to note in the accompanying chart an apparent contradiction to this statement. It will be observed that rather more convulsive movement was recorded with 3 and 5 per cent. of air than with nitrous oxide alone. The explanation of this is that the obstructive stertor which rapidly comes on in a pure

nitrous oxide inhalation often cuts short the administration before convulsive movements have had time, as it were, to make their appearance. The marked degree of stertor with nitrous oxide free from air or oxygen is seen in the stertor chart. The chart now under consideration shows that the greatest degree of anoxæmic convulsion was met with when nitrous oxide was given with 3 per cent. or 5 per cent. of air. As the proportion of air increases, the convulsive movements progressively lessen, till, when 30 per cent. of air is administered with nitrous oxide they cease to appear. The decline in anoxæmic convulsion is, for obvious reasons, more marked in the oxygen cases, the symptom altogether vanishing when this gas is present to the extent of 6 per cent. or more.

In preparing the above chart no attention was paid to any convulsive phenomena which were noted during the operation, the reason for this omission being that during the extraction of teeth operators frequently depress the lower jaw, so that the breathing becomes temporarily obstructed, and convulsive phenomena of a somewhat different origin from those under consideration may therefore become developed.

5. *Alteration in colour during inhalation or immediately after.*—Like other charts, the accompanying one shows very clearly the fitful and irregular results met with in the air cases, and the more reliable and regular effects obtainable when employing oxygen. It will be observed that a somewhat greater degree of lividity was recorded with small percentages of air than with pure nitrous oxide, and the explanation of this apparent anomaly is doubtless the same as that to which I referred when dealing with anoxæmic convulsion, viz. that the obstructive stertor which comes on so quickly with pure nitrous oxide necessitates the withdrawal of the anæsthetic before convulsive phenomena and cyanosis have had time, so to speak, to become pronounced. It will be observed that as much as, or more than 11 per cent. of oxygen is needed to prevent all alteration in colour, a point which

CHART V.—*Showing average degree of alteration in colour.*

Arbitrary Numerical Scale.—No alteration = 0; slight = 10; moderate = 20; extreme = 30.

is of interest, because it proves that in administering nitrous oxide and oxygen we must not endeavour to keep the patient's colour perfectly normal in every case, otherwise we may be administering such a percentage of oxygen as may interfere with proper anæsthesia. Except in the case of children and weakly women, mixtures of nitrous oxide with 11 per cent. of oxygen are liable to lead to intoxication-effects, rather than to deep anæsthesia (see p. 203).

In drawing up the above chart no attention was paid to recorded alterations in colour during the operation period, as such alterations are often dependent upon intercurrent mechanical causes.

6. *Stertor during inhalation.*—The respiratory changes under nitrous oxide and its mixtures are of considerable interest. Under the influence of the pure gas breathing becomes increasingly deeper and quicker, till, at the end

of about 55 or 60 secs., anoxæmic convulsion and obstructive stertor supervene, and the inhalation has to be suspended. In some cases convulsion predominates; in others stertor is more conspicuous. Either, however, is capable of interfering with respiratory rhythm, and of arresting breathing if the administration be pushed sufficiently far.

Three varieties of stertor may be met with under pure nitrous oxide, viz. (1) the so-called "false" stertor—loud, coarse, regular, and coming on before true anæsthesia is established; (2) a softer, snoring sound, identical in its character, and possibly also in its immediate causation, with the usual stertor of ether or chloroform narcosis; and (3) the sharp, loud, irregular, and deeply seated stertor of an obstructive and choking type, so characteristic of pure nitrous oxide when administered to its full extent.

Little need be said as to the first variety. It is most liable to arise in a patient with an elongated or enlarged uvula; it is apparently due to the soft palate vibrating against the pharynx; and it occurs independently of the depth of anæsthesia present.

The two kinds of true stertor are, however, more important. True stertor may become audible in a mild form about two thirds of the way through the administration, and it then has as its immediate cause vibration of the base of the tongue against the pharyngeal wall. As the administration proceeds the softly snoring breathing gradually, or possibly suddenly, becomes replaced by the coarse and obstructive stertor; that is to say, the first variety of true stertor passes into the second.

Respiratory rhythm is not interfered with by simple snoring, although the latter invariably causes the breathing to increase in rate and depth. When, however, deep and obstructive stertor sets in, respiratory rhythm is at once altered, the alteration bearing a direct relation to the degree of obstruction. The coarse and irregular stertor so common at the acme of an administration of

pure nitrous oxide seems to be immediately dependent, in great measure at all events, upon spasmodic elevations of the whole larynx, the upper aperture of which becomes intermittently occluded by the epiglottis. Each time the larynx ascends to meet the epiglottis the air-way closes, and it is this closure which produces the stertor and the altered rhythm of respiration. It is most probable that the spasm which thus raises and lowers the larynx when pure nitrous oxide is administered to its fullest extent is, like the other muscular movements already considered, anoxæmic in its nature. In some cases of deep nitrous oxide stertor the sound is no doubt chiefly dependent upon the swollen tongue intermittently meeting the pharyngeal wall, but the elevation of the larynx here described is certainly a factor in most instances.

When air or oxygen is mixed in moderate proportions with nitrous oxide the breathing does not become as quick and deep as with the pure gas (unless emotional influences come into play); there is not that tendency for forcible expiration to become a conspicuous feature of the administration; and stertor is either present in a mild and non-obstructive form or is absent altogether.

A plentiful supply of oxygen with nitrous oxide leads either to peaceful, sleep-like, and barely perceptible breathing, or to complete arrest of respiratory movements ("physiological apnoea"). The apnoeic state thus induced is distinguished from paralytic cessation of breathing by the presence of a good pulse and colour. "Physiological apnoea" never arises under pure nitrous oxide or under mixtures poor in oxygen. It is, moreover, almost invariably preceded by a phase of rapid breathing, the large proportion of oxygen favouring the development of rapid (emotional) respiration.

The most conspicuous feature of the accompanying chart is that the deepest stertor was met with when nitrous oxide was administered free from air or oxygen.

Although there are considerable fluctuations in the air cases, the gradual tendency for stertor to subside as the

CHART VI.—*Showing average degree of stertor.*

Arbitrary Numerical Scale.—None = 0; slight = 5; moderate = 15; extreme = 40.

proportion of air increases is well shown. The irregularities observed are doubtless due to the fact that the cases under each percentage were not sufficiently numerous to mask the influences of a few exceptional cases. Thus with 16 per cent. of air there were only five cases, and it is fairly certain that amongst these there must have been one or two patients whose respiratory passages were in such a condition that stertor more readily arose than usual.

Patients with enlarged tonsils, post-nasal adenoid growths, and other conditions capable of narrowing the air-channels, become stertorous more quickly and in a greater degree than those whose air-passages are free. As in other charts, the oxygen cases will be seen to be comparatively free from those irregularities which mark the cases in which air was employed as the oxygenating agent.

In preparing the above chart cognizance was only

taken of stertor which occurred during the administration, or at the moment the face-piece was removed.

Should the inhalation of nitrous oxide be continued beyond the proper limits breathing will cease, either from anoxæmic spasm of respiratory muscles, or from mechanical obstruction at the superior aperture of the larynx. Cessation of breathing from pure and simple paralysis of its nervous mechanism is certainly very uncommon as the result of an overdose of nitrous oxide, and when it does occur is usually due quite as much to cerebral anæmia from a feeble or failing circulation as to the direct effects of the unoxygenated blood upon the respiratory centres.

7. *Phonation during inhalation or first 30 secs. after.*—Dealing with the accompanying chart as a whole, it will be seen that the occurrence of phonated sounds during

CHART VII.—*Showing average degree of phonation.*

Arbitrary Numerical Scale.—None = 0; slight = 5; moderate = 15; extreme = 35.

inhalation and the first 30 secs. afterwards was rather more frequent when pure nitrous oxide was given, or when small percentages of air or oxygen were administered

with this gas, than when somewhat greater, though still small percentages of air or oxygen were present in the mixtures. The progressive and steady fall in phonation as we pass from pure nitrous oxide to nitrous oxide with 7 per cent. of air is very obvious. This means that as the percentage of air increased it was found possible to prolong the inhalation, and to obtain a rather deeper anæsthesia, in which phonation was not so liable to arise. The fall in phonation is not so marked in the oxygen cases, although it is present. The next noticeable point in the chart is that in the air cases very considerable phonation was met with in all mixtures containing more than 7 per cent. of air, the most pronounced phonation being recorded in mixtures containing 20 per cent. of air. The air chart is like its predecessors—a very irregular one. The oxygen chart shows far less phonation than the air chart. Indeed, until the percentage of oxygen reached twenty very little phonation was recorded.

8. *Reflex and excitement movements during inhalation or first 30 secs. after.*—There is, as the charts show, a very striking difference between the air and the oxygen cases in the matter of reflex and excitement movements. Dealing with the air cases first, it will be seen that, although there are considerable fluctuations, there is a distinct tendency for reflex and excitement movements to lessen as the percentage of air increases. This lessened tendency, however, soon disappears as the percentages continue to increase, and after 14 per cent. has been reached the chart shows a distinct tendency in the opposite direction, the degree of reflex and excitement movement increasing as the percentages of air are also augmented. The maximum reflex and excitement movement was met with when 30 per cent. of air was employed. In the oxygen cases there is, as in the others, an initial but slight tendency for these to decrease as the percentage of oxygen rises, but with this exception the chart shows a gradual and progressive tendency in the other direction, the maximum movements being met with under the

CHART VIII.—*Showing average degree of reflex and excitement movements.*

Arbitrary Numerical Scale.—None = 0; slight = 0; moderate = 20; extreme = 40.

maximum percentage of oxygen (20). The best cases, so far as the absence of inconvenient reflex and excitement movement is concerned were obtained with 14 per cent. of air, and with 4 per cent. and 5 per cent. of oxygen.

9. *After effects.*—So far as unpleasant after effects are concerned, it would appear that these are rather more liable to follow the inhalation of nitrous oxide and oxygen than that of nitrous oxide and air. The difference, however, is but slight.

10. *General result, from the combined points of view of the patient, surgeon, and anæsthetist.*—By the system which has been already referred to it is possible to give an arbitrary number to every case to indicate its value from a broad and general point of view. The accompanying chart will show under what percentages of air and of oxygen the best general results were obtained.

CHART IX.—*Showing the average general result.*

Arbitrary Numerical Scale.—Perfect type = 0; failure to produce anæsthesia = 200.

It will be seen that the pure nitrous oxide cases are very low in the scale; that the best results in the air cases were obtained with 14 per cent. and 22 per cent. of air; and that the best results in the oxygen cases were obtained with 5—9 per cent. of this gas. The best results of all are recorded with 9 per cent. of oxygen; but directly this percentage is exceeded the general results of the cases begin to decline. It is interesting to observe a much higher general value for the cases in which oxygen was used than for those in which air was employed.

VIII. THE CASES OF SERIES II (NON-COMPARABLE CASES).

Amongst the total of 231 cases dealt with in this investigation there were five which demand special and separate consideration; for in all of these there were conditions present which tended to modify the usual effects of the gas or mixture administered. The cases are as follows.

(1) CASE 85 a. *Nitrous oxide free from air or oxygen.*—Female æt. 43. Sallow complexion; slim build; has pre-systolic mitral murmur. Has been an out-patient at Charing Cross Hospital (see case 81, third case of present series).

Inhalation period.

18 secs., breathing rather restricted. 33 secs., breathing deeper; expiration rather forcible. 51 secs., inspiration irregular. 60 secs., considerable anoxæmic convulsion and stertor, but very little cyanosis. 63 secs., administration discontinued.

Anæsthesia period.

During operation an ashy pallor supervened; aspect alarming; respiration continuing; pulse not observed.

When operation over, pulse very rapid and small, about 160. Two teeth removed. Inhalation 63 secs.; available anæsthesia 24 secs.; 5.02 gallons of nitrous oxide inhaled. "Bad marks" = 150.

(2) CASE 93 a. *Nitrous oxide free from air or oxygen.*—Male æt. 47. Tall; broad shoulders; has thick curly grey beard and moustache.

Inhalation period.

3 secs., good regular breathing. 54 secs., breathing deeper. 75 secs., soft snoring. 87 secs., no conjunctival reflex. 93 secs., colour dusky. 96 secs., slight anoxæmic convulsion. 102 secs., administration discontinued.

Anæsthesia period.

6 secs., no reflex movement or noise. 24 secs., no reflex movement or noise. 36 secs., no conjunctival reflex. 45 secs., anæsthesia at an end.

Five teeth extracted: no knowledge, no pain; very pleasant dream. Inhalation 102 secs. Available anæsthesia 45 secs., 7.4 gallons inhaled. "Bad marks" = 40.

(3) CASE 81. *Nitrous oxide with 20 per cent. of air.*—Same patient as in case 85a (first case of present series).

Inhalation period.

36 secs., good regular breathing. 48 secs., shuts her eyes when requested. 57 secs., expiration rather forcible. 72 secs., respiration quicker. 75 secs., no conjunctival reflex. 78 secs., mild snoring. 84 secs., quick respiration. 99 secs., colour unchanged. 105 secs., eyes fixed and to the left, pupils medium sized. 120 secs., administration discontinued.

Anæsthesia period.

3 secs., colour slightly dusky. 9 secs., quite quiet. 15 secs., no conjunctival reflex. 18 secs., pupils medium. 27 secs., quite quiet. 33 secs., no conjunctival reflex. 36 secs., very slight phonation; operation over. 45 secs., anæsthesia at an end.

Two teeth removed. Inhalation 120 secs. Available anæsthesia 45 secs. "Bad marks" = 10.

(4) CASE 117 a. *Nitrous oxide with 10 per cent. of oxygen.*—Female æt. 31. Same patient as in Case 121 of Series I. Dark complexion, nervous. Corsets not unfastened.

Inhalation period.

3 secs., good regular breathing. 36 secs., holds breath slightly. 57 secs., breathing slightly irregular. 72 secs., breathing very shallow. 90 secs., considerable excitement; has to be held. 111 secs., excitement subsiding. 120 secs., no conjunctival reflex. 123 secs., breathing now regular; excitement subsided. 129 secs., slight snoring. 171 secs., administration discontinued.

Anæsthesia period.

3 secs., no change of colour. 15 secs., breathing quiet. 39 secs., slight phonation. 45 secs., pupils large. 54 secs., considerable phonation. 60 secs., anæsthesia at an end.

Eight teeth removed. No knowledge, no pain; distressing dream; slow recovery. Inhalation 171 secs. Available anæsthesia 60 secs. 9.93 gallons inhaled. "Bad marks" = 85.

(5) CASE 62 *a*. *Nitrous oxide with 5 per cent. of oxygen*.—Male æt. 29. Same patient as in Case 61 of Series I. Healthy-looking; average height; fair moustache; not nervous. Second administration about 10 minutes after first.

Inhalation period.

27 secs., good regular breathing. 42 secs., slight movement of body. 48 secs., deep gasping breathing. 69 secs., considerable movement of body. 75 secs., movement passing off. 78 secs., movement ceased. 81 secs., considerable stertor and rigidity with some duskiness; administration discontinued.

Anæsthesia period.

15 secs., still stertorous. 21 secs., colour normal. 39 secs., anæsthesia at an end.

No pain, no dream. Inhalation 81 secs. Available anæsthesia 39 secs. 10.67 gallons inhaled. "Bad marks" = 100.

An unsatisfactory case, owing to the patient having been anæsthetised but a short time before.

IX. A COMPARISON OF THE EFFECTS PRODUCED IN THE SAME PATIENT BY THE ADMINISTRATION OF DIFFERENT GASES OR GASEOUS MIXTURES.

(1) *Pure nitrous oxide compared with mixtures of nitrous oxide and air.*

CASES 149 (*pure nitrous oxide*) and 164 (*nitrous oxide with 12 per cent. of air*).—Anoxæmic convulsion came on very rapidly in the absence of oxygen, and the face-piece had to be removed after 35 secs. inhalation. With 12

per cent. of air the asphyxial "oscillation" was slight, and the inhalation was continued for 42 secs. The available anæsthesia, however, was about the same as with pure nitrous oxide. It is interesting that loud phonation occurred with the 12 per cent. of air during the operation (at 24 secs. in the anæsthesia period), whereas with the pure gas there was no phonation till after 33 secs. The general result of the two cases from the operator's point of view may be regarded as the same. The objectional phenomena numerically expressed were—with pure nitrous oxide 75; with the mixture 75.

CASES 85 *a* (*pure nitrous oxide*) and 81 (*nitrous oxide with 20 per cent. of air*) (Cases 1 and 3 in Series II just considered).—The effect of withholding oxygen in the case of a patient with mitral stenosis is very well shown. The state of partial syncope during the operation in case 85 *a* was not noticed in Case 81. The long inhalation (120 secs.) which was rendered possible by the presence of 20 per cent. of air led to a more prolonged and more satisfactory form of anæsthesia (45 as compared to 24 secs.). The phonation in the anæsthesia period of the pure nitrous oxide case also testifies to the less profound anæsthesia. It cannot be regarded as good practice to administer pure nitrous oxide to such a patient as this. The 20 per cent. of air completely prevented asphyxial convulsion, and allowed the pulmonary circulation, already embarrassed by the mitral affection, to proceed in its accustomed manner, and the left heart to receive its usual or almost its usual supply of blood.

(2) *Pure nitrous oxide compared with mixtures of nitrous oxide and oxygen.*

CASES 149 (*pure nitrous oxide*) and 176 (*nitrous oxide with 8 per cent. of oxygen*).—The contrast between these cases is very marked. With nitrous oxide free from oxygen there was a rapid onset of asphyxial symptoms in

about 30 secs.; with 8 per cent. of oxygen all obvious asphyxial phenomena were absent, the mixture being a perfectly respirable one. The inhalation with nitrous oxide was 33 secs.; with the mixture 162 secs. The available anæsthesia with the pure gas was 26 secs.; with the mixed gases 42 secs. Although the inhalation lasted so much longer the patient's sensations were of a more pleasant description than when pure nitrous oxide was employed. The objectionable phenomena, numerically expressed, were: with nitrous oxide 75; with the mixture 20.

(3) *Mixtures of nitrous oxide and air compared with mixtures of nitrous oxide and oxygen.*

CASES 17 (*nitrous oxide with 5 per cent. of air*) and 32 (*nitrous oxide with 5 per cent. of oxygen*).—The principal differences between these administrations are (1) the presence of asphyxial symptoms in Case 17, and the absence of such symptoms in Case 32. (2) The shorter inhalation in the air case (63 secs. as compared to 105 secs.) did not lead to a longer anæsthesia (39 secs. as compared to 42 secs.), but to a deeper form of unconsciousness, as is shown by the later onset of reflex movement, and the complete absence of phonation in the oxygen case. The objectionable phenomena, numerically expressed, were, with air 115; with oxygen 15.

CASES 34 (*nitrous oxide with 10 per cent. of air*) and 39 (*nitrous oxide with 10 per cent. of oxygen*).—In addition to the presence of anoxæmic symptoms in the air case, and the total absence of such symptoms under nitrous oxide and oxygen, there was a considerable difference in the patient's sensations under the two mixtures, these having been rather unpleasant after the nitrous oxide and air. With 10 per cent. of air the inhalation lasted 75 secs.; the available anæsthesia was 33 secs.; and the objectionable phenomena came to 70. With 10 per cent. of oxygen

the inhalation was 178 secs. ; the anæsthesia was 45 secs. ; and the objectionable phenomena were 0.

CASES 40 (*nitrous oxide with 12 per cent. of air*) and 33 (*nitrous oxide with 5 per cent. of oxygen*).—A better and deeper form of anæsthesia was secured with 5 per cent. of oxygen than with 12 per cent. of air. Stertor and slight "oscillation" were present on both occasions. With 12 per cent. of air the inhalation lasted 75 secs. ; the anæsthesia 30 secs. ; and the objectionable phenomena numerically expressed came to 90. With 5 per cent. of oxygen the inhalation was 105 secs., the anæsthesia 40 secs., and the objectionable phenomena amounted only to 45. There was no dream in the oxygen case, and a pleasant dream in the air administration.

CASES 164 (*nitrous oxide with 12 per cent. of air*) and 176 (*nitrous oxide with 8 per cent. of oxygen*).—The loud phonation during the available anæsthesia period of the nitrous oxide and air inhalation indicated the rather imperfect type of anæsthesia produced by this mixture : at the corresponding point after the nitrous oxide and oxygen administration the patient was perfectly quiet. The inconvenient movement noted in the air case has a similar significance. With 12 per cent. of air the inhalation was 42 secs., the anæsthesia about 26 secs., and the number representing the objectionable phenomena was 75. With 8 per cent. of oxygen the inhalation was 162 secs., the anæsthesia 42 secs., and the number for the objectionable phenomena 20.

CASES 133 (*nitrous oxide with 15 per cent. of air*) and 130 (*nitrous oxide with 5 per cent. of oxygen*).—Rather forcible expiration was noted with the mixture containing air, but not with that containing oxygen. It is interesting that a state of "physiological apnœa" was recorded with 15 per cent. of air, but not with 5 per cent. of oxygen, the apnœa having come about after the forcible expiration. It is also interesting that the apnœa

came on before consciousness was completely lost, and that breathing recommenced on request about one and a quarter minutes after the inhalation of the nitrous oxide and air had begun. Consciousness was lost almost immediately after this. With nitrous oxide and 5 per cent. of oxygen consciousness was lost about fifteen or eighteen seconds earlier, showing the greater potency of the oxygen mixture, *i. e.* the greater proportion of the anæsthetic element in it. Slight reflex movement and considerable phonation were noted during the available anæsthesia of the air case, but not during that of the oxygen administration. "Mild oscillation" was recorded during the inhalation of the air mixture, but not during the inhalation of the mixture containing oxygen. With 15 per cent. of air the inhalation lasted 105 secs., the anæsthesia 27 secs., and the objectionable phenomena may be represented by the number 80. With 5 per cent. of oxygen the inhalation lasted 129 secs., the anæsthesia 42 secs., and the objectionable phenomena may be represented by 25.

CASES 168 (*nitrous oxide with 22 per cent. of air*) and 187 (*nitrous oxide with 8 per cent. of oxygen*).—The tendency towards "physiological apnœa" in Case 187 was observed after the breathing had been rather deeper than usual. In Case 168 there is no record of deep breathing or of apnœa. In the air case the pupils were dilated at 126 secs. of the inhalation period; in the oxygen case they were of moderate size at 126 secs. The numbers are—Case 168, inhalation 135 secs., anæsthesia 42 secs., and objectionable phenomena 5; Case 187, inhalation 159 secs., anæsthesia 39 secs.; objectionable phenomena 0.

CASES 195 (*nitrous oxide with 22 per cent. of air*) and 184 (*nitrous oxide with 8 per cent. of oxygen*).—There was no muscular rigidity during the inhalation of 22 per cent. of air, but rigidity was noted under the 8 per cent. of

oxygen mixture. The "mild oscillation" and "slight cyanosis" met with under the air mixture were not observed with the nitrous oxide and oxygen. There was "loud phonation" at 24 secs. in the anæsthesia period after the air mixture, but no phonation was noted till 54 secs. after the inhalation of the oxygen mixture, and then it was only slight. The numbers are—Case 195, inhalation 117 secs., anæsthesia 27 secs., objectionable phenomena 75; Case 184, inhalation 207 secs., anæsthesia 60 secs., objectionable phenomena 0.

CASES 195 (*nitrous oxide with 22 per cent. of air*) and 189 (*nitrous oxide with 10 per cent. of oxygen*).—The large percentage of oxygen in Case 189 produced tranquil breathing. The peculiar "secondary rigidity" to which I have elsewhere alluded was met with in this case at 159 secs., and as the conjunctival reflex was present at the time and also afterwards, it would seem that this rigidity is associated with a light rather than with a deep form of anæsthesia. The inconvenient straightening of the body during the operation in Case 189 indicated light anæsthesia, as did subsequent phonation at 39 secs. of the anæsthesia period. It is curious that there was no reflex movement during the operation in Case 195 as one might have expected, seeing that the percentage of nitrous oxide was less in the air than the oxygen mixture. There was, however, loud phonation at 24 secs. of the anæsthesia period in the air case. The numbers are—Case 195, inhalation 117 secs., anæsthesia 27 secs., objectionable phenomena 75; Case 189, inhalation 174 secs., anæsthesia 51 secs., objectionable phenomena 40.

CASES 170 (*nitrous oxide with 22 per cent. of air*) and 201 (*nitrous oxide with 11 per cent. of oxygen*).—There is very little difference between these two administrations. The anæsthesia seems to have been of a rather better type with 22 per cent. of air than with 11 per cent. of

oxygen. The conjunctival reflex was lost at 132 secs. in the air case, and at 156 secs. in the oxygen case. It is interesting to note the deep and slightly strained expiration even with 11 per cent. of oxygen, and the body movement (rhythmic with expirations) in the same case. With 22 per cent. of air the inhalation lasted 147 secs., the anæsthesia 63 secs., and the objectionable phenomena may be represented by the number 30. With 11 per cent. of oxygen the inhalation lasted 192 secs., the anæsthesia 39 secs., and the objectionable phenomena may be represented by 20.

CASES 127 (*nitrous oxide with 33½ per cent. of air*) and 142 (*nitrous oxide with 6 per cent. of oxygen*).—This comparison is of interest because the percentage of oxygen was practically the same on each occasion. With 33½ per cent. of air no true anæsthesia was produced; with 6 per cent. of oxygen a satisfactory result followed. The presence of the large percentage of nitrogen in the former case was doubtless the cause of the failure to produce anæsthesia. Although there is only this one case in which as much as one third of atmospheric air was mixed with nitrous oxide, it would seem that such a mixture is incapable of producing anæsthesia. There are several cases in which 70 per cent. of nitrous oxide with 30 per cent. of air successfully anæsthetised patients.

(4) *Certain mixtures of nitrous oxide and oxygen compared with certain other mixtures of these gases.*

CASES 206 (*nitrous oxide with 5 per cent. of oxygen*) and 222 (*nitrous oxide with 8 per cent. of oxygen*).—The most interesting point in this comparison is the occurrence of "secondary rigidity" (see p. 171) between 114 and 120 secs. of the inhalation period with 8 per cent. of oxygen, and the absence of this condition with 5 per cent. of oxygen. This is suggestive of the phenomenon which takes place always after anæsthesia has become estab-

lished, being dependent, at all events to some extent, on considerable proportions of oxygen. Why more of the 8 per cent. mixture was used in 120 secs. than of the 5 per cent. mixture in 141 secs. is not clear. The anæsthesia with 8 per cent. of oxygen lasted 33 secs. after 120 secs. inhalation; with 5 per cent. of oxygen it lasted 37 secs. after 141 secs. inhalation. The objectionable phenomena in the 8 per cent. case are represented by the number 25; in the 5 per cent. case by 0.

CASES 206 (*nitrous oxide with 5 per cent. of oxygen*) and 200 (*nitrous oxide with 11 per cent. of oxygen*).—There is very little difference between these two administrations. There was rather more reflex movement during the operation in the 11 per cent. of oxygen case than in the other. In both cases an extremely satisfactory state was obtained. The patient was a little lachrymose after the higher percentage of oxygen.

CASES 184 (*nitrous oxide with 8 per cent. of oxygen*) and 189 (*nitrous oxide with 10 per cent. of oxygen*).—"Secondary movement" was observed after 159 secs. inhalation of 10 per cent. of oxygen, but no such phenomenon occurred with 8 per cent. of oxygen. With the larger percentage of oxygen reflex straightening of the body during the operation was met with, whereas with the smaller percentage there was no reflex at all. It must be remembered, however, in making these comparisons that the 8 per cent. of oxygen mixture was administered for 207 secs., whereas the 10 per cent. mixture was given only for 174 secs. It is interesting to note that 33 secs. after the rather protracted administration of the 8 per cent. mixture the patient was quite relaxed. The available anæsthesia was, after 207 secs. inhalation of the 8 per cent. mixture, 60 secs.; after 174 secs. inhalation of a 10 per cent. mixture, 51 secs. The objectionable phenomena may, in the 8 per cent. case, be represented by 0; in the 10 per cent. case by 40. The

comparison of these two administrations only strengthens the opinion formed by comparing other cases, viz. that 10 per cent. of oxygen is rather too high a percentage if we wish to obtain the best type of nitrous oxide anæsthesia.

CASES 222 (*nitrous oxide with 8 per cent. of oxygen*) and 200 (*nitrous oxide with 11 per cent. of oxygen*).—With 8 per cent. of oxygen the conjunctival reflex disappeared at 78 secs.; with 11 per cent. of oxygen there was very slight conjunctival reflex at 99 secs. "Secondary movement" was met with late in the administration of the 8 per cent. mixture, but not with the 11 per cent. mixture. Although the inhalation of the 11 per cent. mixture was carried on for 147 secs., the resulting anæsthesia was not of such a satisfactory type, *i. e.* not so deep as that produced by the inhalation for 120 secs. of an 8 per cent. mixture. This is shown by the reflex movement early in the operation in the former case, and the absence of such movement in the latter. It is interesting that, although the inhalation lasted longer in the 11 per cent. case, the quantity of the mixture used was smaller. This is accounted for by the sleep-like state with quiet breathing which was brought about in the 11 per cent. case. The smaller proportion of oxygen in the other case led to deeper breathing, and hence to the inhalation of more of the mixed gases. The available anæsthesia was the same in both cases. The objectionable phenomena numerically expressed were in each case 25.

CASES 117 *a* (*corsets tight*) and 121 (*corsets loose*).—A 10 per cent. mixture of oxygen and nitrous oxide was used on each occasion. In Case 117 *a* the restricted breathing culminated in excitement which necessitated the patient being held; in Case 121 no such excitement was observed. The most probable explanation for the occurrence of the excitement is that the residual air originally

present in the bases of the lungs took a comparatively long time to be ousted by the mixture, so that a comparatively long time was needed for the nitrous oxide to become absorbed by the blood in sufficient quantities to produce anæsthesia. Slow absorption seems to favour the development of these intoxication effects. A distressing dream was experienced on the occasion when the corsets were not unfastened, but nothing of the kind was complained of on the subsequent occasion. When the corsets were loose there were no objectionable phenomena, but when they were not unfastened objectionable symptoms occurred to an extent which may be expressed by the number 85.

X. CONCLUSIONS.

From the foregoing investigation the following conclusions may be deduced.

1. When pure nitrous oxide is administered to the human subject in such a manner that no free oxygen gains admission during the administration, certain phenomena arise, which for our present purposes may be regarded as being either—

- (a) Phenomena of anæsthesia, or
- (b) Phenomena of asphyxia.

2. The anæsthetic phenomena of nitrous oxide, although apparently very different from those of ether or chloroform, are in their essential features remarkably similar.

3. The most conspicuous of the asphyxial phenomena of pure nitrous oxide are—

- (i) Embarrassed and deeply stertorous breathing ;
- (ii) Cyanosis ; and
- (iii) Anoxæmic convulsion.

All these may be eliminated, without interfering with the anæsthetic effects of the gas, by administering with it certain proportions of oxygen, either pure or as atmospheric air.

4. There are other less obvious asphyxial phenomena,

such as wide dilatation of the pupils, swelling of the tongue and adjacent structures, and rapid cardiac action, which, like the more important symptoms above referred to, may be prevented or modified by similar means.

5. Under the influence of pure nitrous oxide, breathing becomes deeper and quicker than usual. At the end of from 55 to 60 secs. its rhythm becomes altered either by—

(α) Obstructive stertor;

(β) Anoxæmic convulsion attacking the respiratory muscles; or

(γ) Both conditions combined.

If the administration be pushed far enough, breathing becomes arrested in one of these ways. Paralytic cessation of breathing is very rare, and when it occurs is dependent quite as much upon cerebral anæmia from defective circulation as upon the presence of un-oxygenated blood in the vessels supplying the respiratory centres.

6. The deep and obstructive stertor of pure nitrous oxide narcosis is not met with when employing mixtures containing moderate percentages of air or oxygen. With such mixtures only softly snoring breathing is produced. When the percentage of air or oxygen is considerable (30 per cent. of air or 13 per cent. of oxygen), respiration becomes noiseless and free from all obstruction.

7. The most marked cyanosis is met with when very small percentages of air (3 to 6 per cent.) or oxygen (under 3 per cent.) are administered with nitrous oxide (see p. 198). With pure nitrous oxide cyanosis may not have time, as it were, to become pronounced, for the administration may be cut short by deep stertor. As the percentage of air or oxygen increases, cyanosis lessens, till with 30 per cent. of air it is very slight, and with 11 per cent. of oxygen it disappears altogether.

8. Anoxæmic convulsion, like cyanosis, is liable to be greater with small percentages of air or oxygen than with pure nitrous oxide itself, and for the reason just given.

But as the percentages of air or oxygen increase the convulsion decreases, till with 30 per cent. of air and 6 per cent. of oxygen respectively it ceases to occur.

9. Reflex and excitement movements are most likely to arise either with pure nitrous oxide, or with nitrous oxide mixed with small percentages of air (3 to 7 per cent.), or with nitrous oxide mixed with considerable percentages of air (20 to 30 per cent.) or oxygen (10 to 20 per cent.). They are least likely to assert themselves with mixtures containing moderate quantities (12 to 16 per cent.) of air, or moderate quantities (3 to 7 per cent.) of oxygen.

10. Phonated sounds are most common when nitrous oxide is administered with large percentages of air (12 to 30 per cent.) or oxygen (20 per cent.). When nitrous oxide is administered pure, or with small percentages of air (3 to 5 per cent.), they are met with to a moderate extent only. Phonation is least likely to arise with nitrous oxide and air mixtures when air is present to the extent of from 6 to 10 per cent., and with nitrous oxide and oxygen mixtures when oxygen is present to the extent of from 3 to 11 per cent.

11. The duration of available anæsthesia after inhalation was found to be longest after the administration of mixtures containing from 3 to 11 per cent. of oxygen, the maximum duration having been attained with 7 per cent. mixtures. With nitrous oxide and air mixtures the resulting anæsthesia was distinctly longer than with pure nitrous oxide, but the results were very uncertain in these cases. The shortest available anæsthesia was recorded with nitrous oxide alone, and with nitrous oxide mixtures containing 30 per cent. of air.

12. In estimating the respective merits of the various mixtures used as anæsthetic agents, the investigation shows that the best results were obtained with mixtures of nitrous oxide and oxygen; the next best with mixtures of nitrous oxide and air; and the worst with nitrous oxide free from air or oxygen. Air is not nearly so

suitable as oxygen for eliminating the asphyxial factors of a pure nitrous oxide administration, owing to the large volume of useless nitrogen which must necessarily be inhaled. The nitrous oxide and air cases were, as compared with those of nitrous oxide and oxygen, far more uncertain in their course.

13. There is no one mixture of nitrous oxide with air or with oxygen which will successfully anæsthetise every patient.

14. In order to obtain the best form of anæsthesia, oxygen should be administered with nitrous oxide by means of a regulating apparatus, the percentage of the former gas being progressively increased from 2 per cent. or 3 per cent. at the commencement of the administration, to 7, 8, 9, or 10 per cent. according to the circumstances of the case. The longer the administration lasts, the greater may be the percentages of oxygen admitted.

15. The next best results to those obtainable by means of a regulating apparatus for nitrous oxide and oxygen are to be secured by administering certain constant mixtures of these two gases. Mixtures containing 5, 6, or 7 per cent. of oxygen are the best for adult males, and mixtures containing 7, 8, or 9 per cent. are the best for females and children.

16. The next best results to those last mentioned are to be obtained by means of mixtures of nitrous oxide and air, from 14 to 18 per cent. of the latter being advisable in anæsthetising men, and from 18 to 22 per cent. in anæsthetising women and children.

17. Paul Bert, whose valuable researches upon the effects produced by the inhalation of nitrous oxide and oxygen are well known, regarded an increased atmospheric pressure as essential to the production of anæsthesia by means of these gases. It is clear, however, from the foregoing investigation, that deep and satisfactory anæsthesia, unaccompanied by any obvious asphyxial manifestations, may be secured, at ordinary pressures, by mixtures of nitrous oxide and oxygen containing even

as much of the latter gas as is present in our atmosphere.

18. The last-mentioned fact would seem, at first sight, to give a death-blow to the asphyxial theory of nitrous oxide anæsthesia—a theory which supposes that this gas produces its anæsthesia by limiting or arresting normal oxidation processes within the central nervous system. But are we justified in assuming that because no *obvious* asphyxial manifestations make their appearance during the inhalation, no such interference with oxidation is taking place?

(For report of the discussion on this paper, see ‘Proceedings of the Royal Medical and Chirurgical Society,’ Third Series, vol. xi, p. 55.)