

II. *An Account of some new Experiments, relating to the Action of Glass Tubes upon Water and Quicksilver.* By James Jurin, M. D. Reg. Soc. & Coll. Med. Lond. Soc.

IN a * Discourse formerly presented to the *Royal Society*, I maintain'd, that the Suspension of Water in a Capillary Tube was owing to the Attraction of a small annular surface on the inside of the Tube, which touch'd the upper part of the Water. Among the several Experiments made use of to prove this Assertion, was that of a Glass Funnel of several Inches Diameter, having its small end drawn out into a very fine Tube, which Funnel being inverted and fill'd with Water, the whole quantity of Water therein contain'd was sustain'd above the Level by the Attraction of that narrow *Annulus* of Glass, with which the upper surface of the Water was in contact.

Soon after that Discourse was printed, came out a Book publish'd by a very Learned and Ingenious Member of this Society, in which that Experiment was accounted for in the following Manner.

If there be a Funnel, as ABC, Fig. 1. full of Water, and whose wide end stands in a Vessel of Water as BC; and the Top of the Funnel A ends in a Capillary Tube open at A, the whole Water will be sustain'd: the Pillar Aa by the Attraction of the Circle of Glass within the Tube immediately above it; and all the rest of the Pillars of Water, as Ff, Dd, Ee, Gg, &c. in some measure by the Attraction of the parts of the Glass above them, as F,

* *Philos. Transact.* N^o. 355.

D, E, G: And hat the small Pillars or Threads of Water Dd, and Ee, do not slide down to Ff, and Gg, and so go quite down, seems to be owing to their Cohesion with the Pillar Aa, which is sustain'd by the Capillary Tube A: For if you break off the said Tube at DE, the whole Water will presently sink down.

As this Solution was very different from what I had before given, and the Reputation of that Gentleman, whose great Knowledge in Experimental Philosophy is generally known, was sufficient to give weight to any of his Opinions, I thought my self under an Obligation to examine his account of the Experiment, in order either to demonstrate its insufficiency, or to retract my own Solution. Accordingly at the next meeting of the Society, I produced the following Experiment.

The Funnel, A F G B C, *Fig 2.* whose lower part B C F G, was Cylindrical to a considerable height, and whose top was drawn out into a fine Tube at A, being fill'd with Water to the height B F, so that the surface of the Water F G, did not reach to the arched part of the Funnel, I touch'd the end A with a wetted Finger, whereby a small quantity of Water being insinuated into the Capillary Tube at A, the Water contain'd in the Funnel was suspended above the Level of the Water in the Cistern D E, as in the former Experiment.

In this Experiment it is manifest, that the little Columns, into which we may suppose the Cylinder of Water, F G B C, to be divided, are no way sustain'd by the Attraction of the arched part of the Glass above them, since they have no contact with it. Nor is there any such middle Pillar of Water, which, by its contact with the Tube at top. is both sustain'd it self, and helps to support the Pillars about it. Upon the
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supposition of which two Particulars that Gentleman's Solution was founded.

This Experiment may be thus accounted for. The Cylinder of Water F G B C, by its weight balances a part of the pressure of the Atmosphere, which is incumbent on the Water in the Cistern, and endeavours to force that Cylinder upwards. The rest of that pressure is balanced by the Spring of the Air, A F G, which is includ'd between the Cylinder of Water F G B C, and the little Column of Water in the Capillary A. But, as this Air by its Spring presses equally every way, it must balance as much of the pressure of the Atmosphere upon the little Column of Water at A, as it does of that upon the Water in the Cistern. The remainder of the pressure of the Atmosphere upon the Column of Water at A is sustain'd by the force with which that Column adheres to the Capillary Tube, which therefore does exactly balance the weight of the Cylinder of Water F G B C, and is the real, though not the immediate, cause of its Suspension.

The experiment succeeds in the same manner when a Column of Quicksilver is rais'd into the Funnel, instead of the Column of Water F G B C, the top of the Tube being touch'd with a wet Finger as before. But then the height of the Quicksilver in the Funnel must be as much less than that of the Water, as its Specific Gravity is greater.

I proceed now to acquit my self of a Promise I made in the Discourse abovemention'd, of examining whether the Experiments therein contain'd would succeed *in Vacuo*; and whether Water could be suspended in a wide Tube by means of a Capillary at Top, at a greater height, than what it can be rais'd to by the Pressure of the Atmosphere.

In order to this, I boil'd some Water, and afterwards purged it of its Air by means of the Air-pump; which being done, those Experiments all succeeded in the exhausted Receiver, in the same manner as in the open Air.

The 13th Experiment in particular was made with a Tube of about 35 Inches in length, and a quarter of an Inch Diameter, the top of it being drawn out into a fine Capillary. Which being fill'd with Water purged of its Air, as before mention'd, the whole quantity continued suspended in the exhausted Receiver.

This plainly shews, that the success of that Experiment does not depend upon the Pressure of the Air, since the small quantity of Air left in the Receiver was by no means capable of sustaining the Water at so great a height, and consequently that the height, at which Water may be suspended in this manner, is not limited by that Pressure.

But here I must not omit taking notice of a considerable Difficulty, which presents it self to those who attentively consider this Experiment. In order to make which the better appear, it will be proper to observe what happens, when a simple Capillary Tube is fill'd with Water purged of Air, and inclos'd in the exhausted Receiver.

In this case the whole Column of Water contained in the Tube A C B, *Fig. 3d.* is suspended by the Attraction of the *Annulus* at the top of the Tube, A. And though that *Annulus* does not immediately act upon any part of the Water, except what is either contiguous to it, or so near as to be within the Sphere of its Attraction, which extends but to a very small distance; yet it is impossible, that any other part of the Water, as for instance that at C, should part from the Water above it and sink down, because its descent is oppos'd by

by the attraction of the contiguous *Annulus* at C. For this, being equal to the upper *Annulus* at A, is capable of sustaining a Column of Water of the length A B, and consequently is more than sufficient for supporting the Column of Water below it, C B. From which it is plain, that no part of the Water contain'd in the Tube can possibly descend, unless the upper part, assisted by the weight of the Water below it, be sufficient to overcome the Attraction of the *Annulus* of Glass at A.

But in such a compound Tube as that made use of in our Experiment, *Fig. 4th* A C B, the case is very different, and it does not easily appear, why in a *Vacuum* any part of the Water in the wider part of the Tube, as for Example at C, should not leave that which is above it, and descend; since the *Annulus* at C is by much too wide to sustain a Column of Water of so great a length as C B,

The best answer I can give to this difficulty is, that the Cohesion between the Water contain'd in the Capillary and that below it, is sufficient to balance the weight of the Column suspended. But how far this Cohesion may depend upon the Pressure of a Medium subtile enough to penetrate the Receiver, is worthy of Consideration. For though such a Medium will pervade the Pores of the Water, as well as those of the Glass, yet it will act with its intire Pressure upon all the solid Particles, if I may so call them, of the surface of the Water in the Cistern; whereas so many of the solid Particles of the Water in the Tube, which happen to lie directly under the solid Particles of the Water above them, will thereby be secur'd from this Pressure; and consequently there will be a less Pressure of this Medium upon any surface of the Water in the Tube below the Capillary, than upon an equal surface of the Water in the Cistern. So that the Column of Water suspended

in the Tube may be sustain'd by the difference between those two Pressures. This Explication seems to be favour'd by the following Experiments, which may all be accounted for in the same manner, though I shall anon mention another Cause, which contributes to the Success of the first and second.

The first I shall mention, is the famous Experiment of the suspension of Mercury purged of Air, to the height of 70 or 75 Inches, in the *Toricellian Tube*, in the open Air. To which we may add the sustaining of Mercury likewise purged of Air within the exhausted Receiver, as related by that Learned and Successful Promoter of Natural Knowledge, *Monf. Papin*, in his *Continuation du Digesteur*. I forbear to mention the suspension of Water purged of Air, in the *Vacuum*, which he describes in the same Book; because there is little difference between that Experiment and our own abovementioned, the very top of the arched part of his Tube, which top we may suppose as small as we please, supplying the place of the fine Capillary at the top of our Tube. But we must not omit the Experiments made by the famous *Monf. Huygens*, and described by him in *Phil. Transact.* No. 86. of the cohering of polish'd Plates with a considerable force in the exhausted Receiver; as likewise of the running of Water and Mercury, when purged of Air, through a Siphon of unequal Legs in the *Vacuum*: All which he accounts for from the same Principle, and much in the same manner, as we have used for explaining the Experiment above.

As to the Existence of such a Medium, I shall content my self to refer to what has been said by our *Illustrious President* in the Queries at the latter end of the last Edition of his *Opticks*: and as I have lately had the Honour to entertain the Society with some Experiments upon Quicksilver, which were exactly the reverse

reverse of those made by Dr. *Taylor*, the late Mr. *Hawksbee* and my self, upon Water; by which I am now enabled to throw this whole affair into a little System by it self, I shall beg leave to lay it down in the following Propositions, the Proof of which is contain'd in the Experiments annext.

PROPOSITION I.

The Particles of Water attract one another.

This, I think, is now universally acknowledged, and therefore needs no Demonstration; the Sphericity of the drops of Rain, and the running of two drops of Water into one another upon their contact, manifestly proving it.

PROPOSITION II.

The Particles of Quicksilver attract one another.

This is likewise manifest from the Spherical Figure, into which a drop of Mercury forms it self upon a Table; and from two of them immediately running together, as soon as they come to touch.

PROPOSITION III.

Water is attracted by Glass.

This plainly appears from all the Experiments, that we have shewn upon this Subject.

PROPOSITION IV.

Quicksilver is attracted by Glass.

Experiment I. If a small Globule of Quicksilver be laid upon a clean Paper, and be touched with a piece of clean Glass; upon drawing the Glass gently away,

away, the Quicksilver will adhere to it, and be drawn away with it. And if the Glass be lifted up from the Paper, the Quicksilver will be taken up by it, in the same manner as a piece of Iron is drawn up by the Loadstone, and will stick to the Glass by a plain Surface of a considerable breadth, in proportion to the bulk of the drop, as manifestly appears by an ordinary Microscope. Then if the Glass be held a little obliquely, the drop of Mercury will roll slowly upon its Axis along the under side of the Glass, till it comes to the end, where it will be suspended as before.

Exp. 2d. If a pretty large drop of Mercury be laid upon a Paper, and two pieces of Glass be made to touch it, one on each side; upon drawing the Glasses gently from each other, the drop of Mercury will adhere to them both, and will be visibly drawn out from a globular to an oval Shape; the longer Axis passing through the middle of those Surfaces, in which the drop touches the Glasses.

PROPOSITION V.

The Particles of Water are more strongly attracted by Glass, than by one another.

This manifestly appears from the rising of Water in small Tubes above the Level. For when the Water begins to rise into a Capillary Tube, all the Particles of Water, which touch the small *Annulus* at the bottom of the Tube, must have quitted the contact of the other Water, and have risen contrary to their Gravity, to come into contact with the Glass. After the same manner the other Experiments of Dr. Taylor, Mr. Hawksbee and my self, upon this Subject, are easily explicable. For upon a careful Examination, it will be found
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in them all, that some parts of the Water quit the contact of the other Water, and join themselves to the Glass.

PROPOSITION VI.

The Particles of Quicksilver are more strongly attracted by one another, than by Glass.

Exp I. Fig. 5. If a small Tube as AB, open at both ends, be dipt into a Glass Vessel fill'd with Mercury, and be held close to the side of the Vessel, that the rise of the Mercury within it may appear; the Mercury will partly enter into the Tube, but will stand within it at some depth, as CE, below the Surface of the Quicksilver in the Vessel, CD; and this depth will always be reciprocally as the Diameter of the Tube.

In this Experiment a Column of Quicksilver of the height CE endeavours to force the Mercury higher into the Tube; and as Glass has been already provid'd to attract Quicksilver, the Attraction of the annular Surface on the inside of the Tube, which is contiguous to the upper part of the Mercury, will likewise conspire to farther its ascent. What opposes the ascent of the Quicksilver, is the Power, by which that part of it, which endeavours to rise into the Glass, is drawn back by the Attraction of the other Mercury, with which it is in contact laterally, and this does not only balance the Attraction of the Glass, but likewise the weight of the Column of Mercury of the height CE, and consequently this Attraction is considerably stronger than the Attraction of the Glass.

The cause therefore, that suspends the weight of the Column of Mercury CE, being the difference between the Attraction of the annular Surface of the Tube at E, and that of an equal Surface of the Quicksilver in the Cistern, from which the Mercury, that endeavours to

rise into the Tube, must recede, in order to unite it self to such an Annulus of the Glass, will always be proportional to that annular Surface, or to the Diameter of the Tube. And since the Column sustain'd must be proportional to the Cause that suspends it, that Column must likewise be as the Diameter of the Tube. But the Column suspended is as the Square of the Diameter of the Tube and the height CE conjointly; from which it follows, that the height CE must be as the Diameter of the Tube reciprocally, as it is found to be by Experiment.

The Experiment of the Ascent of Water above the Level in a Capillary Tube, is just the Reverse of this.

Exp. II. Fig. 6. Quicksilver being poured into the inverted Siphon ACB , one of whose Legs AC is narrower than the other CB ; the height CE , at which the Mercury stands in the wider Leg CB , is greater than the height CD , at which it stands in the narrower Leg CA .

On the contrary, Water stands higher in the narrower Leg, than in the wider.

Exp. III. Fig. 7. $ABCD$ represents a rectangular plane of Glass, which makes one side of a wooden Box. On the inside of this is another Glass plane of the same size, which at the end AC is prest close to the former, and opens to a small Angle at the opposite end BD . When Mercury is pour'd into this Box to any height as CE , it insinuates it self between the two Glass planes, and rising to different heights between the Glasses where the opening is greater or less, it forms the common Hyperbola CGF ; one of whose Asymptotes EF is the line on which the Surface of the Mercury in the Box touches the inner Glass; the other is the line AC , in which the Planes are join'd. This Hyperbola being carefully examined by Mr. *Hawksbee* and

and my self, the Rectangle E H G, wheresoever taken, proved always equal to it self, to as great an accuracy as could be expected, when the Planes were opened to any considerable Angle: But when the opening was very small, the inequalities of the Planes, though the best I could procure, bearing a greater proportion than before to the distance between them, occasion'd a sensible variation. Which, by the way, I take to be the reason, why the Ordinates found by the late Mr *Hawksbee*, in examining the Curve produced in a contrary situation, upon dipping two Glass Planes so join'd into Spirit of Wine, do not answer to those of the Hyperbola.

Exp. IV. Fig. 8. A B is a perpendicular Section through two Glass Planes join'd at A, and open'd to a small Angle at B. C represents a pretty large drop of Mercury, the larger the better, which, being made to descend as far as C, by holding the Planes in an erect posture, with the end A downwards, retires from the contact of the Planes to D, upon inclining the Planes towards an horizontal Situation; and the distance C D becomes greater or less, as the Planes are more or less inclin'd towards the Horizon.

A drop of any Oily or Watery Liquor moves the contrary way, as has been shewn by the late Mr *Hawksbee*.

Exp. V. Fig. 9. A B is a Tube open at both ends, and a Foot or two in length, whose lower part is drawn out into a fine Capillary at B. This Tube being fill'd with Mercury, the whole Column of Quicksilver will be sustain'd in it, provided the Capillary Tube at B be sufficiently small. But if the Mercury in the end B be suffer'd to touch any other Mercury it runs all out of the Tube. If, without letting it touch any other Mercury, a small part of the end B be broken off,

the Mercury will run out, till it comes to some lesser height as B C, at which it will again stop, the height B C being nearly in a reciprocal proportion to the Diameter of the small end of the Tube.

The Seventh Experiment in *Phil. Transf.* N^o. 355 is the Reverse of this.

Exp. VI. Fig. 10. Is the same in substance with the former, but made with a large Glass Funnel A B, instead of a Tube.

The Reverse of this in Water is the thirteenth Experiment in the same Transaction.

In all these Experiments it is easily seen, that the Effect is owing to the difference between the two Attractions, by which Mercury tends to Glass and to its own body; they being always opposed to one another, so that a particular Explication is no way necessary. But perhaps it may save some little trouble to the Reader, to remove the following Objection, which will readily occur to him.

In the Experiments brought to demonstrate the fourth Proposition, the Globule of Mercury adheres to the Glass in a plane Surface, which cannot be done without increasing the Surface of the Globule, and consequently removing some of its Particles from the contact of one another. If therefore they tend more strongly to one another than to the Glass, why do they not recede from the Glass, and assume a figure perfectly spherical, that they may all have the greatest possible contact with each other?

To this we may answer, that the Power, by which Mercury is attracted either by Glass, or by other Mercury, is proportional to the attracting Surface; and therefore, though, *ceteris paribus*, the tendency of Mercury to Glass is not so strong as its tendency to other Mercury, yet in this case a much greater number of

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Mercurial Particles coming into contact with the Glass, than what recede from the contact of one another, it is no wonder, that the Attraction of the Glass prevails, and causes the Globule to adhere to it. For the number of Mercurial Particles which lose their contact with the other Mercury, is no more than what makes up the difference of Surface, which arises from changing the figure of the Drop: whereas the Particles, which by this means come to adhere to the Glass, are all those that constitute the plane Surface, in which the Globule touches it.

Which Consideration ought likewise to be apply'd to the Suspension of Quicksilver in Glass Tubes, either at extraordinary heights in the open Air, or at lesser heights in a *Vacuum*, as above mention'd. For the top of the Tube being Spherical, or nearly so, it will be found, that the contact of the Mercury with the extremity of the Tube, is to the contact with other Mercury, which would be gain'd by its leaving the Top of the Tube and descending a very small space, in a *Ratio* infinitely great; and consequently that the contact of the Mercury with the top of the Tube is one cause of its Suspension.

Coroll 1st. From this Proposition it appears, that in a Barometer made with a narrow Tube, the Quicksilver will never stand at so great a height as in a wider. Which accounts for the *Phenomenon* so often mention'd in the Yearly History of the Royal Academy of Sciences at *Paris*, by *Monf. De la Hire*; that in the Barometer, which he constantly made use of for his annual Observations, the Quicksilver did not rise so high, as in another he kept by him, by about three Lines and a half, which is near a third of an Inch our Measure: For he tells us, that the Tube of his Barometer is very small. So that there is no need to have recourse to any
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peculiarity either in the Quicksilver or the Glass of which that Tube was made; or to an unperceived remnant of Air left in the Tube, from some of which causes that Effect and some others of the same kind were imagined to proceed.

Cor. 2d. In a Barometer made with a small Tube, the Mercury will rise and fall irregularly. For, as the height of the Mercury depends partly upon the Diameter of that part of the Tube that touches the upper Surface of the Mercury, it is plain, that the unavoidable inequalities in the Diameter of the Tube will be more considerable, in respect to the whole Diameter; and consequently will affect the height of the Mercury more in a small Tube than in a wider. And this I take to be the reason, why it is so very difficult not to say impossible, to make two Barometers, which shall exactly agree in the height of the Quicksilver in all constitutions of the Air, especially if the Tubes be very narrow. This irregularity is still more considerable in the Pendent Barometet, in which the Quicksilver moves through a large space, in order to make a small alteration in the length of the Column suspended: The same consideration is easily extended to those Levels, that depend upon the rising of Mercury to the same height in the opposite Legs of a bent Tube; an Instrument of which kind has been lately offer'd for the service of the Publick. And as the effect is just contrary in Levels made with Water or Spirit of Wine, due regard ought to be had to this Property in the construction of those Instruments, by making the Tubes sufficiently wide, in order to diminish the Error as much as possible.

