would take place in accordance with the following equation :—

$$\underset{\text{Indigo-blue.}}{2(C_{26}H_{13}NO_8)} + 10HO = \underset{\text{Alcohol.}}{2(C_{16}H_5NO_2)} + \underset{\text{Formic acid.}}{3(C_4H_6O_2)} + 4(C_2H_2O_4).$$

It will be seen that the same law regarding the number of atoms of oxygen prevails here as in the case of the bodies before described, this number being either 8 or 10.

If in this process ordinary alcohol is replaced by methylic alcohol, the same effect is produced, provided acetate of soda is employed; but a mixture of methylic alcohol, formiate of soda, and caustic soda does not act in the same manner on indigo-blue, which remains unchanged, however long it may be left in contact with the boiling liquid. It appears, therefore, that one of the two agents, ethylic alcohol or acetic acid, is quite essential. One of the two may be replaced by an homologous body; but when both are so replaced, the indigo-blue remains intact.

IV. *On some Physiological Effects of Carbonic Acid and Ventilation.* By R. Angus Smith, Ph.D., F.R.S., F.C.S., President of the Society.

Read January 24th, 1865.

In a report on the air of mines and confined places, there was given a chapter on the action of the pulse when carbonic acid accumulated in the air. It is proposed to repeat that chapter, and to supplement it with additional experiments. The experiments, when not otherwise explained, were made in an air-tight lead chamber described in the report alluded to. It may be well first to show the amount of carbonic acid exhaled. This will be done by giving the

amount per cent. in the air of the chamber. This experiment was the beginning of the inquiry. I expected that the amount of carbonic acid exhaled would diminish, and with it the amount of strength in the muscles; but these points could not be reached by the methods employed. The amount of oxygen used is for the time the same, although there is less in the atmosphere. I shall not pretend to say how the health is affected further than this, that a change is observed in the respiration and the pulse. I must leave physiologists to tell what mischief this will ultimately cause; but I cannot doubt that the circulation is diminished, and that the lungs endeavour to compensate for this by more rapid action. How much each person can bear of this change will depend on circumstances which, it appears to me, physiologists cannot estimate.

TABLE B.—*One Person in the close Chamber.*

	Carbonic acid.	
	1st day.	2nd day.
After 20 minutes	0·18 per cent.	0·19 per cent.
„ 40 „	0·32 „	0·36 „
„ 1 hour	0·49 „	0·49 „
„ 80 minutes	0·62 „	0·64 „
„ 100 „	0·74 „	0·75 „
„ 2 hours	0·88 „	0·89 „
„ 140 minutes	1·06 „	1·03 „
„ 160 „	1·20 „	1·22 „
„ 3 hours	1·25 „	1·34 „
„ 200 minutes	1·52 „	1·48 „
„ 220 „	1·54 „	1·60 „
„ 4 hours	... „	1·81 „
„ 260 minutes	... „	1·98 „
„ 280 „	... „	2·10 „
„ 5 hours	... „	2·25 „

I have not had time to attend to the full explanation of each experiment, and some require a continuation of the inquiry; but this last must not be passed over without special notice. The amount breathed every hour is the same—no matter

whether there be 0·04 or 2 per cent. of carbonic acid in the air, and no matter although there be 20·94 or only 18·8 of oxygen. This is strongly corroborative of the views taken by Liebig, but other circumstances tend on the other hand to show that this state of things is kept up at the sacrifice of the comfort, to say the least, of other vital functions. There must of course be a limit, but I was afraid to go farther than I went. In one experiment the breathing was changed from 16 inspirations per minute to 22, the pulse fell from 76 to 55, whilst it was so weak that it was difficult to find. My assistant was in the chamber this time; I requested him to attend to his pulse and breathing, as on another occasion when there was still more carbonic acid in the air, namely, 3·9 per cent., my breathing rose up to 26 inspirations, and my pulse became so weak as to cause alarm. This has happened so regularly that it must be put down as the result of poisoning with carbonic acid. On one occasion there was a comparatively large amount of oxygen in the room, viz. 20·1. The carbonic acid had been driven in upon fresh air, and no oxygen removed. Even here the pulse was weak, although the breathing was not very difficult, and the candles burnt moderately well.

The conclusion is, that in the air containing an increased amount of carbonic acid, this gas alone, even without the other hurtful ingredients, such as organic matter, begins to poison, and men exposed to it are really gasping for breath without knowing it. All the other hurtful conditions contribute their powerful aid.

As I came on this result at the end of the inquiry into the composition of the air of mines, it is not easy to do it justice. We learn much from it. We learn that the blood can take its oxygen out of very impure mixtures; but we learn also that some functions are meantime suffering greatly. It is, to my view, a most important thing to show that with an amount of oxygen not less than is

found in the air of some mines, and an amount of carbonic acid actually less, such extraordinary changes should result in the functions of a healthy man. We want no other experiment than this to prove great evil arising from impure air, either in mines or elsewhere.

In order to obtain similar results in a shorter time, five persons entered the lead chamber, expecting to have in one hour the same results that were obtained by one person in five hours. The figures are here given; it is seen that they are not exactly the same as previously. Time causes us to yield, although we may struggle against the evil influences for an hour or so. The effects are not exactly such as were expected. The pulse begins to be irregular very soon, and certainly when the air contains 0·4 per cent. of carbonic acid, in three cases 0·2. It rises and falls, but at last begins to fall. In all cases, however, it becomes very weak, as in the first experiment.

With the younger it rose rapidly at first, and seems to indicate the more rapid struggle for life with the more advanced; it was a steady determination not to be changed by external circumstances, although they gradually caused a change at last.

These figures will probably induce many others to continue the inquiry.

May it not be useful to lower the pulse in this method in some cases? If so, must the experiment be tried with pure carbonic acid? And how much was due to the carbonic acid, and how much to organic matter? All these are interesting questions. Meantime the question is so far answered, that we see the effects due to the want of ventilation.

TABLE C.—*Beats of the Pulse. Five Persons in the Chamber. Observations every 5 minutes.*

	A.	B.	C.	D.	E.	Temp.
To begin	60	78	84	70	73	68° F.
After 5 minutes	60	70	90	70	72	
„ 10 „	59	76	90	75	72	
„ 15 „	72	74	91	74	70	
„ 20 „	70	74	89	74	72	
„ 25 „	79	77	91	71	74	
„ 30 „	74	81	89	70	71	
„ 35 „	78	79	87	74	68	72° F.
„ 40 „	73	76	89	76	70	
„ 45 „	70	70	90	73	72	
„ 50 „	74	72	89	72	71	
„ 55 „	70	73	89	72	70	
„ 60 „	66	73	88	73	72	
„ 65 „	66	74	88	72	70	
„ 70 „	69	73	86	71	69	
„ 75 „	70	70	85	71	70	
„ 80 „	73	70	86	70	69	
„ coming out 5 minutes	66	68	89	68	68	
„ 3 hours	63	74	84	74	73	
„ „	61	75	85	74	73	
Number of Respirations.						
Normal	20	15½	22	20	20	
After 33 minutes	24	16½	25	20	25	
„ 58 „	23	17	25	22	24½	
On coming out after 5 minutes	20	16	23	19	21	

After 5 minutes.

Organic matter not pleasant.

After 15 minutes.

A. Pulse stronger and quicker.

B. Irregular pulse, but strong.

C. Weaker, and already difficult to feel.

D. Same to the feeling.

E. Much weaker.

After 25 minutes.

A. Stronger.

B. Irregular.

C. Irregular and weak.

D. Irregular.

After 45 *minutes.*

Organic matter less sensible than at first to the majority.

D feels air to be bad.

After 50 *minutes.*

A can scarcely feel his pulse; several attempts made to count it. Still feels quite well.

B begins to fell head uneasy.

C feels his heart beat more than usual.

D. Pulse weak.

E. Pulse very weak.

Here every one was observed to be sighing, although all were cheerful.

After 6 *minutes.*

B. Flushed.

C and D. Headache began slightly.

The effect of company was considerable in preventing the lowering of the pulse by keeping the mind cheerful.

But the experiment, Table F, shows that even when quite alone the pulse did not lower when the air was pure.

This experiment differs from that of Table D. The impure air was formed five times more rapidly, and the results were not so perceptible. It would appear that we can resist for a short time when we cannot resist for a long time.

The irregularity of most of the pulses is apparent.

A was the youngest, being about 17, and having a naturally low pulse; his was raised.

B was about 21 years old; his pulse went lower, then higher, then finally lower.

C, about 24; his pulse went higher, then sank to nearly its usual point, but he was the most affected in sensation.

D, 27; his pulse went higher and then lower.

E, 47; his pulse went lower, higher, and lower, but he felt no discomfort; forehead began slightly to warm.

It is remarkable that the breathing increased in all cases, and that it went back to its normal amount very rapidly.

TABLE D.—*One Person in the Lead Chamber. Respiration and Beats of the Pulse taken every* 10 *minutes.*

Time.	Pulse.	Respiration.	Temperature, Celsius.	Carbonic acid in the same periods.
h. m.			°	
10 55	73	15·5	18·2	0·04
min.			°	
After 10.....	73	16	18·2	0·114
„ 20.....	72	16	18·2	0·187
„ 30.....	71	17	18·4	0·261
„ 40.....	71	16	18·4	0·335
„ 50.....	70	16	18·5	0·408
„ 60.....	68	16	18·6	0·482
„ 70.....	67	16·5	18·7	0·556
„ 80.....	67	17	18·8	0·629
„ 90.....	66	17	18·9	0·703
„ 100.....	65	18	19·0	0·777
„ 110.....	65	18·5	19·0	0·850
„ 120.....	64	19	19·0	0·924
„ 130.....	63	19	19·2	0·997
„ 140.....	62	19·5	19·1	1·071
„ 150.....	62	20	19·1	1·145
„ 160.....	62	20	19·1	1·218
„ 170.....	61	20	19·1	1·292
„ 180.....	60	21	19·1	1·366
„ 190.....	60	22	19·2	1·439
„ 200.....	59	23	19·2	1·513
„ 210.....	58	24	19·4	1·587
„ 220.....	57	24	19·4	1·661
„ 230.....	57	24	19·4	1·734

TABLE E.—*When the door was opened.*

Time.	Pulse.	Respiration.
After 10 minutes	59	22
„ 20 „	59	19·5
„ 30 „	60	19
„ 40 „	60	18
„ 50 „	60	17

TABLE F.—*Sitting quiet for an hour in the Lead Chamber in pure air.*

Time.	Pulse.	Respiration.
4^h 50^m	75	17
After 10 minutes	76	17
„ 20 „	76	17
„ 30 „	76	17
„ 40 „	77	17
„ 50 „	76	17
„ 60 „	76	17

From this we learn that the same quiet condition in pure air produced no change.

Experiments B, C, and D, on the beats of the pulse, seem decisive. The air affects the pulse when the ventilation is such that the amount of carbonic acid reaches 0·18. The question of carbonic acid and organic matter, viz., which is the most hurtful, must be decided by other experiments. My belief is that much is due to the carbonic acid, because the progress of the pulse downwards is so regular, and I believe that the organic matter does not increase so regularly. This may not be true at the temperature given, and is another point to be ascertained.

But leaving out all the details, the great broad fact remains that carbonic acid and other emanations from the person diminish the circulation, and hasten the respiration, and that the effect is perceptible when the per-centage of carbonic acid reaches 0·18, or say one-fifth of a per cent. certainly. If, however, we do not wish to infer too much from one beat of the pulse, let us, for rough practice, say $\frac{1}{4}$ per cent.

EFFECT ON THE PULSE AND BREATHING

Artificial carbonic acid being inhaled along with the organic exhalations of the body.

1 *per cent. of Carbonic Acid.*

	Pulsations.
	68.
After 5 minutes	68.
„ 12 to	68, 70, 70, 70, 69, 70.
„ 22 to	70, 70.
„ 30 to	68, 68, 66.
„ 34 to	65, 65, 66, 66, 66.
„ 42 to	67, 68.
„ 51 to	66, 66.
„ 60	64, 63, 63, 63, 63, 63, 63.

2 *per cent. Carbonic Acid.*

	Pulse.	Inspirations.	
		18	
After 5 minutes	64	19	
„ 10 „	66	19	
„ 15 „	65	20	
„ 20 „	64	20	
„ 25 „	63	21	pulse very weak.
„ 30 „	62	21	
„ 35 „	63	21	
„ 40 „	64	21¼	
„ 45 „	63	22	
„ 50 „	62	22¼	
„ 55 „	60	23	
„ 60 „	61	23	
„ 65 „	60	23¼	
„ 70 „	60	23¼	
2 minutes after coming out		68.	

Here the pulse was very much affected even in the number of beats, but the effect was observed principally in its great weakness: it sometimes tried to recover its number, but this was not observed to take place with regard to the strength.

3 *per cent. Carbonic Acid.*

	Pulse.	Inspirations.	
	67	17	
After 10 minutes	67	21	Acidity perceptible
„ 15 „	65	21	to the smell.
„ 20 „	63	22¼	
„ 27 „	62	23	

Here the pulse became so weak that it was difficult to count the beats. There was also a very unpleasant feeling. The door was opened, and two other young men entered. Of course a good deal of carbonic acid was removed, but not more than from $\frac{1}{4}$ to $\frac{1}{2}$ per cent. In ten minutes the pulse of the eldest, B., fell from

79	Inspirations rose from 18
to 75	to 22
Unpleasantness felt.	

Here, as in the experiment recorded previously, the pulse of A. rose.

At first it was 63	Inspirations 21
It rose to 69	rose to 25

A.'s pulse very feeble. There is always a slight rise at the beginning. This rise was very decided in the case of A. It always results in a fall, and would no doubt have done so in this case had A. remained longer. This, however, would not have been safe, as, even in these two minutes, his pulse was almost imperceptible, and he could not count it himself.

In the above cases the persons who breathed sat in the lead chamber, and of course the organic matter from their bodies escaped into the air around them. Still we know that the organic matter would not produce these effects without the carbonic acid, simply because when we remain in the chamber much longer without pouring in carbonic acid the pulse does not become so weak, whilst the organic matter is of course accumulated to an extent much greater than it could have been with artificial carbonic acid.

Whilst I gave abundant credit to the organic matter for doing evil, I could not refuse to blame the carbonic acid; but as a friend was still dissatisfied with the argument if

applied to smaller amounts of carbonic acid, the following experiments were made. In them the organic matter is entirely excluded. For the first, in which 1 per cent. of carbonic acid was mixed with the air, several aspirators of flexible material were filled with the mixture, and the air was inhaled from the aspirators by the mouth, whilst it was exhaled from the nostrils. The carbonic acid was made from bicarbonate of soda, and passed through a solution of bicarbonate of soda to remove mineral acids.

With 1 per cent. of Carbonic Acid.

	Pulse.		Pulse.
	66	After 14 minutes	66
After 2 minutes	67	„ 16 „	64
„ 4 „	67	„ 18 „	64
„ 6 „	68	„ 20 „	64
„ 8 „	67	„ 22 „	63
„ 10 „	68	„ 26 „	63
„ 12 „	67		

In this experiment the difficulty of supplying air was felt to be considerable; and the aspirations having become less agreeable and regular, they were not counted.

In order to remove all difficulty, the lead chamber was charged with the mixture to be breathed, and the operator sat outside inhaling the air through a wide tube with ease. Of course a similar amount of air entered, and this was supplied through some small chinks, which were not carefully filled up. The change taking place in the air of the chamber from this latter cause only would scarcely be perceptible in half an hour, and then it would be against the success of the experiment. The uniformity of results is therefore very remarkable.

With 0·5 per cent. Carbonic Acid.

	Pulse.	Inspirations.
	76	17
After 5 minutes	76	
„ 10 „	76	
„ 15 „	75	20
„ 20 „	73	
„ 25 „	71	
„ 30 „	71	22
„ 35 „	71	
„ 40 „	71	24

With 0·25 per cent. of Carbonic Acid.

	Pulse.	Inspirations.
	70	17
After 5 minutes	72	
„ 10 „	73	
„ 15 „	72	19
„ 20 „	70	
„ 25 „	69	
„ 30 „	69	21

Here a disturbance is seen at once, more fully in the breathing. Owing to the mode of draining the reservoir of air breathed, it would not have been fair to proceed further.

With 0·1 per cent. of Carbonic Acid.

	Pulse.	Inspirations.
	73	18
After 5 minutes	72	
„ 10 „	73	
„ 15 „	73	19
„ 20 „	72	
„ 25 „	71	
„ 30 „	72	
„ 35 „	73	19
„ 40 „	73	
„ 45 „	72	19
Average	72·4	18·75

Here there is a disturbance perceptible of two on the

pulse; and I may say that the experiment is scarcely fair after 25 minutes. The disturbance on the inspirations is more uniform. It is, for example, more perceptible than in the next case.

Pure air was breathed in the same position as in the previous cases, D. sitting outside the lead chamber, which had been well ventilated. This experiment was made in order to ascertain the influence of breathing through a tube, as it was feared lest some mechanical difficulties might have interfered with the value of the operations. The result shows that no such difficulties occurred. There is a little diversity of one above and one below the average of the pulse, and the breathing is a little lower in one case, instead of being resolutely higher as in every other case given, even when so little as one-tenth of a per cent. of carbonic acid was used.

Ordinary Atmosphere in the Lead Chamber; breathing through the tubes as before.

	Pulse.	Inspirations.
	74	18
After 5 minutes	74	
„ 10 „	75	
„ 15 „	74	18
„ 20 „	74	
„ 25 „	75	
„ 30 „	74	18
„ 35 „	74	
„ 40 „	74	
„ 45 „	73	17
„ 50 „	74	
„ 55 „	74	
„ 60 „	75	18
Average	74·1	17·8

In a report on the air of mines I discussed questions relating to the absorption of oxygen and poisoning by carbonic acid, quoting several opinions of eminent chemists. The important point is this: How can the blood be influenced by

a diminution in the amount of oxygen to the extent of 0·1 or even 1 per cent? Liebig says, "In a closed space 8 feet long, 9 feet high, and 8 wide a man could not breathe 24 hours without uneasiness." This is equal to living about 5 hours and a half in my lead chamber; and in that time, by sitting quietly, we may avoid uneasiness; but the air will be very bad, candles will scarcely burn, some will go out, and any person entering suddenly will be very unwell. The sensations are gradually affected, and nothing striking is observed; the senses are diminishing in power. If we look at the important total acts, the circulation of the blood and the respiration, we find that death has begun, so to speak, and the life is going out as quietly as the candle.

Nearly all the usual experiments on breathing in impure air have been made violently and not with small amounts of impurity, and during a very long interval of time; a rabbit has been killed in a few minutes, and the same air has been breathed until it has attained its maximum impurity. Liebig says, "Lavoisier and Seguin found that the carbonic acid of respired air, when again inspired, may be raised to 10 per cent., but not beyond that amount, even when respiration was continued, which it could be only for a very short time. This proportion of carbonic acid may be regarded as the limit at which life is endangered in man."

We can scarcely look on this experiment as sufficient. I became distinctly faint in 4 per cent. of carbonic acid, the others around me were very uncomfortable in even less; one fainted in 2 per cent., which did not affect my senses. We can, when in very good condition, bear 4 per cent. for a quarter of an hour at least, so that life is not endangered suddenly; but I am disposed to think that no one could live long in such air. When hours are spoken of, the danger to life of any amount less than this is not immediate when the person is healthy. The constant

lowering of the pulse, even in much less impure air, must have a gradual effect on the vitality; which effect will be seen in some persons in a few hours, in some after days, and in others perhaps years. It is probable that to live during the whole 24 hours of the day in any air containing above 1 per cent. would bring results on the health very rapidly; but no men are exposed to this, so far as I know; the usual exposure is only for three or four hours, seldom during the whole working time; and even with this the pulse is kept permanently low, as will be seen in Dr. Peacock's report.

Now comes the question, If the oxygen of the air is taken up by the blood by chemical affinity, why should the presence of carbonic acid affect it, and therefore why should it be a matter of importance whether the amount of oxygen be small or great?

1st. The absorption cannot be wholly chemical; it must, to some extent, follow the physical laws of absorption, if we may so call them. In this case the amount absorbed will be in proportion to the bulk of the two gases presented to the liquid. The smallest increase of either gas will make a difference. I entered on this more fully in a former paper.

2nd. If the absorption is purely chemical, knowing as we do that the work of absorption must be done rapidly, the amount absorbed must still depend on the amount presented.

3rd. In either case it will require a certain amount of oxygen to drive out the carbonic acid.

If blood contains 10 per cent. of oxygen and 5 of carbonic acid, add one per cent., or one-tenth, or one-hundredth per cent. of oxygen more, and a certain amount of carbonic acid will be removed.

Viewing blood as a liquid like water, this would be the case, I suppose, if we gave it time. Viewing it as a che-

mical solution, it would be still more the case. If we add oxygen to protocarbonate of iron in water, the carbonic acid is driven out in proportion to the rapidity with which the oxygen is absorbed, and of course the oxygen is absorbed with greater rapidity if the liquid contains less carbonic acid.

If, again, we view the blood and the membranes rather as porous bodies, we have the question still more clearly answered; and there are reasons why we should believe the action somewhat to resemble the action of these bodies. Whenever charcoal, a porous body, is filled with one gas and is put into another, a certain amount of the first is driven out with great force; the result is not a mere mixture taking place quietly, but an instant forcible diffusive and absorbent action. If we view the carbonic acid as driven out by the oxygen, taking any of the three views, the actual amount of the gases present must be of the greatest importance.

The amount of carbonic acid in the lungs is always considerable. If the air inspired has more or less oxygen, the proportions are first changed in the lungs, then the act of absorption takes place, when the proportions must again be changed. We must remember that we breathe every three seconds, so that the change in the lungs is made rapidly; and the absorption will also be rapid, although the chemical changes taking place in the blood may be slower.

I must be careful in speaking of such subjects; but I trust I do not go farther than is legitimate for a chemist.

If we consider the effect of even one beat of the heart in a minute in a mechanical point of view, we need not be surprised at a change of result in the health. If the amount of blood sent by the heart is three ounces, we have, for every beat of the pulse lost per minute, a diminished circulation of many gallons of blood per day; for

every beat less, the corresponding amount is taken from the circulation. But even this is not the whole difference because the beats become excessively feeble. The blood seemed to require to remain in the lungs rather longer, in order to obtain its oxygen, whilst the breathing supplied air more rapidly; so that in some cases there were found to be an addition of nearly one-half the number of inspirations. In one case especially the pulse was raised, not sunk; and in most cases it was raised a little for a short time at first, as if an inferior blood were endeavouring to do equal work by moving more rapidly.

Medical men have objected to the argument that any evil result can arise from these effects, saying that man is formed so as to resist such influences, and is not so weak as to be confined within such small limits. When the ground gives way under a man he cannot resist, he can generate no force contrary to gravitation, except a few movements or leaps from the ground itself if the sinking is not too rapid. When the heart ceases beating man cannot resist, as he needs the beating heart itself to generate his power. If the heart is feeble, he may breathe fast to supply it rapidly with oxidized blood, and to a certain extent succeeds; but he must take this compensation force from some place. I cannot pretend to give an opinion on the result of an unnatural slowness of pulse, and an unnatural rapidity of breathing; but that they are evil omens is true, or we have long been deceived. In mines and such places the evil is exaggerated, because the exertion required to climb the ladders leads to an increased activity of the heart.

If the gas by which the oxygen in air is diluted were insoluble, the result might be very different, and we might probably remain in air with less than 10 per cent. of oxygen. In one condition, namely, in high regions, something similar to this occurs; the amount of oxygen is

diminished by rarefaction. But even if no rarefaction took place, we could breathe in air having much less oxygen than in the worst metal mines we know, if the carbonic acid was removed. This Liebig states, and so far I have proved it, that by removing the carbonic acid by lime from air in which breathing was uncomfortable, the whole seemed quite fresh; candles also burned better. This I have elsewhere described. Nitrogen and some other gases, marsh gas for example, not uniting chemically, and not being altered to a great extent mechanically, but above all not being driven out from any compound in the blood, either by the addition or otherwise of oxygen, do not produce effects so violent as carbonic acid.

Whatever the explanation be, my conclusion from the experiments is, that the smallest diminution of oxygen in the air breathed affects animal life, if its place is supplied with carbonic acid.

V. *Further Observations on the Permian and Triassic Strata of Lancashire.*

By E. W. Binney, F.R.S., F.G.S.

Read March 21st, 1865.

Introductory Remarks.

In previous memoirs, published in the Transactions of the Society,* I have given what information I possessed in a fragmentary state, just as I obtained it, of the Permian strata of Lancashire and the north-western counties of

* Transactions of the Manchester Literary and Philosophical Society, vol. xii. (2nd series), vol. xiii. (2nd series), vol. ii. (3rd series), vol. iii. (3rd series).