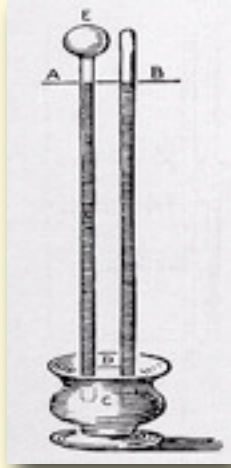


Physics of gases and phenomena of heat



Evangelista Torricelli

(1608-1647)



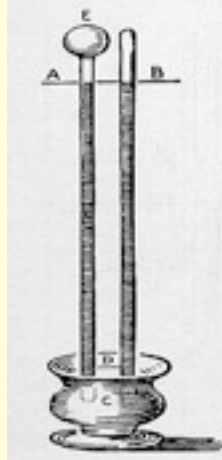
"...We have made many vessels of glass like those shown as A and B and with tubes two cubits long. These were filled with quicksilver, the open end was closed with the finger, and they were then inverted in a vessel where there was quicksilver C; then we saw that an empty space was formed and that nothing happened in the vessel when this space was formed; the tube between A and D remained always full to the height of a cubit and a quarter and an inch high...

Water also in a similar tube, though a much longer one, will rise to about 18 cubits, that is, as much more than quicksilver does as quicksilver is heavier than water, so as to be in equilibrium with the same cause which acts on the one and the other..."

Letter to Michelangelo Ricci, June 11, 1644



Evangelista Torricelli (1608-1647)



"We live immersed at the bottom of a sea of elemental air, which by experiment undoubtedly has weight, and so much weight that the densest air in the neighbourhood of the surface of the earth weighs about one four-hundredth part of the weight of water..."

Letter to Michelangelo Ricci, June 11, 1644

In July 1647 Valeriano Magni
performed experiments
on the vacuum in the presence
of the King of Poland
at the Royal Castle in Warsaw



DEMONSTRATIO
OCULARIS.

*Loci sine locato.
Corporis successive moti in vacuo:
Luminis nulli corpori inherens.*

A
VALERIANO MAGNO
FRATRE CAPVCINO,
exhibita.

SERENISS. PRINCIPIBUS
VLADISLAO IV.
REGI,

LVDOVICÆ MARIÆ
REGINÆ
POLONIÆ & SVECIE,
Magnis Ducibus Lithuaniz, &c.
Virgini Deiparæ ex voto sacra et dicata.

VARSAVIÆ.
In Officina PAULI ELERT S. R. M. Typographi.



Blaise Pascal (1623-1662)



"I am searching for information which could help decide whether the action attributed to *horror vacui* really results from it or perhaps is caused by gravity and the pressure of air. I have planned an experiment which should solve this question, if performed with an adequate accuracy. The well known experiment with vacuum should be made several times on the same day, with the same tube, and the same quicksilver, at the bottom and on the top of a hill of the height of at least five to six hundred toises, to check whether the height of quicksilver will be the same or different in these two..."

Pascal's letter to his brother-in-law Florin Périer, November 15, 1647



"Such an experiment is not easy because a sufficiently high mountain must be found close to a town, and there must be someone able to perform the experiment with adequate accuracy... I am happy that I found both the place and the right person, because the town Clermont is at the foot of the mountain Puy-de-Dôme which is 500 toises high, and I hope that you would do me a favour to make the experiment yourself..."

Pascal's letter to his brother-in-law Florin Périer, November 15, 1647

Letter from Périer to Pascal, September 22, 1648

"On Saturday, September 19, at about five o'clock in the morning the weather looked quite good and the top of Puy-de-Dôme was free from clouds. Thus I decided to climb the mountain that day. I sent messages to several distinguished citizens of Clermont who expressed desire to accompany me; there were several clergymen and the rest secular: among the clergymen there was Reverend Father Superior Bannier, a Canon of the Cathedral, Monsieur Mosnier, and among the secular - Messieurs La Ville and Bégon, councillors, and Monsieur La Porte, doctor of medicine; all were very knowledgeable, so that I was delighted to be able to make the experiment in their company. We therefore met on that day at eight o'clock in the morning in the garden of the Pères Minimes, which is in almost the lowest part of the town, where the experiment was begun in the following way:"

Letter from Périer to Pascal, September 22, 1648

"First, I poured into a vessel sixteen pounds of quicksilver, which I had purified during the three preceding days; and taking two tubes of glass of equal size, each about four feet long, hermetically sealed at one end and open at the other, I made with each of them the ordinary experiment of the vacuum in the same vessel, and when I brought the two tubes near each other without lifting them out of the vessel, it was found that the quicksilver which remained in each of them was at the same level, and that it stood in each of them above the quicksilver in the vessel twenty-six inches three lines and a half. I repeated this experiment twice in the same place, with the same tubes, with the same quicksilver and in the same vessel; and found always that the quicksilver in the tubes was still at the same level and the same height as I found it the first time.."

Letter from Périer to Pascal, September 22, 1648

"When this had been done, I left one of the two tubes in the vessel, for continual observation: I marked on the glass the height of the quicksilver, and leaving the tube in its place, I begged the Reverend Father Chastin, one of the inmates of the house, a man as pious as he is capable, who thinks very clearly in matters of this sort, to take the trouble to observe it from time to time during the day, so as to see if any change occurred."

Letter from Périer to Pascal, September 22, 1648

"And with the other tube and a part of the same quicksilver, I ascended with all these gentlemen to the top of the Puy-de-Dôme, which is higher than the Minimes by about five hundred toises, where, when we made the same experiments in the same way as I had at the Minimes, it was found that there remained in the tube no more than twenty-three inches two lines of quicksilver, whereas at the Minimes there was found in the same tube a height of twenty-six inches, three lines and a half; and so there was between the heights of the quicksilver in these experiments a difference of three inches one line and a half: this result so filled us with admiration and astonishment, and so much surprised us, that for our own satisfaction we wished to repeat it."

Letter from Périer to Pascal, September 22, 1648

"I therefore tried the same thing five times more, with great accuracy, at different places on the top of the mountain, once under cover in the little chapel which is there, once exposed, once in a shelter, once in the wind, once in good weather, and once during the rain and the mists which came over us sometimes, having taken care to get rid of the air in the tube every time; and in all these trials there was found the same height of the quicksilver, twenty-three inches two lines, which makes a difference of three inches one line and a half from the twenty-six inches three lines and a half which were found at the Minimes; this result fully satisfied us..."

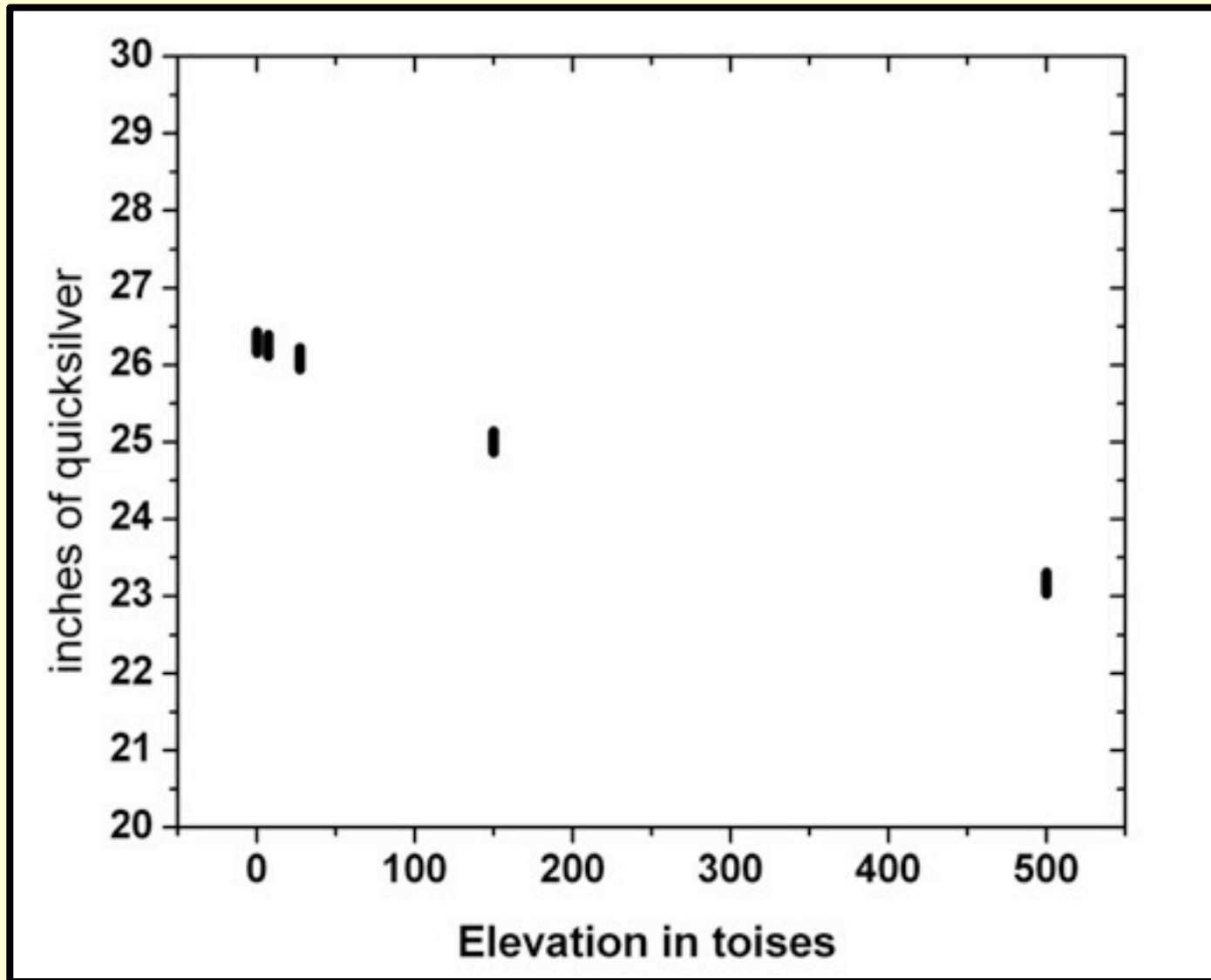


Pascal's comment on this letter:

"This account cleared up all my difficulties and I do not conceal the fact that I was greatly delighted with it; and since I noticed that the distance of twenty toises in height made a difference of two lines in the height of the quicksilver, and that six or seven toises made one of about half a line, a fact which it was easy to test in this city, I made the ordinary experiment of the vacuum at the top and at the bottom of the tower of Saint-Jacques de-la-Boucherie, which is from twenty-four to twenty-five toises high: I found a difference of more than two lines in the height of the quicksilver; and then I made the same experiment in a private house, with ninety-six steps in the stairs, where I found very plainly a difference of half a line; which agrees perfectly with the account of P  rier."

Recit de la Grande Experience dr l'Equilibre de Liqueurs, Paris 1648

Measurements by P rier and Pascal



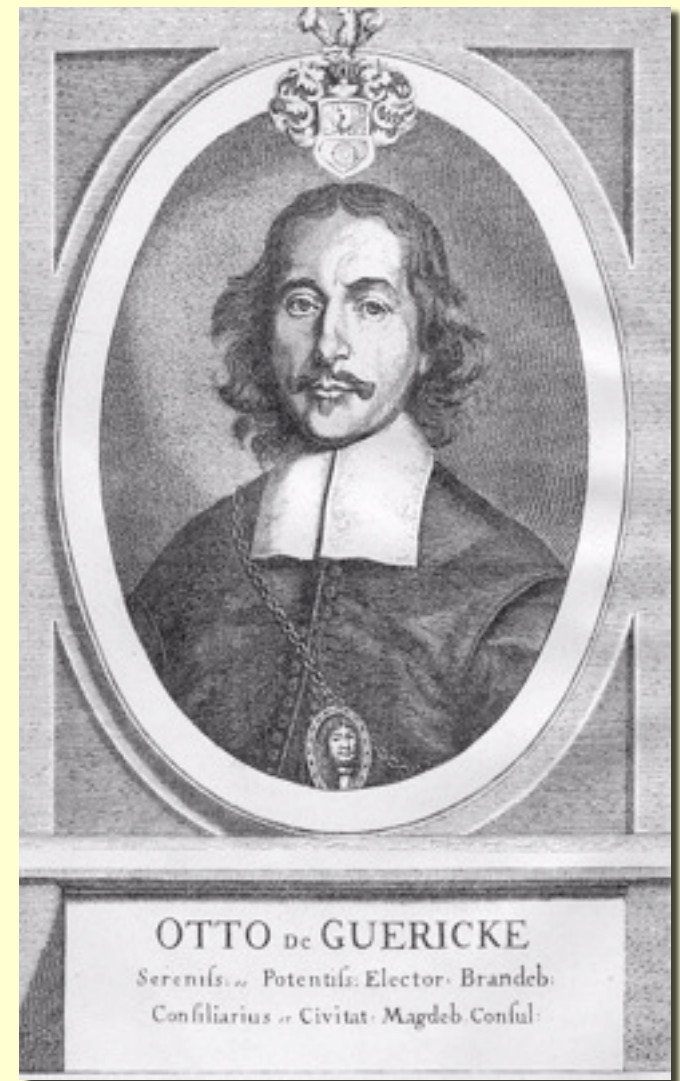
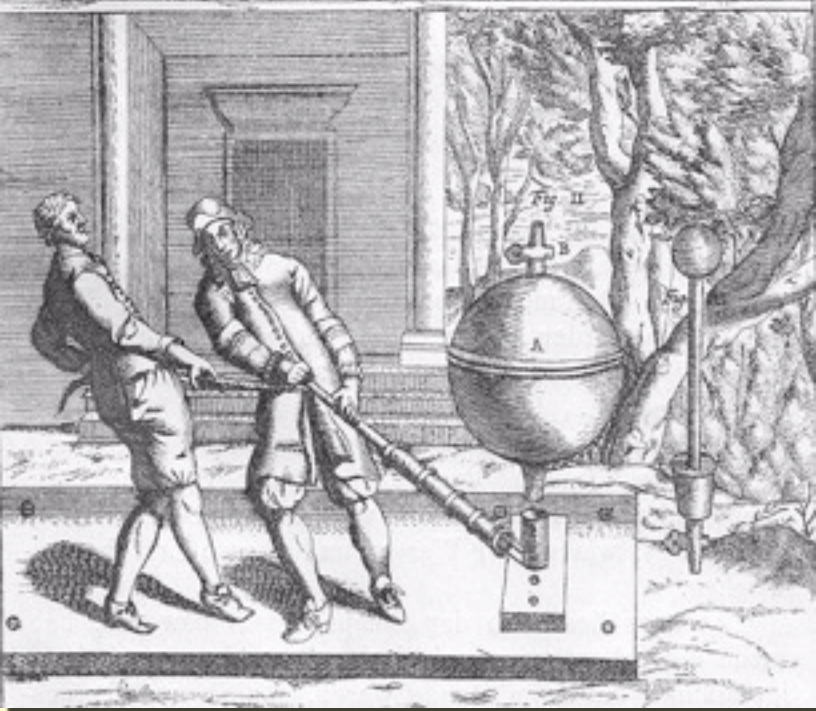
Disbelief in vacuum

25. *That there is no Vacuum in the Top of the Tube.*

25. First then, This may give Occasion to those who believe the Possibility of a *Vacuum* to observe; *That there is no Vacuum in the Top of the Tube*, but the Place which is left by the Mercury, is filled by some Matter, because the visible Objects behind the Tube, (1) affect our Eyes still, and are as plainly sensible as they were before, which they could not do, if there were a *Vacuum*; because their Action would be interrupted. And if the Eye were placed directly against the Tube, we ought not to see any more than in the Dark, or then if an opake Body were between; but we find it otherwise.

Otto Guericke (1602-1686)





Guericke's first pumps

Guericke, Experimenta nova

First Attempt to Produce a Vacuum by Drawing Out Water



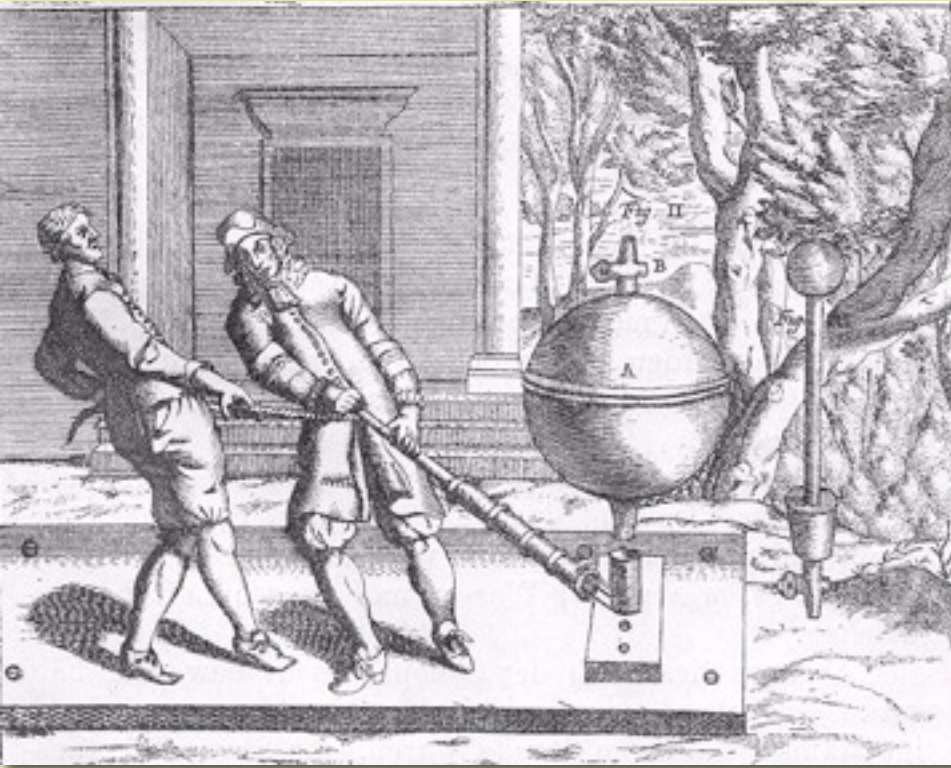
"While I was engaged in the consideration of the immeasurability of space and considered that it must be everywhere present, I thought of the following investigation.

I thought of filling a wine or beer cask with water and caulking it everywhere so that the outside air could not enter. In the

lower part of the cask a metal tube was to be introduced by means of which the water could be drawn out; the water then, in consequence of its weight would sink, and leave behind it in the cask a space empty of air and therefore of any body.

That the result should correspond to this plan, I arranged a brass force pump, *abc*, like those used for fires, with a piston *c* or *f* and a plug *g* which was worked very accurately so entrance of water and air came to an end; therefore, we obtained an only half-emptied cask..."

Second Attempt to Obtain Vacuum by Drawing Out Air



"After the porosity of wood was proved by inspection, as well as by the investigation, it appeared to me that for my purposes a copper sphere (which the Reverend Father Schott, in his book on the Magdeburgian investigation, calls "Cacabus") would be more suitable. This sphere *A* contained from 60 to 70

Magdeburgian quarts and was furnished with a brass stopcock *B* at the top; at the bottom the pump was introduced and joined closely to it. Then I again undertook, as before, to draw out water and air."

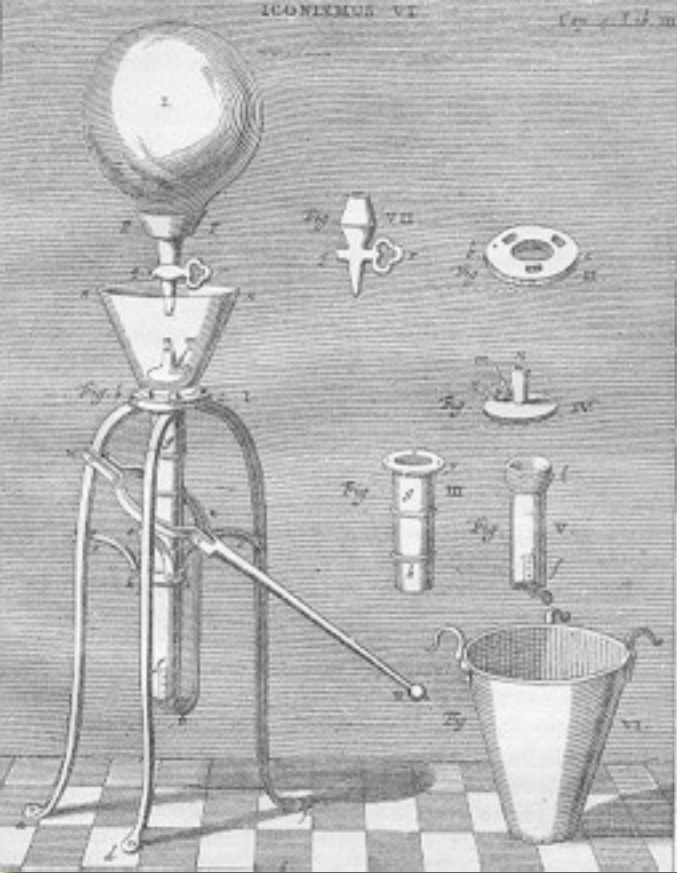
Second Attempt to Obtain Vacuum by Drawing Out Air

"At first the piston moved easily, but soon it became more difficult to move it, so that two strong men were hardly able to pull the piston out. While they were still occupied with pulling it in and out, and already believed that nearly all the air was drawn out, suddenly with a loud noise and to the astonishment of all the metal sphere was crushed in as a cloth can be rolled up between the fingers, or as if the sphere had been thrown down from the summit of a tower with a violent shock.

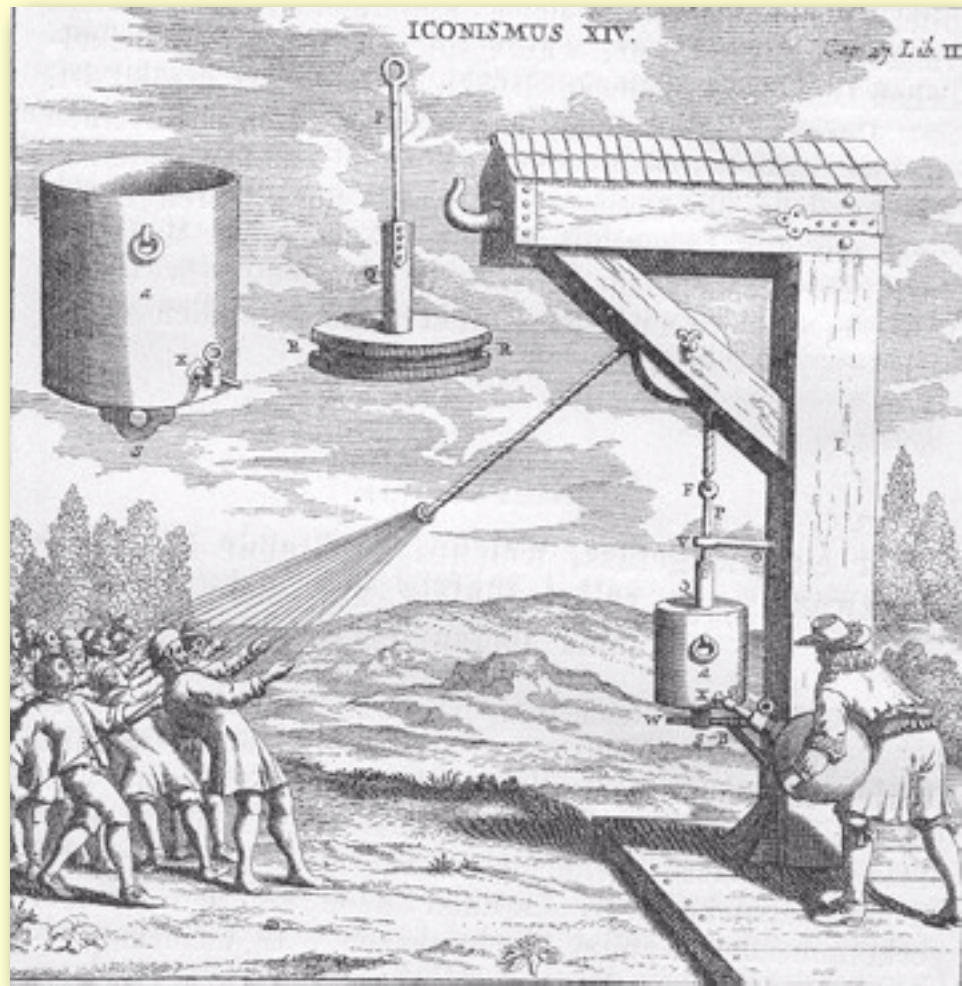
I believe that the cause of this was the inexpertness of the workmen, who perhaps had not made this sphere exactly spherical. The flat part, wherever it was, could not sustain the pressure of the surrounding air, whereas on the other hand an exactly made sphere could easily have sustained it on account of the mutual support of its parts which sustain each other in overcoming resistance."

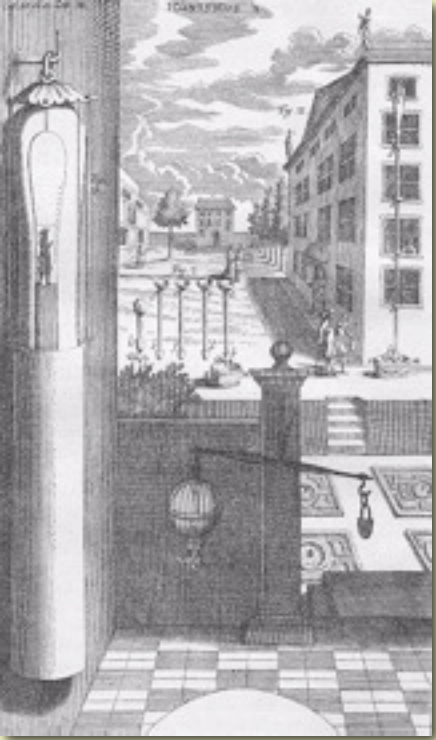
”It was therefore necessary that the workmen should make a perfectly round sphere. From this the air was pumped out, at first easily but with great trouble toward the end.

As a proof that the sphere was completely evacuated, we have the circumstance that at last no more air passed out of the upper valve of the pump. Thus for the second time a vacuum was obtained. On opening the stop-cock *B*, the air rushed with such force into the copper sphere that it seemed as if it would draw in a man standing before it. If the face was brought fairly near, the breath was taken away and one could not hold one's hand above the stop-cock without the risk that it would be violently drawn to it.”

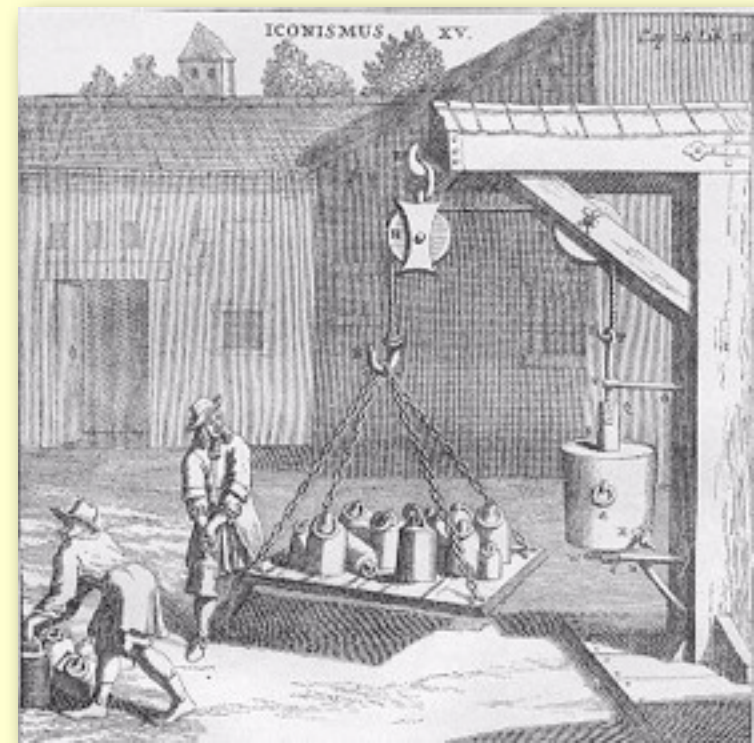
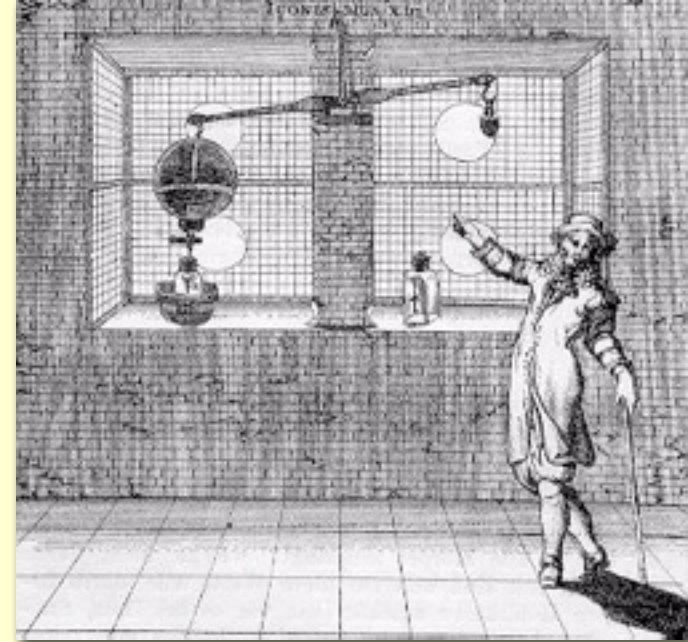


Guericke's second pump

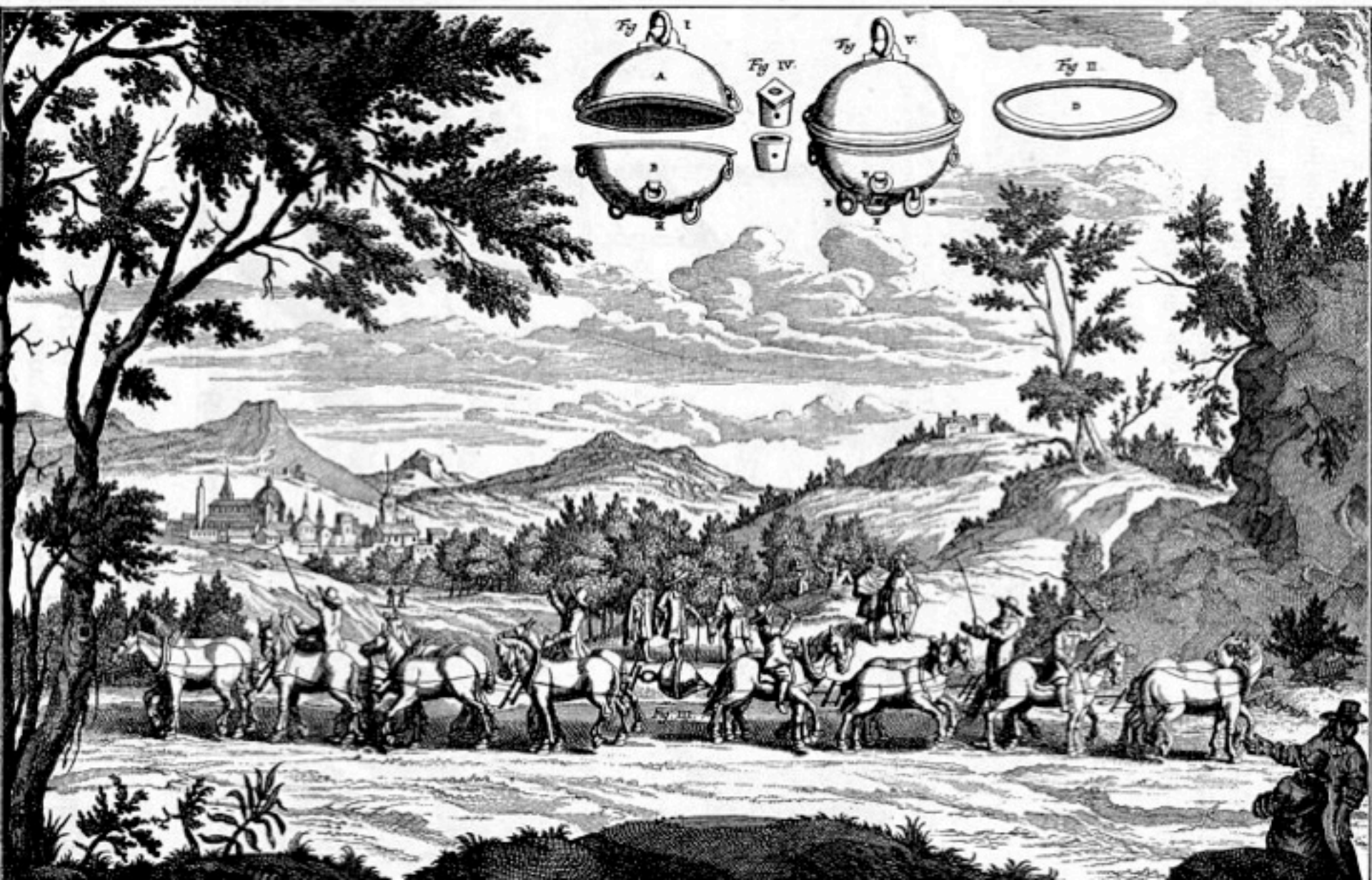




Guericke's experiments



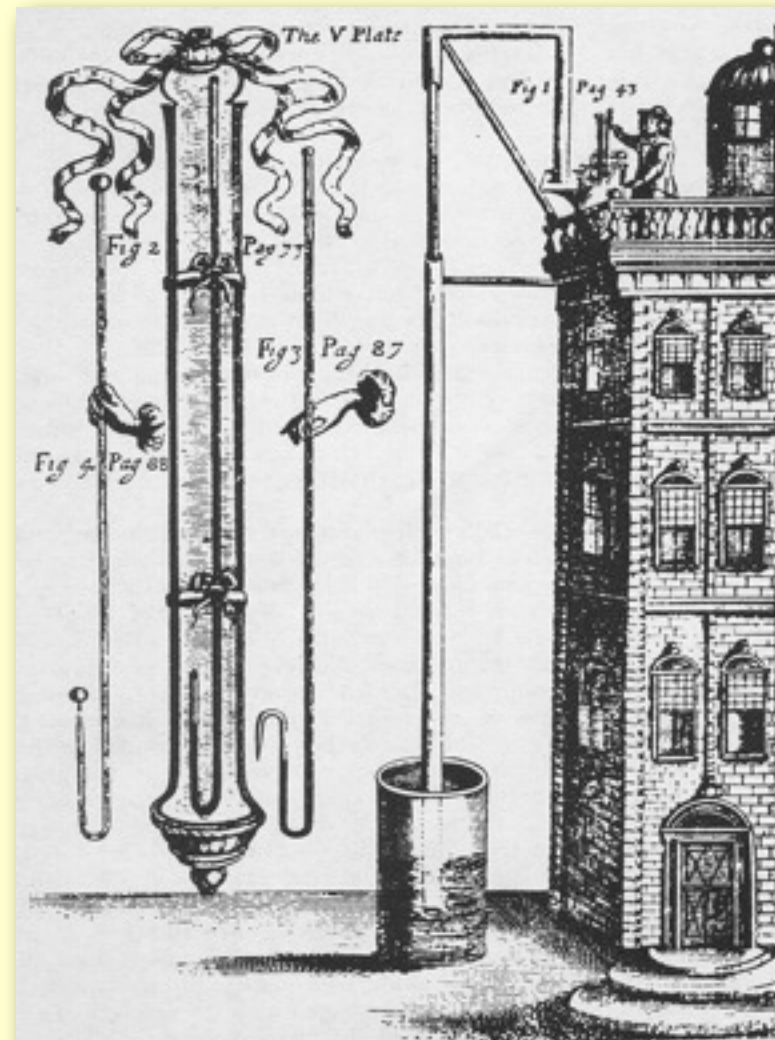
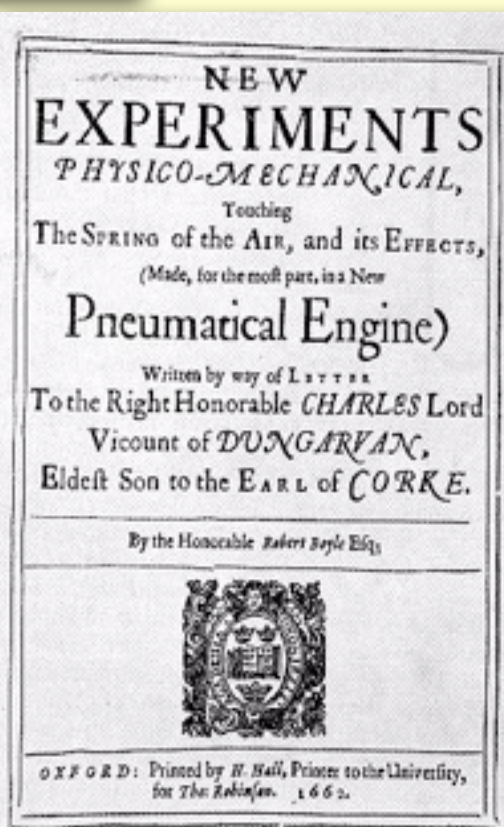
Public demonstration of the "Magdeburg hemispheres" Regensburg, 1657





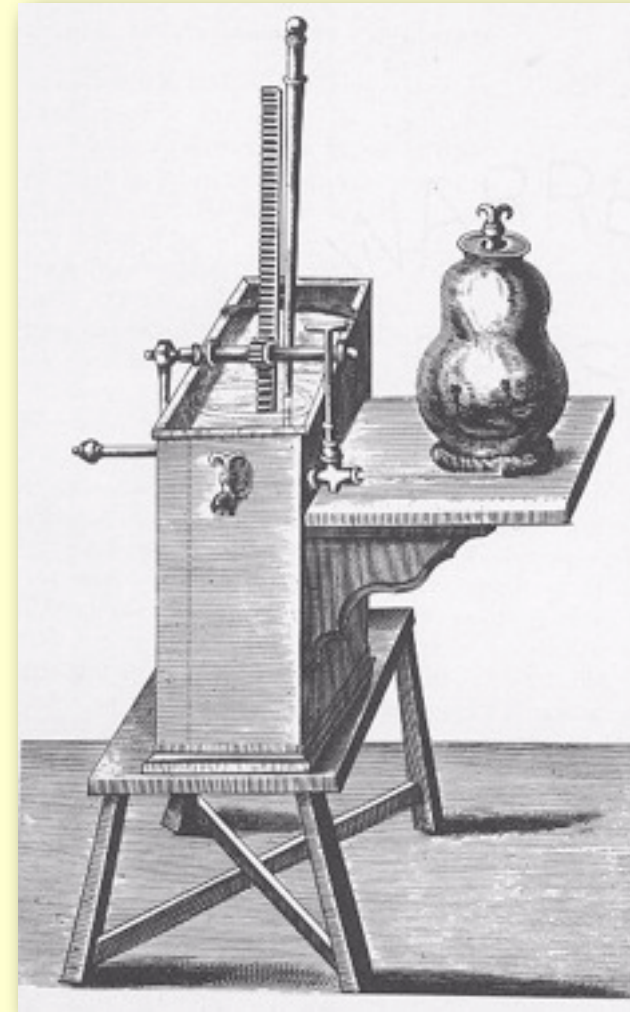
Robert Boyle

(1627-1691)



Boyle's
first pump

Boyle's
second pump



Checking Galileo's conjecture that in a vacuum
all bodies fall with equal acceleration



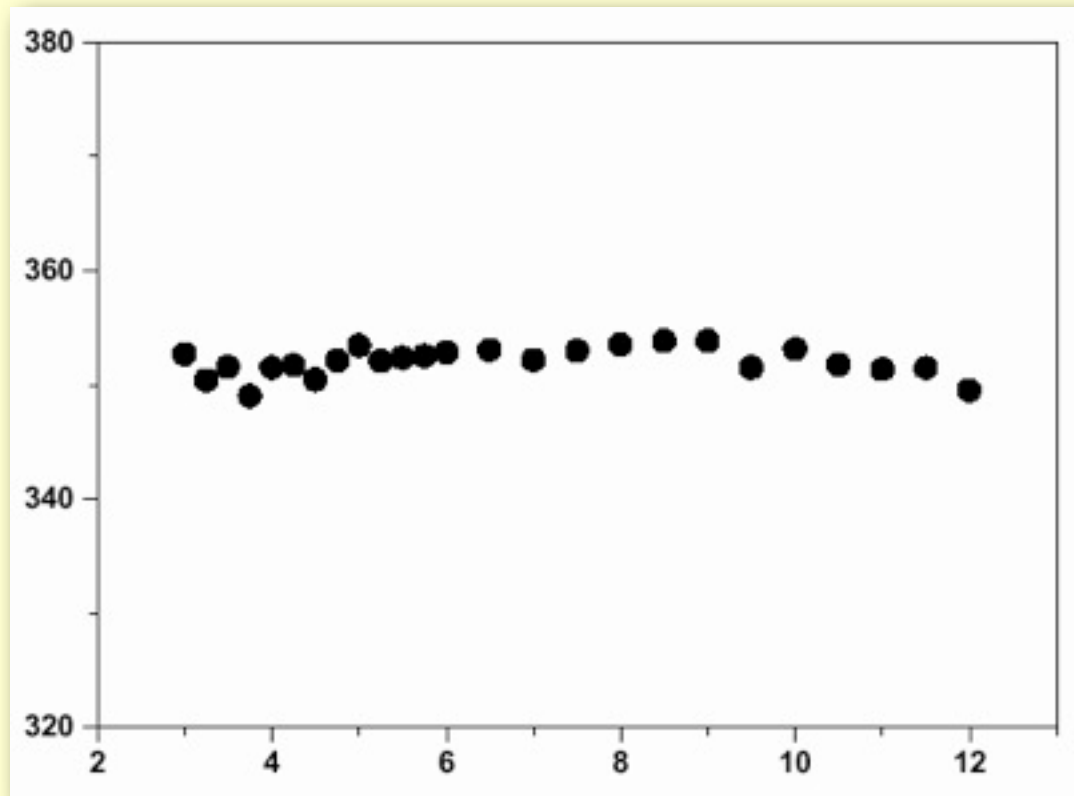
Boyle's measurements (1662)

V	P _{obs}	P _{calc}
12	$29^{2/16}$	$29^{2/16}$
$11^{1/2}$	$30^{9/16}$	$30^{6/16}$
11	$31^{15/16}$	$31^{12/16}$
$10^{1/2}$	$33^{8/16}$	$33^{1/7}$
10	$35^{5/16}$	35
$9^{1/2}$	37	$36^{15/19}$
9	$39^{5/16}$	$38^{7/8}$
$8^{1/2}$	$41^{10/16}$	$41^{2/17}$
8	$44^{3/16}$	$43^{11/16}$
$7^{1/2}$	$47^{1/16}$	$46^{3/5}$
7	$50^{5/16}$	50
$6^{1/2}$	$54^{5/16}$	$53^{10/16}$
6	$58^{13/16}$	$58^{2/8}$

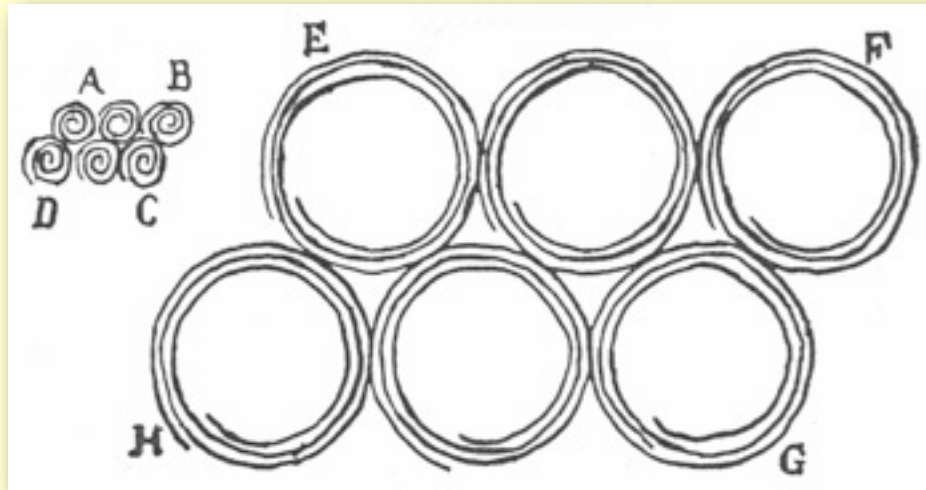
V	P _{obs}	P _{calc}
$5^{3/4}$	$61^{5/16}$	$60^{18/23}$
$5^{1/2}$	$64^{1/16}$	$63^{3/16}$
$5^{1/4}$	$67^{1/16}$	$66^{4/7}$
5	$70^{11/16}$	70
$4^{3/4}$	$74^{2/16}$	$73^{11/19}$
$4^{1/2}$	$77^{14/16}$	$77^{2/3}$
$4^{1/4}$	$82^{12/16}$	$82^{4/17}$
4	$87^{14/16}$	$87^{3/8}$
$3^{3/4}$	$93^{1/16}$	$93^{1/5}$
$3^{1/2}$	$100^{7/16}$	$99^{6/7}$
$3^{1/4}$	$107^{13/16}$	$107^{7/13}$
3	$117^{9/16}$	$116^{4/8}$

Boyle's results (1662)

pV



V (arbitrary units)



Boyle knew that air has weight and that the upper parts of the atmosphere compress the lower. He imagined air as consisting of very small "coiled particles". The whole atmosphere could be compared to a tall pile of fleeces of wool. At lower pressure the particles of the air "uncoiled" and increased their volume.

Pressure and volume of air was measured in Boyle's laboratory by Henry Power and Richard Towneley, and also by Boyle's assistant, Robert Hooke

More than ten years later, but possibly independently of Boyle, Edmé Mariotte in Paris found experimentally the relation between the volume and pressure of air



SECOND ESSAY.
DE LA
NATURE
DE L'AIR,

Par M^r. MARIOTTE,
*de l'Academie Royale
des Sciences.*



A PARIS,
Chez ESTIENNE MICHALLET,
rue Saint Jacques, à l'Image
Saint Paul,

M. DC. LXXIX.

Avec Permission.

Phenomena of heat

Bacon



heat is
motion

thermometers

Lavoisier



caloric = element



Clausius
Maxwell
Boltzmann

Black



specific heat
latent heat



Carnot
heat
engine

1600

1700

1800

1900

calorimeters

conservation
of energy

Galileo



motion
of fire particles

"ignicoli"



Rumford



Mayer Joule Helmholtz

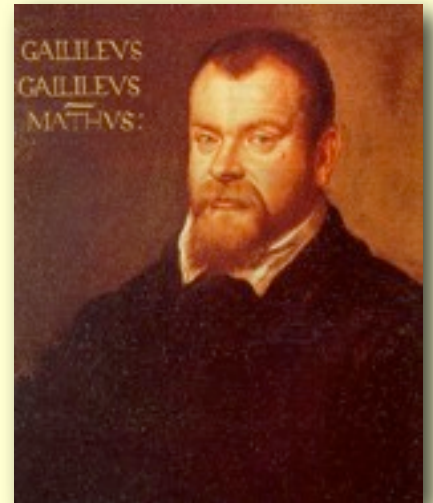
"When I say of motion that it is as the genus of which heat is a species, I would be understood to mean not that heat generates motion or that motion generates heat (though both are true in certain cases), but that heat itself, its essence and quiddity, is motion and nothing else;...heat is a motion of expansion, not uniformly of the whole body together, but in the smaller parts of it; and at the same time checked, repelled, and beaten back, so that the body acquires a motion alternative, perpetually quivering, striving and struggling, and irritated by repercussion, whence springs the fury of fire and heat."



Francis Bacon, *Novum organum*, Book II (1620)

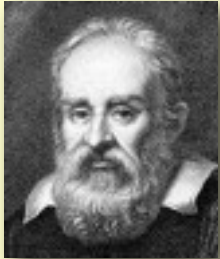
”The operation of fire by means of its particles is merely that in moving it penetrates all bodies by reason of its great subtlety, dissolving them more quickly or more slowly in proportion to the number and velocity of fire-particles (*ignicoli*) and the density or rarity of the material of these bodies, of which many are such that in their decomposition the major part of them passes over into further tiny corpuscles (*ignei*), and the dissolution goes on so long as it meets with matter capable of being so resolved.”

Galileo, *Il Saggiatore*, Chapter 48 (1623)



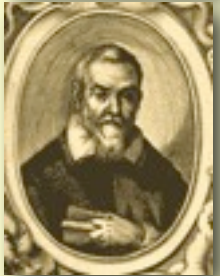
The beginnings of thermometry

First air-thermoscopes (thermometers)



Galileo Galilei

1603? (1592?)



Santorio Santori

< **1612**



Cornelius Drebbel

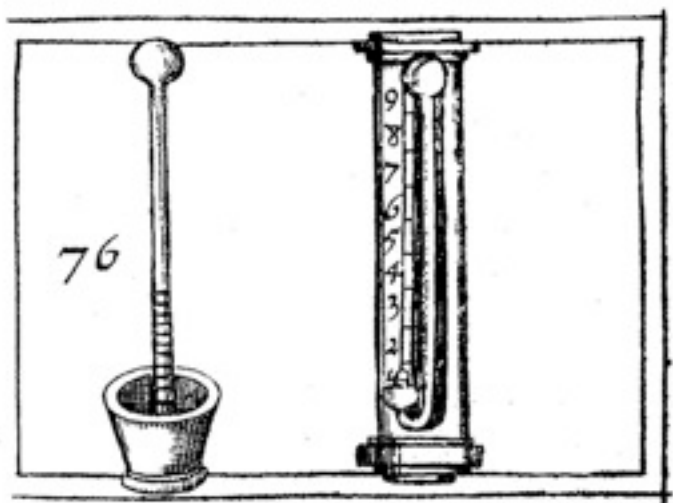
> 1606 (1586?)



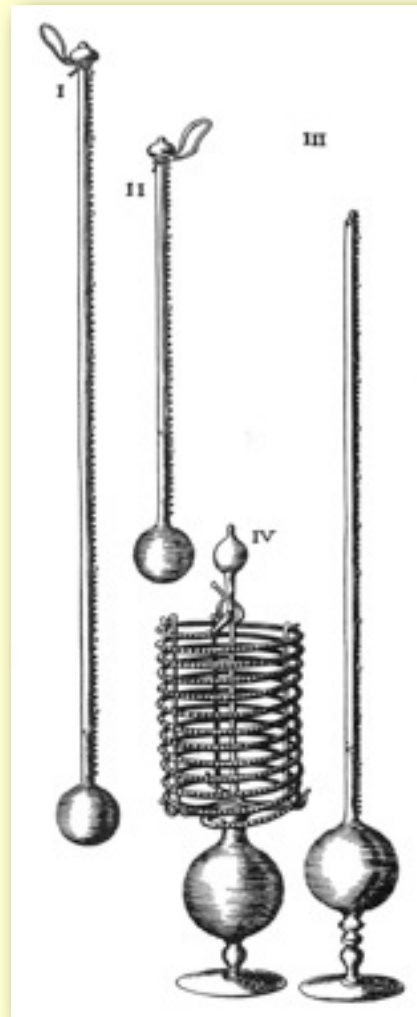
Robert Fludd

1617?

First air-thermoscopes (thermometers)



1624



1688

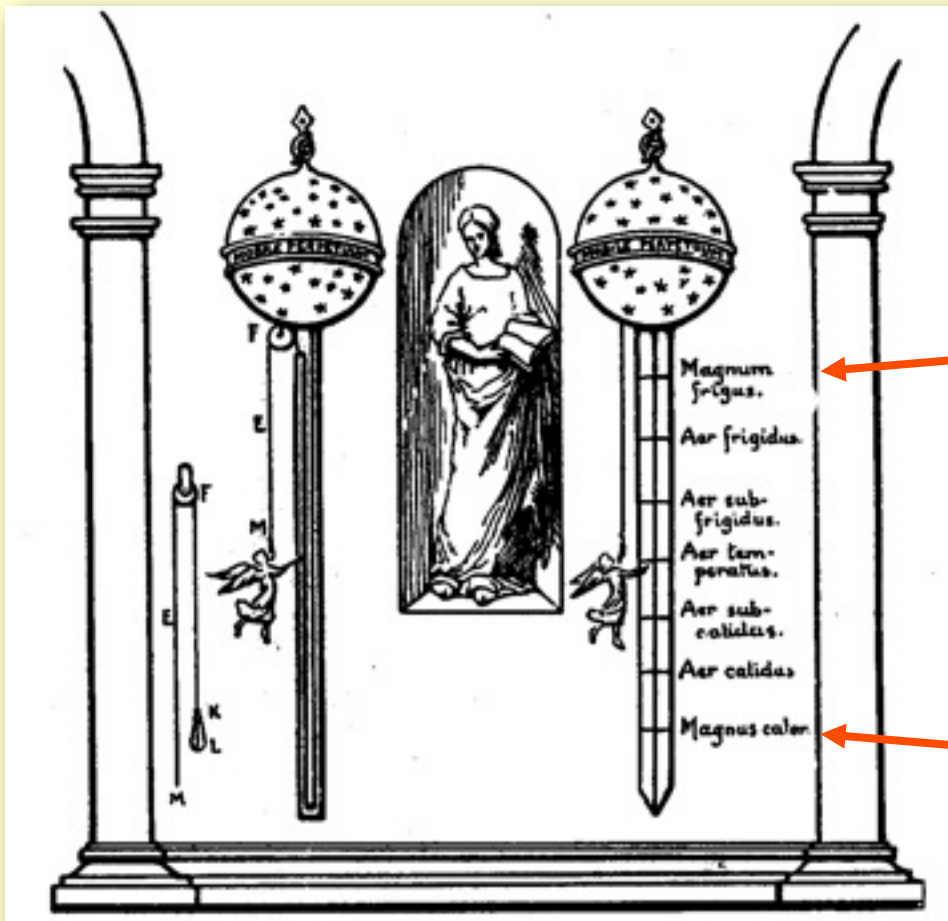
Accademia del Cimento

Early thermometers

Otto Guericke



Experimenta nova (1672)



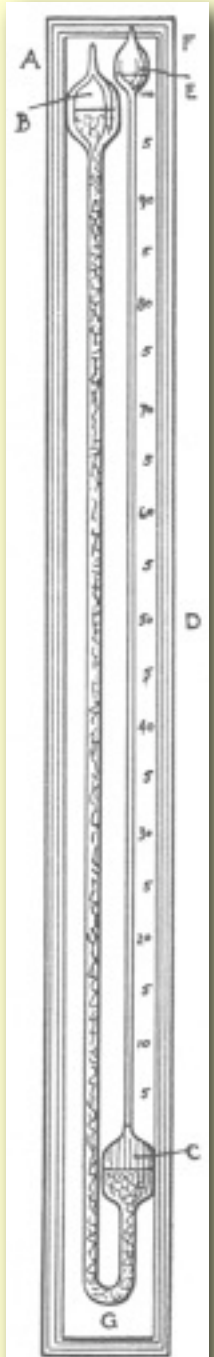
great frost
cold weather
cool weather
temperate weather
warm weather
hot weather
great heat

Fixed points

1665	Boyle	freezing of aniseed oil
	Huygens	freezing (or boiling) of water
	Hooke	freezing of water
1688	Dalencé	melting of snow (-10°) and melting of butter (10°)
1694	Renaldini	freezing and melting of water (interval of 12°)

Jean Rey (1631)
first liquid thermometer

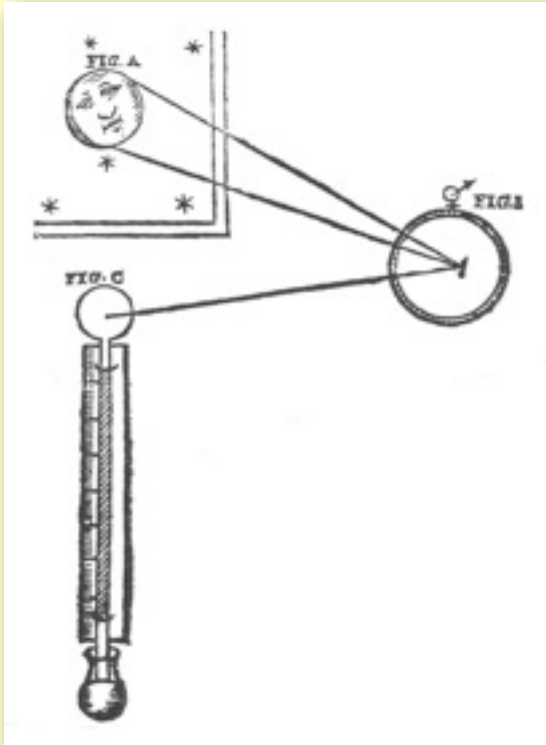
Guillaume Amontons (1688)
first air-thermometer insensitive
to changes in atmospheric pressure



First applications of thermometers



Santorio - a pioneer of astrophysics



The heat of the Sun caused a "fall" of 120 degrees, whereas the heat of the Moon caused a "fall" of only 10 degrees (in arbitrary scale)

Sanctorii Sanctorii Commentaria in primam fen primi libri Canonis Avicennae (Venice, 1625)

First applications of thermometers

This attempt of Santorio contrasted with groundless divagations of astrologers and astronomers



"By the tradition of astronomers some stars are hotter than others. Of planets, Mars is accounted the hottest after the sun; then comes Jupiter, and then Venus. Others, again, are set down as cold: the moon, for instance, and above all Saturn. Of fixed stars, Sirius is said to be the hottest, then Cor Leonis or Regulus, then Canicula, and so on."

Francis Bacon, *Novum Organum*, Book II (1620)