

II. *An Account of some Experiments shown before the Royal Society ; with an enquiry into the cause of the Ascent and Suspension of Water in Capillary Tubes.* By James Jurin, M. D. and R. Soc. S.

SOME Days ago a Method was propos'd to me by an ingenious Friend, for making a perpetual Motion, which seem'd so plausible, and indeed so easily demonstrable from an Observation of the late Mr. *Hawksbee*, said to be grounded upon Experiment. that, tho' I am far from having any Opinion of attempts of this Nature, yet, I confess, I could not see why it should not succeed. Upon tryal indeed I found my self disappointed. But as searches after things impossible in themselves are frequently observ'd to produce other discoveries unexpected by the Inventer; so this Proposal has given occasion not only to rectify some mistakes into which we had been led, by that ingenious and useful Member of the *Royal Society* above named, but likewise to detect the real Principle, by which Water is rais'd and suspended in Capillary Tubes, above the Level.

My Friend's Proposal was as follows.

Fig 1. Let ABC be a capillary Siphon, compos'd of two Legs AB, BC , unequal both in length and Diameter; whose longer and narrower Leg AB having its orifice A immerst in Water, the Water will rise above the Level, till it fills the whole Tube AB , and will then continue suspended. If the wider and shorter Leg BC , be in like manner immerst, the Water

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will only rise to some height as FC , less than the entire height of the Tube BC .

This Siphon being fill'd with Water, and the Orifice A sunk below the Surface of the Water DE , my Friend reasons thus.

Since the two Columns of Water AB and FC , by the Supposition, will be suspended by some Power acting within the Tubes they are contain'd in, they cannot determine the Water to move one way, or the other. But the Column BF , having nothing to support it, must descend, and cause the Water to run out at C . Then the pressure of the Atmosphere driving the Water upward through the Orifice A , to supply the Vacuity, which would otherwise be left in the upper part of the Tube BC , this must necessarily produce a perpetual Motion, since the Water runs into the same Vessel, out of which it rises. But the Fallacy of this reasoning appears upon making the Experiment.

Exp. 1. For the Water, instead of running out at the Orifice C , rises upward towards F , and running all out of the Leg BC , remains suspended in the other Leg to the height AB .

Exp. 2. The same thing succeeds upon taking the Siphon out of the Water, into which its lower Orifice A had been immerst, the Water then falling in drops out of the Orifice A , and standing at last at the height AB . But in making these two Experiments it is necessary that AG the difference of the Legs exceed FC , otherwise the Water will not run either way.

Exp. 3. Upon inverting the Siphon full of Water, it continues without Motion either way.

The reason of all which will plainly appear, when we come to discover the Principle, by which the Water is suspended in Capillary Tubes.

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Mr. *Hawksbee's* Observation is as follows.

Fig. 2. Let $ABFC$ be a capillary Siphon, into the which the Water will rise above the Level to the height CF , and let BA be the depth of the Orifice of its longer Leg below the Surface of the Water DE . Then the Siphon being fill'd with Water, if BA be not greater than CF , the Water will not run out at A , but will remain suspended.

This seems indeed very plausible at first sight. For since the Column of Water FC will be suspended by some power within the Tube, why should not the Column BA , being equal to, or less than the former, continue suspended by the same Power ?

Exp. 4. In fact, if the orifice C be lifted up out of the Water DE , the Water in the Tube will continue suspended, unless BA exceed FC .

Exp. 5. But when C is never so little immerst in the Water, immediately the Water in the Tube runs out in drops at the Orifice A , tho' the length AB be considerably less than the height CF .

Mr. *Hawksbee* in his Book of Experiments has advanced another Observation, namely, that the shorter Leg of a Capillary Siphon, as $ABFC$, must be immerst in the Water to the depth FC , which is equal to the height of the Column, that would be suspended in it, before the Water will run out at the longer Leg.

Exp. 6. From what mistake this has proceeded, I cannot imagine ; for the Water runs out at the longer Leg, as soon as the Orifice of the shorter leg comes to touch the Surface of the stagnant Water, without being at all immerst therein.

Having proceeded thus far in obedience to the commands of this Illustrious Society, I beg leave to go a little farther, and to enquire into the cause of the ascent and suspension of Water in capillary Tubes.

That this Phenomenon is no way owing to the pressure of the Atmosphere, has been, I think sufficiently prov'd by Mr. *Hawksbee's* Experiments.

And that the cause assign'd by the same ingenious and inquisitive Person, namely the attraction of the concave Surface, in which the suspended Liquor is contain'd, is likewise insufficient for producing this effect, I thus demonstrate.

Since in every capillary Tube the height, to which the Water will spontaneously ascend, is reciprocally as the Diameter of the Tube, it follows, that the Surface containing the suspended Water in every Tube is always a given Quantity: but the Column of Water suspended is, as the Diameter of the Tube. Therefore, if the attraction of the containing Surface be the cause of the Waters suspension; it will follow, that equal causes produce unequal effects, which is absurd.

To this it may perhaps be objected, that, in two Tubes of unequal Diameters, the circumstances are different, and therefore the two Causes, tho' they be equal in themselves, may produce effects that are unequal. For the lesser Tube has not only a greater Curvature, but those parts of the Water, which lie in the middle of the Tube, are nearer to the attracting Surface, than in the wider. But from this if any thing follows, it must be, that the narrower Tube will suspend the greater quantity of Water, which is contrary to Experiment. For the Columns suspended are as the Diameters of the Tubes.

But as Experiments are generally more satisfactory in things of this nature, than Mathematical reasonings, it may not be amiss to make use of the following, which appear to me to contain an *Experimentum Cru-*

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Fig. 3: The Tube CD is composed of two Parts; in the wider of which the Water will rise spontaneously to the height BF , but the narrower Part, if it were of a sufficient length, would raise the Water to a height equal to CD .

Exp. 7. This Tube being fill'd with Water, and the wider end C immerst in the stagnant Water AB , the whole continues suspended.

Exp. 8. Fig. 4. The narrower end being immerst, the Water immediately subsides, and stands at last at the height DG equal to BF .

From which it is manifest, that the suspension of the Water in the former of these Experiments is not owing to the attraction of the containing Surface: since, if that were true, this Surface being the same, when the Tube is inverted, would suspend the Water at the same height.

Having shown the insufficiency of this Hypothesis, I come now to the real cause of that Phænomenon, which is the attraction of the Periphery, or Section of the Surface of the Tube, to which the upper Surface of the Water is contiguous and coheres.

For this is the only part of the Tube, from which the Water must recede upon its subsiding, and consequently the only one, which by the force of its cohesion, or attraction, opposes the descent of the Water.

This likewise is a cause proportional to the effect, which it produces; since that Periphery, and the Column suspended, are both in the same proportion as the Diameter of the Tube.

Tho' from either of these particulars it were easy to draw a just Demonstration, yet to put the matter out of all doubt, it may be proper to confirm this assertion, as we have done the former, by actual Experiment:

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Fig. 5. Let therefore EDC be a Tube, like that made use of in the 7th and 8th Experiments, except that the narrower Part is of a greater length; and let AF and BG be the heights, to which the Water would spontaneously rise in the two Tubes ED and DC .

Exp. 9. If this Tube have its wider Orifice C immerst into the Water AE , and be fill'd to any height less than the length of the wider Part, the Water will immediately subside to a Level with the point G ; but if the Surface of the contain'd Water enter never so little within the smaller Tube ED , the whole Column DC will be suspended, provided the length of that Column do not exceed the height AF .

In this Experiment it is plain that there is nothing to sustain the Water at so great a height, except the contact of the Periphery of the lesser Tube, to which the upper Surface of the Water is contiguous. For the Tube DC , by the Supposition, is not able to support the Water at a greater height than BG .

Exp. 10 Fig. 6. When the same Tube is inverted, and the Water is rais'd into the lower extremity of the wider Tube CD , it immediately sinks, if the length of the suspended Column DH be greater than GB ; whereas in the Tube DE it would be suspended to the height AF . From which it manifestly appears, that the suspension of the Column DH does not depend upon the attraction of the Tube DE , but upon the Periphery of the wider Tube, with which its upper Surface is in contact.

For the sake of those, who are pleas'd with seeing the same thing succeed in different manners, we subjoin the two following Experiments, which are in substance the same with the 9th and 10th.

Fig. 7. ABC is a Siphon, in whose narrower, and shorter Leg AB , if it were of a sufficient length, might be

be suspended a Column of Water of the height EF ; but the longer and wider Leg BC will suspend no more than a Column of the length GH .

Exp. 11. This Siphon being fill'd with Water, and held in the same Position as in the Figure, the Water will not run out at C the Orifice of the longer Leg, unless DC , the difference of the Legs AB and BC , exceed the length EF .

Fig. 8. Exp. 12. If the narrower Leg BC be longer than AB , the Water will run out at C , if DC the difference of the Legs exceed EF ; otherwise it will remain suspended.

In these two Experiments it is plain, that the Columns DC are suspended by the attraction of the Peripheries at A , since their lengths are equal to EF , or to the length of the Column, which by the supposition those Peripheries are able to support; whereas the Tubes BC will sustain Columns, whose lengths are equal to GH .

Tho' these Experiments seem to be conclusive, yet it may not be improper to prevent an Objection, which naturally presents it self, and which at first view may be thought sufficient to overturn our Theory.

Fig. 5. For since a Periphery of the Tube ED is able to sustain no more than a Column of the length AF , contain'd in the same Tube; how comes it to sustain a Column of the same length in the wider Tube DC , which is as much greater than the former, as the Section of the wider Tube exceeds that of the narrower?

Fig. 6. Again, if a Periphery of the wider Tube DC be able to sustain a Column of Water in the same Tube, of the length BG ; why will it support no more than a Column of the same length in the narrower Tube ED ?

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Which Queries may likewise be made with regard to the 11th and 12th Experiments.

The answer is easy, for the Moments of those two Columns of Water are precisely the same, as if the sustaining Tubes ED and CD , were continued down to the Surface of the stagnant Water AB ; since the velocities of the Water, where those Columns grow wider, or narrower, are to the velocities at the attracting Peripheries, reciprocally as the different Sections of the Columns.

Fig. 9. Exp. 13. From which consideration arises this remarkable Paradox. That a Vessel being given of whatsoever Form, as ABC , and containing any assignable quantity of Water, how great soever; that whole quantity of Water may be suspended above the Level, if the upper part of the Vessel C be drawn out into a capillary Tube of a sufficient fineness.

But whether this Experiment will succeed, when the height of the Vessel is greater than that, to which Water will be rais'd by the pressure of the Atmosphere, and how far it will be alter'd by a *Vacuum*, I may perhaps have the honour of giving an account to the *Society* some other time, not being perfectly satisfy'd with those Tryals which I have hitherto had the opportunity of making.

Having discover'd the cause of the suspension of Water in capillary Tubes, it will not be difficult to account for the seemingly spontaneous ascent of it. For, since the Water, that enters a capillary Tube as soon as it's Orifice is dipt therein, has it's gravity taken off by the attraction of the Periphery with which it's upper Surface is in contact, it must necessarily rise higher, partly by the pressure of the stagnant Water, and partly by the attraction of the Periphery immediately above that, which is already contiguous to it.

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It might now be shown, how naturally the various, and seemingly contrary appearances of the above mention'd Experiments are deducible from this Theory; but this is so easy, that it is needless to insist upon it; and our discourse upon this minute Subject has been already so tedious, that we could scarce hope for Pardon, unless it were directed to those, who are sensible to how many of the greater, and more considerable, Phænomena of Nature this Doctrine is applicable.

P S. When this Paper was reading before the Society, I found that our incomparable President was already acquainted with the above-mentioned Principle, and I have since met with several Passages in the 3rd Query subjoin'd to the late Edition of his *Opticks* which plainly shew, that he was Master of it, when they were written.

I must do the same Justice to that excellent Mathematician Mr. *John Machin*, Professor of Astronomy in *Gresham College*.

To these two worthy Persons I am obliged for the following Observation, That, what I call a Periphery, or Section of the concave surface of the Tube, is really a small Surface, whose Base is that Periphery, and whose height is the distance, to which the attractive power of the Glass is extended.

