LXIX. *A Letter from Mr.* J. Smeaton *to Mr.* John Ellicott, *F. R. S. concerning ſome Improvements made by himſelf in the* Air-Pump.

SIR,

Read April 16, 1752. I HAVE been informed by ſome of my friends, that my endeavours towards completing the air-pump, have been mentioned with approbation, in papers that Mr. Short and Mr. Watſon have lately communicated to the Royal Society. I underſtand likewiſe, that the latter of thoſe gentlemen has, in a very obliging manner, expreſſed an inclination, that I ſhould lay before them a particular account of my improvements therein.

I ſhall always eſteem it a ſingular honour to be thought capable of producing any thing worthy the attention of the Royal Society; and to be my duty and intereſt ſo to do, upon the leaſt intimation of that kind.

Your ſuperior ſkill in mechanics, together with the aſſiſtance you have given me in making trial of my pump, againſt three very good ones of the common conſtruction, as well as the frequent marks of friendſhip you have ſhewn me on all occaſions, encourage me to trouble you with communicating the following to that Society, of which you are a member, and who, of all others, are the moſt proper judges.

I ſhall

I ſhall not take up time with a particular recital of the alterations I have made, for near four years paſt, in order to remove ſome obſtacles, which I imagined hindred the effects, that the theory I ſet out upon ſeemed to promiſe. It will be ſufficient, that I give an account of what has appeared to anſwer beſt, after a great number of different trials; which, tho' ſhort of what I at firſt expected, yet as this pump performs much better than the common ones, my labour may not be thought wholly uſeleſs; and the reſpect, which I have to the Society, would ſtill have prevented me from troubling you or them about it at this time, could I have thought of any alteration, that promiſed materially to improve it.

The principal cauſes of imperfection in the common pumps ariſe, firſt, from the difficulty in opening the valves at the bottom of the barrels; and, 2dly, from the piſton's not fitting exactly, when put cloſe down to the bottom; which leaves a lodgement for air, that is not got out of the barrel, and proves of bad effect, as I ſhall ſhew in the courſe of this paper.

In regard to the firſt of theſe cauſes; the valves of air-pumps are commonly made of a bit of thin bladder, ſtretch'd over a hole generally much leſs than one tenth of an inch diameter; and to prevent the air from repaſſing between the bladder and the plate, upon which it is ſpread, the valve muſt always be kept moiſt with oil or water.

It is well known, that at each ſtroke of the pump the air is more and more rarefied, in a certain progreſſion, which would be ſuch, that an equal proportion

proportion of the remainder would be taken away, was it not affected by the impediments I have mentioned: ſo that, when the ſpring of the air in the receiver becomes ſo weak, as not to be able to overcome the coheſion of the bladder to the plate, occaſioned by the fluid between them, the weight of the bladder, and the reſiſtance that it makes by being ſtretch'd, the rarefaction cannot be carried farther, tho' the pump ſhould ſtill continue to be worked.

It is evident, that the larger the * hole is, over which the bladder is laid, a proportionably greater force is exerted upon it by the included air, in order to lift it up; but the aperture of the hole cannot be made very large, becauſe the preſſure of the incumbent air would either burſt the valve, or ſo far force it down into the cavity, as to prevent its lying flat and cloſe upon the plate, which is abſolutely neceſſary.

To avoid theſe inconveniences as much as poſſible, inſtead of one hole, I have made uſe of ſeven, all of equal ſize and ſhape; one being in the centre, and the other ſix round it: ſo that the valve is ſupported at proper diſtances, by a kind of grating, made by the ſolid parts between theſe holes: And to render the points of contact, between the bladder and grating, as few as poſſible, the holes are made hexagonal, and the partitions filed almoſt to an edge. As the whole preſſure of the atmoſphere can never be exerted upon this

* If we examine the force, that air rarefied 140 times can exert in a common valve through a hole of one tenth of an inch diameter, we ſhall find it not to exceed 6 grains at a medium.

this valve, in the conſtruction made uſe of in this pump; and as the bladder is faſtened in four places inſtead of two, I have made the breadth of the hexagons three tenths of an inch; ſo that the ſurface of each of them is more than nine times greater than common. But as the circumference of each hole is more than three times greater than common, and as the force, that holds down the valve, ariſing from coheſion, is, in the firſt moment of the air's exerting its force, proportionable to the circumference of the hole; the valve over any of theſe holes will be raiſed with three times more eaſe than common. But as the raiſing of the valve over the center-hole is aſſiſted on all ſides by thoſe placed round it; and as they all together contribute as much to raiſe the bladder over the center-hole, as the air immediately acting under it; upon this account the valve will be raiſed with double the eaſe, that we have before ſuppoſed, or with a ſixth part of the force commonly neceſſary.

It is not material to conſider the force of the coheſion, after the firſt inſtant: For, after the bladder begins to riſe, it expoſes a greater ſurface to the air underneath, which makes it move more eaſily. I have not brought into this account the force, that keeps down the valve, that ariſes from the weight of the bladder, and the reſiſtance from its being ſtretch'd; for I look upon theſe as ſmall, in compariſon of the other.

I was not however contented with this conſtruction of the valves, till I had tried what effect would be produced, when they were opened by the motion of the winch, independent of the ſpring of the air:

And tho' the contrivance I made uſe of ſeemed to me leſs liable to objection than any thing I was acquainted with, that had been deſigned for that purpoſe; yet I did not find it to anſwer the end better than what I have already deſcribed; and therefore laid it aſide, as it render'd the machinery much more complex, and troubleſome to execute.

But ſuppoſing all thoſe difficulties to be abſolutely overcome, the other defect, that I mentioned in the common conſtruction, would hinder the rarefaction from being carried on beyond a certain degree. For, as the piſton cannot be made to fit ſo cloſe to the bottom of the barrel, as totally to exclude all the air; as the piſton riſes, this air will expand itſelf; but ſtill preſſing upon the valve, according to its denſity, hinders the air within the receiver from coming out: Hence, were this vacancy to equal the 150th part of the capacity of the whole barrel, no air could ever paſs out of the receiver, when expanded 150 times, tho' the piſton was conſtantly drawn to the top; becauſe the air in the receiver would be *in æquilibrio* with that in the barrel, when in its moſt expanded ſtate. This I have endeavoured to overcome, by ſhutting up the top of the barrel with a plate, having in the middle a collar of leathers, through which the cylindrical rod works, that carries the piſton. By this means, the external air is prevented from preſſing upon the piſton; but that the air, that paſſes thro' the valve of the piſton from below, may be diſcharged out of the barrel, there is alſo a valve applied to the plate at the top, that opens upwards. The conſequence of this conſtruction is, that when the piſton is put down to the bottom of the cylinder, the air in the lodgment under the piſton will evacuate

itſelf ſo much the more, as the valve of the piſton opens more eaſily, when preſſed by the rarefied air above it, than when preſſed by the whole weight of the atmoſphere. Hence, as the piſton may be made to fit as nearly to the top of the cylinder, as it can to the bottom, the air may be rarefied as much above the piſton, as it could before have been in the receiver. It follows therefore, that the air may now be rarefied in the receiver, in duplicate proportion of what it could be upon the common principle; every thing elſe being ſuppoſed perfect.

Another advantage of this conſtruction is, that tho' the pump is compoſed of a ſingle barrel*, yet the preſſure of the outward air being taken off by the upper plate, the piſton is worked with more eaſe § than the common pumps with two barrels: And not only ſo, but when a conſiderable degree of rarefaction is deſired, it will do it quicker; for the terms of the ſeries expreſſing the quantity of air taken away at each ſtroke do not diminiſh ſo faſt, as the ſeries anſwering to the common one.

I have found the gages, that have been hitherto made uſe of, for meaſuring the expanſion of the air, very unfit to determine in an experiment of ſo much nicety.

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* It is obvious that theſe improvements will equally obtain, whether the pump is conſtructed with a ſingle or a double barrel.

§ Becauſe, tho' the preſſure of a column of air, equal to the diameter of the piſton-rod, ſtill preſſes upon it, yet, as there is only the friction of one piſton, and that not loaded with the weight of the atmoſphere; the friction of the leather againſt the ſide of the barrel, and that of the rack and wheel, is much leſs: ſo that, notwithſtanding the addition of friction in the collar of leathers, that of the whole will be leſs.

nicety. I have therefore contrived one of a different ſort, which meaſures the expanſion with certainty, to much leſs than the 1000th part of the whole. It conſiſts of a bulb of glaſs ſomething in the ſhape of a pear, and ſufficient to hold about half a pound of quickſilver. It is open at one end, and at the other is a tube hermetically cloſed at top. By the help of a nice pair of ſcales, I found what proportion of weight a column of mercury, of a certain length, contained in the tube, bore to that, which filled the whole veſſel. By theſe means I was enabled to mark diviſions upon the tube, anſwering to a 1000th part of the whole capacity, which being of about one tenth of an inch each, may, by eſtimation, be eaſily ſubdivided into ſmaller parts. This gage, during the exhauſting of the receiver, is ſuſpended therein by a ſlip-wire. When the pump is worked as much as ſhall be thought neceſſary, the gage is puſhed down, till the open end is immerged in a ciſtern of quick-ſilver placed underneath: The air being then let in, the quickſilver will be driven into the gage *; till the air remaining in it becomes of the ſame denſity with the external; and as the air always takes the higheſt place, the tube being uppermoſt, the expan-ſion will be determined by the number of diviſions occupied by the air at the top.

The degree, to which I have been able to rarefy the air in experiment, has generally been about 1000 times,

* The bulb of the gage may be emptied of its quickſilver, without taking that out of the tube; and the tube being held horizontal, the column of mercury in it will have power to contract or expand the air at the top.

times, when the pump is put clean together: But the moiſture, that adheres to the inſide of the barrel, as well as other internal parts, upon letting in the air, is in the ſame ſucceeding trials worked together with the oil, which ſoon renders it ſo clammy, as to obſtruct the action of the pump upon a fluid ſo ſubtil as the air is, when ſo much expanded; but in this caſe it ſeldom fails to act upon the air in the receiver, till it is expanded 500 times: And this I have found it to do, after being frequently uſed for ſeveral months, without cleaning. I have alſo generally found it to perform beſt, the firſt trial at each time of uſing; tho' nothing had been at it from the time preceding; which, after a great many trials made with this view, I alſo attribute to the vapours of the air mixing with the oil. An experiment, where the air was expanded 1000 times, was tried about two years ſince in your preſence; at which were preſent alſo Dr. Knight and Mr. Canton; and I lately did the ſame thing with Mr. Watſon. The pump, which I intend myſelf the honour of ſhewing the Society, is the ſame, that I juſt now mention'd, and the ſecond that I made, with a view to improve upon this principle.

The degree of rarefaction, produced by the beſt of the three pumps, that you procured the trial of, and which you eſteemed good in their kind, and in complete order, never exceeded 140 times, when tried by the gage above deſcribed.

I have alſo endeavoured to render the pneumatic apparatus more ſimple and commodious, by making this air-pump act as a condenſing engine at pleaſure, by ſingly turning a cock. This not only enables us

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to try any experiments under different circumſtances of preſſure, without changing the apparatus, but renders the pump an univerſal engine, for ſhewing any effect, that ariſes from an alteration in the denſity or ſpring of the air. Thus, with a little addition of apparatus, it ſhews the experiments of the air-fountain, wind-gun, *&c.*

This is done in the following manner: The air above the piſton being forcibly driven out of the barrel at each ſtroke, and having no-where to eſcape, but by the valve at the top; if this valve be connected with the receiver, by means of a pipe, and at the ſame time the valve at the bottom, inſtead of communicating with the receiver, be made to communicate with the external air, the pump will then perform as a condenſer.

The mechaniſm is thus ordered. There is a cock with three pipes placed round it, at equal diſtances. The key is ſo pierced, that any two may be made to communicate, while the other is left open to the external air. One of theſe pipes goes to the valve at the bottom of the barrel; another goes to the valve at the top, and a third goes to the receiver. Thus, when the pipe from the receiver, and that from the bottom of the barrel, are united, the pump exhauſts: But turn the cock round, till the pipe from the receiver, and that from the top of the barrel, communicate, and it then condenſes. The third pipe, in one caſe, diſcharges the air, taken from the receiver, into the barrel; and in the other, lets it into the barrel,

barrel, that it may be forced into the receiver. I am,

SIR,

Furnival's-Inn-court, April 16, 1752.

Your moſt humble ſervant,

J. Smeaton.

P. S. I have alſo added ſome draughts, and letters of reference, in order to explain myſelf more fully.

Figure I.

Is a perſpective view of the principal parts of the pump together.

A is the barrel.

B the ciſtern, in which are included the cock, with ſeveral joints. Theſe are cover'd with water to keep them air-tight. A little cock to let the water out of the ciſtern, is marked 6.

C c c is the triangular handle of the key of the cock: which, by the marks on its arms, ſhews how it it muſt be turned, that the pump may produce the effect deſired.

D H is the pipe of communication between the cock and the receiver.

E is the pipe, that communicates between the cock and the valve, on the upper plate of the barrel.

F is the upper plate of the pump, which contains the collar of leathers *d*, and *V* the valve, which is covered by the piece *f*.

GI

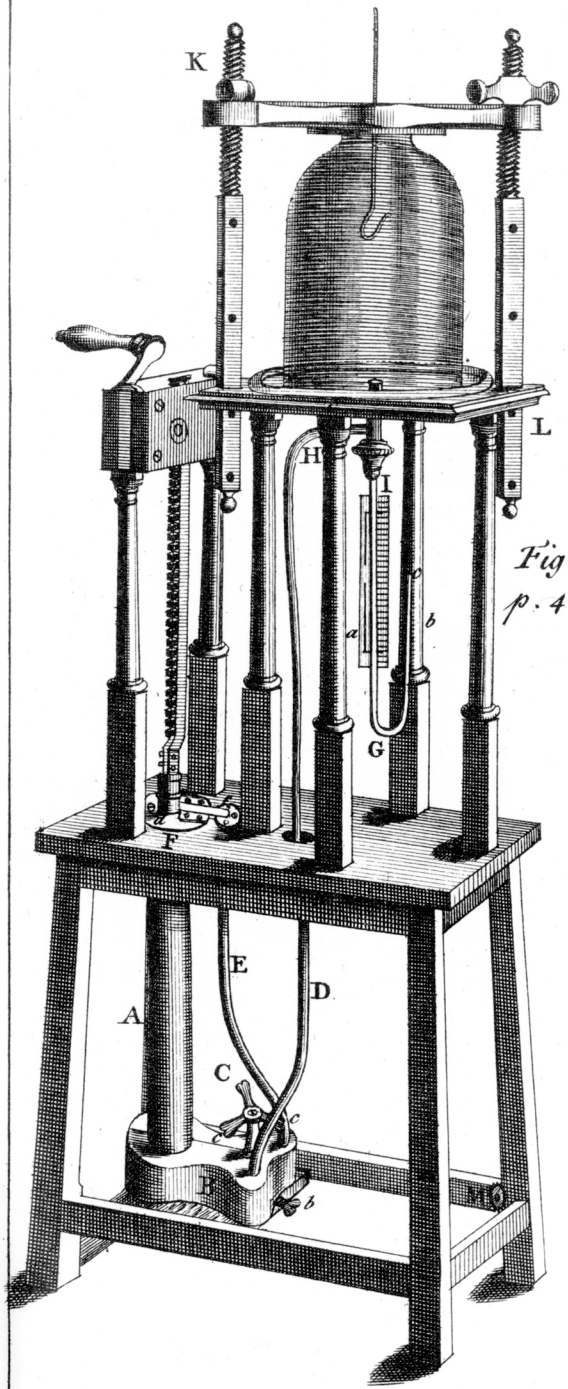

Fig. 1.
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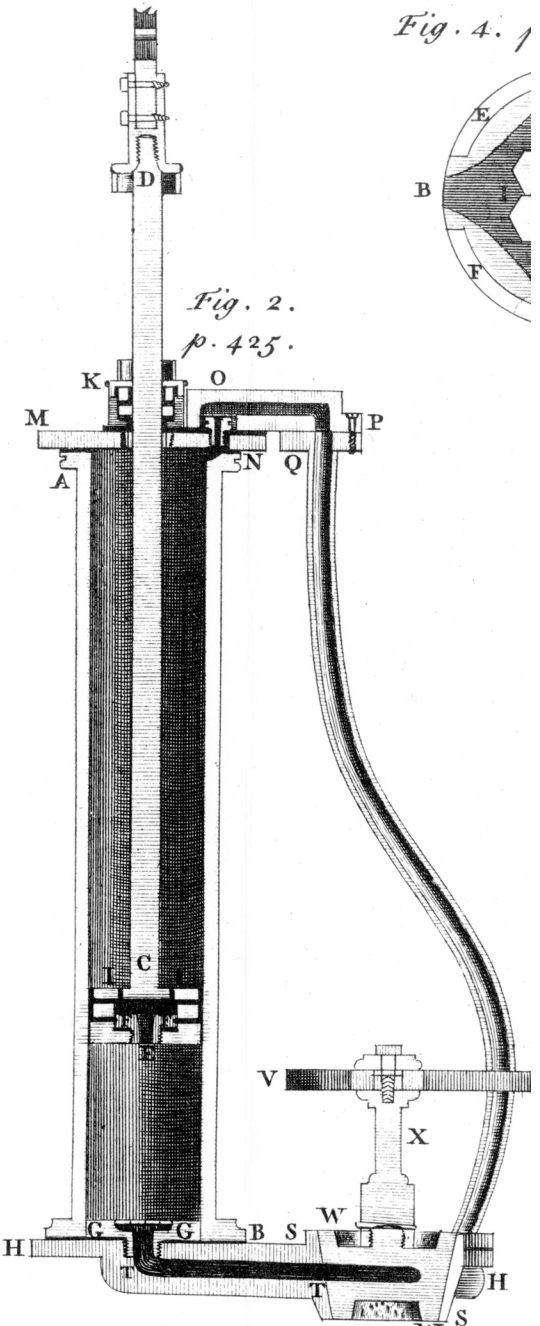


Fig. 2.
p. 425.

Fig. 4. p

Fig. 4. p. 427.

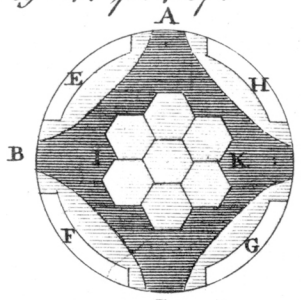


Fig. 2. p. 425.

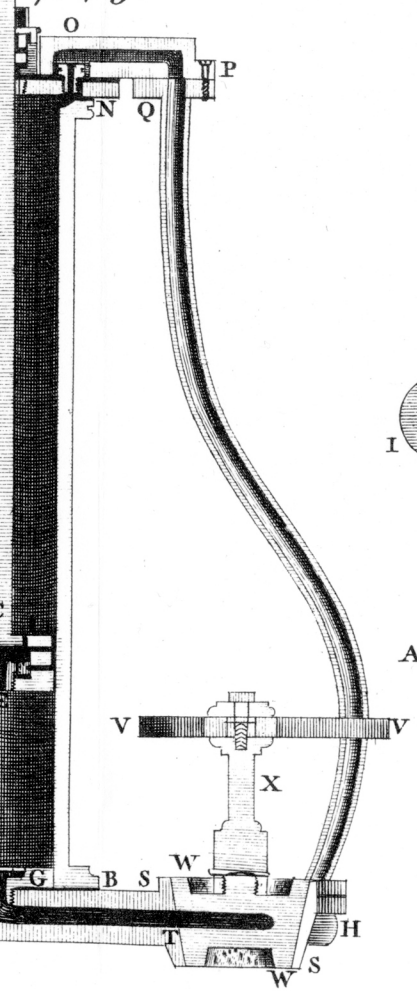
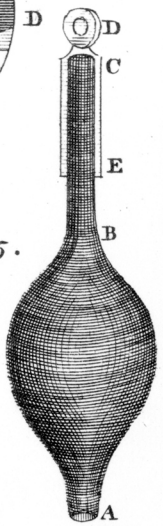


Fig. 5. p. 428.



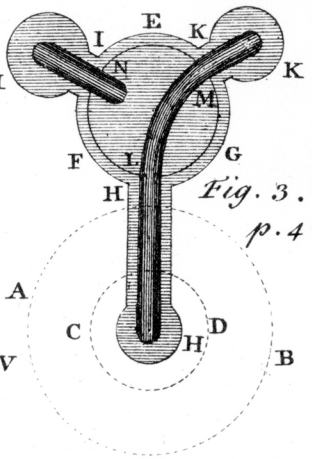
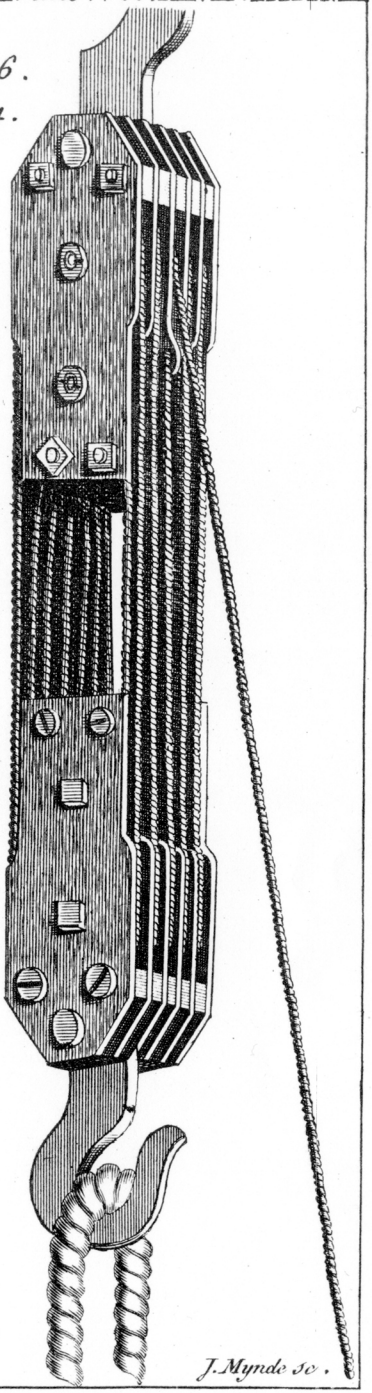
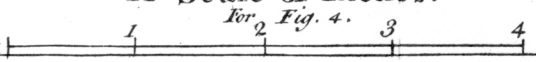


Fig. 3. p. 426.

Fig. 6. p. 494.



A Scale of Inches. For Fig. 4.



J. Mynde sc.

GI is the ſiphon-gage; which ſcrews on and off, and is adapted to common purpoſes. It conſiſts of a glaſs tube hermetically ſealed at *c*, and furniſhed with quickſilver in each leg; which, before the pump begins to work, lies level in the line *a b*; the ſpace *b c* being filled with air of the common denſity. When the pump exhauſts, the air in *b c* expands, and the quickſilver in the oppoſite leg riſes, till it becomes a counter-balance to it. Its riſe is ſhewn upon the ſcale *Ie*, by which the expanſion of the air in the receiver may be nearly judged of. When the pump condenſes, the quickſilver riſes in the other leg, and the degree may be nearly judged of by the contraction of the air in *b c*: marks being placed at $\frac{1}{2}$ and $\frac{1}{3}$ of the length of *b c* from *c*; which ſhews when the receiver contains double or treble its common quantity.

KL is a ſcrew-frame to hold down the receiver, in condenſing experiments, which takes off at pleaſure; and is ſufficient to hold down a receiver, the diameter of whoſe baſe is 7 inches, when charged with a treble atmoſphere: in which caſe it acts with a force of about 1200 pounds againſt the ſcrew-frame.

M is a ſcrew, that faſtens a bolt, which ſlides up and down in that leg, by means whereof the machine is made to ſtand faſt on uneven ground.

Fig. II.

Is a perpendicular ſection of the barrel and cock, &c. where

AB repreſents the barrel.

CD the rod of the piſton, which paſſes through
MN the plate, which cloſes the top of the barrel.
K is the collar of leathers, through which the piſton-rod paſſes. When the piſton is at the bottom of the cylinder, the upper part of *K* is covered by the cap at *D*, to keep out duſt, *&c.*
L is the valve on the upper plate, which is covered by the piece
OP, which is connected with the pipe
QR, which makes the communication between the valve and cock.
CE is the piſton; and
EFF is the piſton-valve.
II are two little holes to let the air paſs from the piſton-valve into the upper part of the barrel.
GGK is the principal valve at the bottom of the cylinder.
IIH is a piece of metal, into which the valve *GGK* is ſcrew'd, and cloſes the bottom of the cylinder; out of which alſo is compoſed
SS the cock, and
KTT the duct from the cock to the bottom of the barrel.
WW is the key of the cock.
X the ſtem; and
VV the handle.

Fig. III.

Is an horizontal ſection of the cock, through the middle of the duct *TT*.

AB repreſents the bigneſs of the circular plate, that cloſes the bottom of the barrel.

CD

CD repreſents the bigneſs of the inſide of the barrel.

EFG is the body of the cock; the outward ſhell being pierced with 3 holes at equal diſtances, and correſponding to the three ducts *HH*, *II*, *KK*, whereof

HH is the duct, that goes to the bottom of the barrel.

II, the duct, that communicates with the top of the barrel; and

KK is the duct, that paſſes from the cock to the receiver.

LMN is the key, or ſolid part of the cock, moveable round in the ſhell *EFG*. When the canal *LM* anſwers to the ducts *HH* and *KK*, the pump exhauſts, and the air is diſcharged by the perforation *N*. But the key *LMN* being turned till the canal *LM* anſwers to *II* and *KK*, the perforation *N* will then anſwer to *HH*; and in this caſe the pump condenſes. Laſtly, when *N* anſwers to *KK*, the air is then let in or diſcharged from the receiver, as the circumſtance requires.

Fig. IV.

Is the plan of the principal valve.

ABCD repreſents the bladder faſten'd in 4 places, and ſtretch'd over the 7 holes *IK*, formed into an hexagonal grating; which I ſhall call the honeycomb.

EFGH ſhews where the metal is a little protuberant, to hinder the piſton from ſtriking againſt the bladder.

Fig. V.

Repreſents the new gage; which I call the pear-gage. It is open at *A*; *BC* is the graduated tube, which is hermetically cloſed at *C*, and is ſuſpended by the piece of braſs *DE*, that is hollowed into a cylinder, and claſps the tube.

LXX. *An Account of* Aphyllon *and* Dentaria heptaphyllos *of* Cluſius, *omitted by Mr.* Ray: *by Mr.* William Watſon, *F. R. S.*

Read April 16, 1752.

MR. Watſon preſented to the Society ſome ſpecimens of two plants, now in flower, which he ſaid were not frequently found in England. One of them was the *Anblatum* of Cordus, or *Aphyllon* of John Bauhin. This plant is denominated *Squamaria* by Rivinus, and *Dentaria crocodylia* by Tabernamontanus. Linnæus, in the *Flora Suecica*, calls it *Lathræa caule ſimpliciſſimo, corollis nutantibus, labio inferiore trifido.* Mr. Ray, in his *Synopſis plantarum Angliæ*, takes notice of its being found near Darking in Surrey, but the plant now preſented was collected near Harefield in Middleſex.

The other plant offered was the *Dentaria heptaphyllos baccifera* of Caſpar Bauhin, or *Dentaria tertia baccifera* of Cluſius. This plant is treated of by Linnæus, in the *Hortus Cliffortianus*, and by Van Royen, in the *Floræ Leydenſis prodromus*, under the appellation of *Dentaria foliis inferioribus palmatis, ſummis ſimplicibus.*

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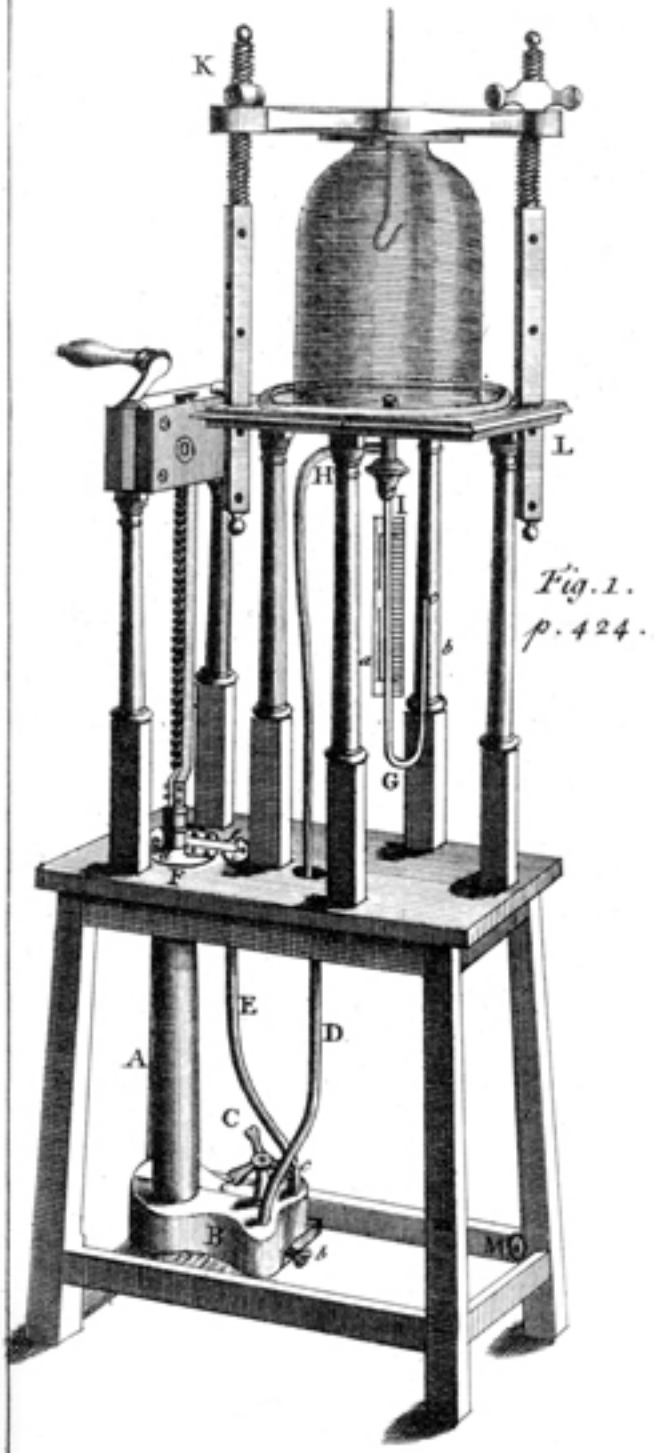

Fig. 1.
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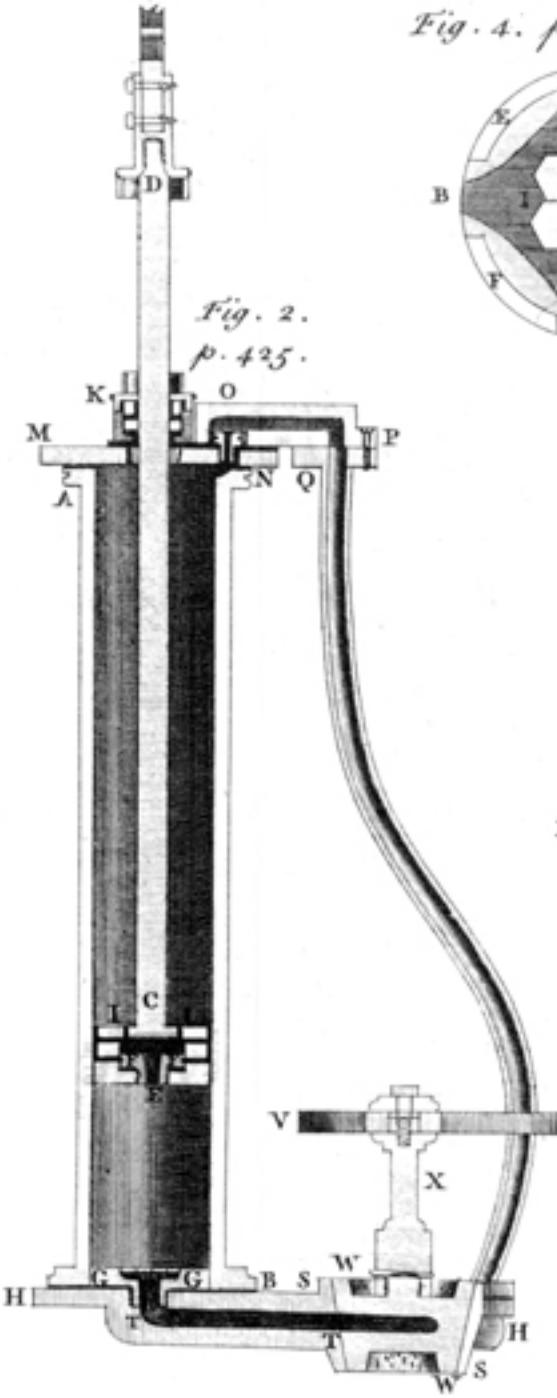

Fig. 2.
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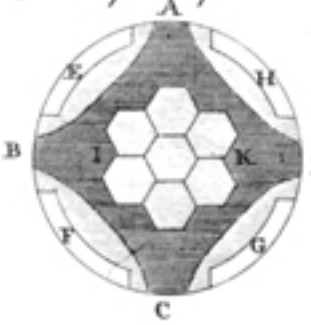
Fig. 4. p. 427.



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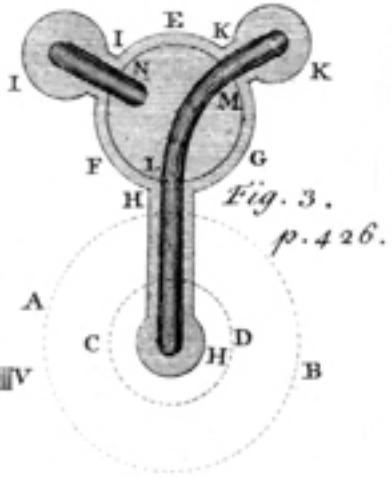

Fig. 3.
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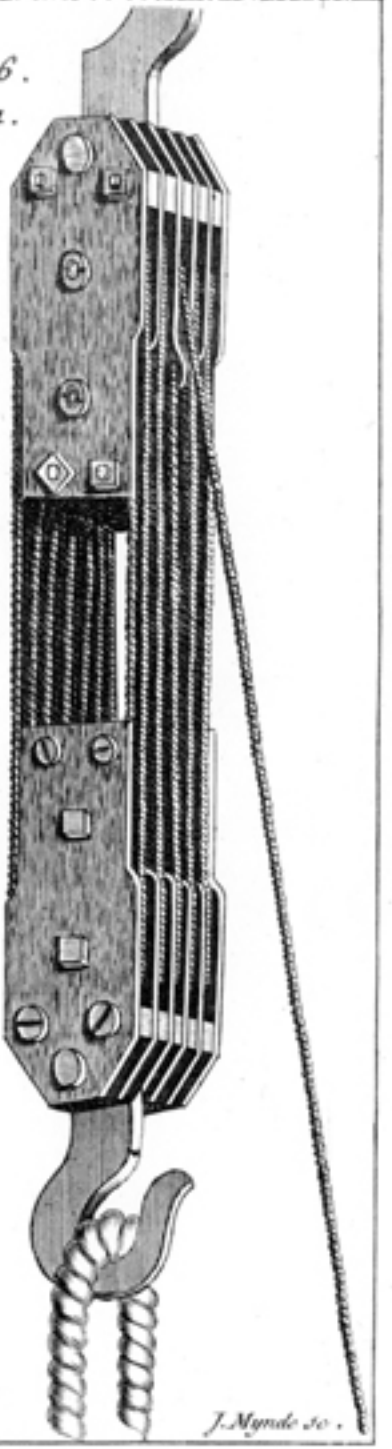

Fig. 6.
p. 494.

A Scale of Inches.
For Fig. 4.
1 2 3 4

J. Mynde sc.