

PHILOSOPHICAL TRANSACTIONS.

August 8. 1670.

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NEW PNEUMATICAL EXPERIMENTS about RESPIRATION.

These Experiments, made by that Indefatigable Benefactour to Philosophy, the Honourable Robert Boyle, in order to bring some more Light to the Doctrine of RESPIRATION, as well as to minister occasion to Inquisitive Naturalists to make farther Researches into the same, were by their Noble Author communicated to the Publisher of these Papers; who esteem'd it more convenient to make them a part of these Traits (they taking up the room but of a few Sheets) than to publish them any other way.

The I. Title.

Observations made about the lasting of Ducks included in the Exhausted Receiver.

Nature having, as Zoologists teach us, furnished Ducks and other water-Fowl with a peculiar structure of some vessels about the heart, to enable them, when they have occasion to

Dive, to forbear for a pretty while respiring under water without prejudice; I thought it worth the tryal, whether such Birds would much better than other Animals endure the absence of the Air in our exhausted Receiver. The Accounts of which tryals were, when they were made, registered as follows.

Experiment the 1.

We put a full-grown *Duck* (being not then able to procure a fitter) into a Receiver, whereof she fill'd, by our guess, a third part or somewhat more, but was not able to stand in any easy posture in it; then pumping out the Air, though she seemed at first (which yet I am not too confident of, upon a single tryal,) to continue well somewhat longer than a Hen in her condition would have done; yet within the short space of one minute she appeared much discomposed, and between that and the second minute, her strugling and convulsive motions increased so much, that, her head also hanging carelessly down, she seemed to be just at the point of death; from which we presently rescued her by letting in the Air upon her: So that, this Duck being reduced in our Receiver to a gasping condition within less than two minutes, it did not appear, that, notwithstanding the peculiar contrivance of nature to enable these water-Birds to continue without respiration for some time under water, this Duck was able to hold out considerably longer than a Hen, or other Bird not-Aquatrick, might have done: and to manifest, that it was not closeness and narrowness of the vessel, in reference to so bulky an Animal, that produced in the subject of our tryal the great and sudden change above-recited, we soon after included the same Bird in the same Receiver, and having by a special way cemented it on very close, we suffered her to stay thus shut up with the Air for five times as long as formerly (by our guesse, helped by a watch,) without perceiving her to be discomposed; and she would probably have continued longer in the same condition, if my patience and leisure would have held out so long, as she could have done in that prison.

Experiment the 2.

Having at the season of the year procured a *Duckling*, that was yet Callow, we conveyed her into the same Receiver wherein the former had been included, and observed, that, though for a while she appeared not much disquieted, whilst the Air was pumping out of the glass, yet before the first minute was quite ended, she gave

gave manifest tokens of being much disordered ; and the operation being continued a while longer , she grew so much worse , that several convulsive motions , she fell into before a second minute was expired , obliged us to let in the Air upon her , whereby she quickly recovered .

NB. I determine not, whether it be proper in this place to add , that when the Receiver was pretty well exhausted , the included Bird appeared to the Spectators manifestly bigger , than before the Air was withdrawn , especially about the crop , though that was very turgid before . And to manifest , that in this Duck , as in the former , the convulsions , that used to be immediately followed by Death , proceeded from the *withdrawing* of the ambient Air , and not from the *clogging* of it ; we kept the same Duckling in the same Receiver very close , to keep out all external Air , and to keep in the excrementitious steams of her body for above 6 min . without perceiving her to grow sick upon her imprisonment ; which yet lasted above thrice the time , that sufficed to reduce her in the absence of the Air to a gasping condition .

NB. It not being intended , that Ducks and other water-Fowl should any more than other Birds live in an exceeding rarified Air , but only be able to continue upon occasion a pretty while under water , it may suffice , that the contrivance of those parts , which relate to Respiration , be so far fitted for the purpose , as we shall see it is when we come to the *Tenth Title* .

The II. Title .

Of the Phænomena afforded by Vipers included in an Exhausted Receiver .

Considering that Vipers are Animals endowed with Lungs (though of a differing structure from those of Men , Dogs , Cats , Birds , &c .) and that their bloud is , as to sense , actually cold ; I thought , it might upon both those accounts be very well worth trying , what effect the withdrawing and absence of the Air would have upon Animals so constituted . I therefore mad divers tryals , some of which did not displease me ; but I know not by what misfortune the memorials of them were lost , except two or three (which were not perfect ,) that I shall here subjoine .

Experiment the I.

We included a Viper in a small Receiver , and as we drew out the Air ; she began to swell , and afford- Jan. 2. 1662 .
ed us these Phænomena . 3

1. It was a good while after we had left pumping, ere the Viper began to swell so much as to be forced to gape, which afterwards she did.

2. That she continued, by our estimate, above $2\frac{1}{2}$ hours in the exhausted Receiver without giving clear proof of her being killed.

3. That after she was once so swelled, as to be compelled to open her jaws, she appeared slender and lank again, and yet very soon after appeared swelled again, and had her jaws disjoined as before.

Experiment the 2.

We took a Viper, and including her in the greatest sort of small Receivers, we emptied the glass very carefully, and the Viper moved up and down within, as if it were to seek for Air, and after a while foamed a little at the mouth, and left of that foam sticking to the inside of the glasse : Her body swelled not considerably, and her neck lesse, till a pretty while after we had left pumping ; but afterwards the body and neck grew prodigiously tumid, and a blister appeared upon the back. An hour and an half after the Exhaustion of the Receiver (which we then by tryal found to be pretty staunch) the distended Viper did give by motion manifest signs of life ; but we observed none afterwards. The Tumor reached to the neck, but did not seem much to swell the under-chap. Both the neck and a great part of the throat, being held betwixt the eye and the candle, were transparent enough, where the scales did not darken them. The jaws remained mightily opened, and somewhat distorted ; the *Epiglottis* with the *rimula Laryngis* (which remained gaping) was protruded almost to the further end of the nether-chap. As it were from beneath this *Epiglottis* came the black tongue, and reached beyond it, but seemed by its posture not to have any life, and the mouth also was grown blackish within : but the Air being readmitted after $2\frac{1}{2}$ hours in all, the Viper's mouth was presently closed, though soon after it was opened again, and continued long so ; and scorching or pinching the tail made a motion in the whole body, that argued some life.

Experiment the 3.

April 25. To these Experiments upon Vipers, I shall add one, made upon an ordinary harmless *Snake*.

We included such an Animal, together with a *Gage*, in a pretty portable Receiver, which, being exhausted and well secured against

gainst the ingress of the Air, was laid aside in a quiet place, where it continued from 10 or 11 a clock in the forenoon, till about 9 the next morning; and then my occasions calling me abroad, I looked upon the Snake, which, though he seemed to be dead, and gave no signs of life upon the shaking of the Receiver, yet upon holding the glass a convenient distance from a moderate fire, he did in a short time manifest himself to be alive by several tokens, and even by putting forth his forked tongue. In that condition I left him, and, by reason of several avocations, came not to look upon him again till the next day early in the after-noon; at which time he was grown past recovery, and his jaws, which were formerly shut, gaped exceeding wide, as if they had been stretched open by some external violence.

The III. Title.

Of the Phænomena afforded by Frogs in an Exhausted Receiver.

The same considerations that induced me to make tryals upon Vipers, did also invite me to make several upon Frogs; the success of some of which, the following Notes will declare.

Sept. 9. 1552.

Experiment the II.

We took a large lusty Frog; and having included her in a small Receiver, we drew out the Air, and left her not very much swelled, and able to move her throat from time to time, though not so fast as when she freely breathed before the Exuption of the Air. She continued alive about two hours, that we took notice of, sometimes removing from the one side of the Receiver to the other; but she swelled more than before, and did not appear by any motion of her Throat or Thorax to exercise Respiration, but her head was not very much swelled, nor her mouth forced open. After she had remained there somewhat above three hours (for it was not $3\frac{1}{2}$ hours) perceiving no sign of life in her, we let in the Air upon her, with which the formerly tumid body shrunk very much, but seemed not to have any other change wrought in it; and though we took her out of the Receiver, yet in the free Air itself, she continued to appear stark dead. Nevertheless to see the utmost of the Experiment, having caused her to be laid upon the grass in a Garden all night, the next morning we found her perfectly alive again.

Experiment:

Experiment the 2.

June 29. 1660.

About 11 of the Clock in the fore noon, we put a Frog into a small Receiver, containing about $15\frac{1}{4}$ ounc. Troy weight of water, out of which we had tolerably well drawn the Air, (so that when we turned the cock under water, it sucked in about $13\frac{1}{4}$ ounc. of water:) The Frog continued in it (the Receiver all the while under water) lively enough till about 5 of the clock in the afternoon, when it expired. The Frog at the first seemed not to be much altered by the exuation of the Air, but continued breathing both with her throat and lungs.

Experiment the 3.

Sept 6. 1662.

We included into a pretty large Receiver a couple of Frogs newly taken, the one not above an inch long, and proportionally slender; the other, very large and lusty. Whilst the Air was drawing out, the lesser Frog skipped up and down very lively, and, somewhat to our wonder, clambered up several times to the sides of the Receiver, insomuch that he sometimes wrested himself against the side of the glass. When his body seemed to be perpendicular to the Horizon, if not in a reclining posture, he continued to skip up and down a while after the exuation of the Air, but within a quarter of an hour (measured by a minute-watch) we perceived him to lye stark dead with his belly upwards. The other Frog, that was very large and strong, though he began to swell much upon the withdrawing of the Air, and seemed to be distressed, by his frequently leaping up after the Air was drawn out, which he did not before, yet being as we said very lusty, he held out half an hour, at which time it was remarkable, that the Receiver, though it had held out against the pressure of the outward Air, during that space of time, notwithstanding that a piece of it had been cracked out, and was mended with a cloth deep'd in Cement, yet at the end of the half hour, the weight of the outward Air suddenly beat it in, and thereby brought the imprisoned Frog a reprieve, which hindered us from bringing the Experiment to an issue.

Experiment the 4th.

Sept. 11.

We took a small Frog, and having conveyed her into a very small portable Receiver, we began to pump out the Air. At first she was lively enough, but when the Air began to be considerably withdrawn, she appeared to be very much disquieted (leaping sometimes after an odd manner, as it were to get out

out of the uneasy prison,) but yet not so, but that, after the operation was ended and the Receiver taken off, the Frog was perfectly alive, and continued to appear so (if I am not mistaken) near an hour, though the Abdomen was *very much*, and the throat *somewhat* extended; this latter part having also left that wonted panting motion, that is supposed to argue and accompany the respiration of Frogs. At the end of about $3\frac{1}{4}$ hours, after the removal of the Receiver from the pump, the Air was let in; whereupon the Abdomen, which by that time was strongly swelled, did not only subside, but seemed to have a great cavity in it, as the throat also proportionably had; which cavityes continued, the Frog being gone past all recovery.

Experiment the 5th.

April 14. A large Frog was conveyed into a plated Receiver, and the Air being withdrawn, her body by degrees was distended; as appeared very notably, when by a casual springing of a leak, the Air got in again, and made her look much more lank and hollow than ever. The Receiver with the *Gage* were kept under water near seven hours, because I was obliged to stay long abroad; at the end of which coming home I found the Receiver staunch, but the Frog dead and exceedingly swelled: upon the letting in of the Air, she became more hollow and lank than ever.

NB. I have purposely, both under this *Title* and some others, subjoyned some Tryals, whose events are not altogether such, as others, recited under the same head, would invite one to expect; but I purposely do it, not only to be true to the Impartiality, I proposed to my self in writing these Narratives, but to awaken the curious to consider and observe what variety of *Phænomena*, in such tryals, may be attributed to the season of the year, wherein they are made; and to the strength, bulk, age, peculiar constitutions, &c. that relate to the respective Animal, on which the Experiments are made; besides, what things may on other accounts be fit to be also considered.

The IV. Title.

Of the Phænomena afforded by a newly kitten'd Kitling in the Exhausted Receiver.

Being desirous to try, whether Animals, that had lately been accustomed to live either without *any*, or without a *full* Respiration,

spiration, would not be more difficultly or slowly killed by the want of the Air, than others, which had been longer used to a free Respiration; We took a *Kitling* that had been kitten'd the day before, and put it into a very small Receiver (that we guessed to hold about a pint or less) that it might be the sooner exhausted. As soon as the pump began to play, I took notice of the time, and found by a Watch, that marks Minutes and Quarter-Minutes, within one minute or a little more after the Air first began to be withdrawn, that the little Animal, who in the mean time had gasped for life, and had some violent convulsions, lay as dead with his head downwards, and his tongue out; but upon letting in of the Air, he did in a trice shew signs of life, and being taken out of the Receiver quickly recovered: And to allow him the benefit of his good fortune, we sent for a *Kitling* of the same age and litter, which being put into the same Receiver, quickly began, like the other, to have convulsions, after which he lay as dead; but observing very narrowly, I perceived some little motions, which made me conclude him alive; which I soon found I had cause to do. For though we continued pumping, and could not perceive that the Engine leaked more than in the former Experiments; the *Kitling* began to stir again, and after a while had stronger and more general convulsions than before; till at the end of full six minutes after the Exu^ction of the Air was begun, the Animal seeming quite dead, the outward Air was readmitted into the Receiver, which not reviving him as it had done the other, he was taken out of the vessel, and lay with his mouth open, and his tongue lolling out without any sensible breathing, and pulsation; till having ordered him to be pinched, the pain or some internal motion, produced by the external violence done to him, mad^d him immediately give manifest signs of life, though there was yet no sensible motion of the heart or the lungs; but afterwards gaping and fetching his breath in an odd manner, and with much straining, as I have seen some *Fetus*'s do, when cut out of the womb, he little by little, within about a quarter of an hour, recovered: wherefore thinking it severe to make him undergo the same measure again, we sent for another, kitten'd at the same time, and inclosing that also in the Receiver, observed, that divers violent convulsions, as it were gasping for breath, into which he began to fall at the second or third suck, ended in a seeming death, within about a minute and an half. But being made more diffident

diffident by the late Experiments, I caused the pump to be pleyed, and the rather, because I had a mind to observe, whether when the Air was from time to time drawn away, there would not, upon the opening of the stop-kock to let it out, appear some sudden swelling, greater or less, of the body of the Animal, by the spring and expansion of some Air (or Aërial matter) included in the Thorax, or the Abdomen. Such an inflation (though not great) we thought we observed ; but till further tryal I dare not acquiesce in it. A while after, notwithstanding our continuing to pump, the Kitling gave manifest signs of life, which was not till it had endured divers convulsions, as great as those of the first fit, if not greater. When 7 min. from the beginning of the exhaustion were compleated, we let in the Air ; upon which the little creature, that seemed stark dead before, made us suspect that he might recover ; but though we took him out of the Receiver, and put *Aqua-vite* into his mouth, yet he irrecoverably dyed in our hands.

These tryals may deserve to be prosecuted with further ones, to be made not only with such Kittens, but with other very young Animals of different kinds ; for by what has been related it appears, that those Animals continued 3 times longer in the Exhausted Receiver, than other Animals of that bigness would probably have done.

The V. Tittle.

some tryals about the Air usually harboured and concealed in the Pores of Water, &c.

IT might assist us to make the more rational conjectures about the Phænomena of divers of our Experiments, if we knew (something near) what quantity of Aërial substance is usually found in the liquors, we employ about them, especially in that most common of them, Water. And therefore, though it be very difficult, (if at all possible) to determine the proportion of the Air, that lurks in water, with any thing of certainty, many circumstances making it subject to vary very much, yet to make the best estimate, I easily could, where none at all that I know of hath been hitherto made by any man, I considered, that it might afford us some light, if we discovered at least what proportion, as to bulk, the Air latitant in a quantity of water would have to the liquor it came from, when the Aërial particles should be gathered together into one place. For, though about this union, and the Spring

that may be consequent to it, some doubts may be suggested, which I have not now time to discuss; yet I supposed, that at least some discoveries would by this way be made, though not of the true proportion between the Air and the Water, yet about two or three particulars, in due time to be taken notice of.

To find Instruments, which would any way accommodate our purpose, proved a very difficult work; so that among other things, that we were fain to do, this was one, that to evince how little the Air, latitant in water, did appear to lessen the bulk of that water, if it were suffered to flye away in an open Tube; we suffered it to escape in an exhausted Receiver without any artifice to catch it; by which tryal the water did not part with any thing of its bulk, that made a diminution sensible to the eye. Wherefore we endeavoured to make this loss visible by some other tryals, of which I can find but a few hasty memorials among my lose Entries.

A Chymical pipe sealed at one end, and 36 inches (or somewhat less) in length, was fill'd with water, and inverted into a glass vessel, not two inches in diameter, and but $\frac{1}{4}$ of an inch or little more in depth. These glasses being conveyed into a fit Receiver, and the Air being leisurely pumped out, and somewhat slowly readmitted, the numerous bubbles, that had ascended during the operation, constituted at the top an Aërial Aggregate, mounting to $\frac{8}{10}$ wanting about 100 part of an inch.

These are two Experiments. Presently after, the Tube (by and by to be described) was filled again with the same water, and inverted, and the water being drawn down to the surface of the vesselled water, and the Air let in again, the water was impelled up to the very top within a $\frac{1}{10}$ th and half a tenth of an inch.

The Tube for measuring the Air latitant in water was $4\frac{1}{2}$ inches above the surface of the stagnant water: the Air collected out of the bubbles at the top of the water, was the first time $\frac{1}{4}$ of an inch and somewhat better; the second time we estimated it but $\frac{1}{4}$ and $\frac{7}{8}$. The first time the water in the pipe was made to subside full as low as the surface of the restagnant water: the second time the lowest, we made it subside, seemed to be 4 or 5 inches above the surface of the water in the open vessel.

Matter of *fact* thus recited would afford divers difficulties worthy to be considered, which I have not leisure to discuss; especially the Odd thing that happens to the Aërial particles of water:

water : For though, whilst they lay concealed in the water, they took up so little room in it, that it was insensible , and when they were permitted to escape out of the Tube , the water was not manifestly diminished by their recess ; yet when they were associated at the top of the Tube , their aggregate did sometimes maintain a place , that was considerable enough in reference to the capacity of the whole Tube ; though I must here advertise, that this Aggregate did at the top of the Tube possess more room than its bulk did absolutely require , because it was somewhat defended from the pressure of the Atmosphere by the weight of the subjacent Cylinder of water, which might be about three or four foot long.

Quere : Whether any considerable proportion of Bubbles will be afforded by the same liquor, if it be suffered to continue in the glass for some competent time, after it has been once, or oftener, freed from bubbles already ?

Quere : How far it may be worthy our consideration, whether in common water there may not be concealed Air enough to be of use to such cold Animals as *Fishes* ; and whether it may be separable from the water, that strains through their gills ?

But though I was at first content to make use of this way of estimating the Air concealed in water , yet when I came where I could be a little better accommodated with glasses , I bethought my self of a small Instrument, that would much better disclose the wonderful plenty of the Aërial particles I designed to discover. The structure and use of this Glass may be easily enough understood by the recital of the first Experiment, that was made with it, whereof take the following *Transcript*.

We provided a clear round Glass , furnished with a pipe or stem of about 9 inches in length, the globulous part of the glass being on the outside about $3\frac{1}{2}$ inches in diameter ; the Pipe of this glass was within an inch of the top, melted at the flame of a Lamp , and drawn out for two or three inches as slender as a Crow's-quill, that the decrement of the water upon the Recess of the Air, harboured in its pores, might, if any should happen, be the more easily observed and estimated. Above this slender part of the Pipe, the Glass, as was before intimated, was of the same largeness (or near it) with the rest of the Pipe , that the Aërial bubbles, ascending through the slender part, might there find room to break , and so prevent the overflowing , or loss of any part of the water.

This Vessel being not without difficulty and some Industry filled, till the liquor reached to the top of the slender part, where not being uniformly enough drawn out, it was somewhat broader than elsewhere; we conveyed the Glass, together with a pedestal for it to rest upon, into a tall Receiver, and pumping out the Air, there disclosed themselves numerous bubbles ascending nimblly to the upper part of the Glass, where they made a kind of froth or foam; but by reason of the above-mentioned figure of the Vessel, they broke at the top of the slender part, and so never came to overflow.

This done, the pump was suffered to rest a while, to give the Aerial particles, lodged in the water, time to separate themselves and emerge, which when they had done a pretty while, the pump was plyed again, for fear some Air should have stolen into so large a Receiver. These vicissitudes of pumping and resting lasted for a considerable time, till at length the bubbles began to be very rare, and we weary of waiting any longer; soon after which the external Air was let into the Receiver, and it appeared somewhat strange to the Spectators, that notwithstanding so great a multitude of Bubbles, as had escaped out of the water, I could not by attentively comparing the place where the surface of the water rested at first (to which a mark had been affix'd) with that where it now stood; I could not, I say, discern the difference to amount to above, if so much, as an hairs breadth; and the chief Operator in the Experiment professed that, for his part, he could not perceive any difference at all.

Thus far for the Narrative of the tryal made by *Water*; but that was not the only Liquor, into whose Aerial particles I designed by our little Instrument to enquire; and therefore filling a Glass of the same shape, and much of the same bigness, with *Claret wine*, and placing it upon a convenient Pedestal in a tall Receiver, we caused some of the Air to be pumped out; whereupon in a short time there emerged, through the slender Pipe, so very great a multitude of Bubbles, that were darted, as it were, upwards, as did not a little both please and surprize the Beholders: but it forced us to go warily to work, for fear the Glass should break, or the wine overflow. Wherefore we seasonably left off pumping, before the Receiver was any thing near exhausted, and suffered the Bubbles to get away as they could, till

till the present danger was overpassed, and then from time to time we pump'd a little more Air out of the Receiver, till we were weary, the withdrawing of a moderate quantity of Air at a time sufficing, even at the latter end, to make the Bubbles not only copiously, but very swiftly ascend, (by a minute Watch) for above a quarter of an hour together.

The little Instrument, made use of about these tryals, being designed to examine, among other things, the quantity of Bubbles lurking in several Liquors, is to be applyed to *Spirit of Wine* and *Chymical Oyles*, that are more subtil Liquors than Wine it self. And some circumstances of our tryals made us think, that it might be worth examining, what kind of substance may be obtained by this way of handling Aerial and Spirituous Corpuscles. But of the other uses of our Instrument elsewhere.

The VI. Title.

Of some Phænomena, afforded by Shell-Fishes in an exhausted Receiver.

Experiment the 1.

AN oyster being but into a very small Receiver, and kept in long enough to have successively kill'd three or four Birds or Beasts, &c. was not thereby kill'd, nor, for ought we could perceive, considerably disturb'd; only at each suck we perceiv'd, that the Air contain'd between the two Shells broke out at their Commissure; as we concluded from the foam which at those times came forth all round that Commissure. About twenty four hours after, coming to see in what condition this Oyster was, I found, that both this, and another that had been put at the same time into the Receiver, were alive; but how long afterwards they continued so, I did not observe.

Experiment the 2.

That same day we put a pretty large *Craw-Fish* into a pretty large Receiver, and found, that though he had been injur'd by a fall before he was brought thither, yet he seem'd not to be much incommoded by being included, till the Air was in great measure pump'd out, and then its former motion presently ceased, and he lay as dead; till, upon the letting in a little Air into the Receiver, he began forthwith to move a fresh. And upon the withdrawing the Air again, he presently, as before, became moveless. Having repeated this tryal two or three times, we took

took him out of the Receiver, where he appear'd not to have suffer'd any harm.

Experiment the 3.

But I thought it not unlikely, that there may be some such inequality in the strength or vivacity of Animals, as to such kind of Experiments as ours, that it might be well worth while in several cases to reiterate our Tryals. And on this occasion I shall here add, that having put an *Oyster* into a viol full of Water, before we included it in the Receiver, that through the liquor the motion of the Bubbles, expected from the Fish, might be the more pleasantly seen and consider'd, this Oyster prov'd so strong, as to keep it self close shut, and repress'd the Eruption of the Bubbles, that in the other did force open the shells from time to time; and kept in its own Air as long as we had occasion to continue the Tryals.

Experiment the 4th.

Moreover a *Craw-Fish*, that was thought more vigorous, being substituted in the place of the former *Craw-Fish*, though once he seem'd to lose his motion together with the Air, yet afterwards he continued moving in the Receiver, in spight of our pumping: Whether because there was some unperceiv'd leaking, that hinder'd a sufficient Exhaustion of the Air, or because this particular Animal was more strong or vivid than the other, we could not positively determine.

The VII. Title.

Of the Phenomena of a Scale-Fish in an Exhausted Receiver.

THe following Experiment is far from being the first that was made on a Scale-Fish in our *Vacuum*; but in regard that the Receivers, wherein those tryals were made, the External Air could not be kept out near so long, and so well as in the Vessel I am about to mention, I judg'd it well worth the pains to observe, what would happen to a Fish in an exhausted Vessel, where it should be kept for some hours together from all supply of fresh Air. And therefore I made several Tryals to that purpose; whereof that, which I think the most considerable, was Registered as follows:

We took a Receiver shap'd almost like a Bolthead, containing by estimation near a Pint, and the Globulous part of it being almost

almost half full of water, we put into it, at the *Orifice* (which was pretty large) a small *Gudgeon*, about three Inches long, which when it was in the Water swam nimbly up and down therein. Then having drawn out the Air so well, that we guess'd by a Gage, that about nineteen parts of twenty or more might be exhausted, we secur'd our selves, that the regress of the Air should not injure our Experiment; about which we observ'd these particulars.

First, The neck of the Glass being very long, though there appeared great store of Bubbles all about the Fish; yet the rest of the Water, notwithstanding the withdrawing of so much Air as has been mention'd, emitted no froth, and but few Bubbles.

Secondly, The Fish both at his mouth and gills did, for a great while, discharge such a quantity of Bubbles as appear'd strange, and for about half an hour or more (for much longer I had not opportunity to watch it;) when ever he rested a while, new Bubbles would adhere to many parts of his Body (as if they were generated there) especially his Fins and Tayle: So that he would appear almost beset with Bubbles; and if, being excited to swim, he was made to shake them off, he would quickly, upon a little Rest, be beset with new ones as before.

Thirdly, Almost all the while he would gape and move his Gills, as before he was included; though towards the end of the time that I watch'd, it often happen'd, that he neither took in, nor emitted any Aerial particles that I could perceive.

Fourthly, After a while he lay almost constantly with his Belly upwards, and yet would in that posture swim briskly as before.

Fifthly, Nay after a while he seem'd to be more lively than at first putting in; whether by reason, that by discharge of so many Bubbles, which by their distension perhaps put him to pain, he found himself reliev'd, or for some other cause, I examine not.

Having occasion to go abroad, I return'd about an hour and a half after he had been seal'd up, and found him almost free from Bubbles, and with his Belly upwards, and seeming somewhat tumid, but yet lively as before. But an hour and a quarter after that, when rising from dinner I went to look upon him again, he seem'd to be moveless and somewhat stiff; yet upon shaking:

the

the Glass, observing some faint signs of life in him by some Languid motions, he attempted to make when excited to them, I open'd the Receiver under water, to try if that Liquor and Air would recover him; and the external water rushing in till it had fill'd the vacant part of the Ball and the greatest part of the stem too, the Fish sunk to the bottom of it, with a greater appearance than ever of being alive; in which state after he had continu'd a pretty while, I made a shift, by the help of the water he swam in, to get him through the Pipe into a Bason of water, where he gave more manifest signs of life: but yet for some hours lay on one side or other, without being able to swim or ly on his belly, which appear'd very much shrunk in, as if something during the time of its being seal'd up had been broken in his body, or his Belly had been exceedingly distended, beyond restitution to its former Tone.

All the while he continued in the Bason of water, though he mov'd his Gills as before he had been seal'd up; yet I could not perceive, that he did, even in his new water, emit, as formerly, any Bubbles, though two or three times I held him by the Tayl in the Air, and put him into the Water again; where at length he grew able to lye constantly upon his Belly (which yet retain'd much of its former lankness;) and though it be now about or above twenty four hours since he was first included, he continues yet alive.

(*Postscript.* He liv'd in the Bason eight or ten dayes longer; though divers Gudgeons since taken dy'd there in much fewer dayes.)

The VIII. Title.

Of two Animals included, with large wounds in the Abdomen, in the Pneumatical Receiver.

Experiment the I.

Sept. 12. **A** Small Bird, having the Abdomen opened almost from flank to flank, without injuring the Guts, was put into a small Receiver, and the Pump being set a work continued for some little time without giving any signs of distress, but at the end of about a minute and an half from the beginning of the exhaustion, he began to have convulsive motions in the wings; and though the convulsions were not universal, or did appear violent, as is usual in other Birds from whom the

the Air is withdrawn by the Engin, yet at the end of two full minutes, letting in the Air, and then taking off the Receiver we found the Bird irrecoverable; notwithstanding which we did not find any notable alteration in the Lungs, and found the Heart (or at least the Atricles of it) to be yet beating, and so it continued for a while after.

Experiment the 2.

We took also a pretty large *Frog*, and having without violating the Lungs or the Guts made two such incisions in the Abdomen, that the two curled bladders or lobes of the Lungs *The same day* came out almost totally at them, we suspended the Frog by the legs in a small Receiver, and after we had pumped out a good part of the Air, the Animal struggled very much, and seemed to be much disordered, and when the Receiver was well exhausted, she lay still for a while as if she had been dead, the Abdomen and thigh very much swelled, as if some rarified Air or Vapor forcibly distended them. But as, when the Frog was put in, one of the Lobes was almost full, and the other almost shrunk up, so they continued to appear, after the Receiver had been exhausted; but upon letting in of the Air, not only the body ceased to be tumid, but the plump bladder appeared for a while shrunk up as the other, and the Receiver being removed, the Frog presently revived, and quickly began to fill the Lobe again with Air.

The IX. Title.

Of the motion of the separated Heart of a Cold Animal in the Exhausted Receiver.

Without discussing the opinions of Learned men about the connexion and dependency of the Motion of the Bloud, and Beating of the Heart, I thought, it might give me a sufficient inducement to make the following Experiment, that several sorts of Animals would be presently killed in our *Vacuum* by the withdrawing of the Air, and even the Insects mentioned in the formerly published *Digression* about Respiration, though they also were not totally deprived of *life* by the absence of the Air, yet they were of *visible motion*: Wherefore some good hint or other being to be hoped for from the discovering, whether or no a separated Heart, which is but a part of an Animal, would continue its motions in our *Vacuum*; we made some tryals to that purpose, whose success I find thus set down.

Experiment the 1.

The Heart of an *Eole* being taken out and laid upon a plate of Tin in a small Receiver, when we perceived it to beat there as it had done in

the open Air, we exhausted the Vessel, and saw, that, though the heart grew very tumid, and here and there sent forth little Bubbles, yet it continued to beat as manifestly as before, and seemed to do so more swiftly; as we tryed by numbring the pulsations it made in a minute, whilst it was in the exhausted Receiver, and when we had readmitted the Air, and also when we took it out of the Glass, and suffered it to continue its motion in the open Air. The heart of an other Ele, being likewise taken out, continued to beat in the emptied Receiver, as the other had done.

Experiment the 2.

The Heart of an other Ele, after having been included in a Receiver first exhausted, and then accurately secured from leaking, though it appeared very tumid, continued to beat there an hour; after which looking upon it and finding its motion very languid, and almost ceased, by breathing a little upon that part of the glass where the heart was, it quickly regained motion, which I observed a while; and an hour after finding it to seem almost quite gone, I was able to renew it by the application of a little more warmth. At the end of the third hour, coming to look at it once more, a bubble, that appeared to be placed between the Auricle and the Heart, seemed to have now and then a little trembling motion; but I found it so faint, that I could no more by warmth excite it, so as plainly to perceive the heart to move: wherefore I suffered the outward Air to rush in, but could not discern, that thereby the heart regained any sensible motion, though assisted with the warmth of my breath and hands.

The X. Title.

A Comparison of the Times wherein Animals may be kill'd by Drowning, or withdrawing of the Air.

TO help my self and others to judge the better of some difficulty's concerning Respiration, I thought it might be useful, that we compar'd together the Times, wherein Animals may be kill'd by *that want* of Respiration, which in those that are drown'd is caused by the water that suffocates them, and *that other want*, which proceeds from withdrawing the ambient Air. Of the latter of these a sufficient number of Instances is to be met with among our other Experiments, and therefore I shall now subjoyn about the former the more Tryals, because this Comparison hath not, that I know of, been yet thought on by any.

Experiment the 1.

Sept. 10. A Green-Finch, having his legs and wings tyed to a weight, was gently let down into a glass-body fill'd with water; the time

time of its total immersion being mark'd: At the end of half a minute after that time the struglings of the Bird seeming finish'd, he was nimbly drawn up again, but found quite dead.

Experiment the 2.

Whereupon a Sparrow, that was very lusty, and quarrelsome, was ty'd to the same weight, and let down after the same manner; but though he seem'd to be under water more vigorous than the other Bird, and continued strugling almost to the very end of half a minute from the time of his being totally immers'd (during which stay under water there ascended from time to time, pretty large bubbles from his mouth,) yet notwithstanding, that as soon as ever the half minute was compleat'd, he was drawn up, we found him to our wonder, irrecoverably gone.

Experiment the 3.

A small Mouse, being held under water by the tail, emitted from time to time divers Aerial Bubbles out of his mouth; and at last, as one of the Spectators affirm'd, he saw at one of his Eyes, being taken out at the end of half a minute and some few seconds, he yet retain'd some motions; but they prov'd but Convulsive ones, which at last ended in Death.

By what is related under the I. Title, it does not appear, that Water-Fowl, at least that Ducks, could in our Receivers endure the want of Air much longer than other Birds: But now to shew, that the Contrivance of Nature is not insignificant, as to the enabling them to continue much longer under Water, without fresh Air, than the Land-birds abovemention'd, it will not be amiss, to subjoyn the two following Experiments.

Experiment the 4th.

We took the Duck mention'd in the I. Title, and so ty'd a considerable weight of Lead to her body, as it did not hinder her Respiration, and yet would be sure to keep her down under water; which we had found that a small weight would not do by reason of her strength, nor yet a great weight, if ty'd only to her feet, in such a middle-liz'd Tub as ours was, because of the height of her neck and beak. With the above-mention'd Clog, the Duck was put into a Tub full of clear water, under whose Surface she continued, about a minute by my Watch, quietly enough, but afterwards began to appear for a while much disturb'd; which fit being over, our not perceiving any motion in her made us, at the end of the second minute, take her out of the water, to see in what condition she was, and finding her in a good one, after we had allowed her some breathing time to recruit her self with fresh

Air; we let her down again into the Tub, which in the mean time had been fill'd with fresh water, least the other, which had been troubled with the steams and foulness of the Ducks Body, might either hasten her death by its being infected with them, or hinder our discerning what should happen, by its being opacated by them.

The Bird being thus under water did, after a while, begin, and from time to time continue, to emit divers Bubbles at her Beak. There also came out at her Nostrils divers real Bubbles from time to time; and when the Animal had continued about two minutes or better under water, she began to struggle very much, and to endeavour either to emerge or chang Postures; the latter of which she had liberty to do, but not the former. After four minutes, the Bubbles came much more sparingly from her: then also she began to gape from time to time, (which we had not observ'd her to do before,) but without emitting Bubbles; and so she continued gaping till near the end of the sixth minute, at which time all her motions, some of which were judg'd convulsive, and others that had been excited by our rouzing her with a *forceps*, appear'd to cease and her head to hang carelessly down, as if she were quite dead. Notwithstanding which, we thought fit for greater security to continue her under water a full minute longer, and then finding no signs of life, we took her out, and being hung by the heels, and gently press'd in convenient places, she was made to void a pretty quantity of water, of which whether any had been receiv'd into the Lungs themselves, we had not time and opportunity to examine. But all the means, that were to recover the Bird to life, proving Ineffectual, we concluded, she had been dead a full minure before we removed her out of the water: So that, to sum up the Event of our Experiment, even this Water-Bird was not able to live in Cold water, without taking in fresh Air, above six minutes; which is but $\frac{1}{10}$ of an hour.

Experiment the 5th.

The *Duckling* mention'd in the *I. Title* and *second Experiment*, having a competent weight tyed to her legs, was let down into a Tub of Water which reached not above an inch or two higher than her Beak: during the most part of her continuance, there came out store of Bubbles at her Nostrils, but there seem'd to come out more and greater, from a certain place in her head almost equidistant from her eyes, but somewhat less remote from her Neck than they. Whilst she was kept in this condition, she seem'd frequently to endeavour to dive lower under water, and after much strugling and frequent gaping, she had divers convulsive motions, and then let her Head fall down backward, with her Throat upwards. To which moveless posture she was reduc'd at the end of the third minute, if not a little sooner; but a while after there appear'd a manifest but tremulous motion in the two parts of her Bill, which continued for some time, but afforded no Circumstances, whereby

by we could be sure, that they were not Convulsive Motions; but these also ceasing upon the end of the fourth minute, the Bird was taken out and found irrecoverable.

Experiment the 6th.

A Viper that was kept so many hours in an Exhausted Receiver, till it was concluded to be stark dead, and to have been so for a good while, was nevertheless resolutely hindered by me from being thrown away, till I had try'd, what could be done by keeping it all night in a glas-body upon a warm digestive Furnace. Whereupon this Viper was found the next morning not only to be reviv'd, but to be very lively, so as to invite me to make with Her, without seeking for another, the following Experiment.

We put her into a tall Glass-body, fitted with a Cork to the Orifice of it, and depress'd with weight, so that she could come at no Air. In this case we observ'd her from time to time; and after she had been duck't a while, she lay with very little motion for a considerable space of time. At an hour and a quarter she often put out her black tongue: at near four hours she appear'd much alive, and, as I remember, about that time also put out her tongue, swimming all this while, as far as we observ'd, above the bottom of the water. At the end of about seven hours or more, she seem'd yet to have some life in her, her posture being manifestly chang'd in the Glas, from what it was a while before; unless that might proceed from some difference made in her Body as to Gravity and Levity. Not long after she appear'd quite dead, her head and tayl hanging down movelessly, and directly towards the bottom of the vessel, whilst the middle of the Body floated as much as the above-mention'd Cork would permit it.

Haste maketh me pretermit the mention of divers things suggested by what hath been delivered upon the present *Title*. But this one thing would be taken notice of, that, though some of the abovementioned Animals seem, by the Relations we have given of them, to have been a little sooner destroyed by drowning, than any we have mentio'nd were by our Engin, that is no sure proof, that suffocation does kill Animals faster, than the deprivation of Air, they are exposed to in our Engin. For in drowning, that which destroys is applyed to its full vigour at the very first, and all at once; whereas, our Receivers being made for several purposes, the Deprivation of the Air, that they make, cannot be made all at once, but the Air must be pump't out by degrees; so that till the last the Receiver will be but partly emptied. For confirmation of which, I have this to alledge, that, having in the presence of some *Virtuosi* provided for the nonce a very small Receiver, wherein yet a Mouse could live sometime, if the Air were left in it, we were able to evacuate it at one suck, and by that advantage we were enabled, to the wonder of the Beholders, to kill the Animal in less than half a minute.