WHY DO WE BREATHE?

RESPIRATION

OR

WHY DO WE BREATHE?

A LECTURE DELIVERED BEFORE A POPULAR AUDIENCE

BY

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LONDON
SMITH, ELDER, & CO., 15 WATERLOO PLACE
1876

PREFACE.

Some apology seems to be needed for putting the following Lecture into print, because so much, even the greater part, it contains has been so long public property, or been better said or written by others. Still, after making the freest admissions on this head, the Author is conscious of having thought out his subject in a way of his own; and, if this alone might not adequately excuse him, he would desire to rest his justification in the fact that some theories or doctrines he has ventured to call into question and to oppose, are not only of the highest philosophic interest, but involve the most important practical results.

The doctrine of Asphyxia, as laid down by the highest authorities, cannot, he believes, be maintained; and, as this subject is very closely connected with the Heart's physiology—so closely, indeed, that his reasoning on each of these subjects must stand or fall together—it is necessary to give such an account of the latter as shall be in perfect harmony with all the phenomena of the former.

It seems a bold assertion to make, that the Heart's physiology has been in some important points entirely misapprehended; nevertheless the Writer must speak as he is convinced; and he again brings before the public the views to which he gave utterance more than twenty years ago, in the Croonian Lectures delivered by him at the Royal College of Physicians.

He now challenges the verdict of philosophic minds on these questions, believing them to be of the greatest interest and importance, and respectfully asks that they be considered.

Should his explanation of the Heart's *thin* Pulmonary Chamber be untenable, the sooner it is consigned to the heap of 'mountainous error' the better.

SYLLABUS.

Introduction.

The 'breath of life.'

Supposed identity of 'breath' and 'life': Language founded on the idea. Illustrations from Shakespeare.

Why do we breathe? Popular view of the subject. Scientific view.

Heat and force dependent on respiration.

Liebig's philosophy on this subject constituting an epoch in medical science.

Constitution of blood in relation to its function of laying hold of oxygen, and again surrendering it, in circulating throughout the body.

Questions connected with the constitution of atmospheric air.

Movements of respiration considered apart from the chymical results.

'Respirable' and 'irrespirable' gases.

Doctrine of asphyxia.

Criticism of views generally held on the subject. Author's view.

Illustrations from the effects of breathing Ether, Chloroform, and Nitrous Oxyde.

Anæsthesia.

Mechanism of respiration.

An automatic, self-regulating function.

Respiration *waits upon the heart*, and is active or quiet according to demands made on it.

Illustration from hybernating animals.

Physiological explanation of being 'out of breath.'

Breathing in a diving-bell: in a balloon.

Emotional breathing.

Pulmonary circulation and its relation to the heart's structure.

Physiology of the *thin* right (pulmonary) ventricle.

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Some time ago, when I was honoured with a request that I would give one of the Lectures that are offered to the public in this Hall, thinking it my duty to accept the invitation, I sat down to consider carefully what part of the science of Physiology—that noble and most interesting science, which, gathering its information from every possible source, and laying its contributions on every branch of knowledge, endeavours therewith to explain how we live and move and have our being—what little part of this boundless science might be at the same time not altogether unsuited to the very limited knowledge of an amateur (for I have indeed no higher pretensions) and also be well adapted to a popular audience. I thought long and earnestly on my choice of a subject, and I seemed indeed to have passed in review the whole field of Physiological Science without arriving at any definite or satisfactory conclusion. Whilst, however, I was thus engaged, it chanced that a letter was brought to me, which bore on its envelope a motto in so clear, so conspicuous characters, that I could not help being attracted by it; and as I read it and repeated it aloud, as people are sometimes wont to do even when they are quite alone, the words seemed to have some phonetic virtue; at all events they had some little merit of alliteration, which hung about the sense, and seemed to give them an interest, which at any other time they might not perhaps have had; for now they either suggested a thought, or if this was not the case, they chimed in with some thoughts that had been passing through my mind, and made, as it were, a channel for them to flow in.

The motto was perhaps the most common of all common Latin mottoes: it needs no translation, for it consisted of the familiar words '*dum spiro spero.*'

I began to muse over them, which, whether we consider them as expressing the sentiment of some individual man, or rather and better perhaps as conveying some great truth which belongs to mankind in general, would seem to have this meaning, viz. that Hope is the latest faculty of the human breast; that, let adversity befall a man—come loss of fortune, loss of friends (this, alas! is too apt to follow loss of fortune); loss of reputation, whether merited or undeserved; loss of health; of anything, indeed, which seems to make life sweet and precious to a man—there is still a Divine faculty which will not desert him; which will comfort him in the midst of almost any affliction, or animate him to successful, aye, even to triumphant exertion.

The motto recalled to me the old story of Pandora and the pleasure I may at some time have received either from the painter's or the sculptor's art, which has presented to me a beautiful woman hastily shutting down the lid of a casket, as if she were eager to retain something which was far too precious to be permitted to escape, but was just raising its wings to take flight and be away; or it may have been the pleasure of an earlier period of life—the years of our childhood, in which we drink in the mythological tales that have been bequeathed to us by the wisdom of the ancients, accepting them in their simple, literal, unfigurative meaning, and enjoying them not less, but probably a great deal more, because we are at that time entirely ignorant of the great truths—the often sublime truths—that lie hidden under the poetic language of allegory.

But it was not the word 'spero,' but 'spiro,' that gave the motto this momentary interest, and for this reason—that 'breath' and 'life' were used as synonymous terms. The motto has exactly this force—as long as I live this Divine gift of Hope shall not be taken from me.

Now this intimate union—this all but identity of 'life' and 'breath'—must receive some explanation in the course of my address; meanwhile let me say it is one of the earliest facts that can come to our knowledge. Though we learn it by experience, we seem to know it by instinct. We learn that its intermission (that of breathing) for even a few seconds is painful to us, for any longer period by any effort of the will is impossible; if enforced, it is fatal.

Breathing is the Alpha and Omega of our existence, the beginning and the end.[1] It gives the first sign that a living being has been born into the world; to expire is synonymous with 'to die.'

Hence the 'breath of life'[2] seems to be the fittest expression that could possibly be used. So also an expression we meet with in the Book of Kings, though perhaps appearing a little quaint, has the same truthlike simplicity. In the story of the widow who fed and comforted Elijah, her son's death is thus described: 'His sickness was so sore, that there was no breath left in him.'[3]

I have somewhere read that Sir Thomas Browne designated 'Respiration' as the 'critical test' of life or death, and it is remarkable how constantly Shakespeare makes reference to it in this sense.

Let me give one or two illustrations. When Friar

[1] Dr. Paris has drawn attention to the fact that the Greek word, signifying 'I breathe,' or 'blow,' is formed of these two letters—ἄω.

[2] Genesis, ii. 7.

[3] 1 Kings, xvii.

Laurence gives Juliet the sleeping draught which is to transform her living, breathing, palpitating form into the 'borrowed likeness of shrunk death,' he enumerates the cessation of breathing among other signs of the effect the draught is to produce.

> 'No warmth, no *breath* shall testify thou livest.' [1]

And in the Second Part of Henry IV., when the young Prince is watching by his father's sick couch, and observing that he scarcely seems to breathe, he says:

> 'By his gates of breath
> There lies a downy feather, that stirs not.
> Did he suspire, that light and weightless down
> Perforce must move.' [2]

And when King Lear brings on the stage Cordelia lying dead in his arms, he says, in the agony of his doubt as to whether she really is so or not,

> 'Lend me a looking-glass;
> If that her breath will mist or stain the stone,
> Why then she lives.' [3]

And a few lines further on, as if he had actually applied the so-called feather test, he adds

> 'This feather stirs, she lives!'

Again, in Romeo and Juliet, Montague says, near the end,

> 'Alas! my liege, my wife is dead to-night;
> Grief of my son's exile hath stopped her breath.'

And when Romeo asks the Apothecary for some quick poison, he says:

> 'Let me have a dram of poison,
> That the life-weary taker may fall dead,
> And that the trunk may be discharged of breath.'

[1] 'Romeo and Juliet,' Act iv. sc. i. [2] 'Henry IV., Part II.'
[3] 'King Lear,' Act v. sc. iii.

Let these suffice, as we must get into our subject. Now, to do this, it seems right we should start from a popular point of view; and in order to get this view I thought it well to put one or two questions to some persons of excellent knowledge and ability, but without scientific culture. I did not select these persons; they casually came before me, and consisted of a lady, a clergyman, and a lawyer.

It so happened that I asked the lady first, and I put this question to her, giving my reason for so doing. 'Why do you breathe?' After a little thought she said, 'Well, I suppose it's to keep me going.' I then put a second question to her. 'Why do you eat and drink?' The answer was, 'I suppose that's to keep me going too.' The lawyer agreed with the answers I had already received, and offered nothing in addition. The clergyman's answer was copious in words and rhetorically amplified, but it had no clearer meaning, and betrayed no deeper insight or analysis of the question than that which was implied in the former answer.

Let me then start with the question, 'How does Respiration keep us going?' for we must admit that it is necessary for this primary end.

Now everyone is conscious of two great facts, which he considers inseparable from life; these are 'warmth' and power of motion or 'force.'

Has Respiration anything to do in producing these results? Yes. It has everything to do with them. It is through Respiration that oxygen is introduced into our bodies, and it is through the mutual action of oxygen and certain elements in our bodies that both heat and 'vital activity' or 'force' is produced.

This is one of the most fundamental truths in the whole science of Physiology. It does not yield in importance to the discovery of the circulation itself. It as clearly marks a great epoch in its progress. Yet, if we turn back the pages of the history of our science, we are almost startled on finding how recently this knowledge has been acquired. I commenced my profession in entire ignorance of it—the fact had not yet been disclosed; and I can remember as if it were but yesterday the intense interest with which I read such passages as the following—

'All *vital activity* arises from the mutual action of the oxygen of the atmosphere and the elements of the food.'

And again—

'The mutual action between the elements of the food and the oxygen conveyed by the circulation of the blood to every part of the body is the "source of animal heat."'

These passages are from the writings of the late Professor Liebig, of whom it is not too much to say, that if he had done nothing else, this alone would have sufficed to place him in the highest rank of the philosophers of any age.

I have thought it worth while to note the period at which this great advance in scientific knowledge was made, and it appears that it was in or about the year 1842 that the announcement of these facts was first made to British readers through the translation of Professor Liebig's work.[1]

A few years before this we may read, in the 'Outlines of Physiology,' by Professor Mayo, a work which was used as a text-book in most of our medical schools: 'Upon the whole (he writes) we must admit that the source of vital heat remains unknown.'

We are dealing for the moment with the two great facts of 'heat' and 'vital force,' as dependent on Respiration in its chemical relations. Let me explain this a little further. Life is a state of continual change, rest is absolute death. At every instant of our lives we are laying up and consuming stores of potential energy, consuming them just as the fuel is consumed that has been stored up in our cellars—if the latter passes into smoke and ashes, and

[1] 'Animal Chemistry.' Translated by Wm. Gregory, 1842.

gives forth heat or force (for the terms are convertible), there is no other result for the material of which we are made—the smoke passes out in breath, whilst the ashes find an exit in solution by other channels; and the force we give out or expend is exactly equivalent to the potential force we have stored up.

How wonderful must be the fluid, *i.e.* the blood, through which these effects are produced! yet it is so constituted that in its passage through the lungs, at every breath we inspire, it first lays hold of the oxygen of the air which circulates around its channels, and thus oxydises or partially burns its minute globules, changing their colour from purple or black to crimson—from venous to arterial—and at the same time slightly raising its temperature; then circulating throughout the body, carrying with it the oxygen thus obtained, but ready to dissolve its first union and enter into a new combustion and to take its part perhaps in the disruption of those compound bodies which in being thus rent asunder give out that force which has originally built them up.

I used the term 'blood-globules' with the object of drawing your attention to it. The blood is not simply a red homogeneous fluid, but a clear or yellowish fluid containing minute red globules diffused throughout it, which give it its colour. If blood is drawn and allowed to stand, this would at once be apparent, but many of you are probably acquainted with the fact from having seen the circulation by aid of a microscope in the living vessels.

Now these minute bodies have been called the 'carriers of oxygen.' Iron enters largely into their composition, constituting from 35 to 43 per cent.; it is therefore extremely probable, from the strong affinity of iron for oxygen, that it is the active agent in the oxydation of the blood.

Let us then assume that it is so. Each little globule will therefore carry with it the oxygen sufficient for the ignition of a minute carbon point or atom, and there will be as many distinct fires lit up in our bodies by the union of carbon and oxygen as there are red blood-globules circulating in it.

Now to give you some vague idea of the number of these fires, let us suppose, as has been estimated, that the diameter of a blood-globule is about $\frac{1}{4000}$ inch, and that they form only the quarter of the whole amount of the blood; therefore the quarter of the cube of 4,000 or 16,000 millions will be about the number of these globules contained in a single cubic inch.[1] This, I say, would represent the number of points of oxydation, *i.e.* of combustion, which would belong to a single cubic inch of blood. If I had to make some approximate calculation of the number which would belong to the whole mass of the blood, I might have to ask you to widen the room in order to exhibit the sum in an unbroken line.

There is yet another point before I pass on from the chemical results of the function of Respiration, and that is the composition of the atmosphere. It may be asked, Does the proportion of oxygen contained in atmospheric air bear any distinct relation to the work done by it in the function of Respiration? It is a matter of perfect indifference whether the air we draw in at each breath contains only 20 per cent. or 80 per cent. of this, the active agent concerned. In the combustion of all other matter, we know it to be quite otherwise. Were there to be any great difference in the quantity of oxygen contained in the air, the world would have to be reconstituted, all the affinities of matter to be rearranged. A large percentage of oxygen would lead to universal destruction. Reduce it very much, and we should have the stagnation of death.

Now I am not in a position to press this point, for some physiologists tell us that it makes no difference whether we breathe pure oxygen or atmospheric air which contains only

[1] As the quantity of the blood-globules is only one-fourth of the blood, so the distance of the centres of the globules from each other would be $\frac{4}{4000}$ inch.

20 per cent., the rest consisting chiefly of nitrogen, which is probably inert. It has doubtless been ascertained that an animal can breathe oxygen gas without appearing to suffer from it; but I think it must be at least open to doubt whether any great increase of oxygen would not lead to the same results which would be allowed to take place in all other matter; and should it be so, what would then ensue? Let the air contain 80 instead of 20 per cent. of oxygen; the combustion of our bodies, on the analogy of other matter, would be rapid in proportion; and, if the waste was so great, the supply must be proportionate to it. In such altered circumstances, a fowl or half-a-dozen cutlets might be a young lady's moderate luncheon; a goose or leg of mutton, bread, potatoes in proportion, her customary dinner repast.

Nature, bountiful nature, surrounds our life with enjoyment. That which is necessary to us is ensured to us by the pleasure and enjoyment it affords. We call hunger 'appetite,' a word, which has pleasure wrapped up in it when the desire is gratified. There is little danger of our undervaluing this gift. One may therefore fancy the said young lady, with just appreciation of nature's gifts, giving reins to her imagination, raising up visions of unbounded feasting, and saying 'Oh! how delightful!' But there is another side to the picture. We must accept all the consequences of the change. Would it then be agreeable to hear that our coal was roaring up our chimneys at the rate of a ton or more a day; or should we accept it as a pleasant jest, were we to be told that some one, on scratching his lucifer as he passed our door, had actually set fire to the iron railings? These statements may appear to some as gross exaggerations; possibly they may be so, perhaps even intentionally; but principles are best seen in extreme cases; and when results are undefined, an extreme case is best fitted to show the tendency in which any great change would operate.

But let us suppose, on the other hand, that the air we breathed contained only 15 or even 10 per cent. of oxygen. How should we then be affected by the change? It might be pleasant to breathe such an air—I know nothing to the contrary—and it might at the first view seem to carry some advantages with it. We should certainly have no difficulty in keeping ourselves cool in even the warmest summer, but the most genial winter would be fatal to us; neither could we keep ourselves warm by means of our fires, for these would inevitably go out.

A few minutes ago I spoke of respiration as necessary for the primary end of introducing oxygen into our bodies, and thereby giving rise to 'heat' and 'vital force.' The word 'primary' seemed good at the moment, but as I have now another use for it, I must withdraw it from where I first applied it and replace it there by the word 'ultimate,' which would seem to be the exact opposite.

I may perhaps startle some of my professional or philosophic friends in saying that the replacement of carbonic acid by oxygen—the renewal of the blood's life—its conversion from black to crimson—is *not* the primary end of Respiration. What, they will ask, is it, if not this? My answer is, that the movement of Respiration considered as *movement only*, and altogether irrespective and independent of the chymical result of Respiration, is absolutely necessary to the maintenance of life, for without this movement the blood is obstructed in its progress through the lungs.[1] Arrest

[1] The thin right ventricle is unable to propel it unless the air vesicles of the lungs are dilated by inspiration. Hales has some valuable remarks on this subject which have not (the author thinks) been sufficiently appreciated by writers on Physiology, *e.g.*: 'The dilatation of the lungs, which arises only from the force of the blood in the pulmonary artery, is not *alone* sufficient to promote the passage of the blood through them (*i.e.* the lungs); but there is also requisite a further dilatation of the coats of the vesicles with inspired air; thereby probably to unfold the corrugated extremities of the arteries and veins, and so to give the blood a free course through them. For though (Exp. I.) it was observed that on deep sighing—*i.e.* on much dilating the lungs—the force of the

the movement, and you have immediate asphyxia; allow the movement, even if the air admitted contains no free oxygen, and is therefore wholly unfitted to vivify or arterialise the blood, and the circulation will go on for a considerable time without let or hindrance. Let me therefore say that the lady who told me that breathing was necessary 'to keep her going' uttered a grand scientific truth, though I fear at the same time she was '*philosophe sans le savoir*.' I am therefore prepared to maintain that the first requirement of Respiration as an *incessant* movement is to enable the blood to circulate, *i.e.* to pass through the lungs, where it would otherwise be obstructed in its course with all the phenomena of asphyxia.

Now this consideration, this mode of viewing the facts, brings at once before us the question of 'respirable' and 'irrespirable' gases. What, therefore, is a 'respirable,' what an 'irrespirable' gas? The answer is a very simple one. Any gas or air which I can inspire or draw into my lungs without let or hindrance is a 'respirable' air; any gas or air in which I may be placed, which from its pungency or irritating properties I am unable to inspire, that gas is justly designated 'irrespirable.' The first named, the 'respirable' air, may be wholly unfitted to satisfy the chemical end of Respiration, it may contain no free oxygen, it does not redden or revivify the venous blood which is exposed to it, but it does not restrain the free expansion of the lungs, which, I repeat, is a prime necessity to enable the blood to pass onwards to the left side of the heart.

Now, on the other hand, an 'irrespirable' air may be quite fitted to meet the chemical requirements for the

blood in the horse's arteries was greatly increased, which was occasioned by the blood's flowing more plentifully through them when they are dilated than when fallen; yet, we cannot hence infer that the blood flows more freely through them also when they are dilated by the force of the arterial blood (*i.e.* in pulmonary artery) without the joint dilatation also by the inspired air.'—Hales' 'Hæmastatics,' p. 73, sec. 3.

aëration of the blood; it may contain more free oxygen than is necessary for this purpose; but if it contain a very minute percentage of an extremely irritating gas, such as is produced by burning sulphur, by the fumes of muriatic acid or of strong ammonia, it at once becomes 'irrespirable,' and anyone plunged into such a gas will infallibly perish by suffocation, because the mere pungency of the vapour will, by its action on sensitive parts, restrain the movements of inspiration.

We are thus brought to the subject of Asphyxia, of which I must give some explanation.

In its etymological sense, the word means the absence or cessation of the heart's pulsation; but, though such may be its general meaning, it is only used in a special or restricted sense, being applied solely to cases of death by strangling, drowning, and other analogous causes of suffocation. The heart might falter, and a person die in a fainting fit; but this would not be designated as 'death by asphyxia.' In faintness the heart's chamber is full of blood, but it is powerless to contract upon it; in asphyxia the heart's chamber is empty, and has nothing to contract upon, the onward passage of the blood having been barred by the non-expansion of the lungs.

There has, it seems to me, been much erroneous reasoning on this subject, and the doctrines of chemistry have been unduly imported into a question which should rest on a physical or mechanical basis. It has been said, for instance, that the introduction of an irrespirable gas into the lungs (an expression, by the way, which is self-contradictory), or the prevention of the access of the atmosphere, brings the circulation of the blood to a stop, because that movement depends on the aëration taking place in the pulmonary capillaries.[1] Another physiologist, whose writings I regard

[1] See Draper's Physiology, p. 167. 'The introduction of an irrespirable gas into the lungs, or the prevention of the access of the atmosphere, brings

as masterpieces of philosophic thought and perspicuous writing, has, I submit, fallen into the same error in referring 'asphyxia' to the double cause of privation of oxygen and excessive accumulation of carbonic acid in the blood. He says, 'Oxygen starvation, and carbonic acid poisoning, each of which may be fatal in itself, are at work together,' and thus united in destruction. (Huxley's 'Lessons in Physiology,' p. 113.)

These remarks on 'asphyxia' may receive an appropriate illustration from the phenomena that may be observed in the inhalation of certain anæsthetic vapours, such as Ether, Chloroform, and Nitrous oxide, for it is by Respiration that these gases are introduced into our bodies, and it is by the neglect or the non-reception of the doctrine of asphyxia, such as I have presented it to you, that those lamentable accidents of death by chloroform have in my opinion so often occurred.

Let me speak first of ether and chloroform. Now these vapours rest on exactly the same principle—they are equally safe in the hands of the scientific, equally dangerous in the hands of the ignorant. You all know something about these matters; some of you have perhaps experienced the beneficial effects of them in your own persons. Now in breathing ether and chloroform we do not breathe pure ether

the circulation of the blood to a stop, for that movement depends, as I have shown, on the aëration taking place in the pulmonary capillaries, &c., &c. In the respiration of the protoxyde of nitrogen, which is an energetic supporter of combustion, and acting more powerfully on the animal system when respired than even oxygen itself, &c.' In these and other passages Professor Draper seems to have fallen into the error of supposing that nitrous oxyde is a supporter of combustion at *low temperatures*, and satisfies the blood's affinity for oxygen, whereas it is as unfitted for this purpose as carbonic acid itself. Cf. Valentine's 'Chemistry,' p. 125. A piece of sulphur placed in a deflagrating spoon, and introduced into the gas (nitrous oxyde) immediately after kindling and whilst it burns only feebly, is *extinguished*. Introduce it when burning briskly, and it will burn with increased brilliancy, almost as if in oxygen itself.

or pure chloroform (this is a physical impossibility), but atmospheric air which is charged with a certain percentage of one or the other of these liquids. Now atmospheric air at ordinary temperatures will only take up or carry a certain quantity, which is said to be about 10 per cent. At this point, whatever it may be, air is saturated. Here arises this important question: Is atmospheric air, thus saturated with ether or chloroform, a 'respirable' or an 'irrespirable' air? This is a momentous question. What answer shall we give to it? The advocates of that theory of asphyxia which I have endeavoured to refute will say, 'Oh, it is clearly respirable, for there is abundance of free oxygen; there will be no privation of this life-giving principle; the blood will be properly changed from black to scarlet as it passes through the lungs; there will be no stagnation in the pulmonary capillaries; the demands of Respiration will be fully satisfied. We may therefore throw it upon the lungs with perfect security.'

Now all this is quite true, as far as the chemical question is involved; but, I ask, will it be safe to accept the practical inference thus suggested? Shall we be justified, say in the case of a surgical operation, or, it may be, in dental practice, in depriving a patient of all freedom of motion, in binding his hands, in restraining him against all efforts to free himself? If we do so, we shall indeed be guilty of his death. Doubtless the air thus saturated is *chemically* respirable, but *vitally* it is not so, and for this reason—that air, when saturated with these anodynes, is so pungent, that it is impossible to inhale it until partial insensibility has been induced; for, as soon as this concentrated vapour comes into contact with the sensitive passages leading to the lungs, the act of inspiration is arrested, and no voluntary effort, if it were possible to make one, would be able to overcome nature's instinct in rejecting it. The movements of Respiration are thus arrested, and death by asphyxia thus ensues;

not, you will observe, because too much chloroform or too much ether has been inhaled, but from the very opposite cause, *i.e.* because actually none has entered the lungs, having been checked at the very portals of these organs.[1]

But let these vapours be administered in a more diluted form; let the air contain say 3 or 5 per cent., or any proportion you like (for the exact amount is unimportant), which does not by its pungency restrain the freedom of inspiration, and you will soon be able, as the sense becomes gradually dulled or blunted, to administer it in that degree of full concentration which in the first instance was resented and effectually opposed by the natural sensibility of the air-passages. The answer that I give, then, to the question I previously put, is, that air saturated with ether or chloroform is both 'respirable' and 'irrespirable.' It is 'irrespirable' in the first instance, and until a considerable degree of insensibility has been induced; but, when this state has been attained, it may be breathed (under medical supervision) with perfect safety, and this is indeed often done when it is thought desirable to deepen the anæsthetic or unconscious state.

It is then clear, I trust, that air saturated with chloroform is (chemically considered) 'respirable' at all times; it can never fail to satisfy the blood's requirements and affinity for oxygen, it is only 'irrespirable' from its pungency, which, arresting the *movements* of respiration, will thus prevent the onward passage of the blood, and cause death by asphyxia; and should this occur, what phenomena will be observed?

Asphyxia, I said before, means pulselessness, but only in a restricted sense; it is not a primary failure of the heart's

[1] The evidence at coroners' inquests invariably shows this. Take the following as an example (*Times*, October 1875). The patient was a hearty-looking muscular man. 'During the next five minutes he struggled violently, and became blue in the face, when it was decided not to administer any more; but he suddenly became black in the face and expired.'

energies, a state which would be designated as fainting; but the heart is without pulsation because its chamber is empty; it has nothing to contract upon. The phenomena of asphyxia are generally too marked to be misunderstood. There is lividity of the countenance, turgescence of the veins, which cannot discharge themselves, prominence of the eye-balls, a struggle or convulsion, and then the quiescence of death.

Shakespeare has well contrasted the two conditions of primary faintness, which would be a natural death, with death by asphyxia, which would be one of violence.

When the Earl of Warwick is gazing on the lifeless corpse of Duke Humphrey,[1] he says:—

'See how the blood is settled in his face;'

and he then contrasts the natural death of faintness with the signs of violent death, or enforced stoppage of the respiration, as they were presented before him.

'Oft have I seen a timely-parted ghost
Of ashy semblance, meagre, pale and bloodless,
Being all descended to the labouring heart;
Who, in the conflict that it holds with death,
Attracts the same for aidance 'gainst the enemy;
Which with the heart there cools, and ne'er returneth
To blush and beautify the cheek again.'

Then follows the contrast of death by strangling or asphyxia:—

'But see, his face is black and full of blood,
His eye-balls further out than when he lived,
Staring full ghastly like a strangled man,
His hair upreared, his nostrils stretched with struggling;
His hands abroad displayed as one that grasped,
And tugged for life, and was by strength subdued.
It cannot be but he was murdered here;
The least of all these signs were probable.'

[1] Second Part of Henry VI., Act III. sc. ii.

Anyone, who looks at the advertisements in the newspapers, may read frequent invitations to have his teeth extracted under the composing influence of nitrous oxyde gas. Now what is the relation of this gas to the chymical requirements of Respiration? It contains a great deal of oxygen, in a far larger proportion than atmospheric air; it has no irritating properties; it is not only respirable, but it is even agreeable to breathe it; and it both rapidly and easily ensures a state of unconsciousness. But is this all? Have I stated the whole case? For, so far, it would seem as if there need be little or no hesitation as to which of the two gases we should prefer. In the case of ether and chloroform, the air we breathe takes along with it only a limited quantity of the narcotic, and always remains sufficiently charged with oxygen for the necessary changes in the blood; but in the case of nitrous oxyde, this gas altogether replaces atmospheric air, and although it contains a large proportion of oxygen, this is not in a free uncombined state, but in a state of union with something else, and as it clings to this first bond, the nitrous oxyde passes out of the lungs as nitrous oxyde, or in exactly the same state in which it entered them. The oxygen is not then separated from the nitrogen and surrendered to the blood, aërating and revivifying it, as it does, in atmospheric air; but inasmuch as it has no irritating properties, it does not interrupt the free movement or expansion of the lungs, and accordingly no asphyxia results.

Looking, therefore, at nitrous oxyde with a chymist's eyes, and with a chymist's understanding, this gas is clearly irrespirable; nevertheless, it is vitally respirable in this limited sense, that it does not interrupt the function of breathing.

You see, therefore, that the two modes of producing unconsciousness stand in exact contrast in their physiological relations. Ether and chloroform are always fitted to satisfy the chymical Requirements of respiration. Nitrous oxyde never is. Ether and chloroform may give offence by their pungency, and thus fatally restrain the necessary expansion of the lungs, giving rise to asphyxia. Nitrous oxyde has no pungent properties, and cannot therefore asphyxiate, in the way in which I have used the term. It may indeed narcotise even unto death, and there is danger, which must not be overlooked; but this is a process which would involve new physiological considerations.

In these remarks on so-called anæsthetic vapours, I have not thought it my duty to enter on the consideration of anæsthesia or unconsciousness in reference to its most interesting relations to the nervous system, and have only spoken of it in its relation to respiration; still, as it is not wholly out of place, I will not resist the temptation to say, that, if we divide the nervous system into two great parts, one of which we may regard as the organ of the mind, which gives us self-consciousness, and consciousness of the world external to ourselves—which says of itself 'Volition is mine; I am supreme in power, as I am supreme in position;' it is that part which I almost enclose, if I place my outspread fingers over the crown of my head, and which constitutes the cerebrum or brain proper; the other, which is chiefly represented by a very limited portion of nervous matter, named, from position, medulla oblongata, is, nevertheless, the very guardian of our lives; it is the animating source of our respiratory movements: for, whilst the sleep of the cerebrum is unconsciousness, the sleep of medulla oblongata is death.

The word anæsthesia is very technical; it has other disadvantages: had I lisped, I should have avoided it altogether. I will now, however, discard it, and give you in Shakespeare's language its exact meaning.

In that well-known speech in 'Hamlet' beginning with 'Look here upon this picture, and on this,' that speech in which the Prince of Denmark upbraids the Queen with such terrible earnestness, there occurs this passage—

'. . . Sense, sure you have,
Else could you not have motion; but, sure, that sense
Is apoplexed.'

'Sense apoplexed' is the condition of the body we desire to produce in the inhalation of those gases of which I have just spoken.

The mechanism of Respiration is not less interesting than are its chymical relations. Let me now speak of this in its broadest characters, and in its mutual relation to the heart's structure and function.

Respiration, then, is an automatic, self-regulating function, and consists in the alternate expansion and contraction of the two chambers in which the lungs are made to play.

The enlargement of these chambers is effected by muscular power; the contraction is due, in ordinary circumstances, to the elastic resiliency of the lungs themselves.

When I used the words 'automatic' and 'self-regulating,' I did not mean precisely the same thing; the latter term being intended to express the perfection of its action, or that this exactly responded to the calls that were made upon it. In speaking of the chymistry of Respiration, I seemed to show that although the blood's aëration was the ultimate end to be attained, yet this might in a certain sense be considered incidental to the primary end, viz., that of the expansion of the air-vesicles, without which expansion the blood could not pass onwards. Now, there are two forces which tend to expand the lungs: one is the expansion due to the heart's vigorous contractions, such as take place in violent exertion, when the heart is beating with almost twice its usual frequency; this is a force acting from within, and tending to push outwards the walls of the chest.[1]

[1] See on this point an extract from Hales, previously referred to. I will now add the following, in illustration of the heart's power in distending the lungs. 'But when, on straining, the dog, by the joint action of all the muscles

The other force is a power acting from without, one which tends to enlarge the chamber, to fill which the lung will swell out by the air rushing in through the windpipe and its branches. In the one case the lungs are distended with blood; in the other they are only filled with air.

Now the perfection of this automatic function, *i.e.* its self-regulating power, is shown in this, that it responds exactly to the demands that are made upon it. Does the heart act with increased vigour or frequency, inspiration is quickened in proportion; does the heart slacken or falter, respiration becomes languid in concert with it; does it cease to beat, respiration ceases also. Hence the function of Respiration is 'to wait upon the heart,' for without the moving streams of blood the movement of breathing would be useless, and Nature's movements are not of this kind.

Perhaps one of the best illustrations of this position is to be found in the torpor of hybernating animals, when life itself is almost sleeping, and the limbs have become so stiffened and cold as to have almost put on the rigidity of death. It is found in these, that when the heart has almost ceased to beat, the respiration ceases also, and that they may be even immersed for a considerable time in water, or placed in an atmosphere which in different circumstances would immediately suffocate them.

Physiologists have taken account of the number of cubic inches of air we inspire in ordinary circumstances, and also of the greatest quantity we can draw in and give out under the most forced efforts. Now it is obvious there must be a limit to the extent to which the chest will admit of expan-

of the abdomen, thereby compressed the venal blood forcibly up into the ascending vena cava, the right ventricle of the heart being thereby more plentifully supplied with blood, impelled it also more forcibly into the pulmonary artery, so as to make the collapsed right lobe of the lung instantly to dilate so vigorously as to push the lower part of the lobe one, two and sometimes three inches' length out through the incision; and that after he had lost half a pint of blood.' *Hæmastatics*, 76.

sion, and as some important results seem to flow from this, I will dwell on it for a few moments. The chest at its fullest expansion after a forced inspiration is said to contain about 330 cubic inches of air, in its medium condition about 200. Now this gives us a proportion of about 20 : 12; 20 representing that degree beyond which the chest will not admit of any further expansion. Now, if it were possible that the heart, by its own energetic action, could so enlarge the lungs as to bring them up to this limit of 20, life would not only be imperilled, but if such a state of things were to continue for a minute, or perhaps a little longer, death would be certain. Who cannot remember instances, when, either in his own person or in that of others, he has been made conscious of that intense distress, when after the utmost exertion, he has found it impossible to draw his breath? I have heard people describe it in the words, 'I thought I should have died.' I have sometimes put to young students of medicine the following question:—A man runs a few hundred yards at the top of his speed, at the end of which he is out of breath. What is the physiological explanation of this condition? I have just given it you, but I will repeat it. The lungs are filled with blood, not with air, though indeed they contain probably more air than at any lower point of expansion. To enable this blood to pass onwards to the left chambers of the heart, expansion of the air-cells is now necessary, but the limit of expansion has already been reached, and death is inevitable, because this left chamber of the heart is starved of its supply; it has nothing to contract upon.

You see, then, what a difference it makes whether the chest is expanded by the muscular forces external to the lungs, or by the force of the circulation within them, which imperatively demands a still further effort from without. In the first case we draw in air, and blow it out again at our will; in the second we pant in our almost vain efforts to give further expansion to the lungs; and this state continues until the circulation slackens from enforced quietude.

I might illustrate my meaning in the following manner. A son of Æolus, a blustering, boastful fellow, descended from Atalanta on his mother's side, and therefore sound in wind and limb, was seen one day to be railing a poor asthmatic fellow in Monument Yard. His insolence became so great that a passer-by was provoked to say he would back the other against him, if this son of Æolus was only fairly handicapped. The match was at once accepted, and it was agreed to try their respective wind or breathing power, for the asthmatic man could not run, having only one leg. It was to be done in the following manner: Lighted candles were to be made to pass before them at a given rate, and he who should blow out the greater number in the space of one minute was to be declared the victor.

Now to handicap a man in such circumstances was a novel proceeding requiring professional skill. The nearest surgeon was selected for the duty, who proceeded with his task *secundum artem*. On examining their chests, he found that the asthmatic man had only a range of breathing power represented by the figure 3, for disease had brought his lungs up to 17, and 20 he found to be his maximum expansion. In the case of the other the chest was of model excellence, and gave a range from 12 to 21. Now to handicap such a man we must fill the lungs with blood, and this can only be done by strong exercise. The surgeon therefore decided that he must run up the monument at the very top of his speed, and that on the very instant of his reaching it the candles were to be made to pass before them. What was the result? The asthmatic man had quite sufficient power to extinguish every candle for the first three-quarters of the minute, and then his breath began to fail him with the exertion, and the last few remained ignited. But how was it with the other? He could do nothing with his candles for a considerable time, and missed so many that he lost the match; nevertheless, before the minute was out, his circulation had so far subsided as to give him full power over his candles, though now too late, during the last ten seconds.

It is rare indeed for any fatal occurrence to arise from overtaxed energies in the manner I have been speaking of. Generally some little element of disease or imperfection (itself quite unimportant) is made to bear the blame. Of such examples I am not without experience in some who had passed the middle period of life;[1] but in the young and vigorous, though rare, it is by no means impossible, nor is it necessary to go into the regions of Poetry and Romance to find a fitting illustration of what the records of science might readily afford. Nevertheless, I will now ask your permission to do this, and will endeavour to convey the fact to your minds through the medium of a pictorial example.

Those of you who take pleasure (and who does not) in the Annual Exhibitions of our Royal Academy may perhaps recall to your minds a picture in this year's collection designated 'The Crown of Love.' To myself, it is now before the eye of memory, as it stood in May last before the eye of sense. It presents a stalwart youth, carrying a maiden in his arms up a steep acclivity. To reach the summit so burdened and live was justly deemed impossible; nevertheless for so priceless a reward the task must be attempted. In this picture the lover's back is turned to the spectator, but

[1] In April of the current year, an example of this occurred, in the person of a gentleman who died in a railway carriage, and whose body was brought to St. Bartholomew's Hospital. I was present at the post-mortem examination, and enabled to ascertain the cause of death, which corresponded with the evidence tendered at the inquest. It appears that deceased was in the habit of travelling by an early train, and on Wednesday was somewhat late in leaving home. To make up for lost time he hurried to the station, and just managed to catch the train. He continued at intervals to wipe perspiration from his forehead, and just as the train reached Ludgate Hill, he fell backward and expired. (*Times*, April, 1875.)

his mortal agony is reflected in the countenance of the maiden, whose affrighted, terror-stricken look, as she gazes upon it, speaks too surely of the awful consummation of his efforts.

Art, poetry and scientific truth are thus happily blended; but the poet must tell it in his own words:

'O, might I load my arms with thee,
 Like that young lover of romance,
Who loved and gained so gloriously
 The fair Princess of France!

Because he dared to love so high,
 He, bearing her dear weight, must speed
To where the mountain touched the sky:
 So the proud king decreed.

Unhalting he must bear her on,
 Nor pause a space to gather breath,
And on the height she would be won;
 And she was won in death!'[1]

Geo. Meredith.

When my thoughts were first directed to this popular handling of Respiration, I intended to make breathing in a diving-bell, and in the exactly opposite condition, *i.e.* breathing in a balloon, some of the points to which I should invite your attention; and had my ability been sufficient I should have endeavoured to show approximately what are the limits compatible with life in both of these opposite circumstances.

The subject is one of considerable theoretic difficulty; but it seems evident that mechanical or physical considerations must have the most important place in determining the conditions, or, in other words, we must bring in these principles to explain the facts that are ascertained by experience.

Now, it is a law in physics that the volume of a given

[1] 'Catalogue of Royal Academy.' No. 214. The Crown of Love. J. E. Millais, R.A.

quantity of gas or air (in equal temperatures) is inversely as the pressure it bears; and applying this law to the air in our lungs, it is obvious that, in diving, when at a pressure equal to 34 ft. head of water, there will be twice the quantity of air in our lungs, but occupying the same space that was filled by half the quantity at the ordinary atmospheric pressure—*i.e.* we shall be breathing condensed air: increase the depth and you will increase the density of the air in the same ratio. But it is not only the air contained in the body which is affected by pressure, but the circulation also is lowered by it, the pulse beats with less frequency, and various feelings have been recorded which point to the benumbing influence of considerable pressure; in some cases muscular paralysis of the lower limbs took place; in others the arms felt this influence, and then the men suffered pain at the joints. But these effects are exceptional, and have only been observed in a few cases.

Nature has made us of very pliant material, and our bodies are readily adapted to a greatly-varying change of condition. But there are limits which cannot be transgressed; and in regard to diving, the pressure on our bodies, when a certain depth has been reached, is felt to act with such intensity on the chest and abdomen that it becomes impossible to bear it. Nevertheless, I am informed by Messrs. Siebe and Gorman, the eminent sub-marine engineers, that one of their divers has actually descended to a depth of 204 ft. Now, at this depth, the greatest ever attained, the diver's body had to bear a pressure equal to about 90 lbs. on the square inch, or a pressure in all equal to seven atmospheres.

Let us see now how our respiration would be affected in such circumstances. I have already attempted to show that the function of that small nervous centre—the medulla oblongata—is to wait upon the heart, and to adapt the movements it governs in exact accordance with the requirements of this organ.

Although, doubtless, the supply of oxygen is the end to be attained, Medulla does not ask for this: she asks only for movement, and the other will follow as a matter of course. This, I say, is Nature's method of ensuring the blood's aëration: she asks for the means of effecting a great end, and the means being granted, the end accomplishes itself.

Medulla, speaking of her function, and addressing the blood-globules might say, 'Shall the heart act forcibly and send you in crowds to my gates, I will fling them open to give you free passage: there shall be no thronging or pressure, as far as I can help it. If I might affect the language of Parliaments, I should say, I will take the exact sense of the occasion, and conclude with a motion which shall be in precise accordance with the emergency. My function is to let you pass; I am only a doorkeeper; you must put on your red mantles yourselves.'

Now, if in diving the pressure on our bodies is such as to affect, *i.e.* to diminish, the rate of the circulation, our respiratory movements will be simultaneously lowered with it. The demands which will now be made on the lungs' movement will be reduced in accordance with the smaller streams of blood which are now delivered to them for aëration. In such circumstances should we be surprised to find that an animal could hold its breath for a much longer time than under the ordinary pressure of the atmosphere? Should we be startled on discovering that if two minutes or less would be sufficient to drown a person in ordinary circumstances, it would require a much longer period if the circulation had been going on and was still continued under a pressure of some forty feet of water?

Reasoning *à priori* would certainly lead us to expect this result; but we all know how deceptive this is, and a philosópher would justly say, '*fiat experimentum.*' Now this experiment has been made, aye, and repeated, with this exact result; and this, too, not *in corpore vili*, but in the person of a scientific man of the highest order, and in the presence of competent witnesses, so that doubt would be unreasonable. The experiment was not made to try the point, but this only enhances its value. It is thus narrated in 'Knight's Cyclopædia'[1]—

'After one of the disastrous occurrences at the Thames Tunnel, Mr. Brunel, the engineer, descended in a diving-bell to examine the breach made by the irruption of the river into the tunnel. The bell descended to the mouth of the opening, a depth of about 30 ft., but the breach was too narrow to allow it to go lower, in order that the shield and other works, which lay 8 ft. or 10 ft. deeper, might be examined from the bell. Brunel therefore took hold of a rope, and dived below the bell for the purpose. After he had remained under water about two minutes, his companion in the bell became alarmed, and gave a signal which occasioned Brunel to rise. On doing so he was surprised to find how much time had elapsed, and on repeating the experiment he ascertained that he could with ease remain fully two minutes under water.'

The peculiar danger of great aërial ascents must, I think, be considered an unsolved problem in physiology; not, perhaps, on account of any inherent difficulty in the subject, but partly because due attention has not been given to it by men of physiological science, and partly because opportunities have been lost of gaining most valuable—I might almost say conclusive—evidence from the autopsy of those who have been either the victims of their rashness, or, as some might say, have fallen a sacrifice to their passion for scientific enterprise.

This opportunity was lost, I believe, after that memorable

[1] Art. 'Submarine Descent,' vol 23.

ascent at Paris in April last, which proved fatal to two out of the three aëronauts.

It appears that the height then attained was over five miles.

The feelings of the travellers at various times during the ascent have been thus given by the survivor:—

'At 7,500 mètres (about 4½ miles) we were motionless and benumbed (with cold?).' The numbness increased, and both body and mind gradually grew feebler. We did not suffer; we became indifferent, and thought no more of the danger. I became very weak, without the power of turning my head, and was unable to raise my arms to inhale the oxygen. Nevertheless, I preserved my faculties. My tongue became paralysed, and I fell senseless. This happened to me a second, and again a third time. On my recovering my senses, I now found my companions lifeless, their faces black, their eyes half-shut, their mouths open, and, though bloody, cold.'

In the feelings thus recorded we may observe the well-known benumbing influence of cold, which is said to lull people into sleep, and to make them perfectly indifferent, even though that sleep be the sleep of death. It is so painless that no effort is made to resist it.

Dr. Solander has described its fascination in what befell himself on his ascent of the mountains of Terra del Fuego, when after having earnestly enjoined his companions to resist its treacherous influence, he was the first to give an example of it, and, at once forgetful of his own precepts, entreated his friends to allow him to sleep only for a few minutes. Alison, too, in his account of the retreat from Moscow, tells us how the French soldiers were beguiled by it out of their lives.

'We did not suffer' (said the aëronaut), 'we became indifferent, and thought no more of the danger.' Now, I am not of opinion that 'cold' was the cause of the death of these adventurers, though it had much to do with the feelings that have been described. I think we must look for the cause of their death in the rarefaction of the air.

Now, one of the immediate effects of this, or of diminished pressure, must be exactly the opposite of what we have referred to in the diving-bell. In the latter, the rate of the circulation was lowered, and with this the demand made on the Respiration; now, the circulation is increased, with accelerated respiratory movements. The pulse of two of the aëronauts, which on earth stood respectively at 70 and 76, rose at an elevation of 5,400 mètres to 110 and 155. Can we doubt that in such circumstances, with lungs distended by the heart's force and frequency under diminished pressure, the respiration would be hurried and frequent, *i.e.* panting?

Let me now refer back to one or two points in the account given us by the survivor. He says, 'I fell senseless at 1.30. In about forty minutes I came to myself. I fainted again, and a third time I lost my senses, &c.'

Now it might be a question whether that state which he speaks of as 'faintness,' though not always using this term, was in reality a temporary failure of the heart's action (the only true faintness), or whether it was that state of unconsciousness which might arise (as in breathing nitrous oxide) from imperfectly oxygenated blood; was it the sleep of the cerebrum, or the heart's momentary exhaustion? for the two states are physiologically quite distinct, though in such circumstances not unlikely to be confounded.

If Tissandier (the survivor) experienced true faintness, this clearly was not the mode of death in his companions, which, on the contrary, suggests the conclusion that Tissandier's so-called faintness was rather a temporary '*narcotism*' than an actual failure of the heart's energies. But what caused the death of Sivel and Croce-Spinelli? It was said to be asphyxia, an opinion deriving some support from the outward appearance of their bodies. Still it is not conclusive, for the blackness of their faces would agree either with asphyxia proper, or with imperfectly oxygenated blood, which, as I said before, is not 'asphyxia,' but 'narcotism.'[1] A careful autopsy would have been of great value in determining this point.

In the newspapers of the day it was stated that the object of this memorable ascent was 'to study the effects of irrespirable air.' What would medulla oblongata say to this? Might she not protest and say 'Mine is a *limited* liability; I can have nothing to do with irrespirable air, my function is only with air that is respirable.' In another print I read, 'the fearful end of the two travellers has not slackened the zeal of others; already preparations are being made for further explorations in the unknown regions. So science preserves its magic attractions.'

Is there not another conclusion which suggests itself to our minds, and is it not this? Man's place is on the earth, and not in the clouds.

A few words only on the subject of 'emotional' breathing.

The relations of the brain-proper to those nerve-centres which govern 'organic,' as distinct from 'animal' life, would carry me into deeper water than I am now disposed to sail in. Suffice it, therefore, to say that if we consider respiration simply as a function of organic life, it will be governed by the medulla oblongata, and so far be altogether

[1] I have already explained the word 'asphyxia,' and will now illustrate it once for all. If a person descends incautiously into a well, he might find himself suddenly in an atmosphere of carbonic acid. To draw in his breath would be impossible. The heart's left chambers would be deprived of blood, and within two, perhaps one, minutes his life would be gone. In common language he would be suffocated—in technical, asphyxiated. Let another be shut up in a chamber with burning charcoal. Death would ensue in this case, but in an altogether different manner. His breathing would not be arrested, as in the other case; it would continue, but his blood would be imperfectly changed. The sleep of the cerebrum or unconsciousness would occur first, but after a time this influence would extend and effect the sensorium of the respiratory movements, and as I said before, the sleep of medulla oblongata is death. But this is not asphyxia—it is narcotism. The use of the first term involves a physiological misapprehension.

independent of the brain, whose function places this nerve-centre on a higher pedestal. So long as the heart continues to beat, so long will our respiration continue. The sleep of the cerebrum will not disturb it; aye, let the brain be rent asunder, as in apoplexies, and all consciousness or animal life be utterly extinct, if only medulla oblongata remain intact, our respiration will continue,[1] and cease only with those streams which demand a passage through her intervention.

But has the brain nothing to do with this great function? Oh, yes! the brain is the organ of the mind, the all but absolute master, and medulla is his favourite handmaid, giving expression to his every wish, and only limited in his service by the laws that Nature has imposed on her.

Cerebrum saith to her—Am I dejected or in sorrow, you shall sigh in concert with my feelings; am I elated with mirth, you shall shake my sides with laughter. Do I desire the pleasure of music, you shall fill your pipes with air; it is mine to touch the keys; and yet though my absolute slave, my existence is in your hands, and it is the very inferiority of your position that makes you the very mistress of my life.

'Diis te minorem quod geris, imperas.'[2]

As the body may be said to exist only for the mind, so the former is made to express every mood and feeling of the latter. One part thus plays in concert with another, and perfect harmony is thus preserved.

Even the play of our features is co-ordinated with our breathing—both the *sob* of grief, and the emotion which bursts into laughter. Ask the young mother, whose infant is lying on her lap and answering her loving looks and chirping

[1] A patient admitted into St. Bartholomew's Hospital in a state of apoplexy, Nov. 18, continued to live during eight days.

[2] Horat.: 'Carm:' Lib. III., carm. vi.

noises with smiles and loud merriment, ask her if her heart can tell her what the 'respiratory nerve of the face'[1] is, and she will answer: Oh, yes! I know it.

When the mind is forcibly arrested, as in grief or expectancy,[2] the movement of breathing will be checked in concert with the feeling, till at length a sigh or long-drawn breath gives the necessary relief to a too-long deferred function.

Emotional breathing is well illustrated in the brute. It may be studied in the Zoological Gardens, in the so-called laughter of the hyæna, when expecting his food; in the feline tribe (lions and tigers) when gloating over their piece of raw flesh, &c.

I scarcely enter my stables without exciting it in my horses, who expect apples or a handful from the corn-bin.

Come we, in the last place, to the mutual relation of breathing to the heart's structure and function; and here we have to consider what provision Nature has made for the accomplishment of that great end, 'the aëration of the blood.'

I have already shown that the function of 'medulla oblongata' is to wait upon the heart, and to regulate the movements she governs in the most exact accordance with the demands that are laid upon her.

I have shown moreover that these movements are absolutely necessary to enable the blood to pass through the lungs, and that this passage of the blood is entirely independent of the chymical changes which are in a manner incidental to the movement.

Hence both the change in the blood and its ownward passage through the lungs are made dependent on one and the same cause, that is, the expansion of the air-vesicles: they are collateral results of this, and not mutually dependent.

[1] So named by Sir Charles Bell.

[2] 'Breathless attention' is a common expression.

If I now affirm that the pulmonary heart is unable to send the blood through the lungs without the expansion of the air-vesicles, I am only stating a fact, not constructing a theory. I do not affirm—indeed I deny, that the lungs' expansion has any force of its own in propelling the blood; that force belongs solely to the heart: but it removes an obstacle which otherwise bars the passage; it gives effect to a power, which, without this expansion, would be wholly inoperative.

Hence Nature (*i.e.* the Author of Nature), in placing this barrier to the pulmonary streams, has by this very act ensured the blood's aëration. For, had she endowed the Right-heart with sufficient power to sweep the hindrance before it, instead of requiring that it should be lifted away by the act of inspiration, the necessity for this act would not have been felt; medulla's function would not be invoked, the blood would pass through the lungs without her sanction, it would not put on its red garment, for it would pass unchanged. But Nature has so weakened the Heart, that the barrier is effectual, until another power is called in, and, as every inspiration lifts off this barrier, so the circulation through the lungs is continued, and the blood's changes are duly accomplished.

Now, what is this condition in the Heart's structure which is so beneficial, so absolutely necessary to the continuance of our lives?

Though our circulation may be truly spoken of as one continuous stream, yet it may also be presented to you in its dual nature, according to which one equal half is passing through the lungs, whilst the other is distributing itself throughout the rest of the body; one-half (the pulmonary) is constantly recruiting itself with strength, the other is expending its newly acquired powers in maintaining the warmth of our bodies or in the development of force.

The Heart accordingly is a double organ, fitted with its two chambers of equal size, acting simultaneously and with equal velocity, and discharging their contents through orifices of exactly the same diameter. So far they are in exact accordance with each other, but here the resemblance terminates; for we find that one of them (*i.e.* the systemic chamber) is at least three times the thickness of the other,—and this is not all; for, if we examine the great vessels, which are respectively attached to these chambers, we find a corresponding strength or thickness to exist between these vessels and the chambers from which they severally spring.

Now as the Heart's intermittent action is converted into a continuous power through the reaction of a spring (that is, the elastic coats of the vessels), it will be conceded that the power of this spring must bear some relation not only to the force that acts on it, but also to the resistance which its reaction has to overcome.

For it is the elastic reaction of the blood-vessels which is the immediate power in the circulation, though it has derived this power from the heart's intermittent action just in the same way as the main-spring of my watch keeps this in continual motion, though it derived this power from the muscular strength of my fingers.

In our faulty human contrivances a spring may be so strong that the force called upon to act on it may be found inadequate for the purpose; or again, that its reaction is unequal to the resistances it has to overcome.

Some relation is obviously required in every piece of mechanism.

Such then as is the relation of the heart's force to the spring (*i.e.* the elastic reaction of the vessels), so should this be to the resistance it has to overcome.

Now what and where is this resistance? It must be found, and indeed it is found in the capillary circulation. If the Left or systemic Heart gives an intensity of force over the Pulmonary in the ratio of three to one; if the spring, which receives this force, gives the same proportion; can we doubt that the resistances which are to be influenced by these powers shall stand in exactly the same proportion? The *fine* systemic capillaries will give the strong resistance to the left ventricle; the *wider* pulmonary capillaries will give the far slighter resistance to the pulmonary ventricle.

It is not in the *length* of the circuit, as our great Harvey[1] and others have erroneously supposed, that the *thin* pulmonary ventricle finds its proper explanation, but in a different '*scheme*' of the capillaries, which is exactly suited to the altered requirements.

Had, indeed, the lungs been expanded to an equal or even greater length than the body, and the body itself contracted to the smaller circle of the lungs, the right ventricle would in such altered circumstances be quite adequate to its function, the left only just sufficient for its task. And thus the left (systemic) ventricle of a mouse would stem or overpower the streams that issue from the pulmonary heart of an ox.[2]

Finally, had our pulmonary heart been endowed with the powers of its twin-brother, it would have driven the blood freely through the *wide* pulmonary capillaries, and the urgent necessity of breathing would not have been felt. The blood would pass unchanged through the lungs, and its aëration would have to be accomplished on some other plan.

The pulmonary ventricle is therefore strong; yes, even all-powerful, because it is so weak.

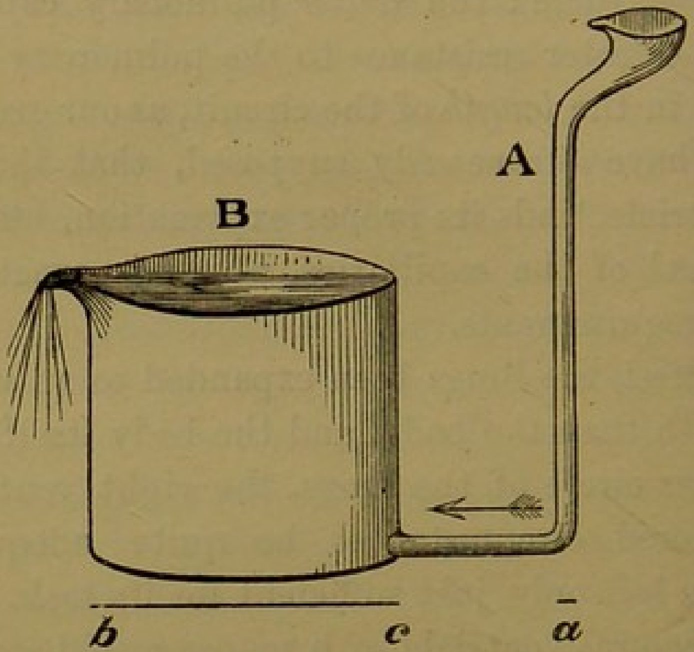
[1] Harvey's works. (Willis) p. 78, *et seq.*

'In the altered circumstances (*i.e.* after birth) the right ventricle has only to throw the blood through the lungs, whilst the left has to impel it through the whole body.'—Again: 'The left ventricle requires to be stronger, inasmuch as the blood which it propels has to be driven through the whole body.'

Other physiologists (as far as the writer knows) have taken the same false view.

[2] These views were developed in greater length in the author's Croonian Lectures, delivered before the College of Physicians in 1855, and may be illustrated in the accompanying diagram:—

If now you ask me 'Why I breathe?' and I am expected to return you a physiological answer, I say, It is because I am powerless to resist the absolute, the imperative demand of my *thin* right ventricle.



A. is the Mouse's 'Systemic' Heart. B. The Pulmonary Ventricle of the Ox. There is obviously a greater *intensity* of force pressing on *a* than on *b—c*, and will therefore overpower the latter. The *amount* on *b—c* is, of course, much greater.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET