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

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

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

Since the two Columns of Water *A B* 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 *B F*, 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 *B C*, 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 *B C*, remains ſuſpended in the other Leg to the height *A B*.

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 *A B*. But in making theſe two Experiments it is neceſſary that *A G* 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.

Mr.

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

Fig. 2. Let *A B F C* be a capillary Siphon, into the which the Water will riſe above the Level to the height *C F*, and let *B A* be the depth of the Orifice of its longer Leg below the Surface of the Water *D E*. Then the Siphon being fill'd with Water, if *B A* be not greater than *C F*, 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 *F C* will be ſuſpended by ſome power within the Tube, why ſhould not the Column *B A*, 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 *D E*, the Water in the Tube will continue ſuſpended, unleſs *B A* exceed *F C*.

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 *A B* be conſiderably leſs than the height *C F*.

Mr. *Hawksbee* in his Book of Experiments has advanced another Obſervation, namely, that the ſhorter Leg of a Capillary Siphon, as *A B F C*, muſt be immerſt in the Water to the depth *F C*, 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 Phænomenon 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-*

cis.

Fig.

Fig. 3. The Tube *C D* is compoſed of two Parts, in the wider of which the Water will riſe ſpontaneouſly to the height *B F*, but the narrower Part, if it were of a ſufficient length, would raiſe the Water to a height equal to *C D*

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

Exp. 8. *Fig.* 4. The narrower end being immerſt, the Water immediately ſubſides, and ſtands at laſt at the height *D G* equal to *B F*.

From which it is manifeſt, that the ſuſpenſion of the Water in the former of theſe Experimens 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.

Fig.

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 *E F*; but the longer and wider Leg *B C* will ſuſpend no more than a Column of the length *G H*.

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 *D C*, the difference of the Legs *A B* and *B C*, exceed the length *E F*.

Fig. 8. *Exp.* 12. If the narrower Leg *B C* be longer than *A B*, the Water will run out at *C*, if *D C* the difference of the Legs exceed *E F*; otherwiſe it will remain ſuſpended.

In theſe two Experiments it is plain, that the Columns *D C* are ſuſpended by the attraction of the Peripheries at *A*, ſince their lengths are equal to *E F*, or to the length of the Column, which by the ſuppoſition thoſe Peripheries are able to ſupport; whereas the Tubes *B C* will ſuſtain Columns, whoſe lengths are equal to *G H*.

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 *E D* is able to ſuſtain no more than a Column of the length *A F*, contain'd in the ſame Tube; how comes it to ſuſtain a Column of the ſame length in the wider Tube *D C*, 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 *D C* be able to ſuſtain a Column of Water in the ſame Tube, of the length *B G*; why will it ſupport no more than a Column of the ſame length in the narrower Tube *E D*?

Which

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 *E D* and *C D*, were continued down to the Surface of the ſtagnant Water *A B*; 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 *A B C*, 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.

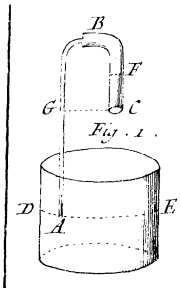
It

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 31ſt 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.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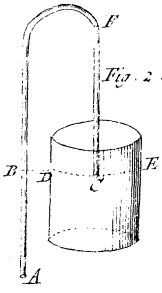
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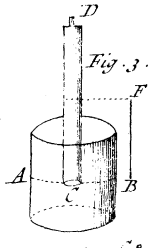
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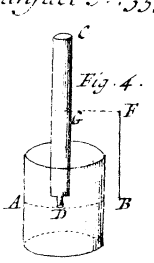
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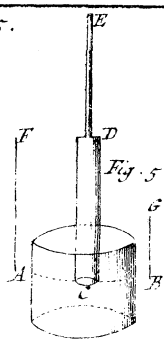
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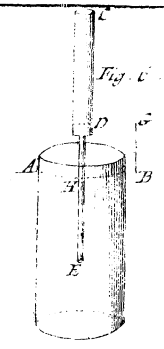
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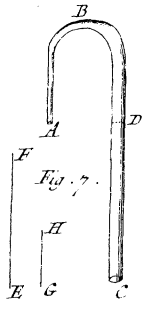
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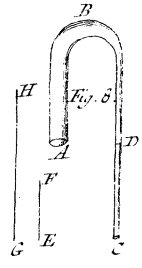
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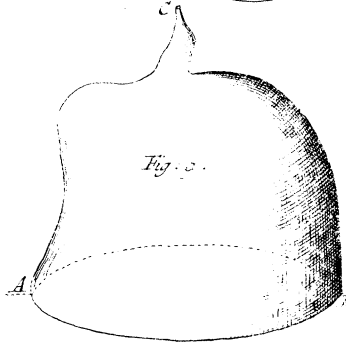
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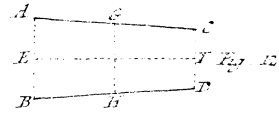
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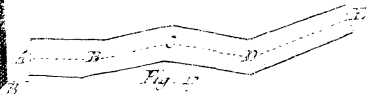
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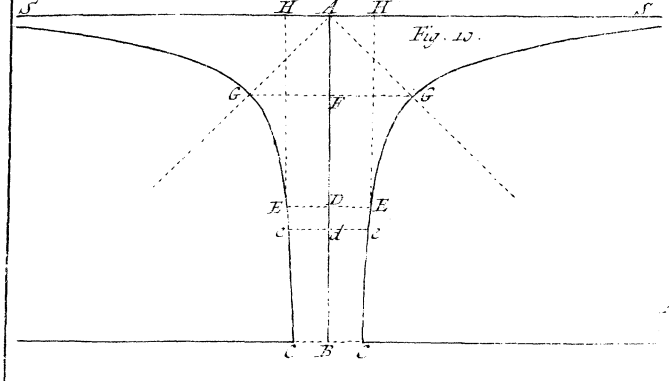
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Fig. 10.
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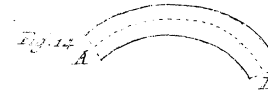
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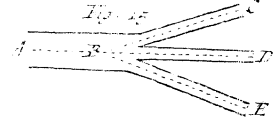
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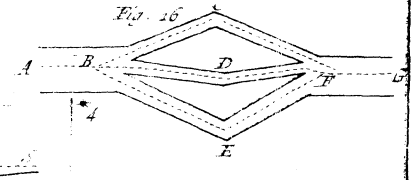
Fig. 16.
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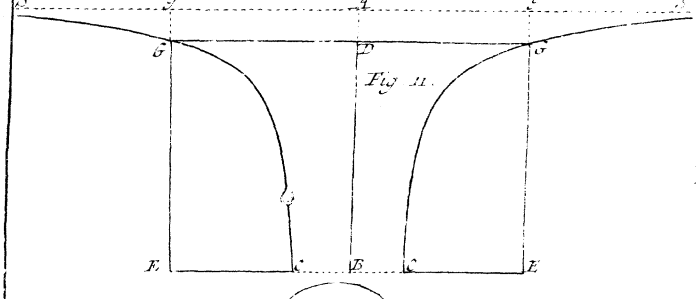
Fig. 11.
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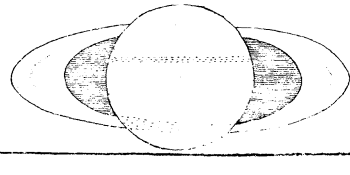
Fig. 19

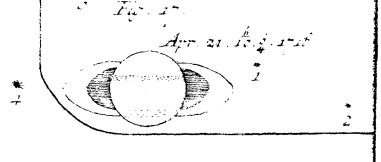
Fig. 17.
Apr. 21. h. 5. 17'.


Fig. 18.
Apr. 22. h. 1m 18'.