THE UNIVERSITY OF CHICAGO

ENRICO FERMI INSTITUTE

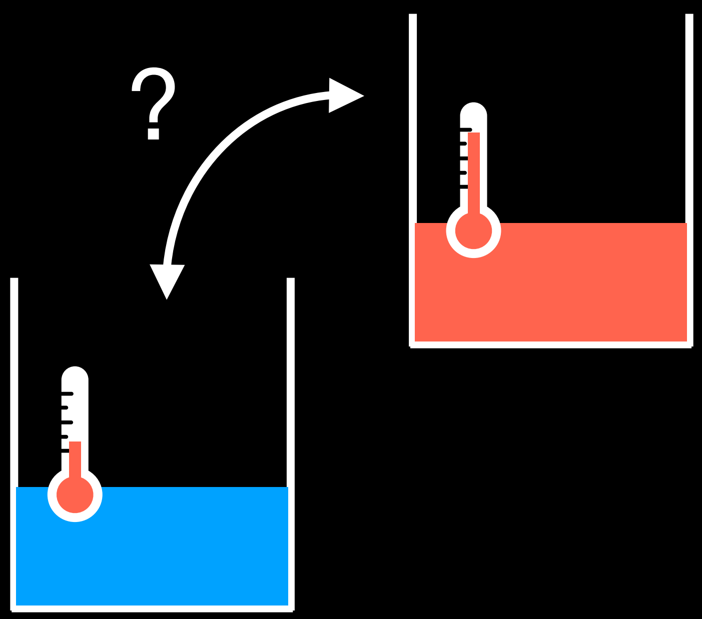
HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD

A STORY OF INVENTION AND DISCOVERY

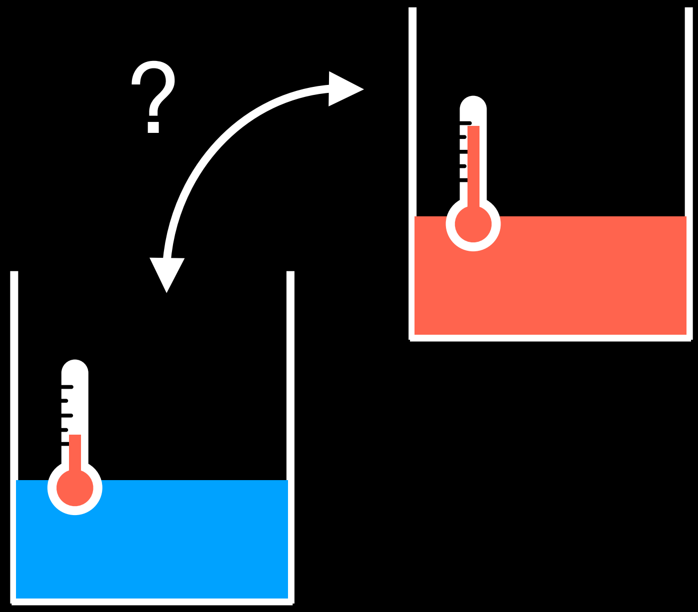
Philipp Windischhofer

October 7, 2023

Composite image created by combining representation of universe sphere by Pablo Carlos Budassi with human eye by Kamil Saitov (Google Commons).



“What changes when cold water is made hot?”



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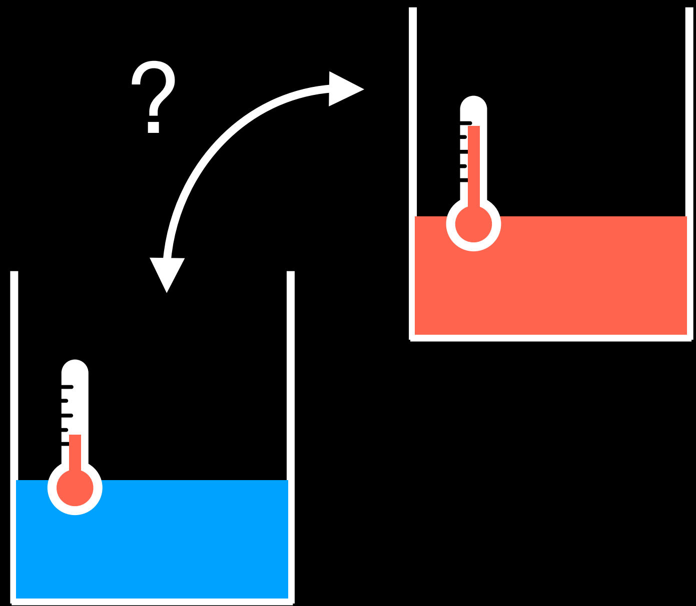

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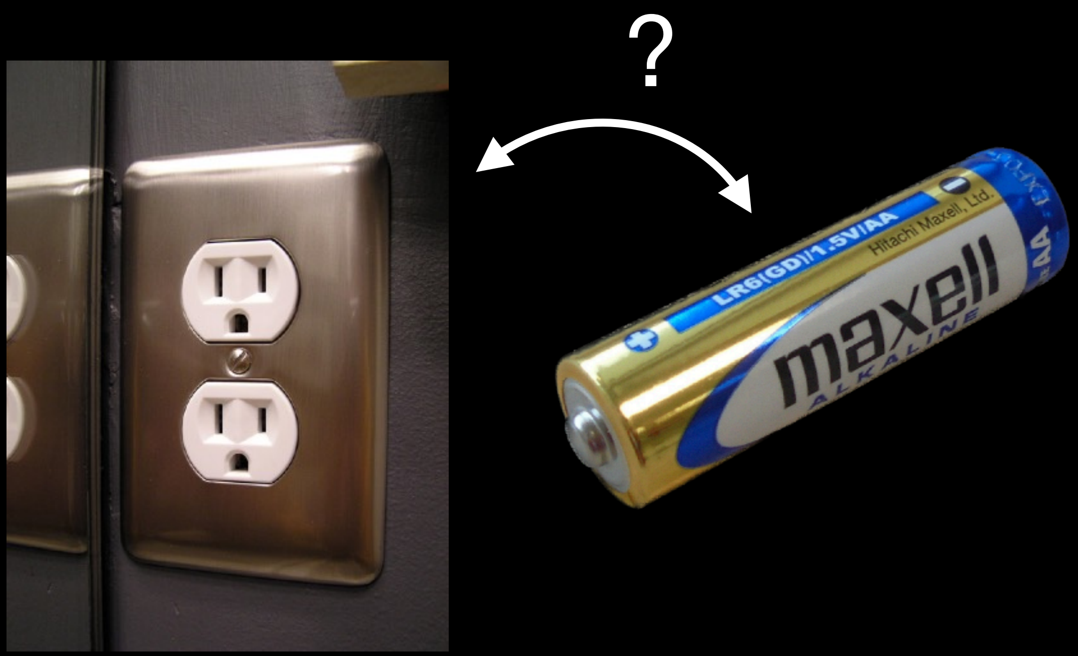

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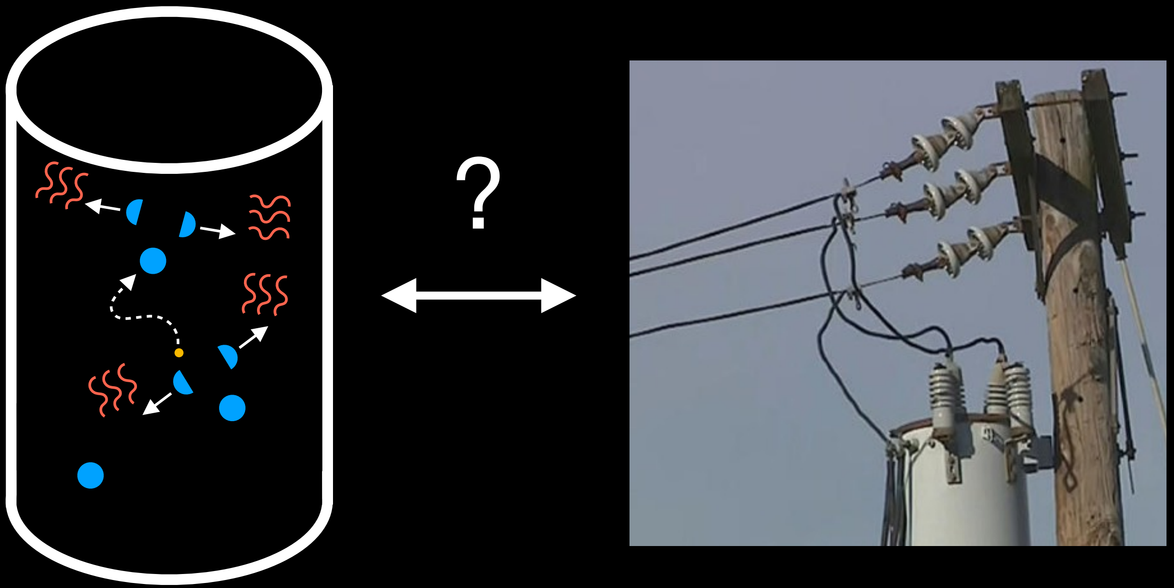


"If matter is made of atoms, what
are the atoms of electricity?"

“How did we get here?”

4th century BC

Ca. 1900

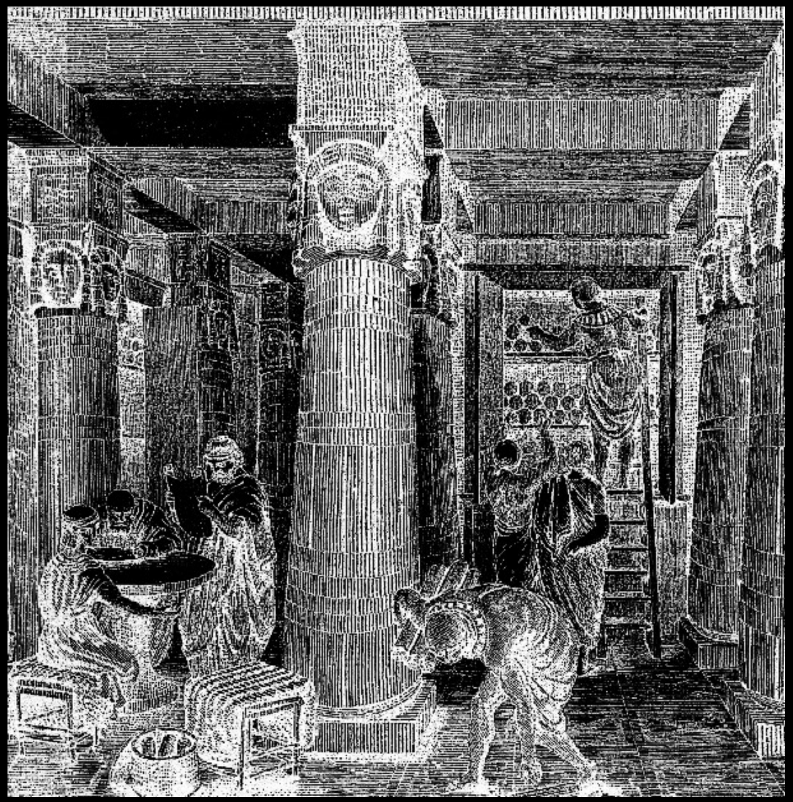
Our question for this lecture

(and the next):

What is heat?

Heat in antiquity

Hero of Alexandria *(ca. 70 AD)*



Mouseion of Alexandria

"Seat of the muses"

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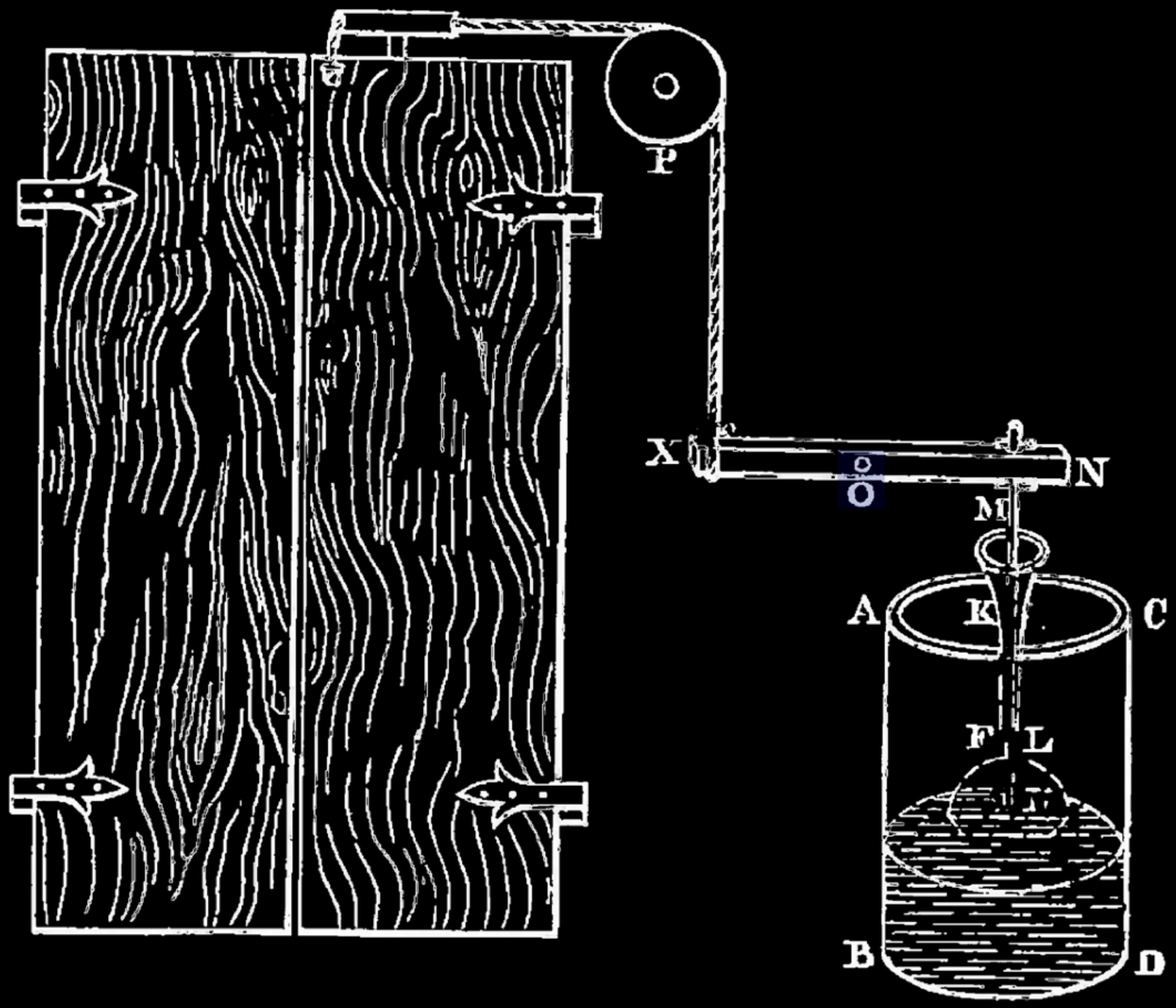
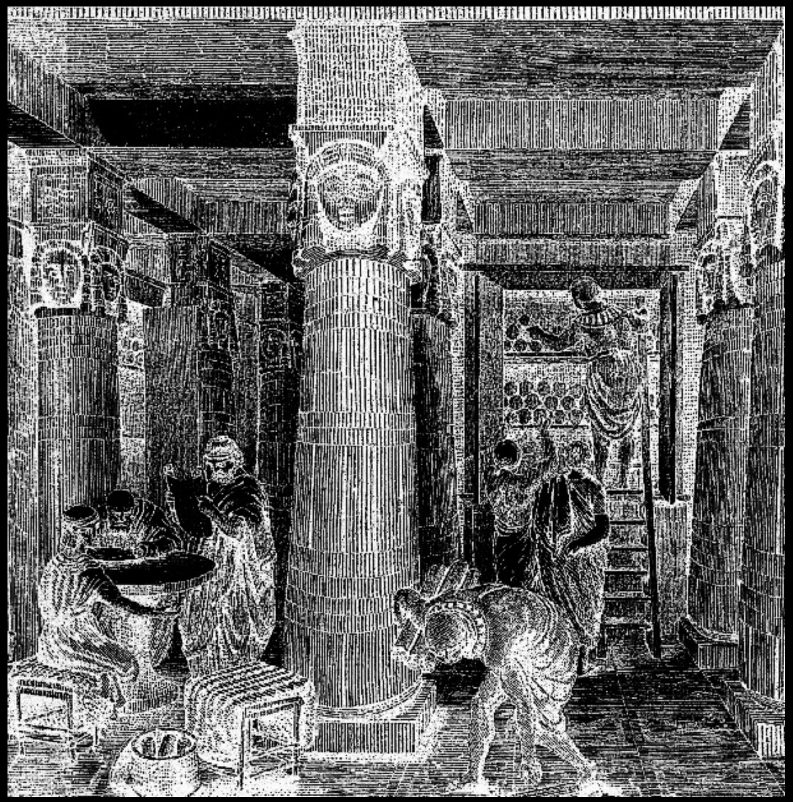
"Sounds produced on the opening of a Temple Door"





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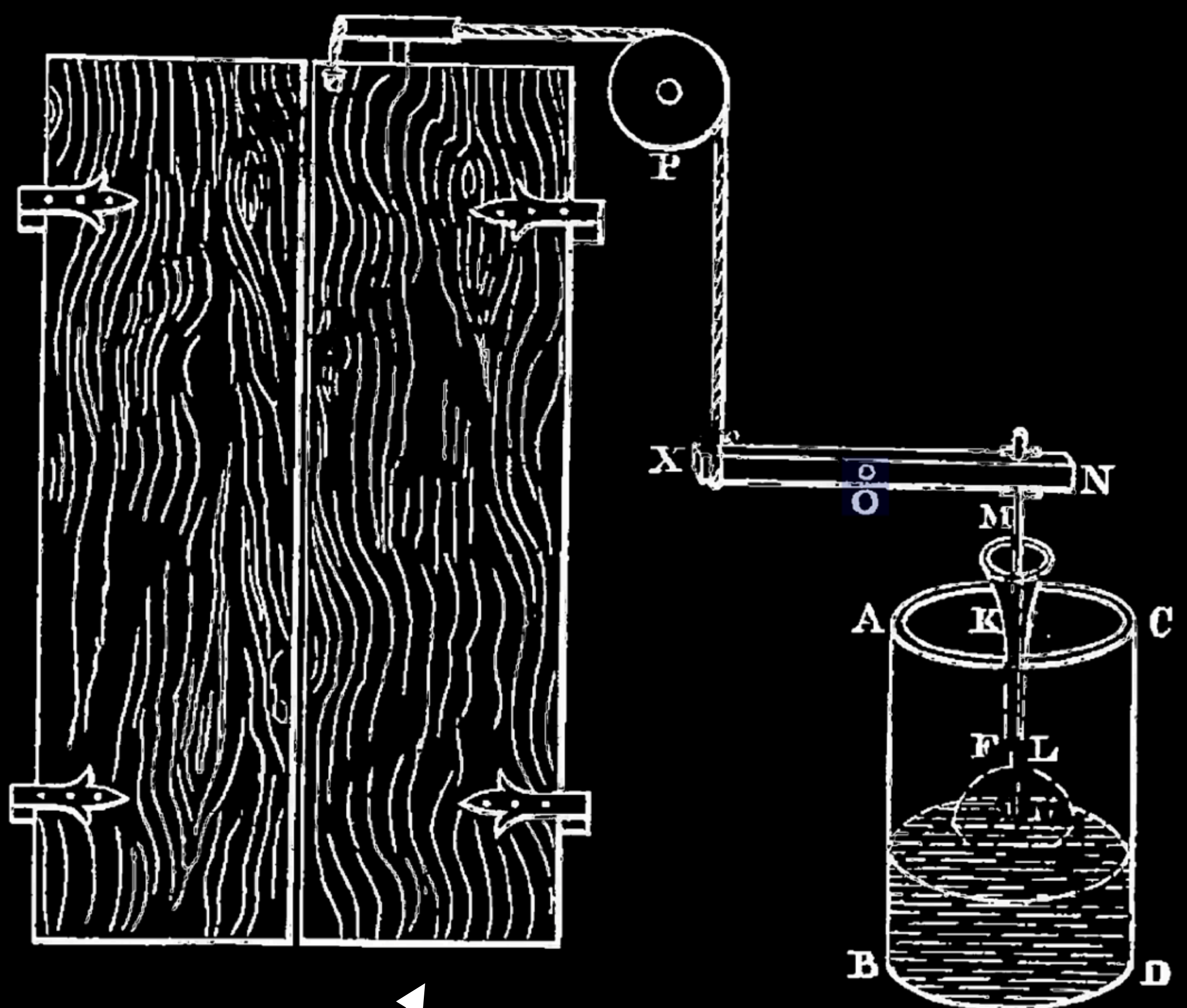
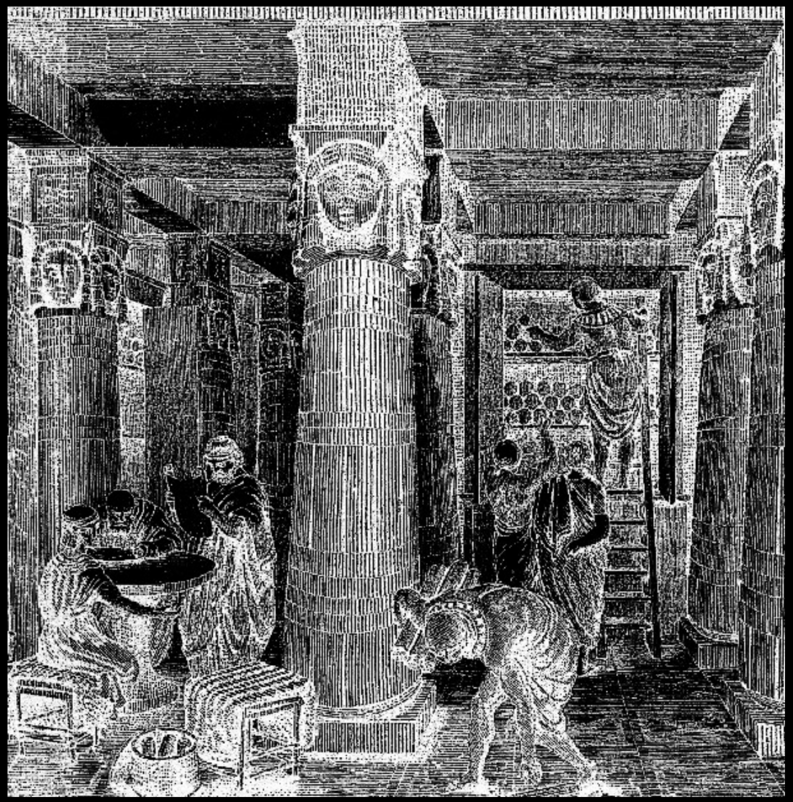


Temple door



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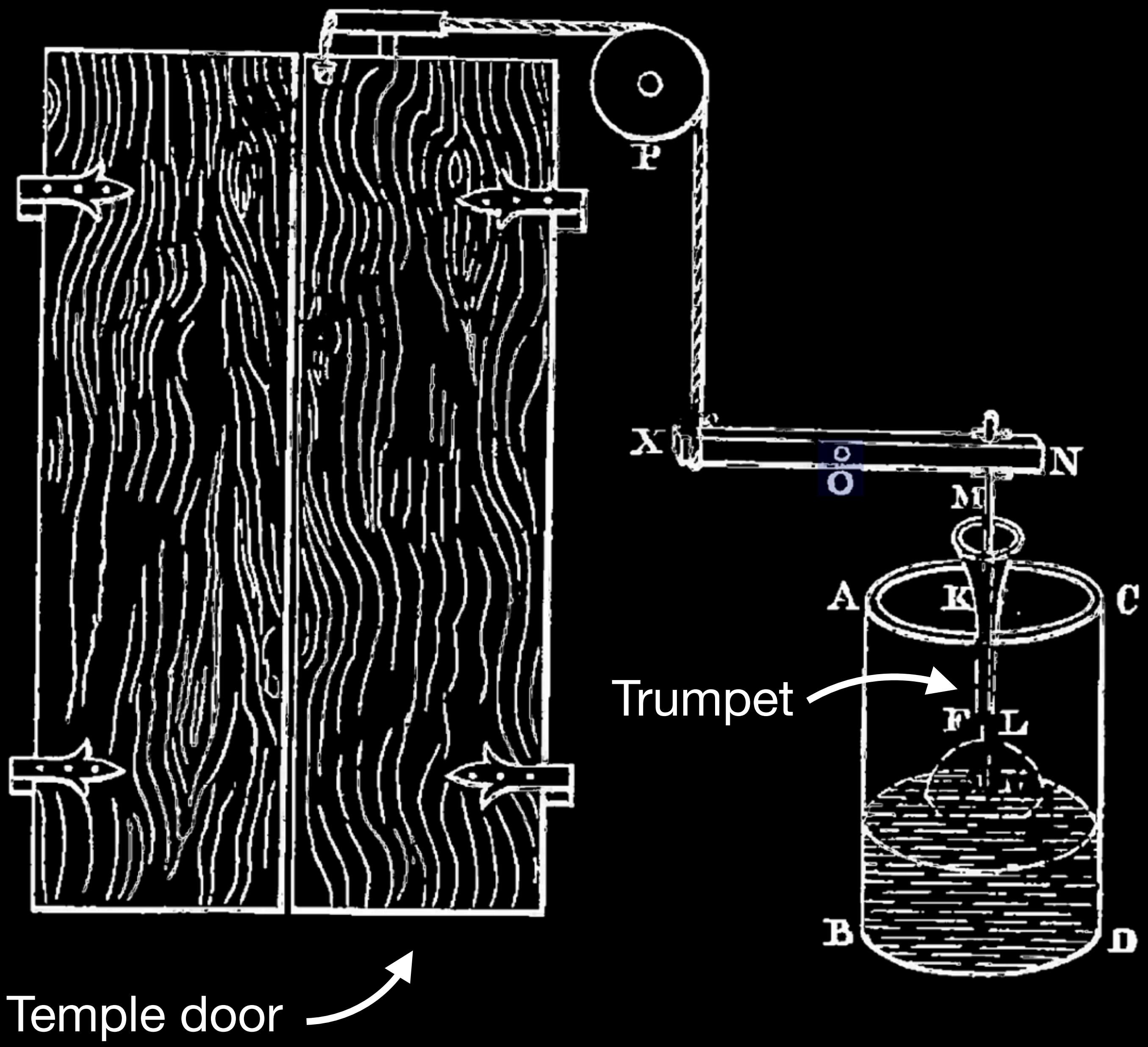

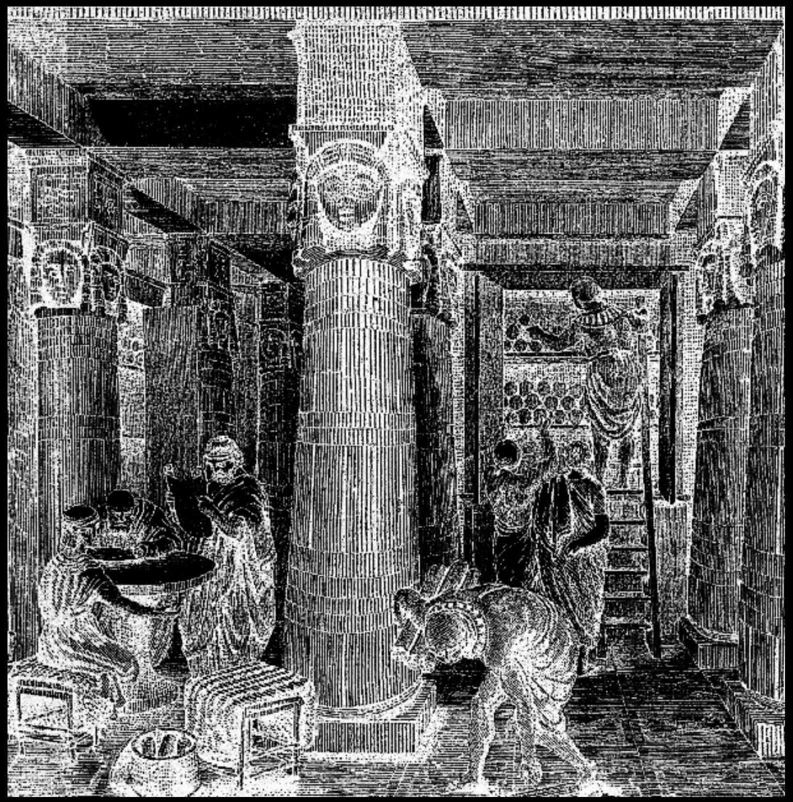

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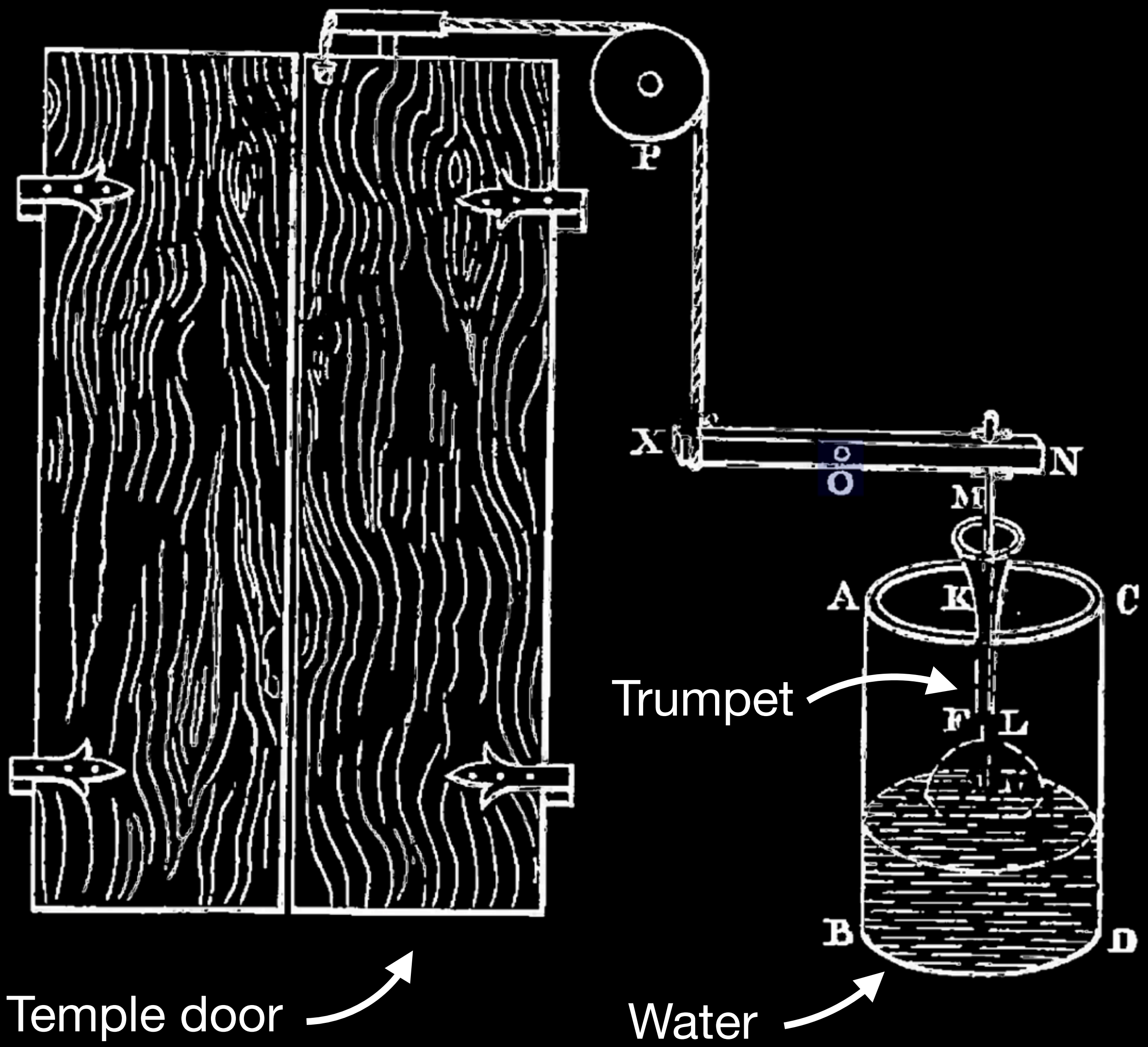

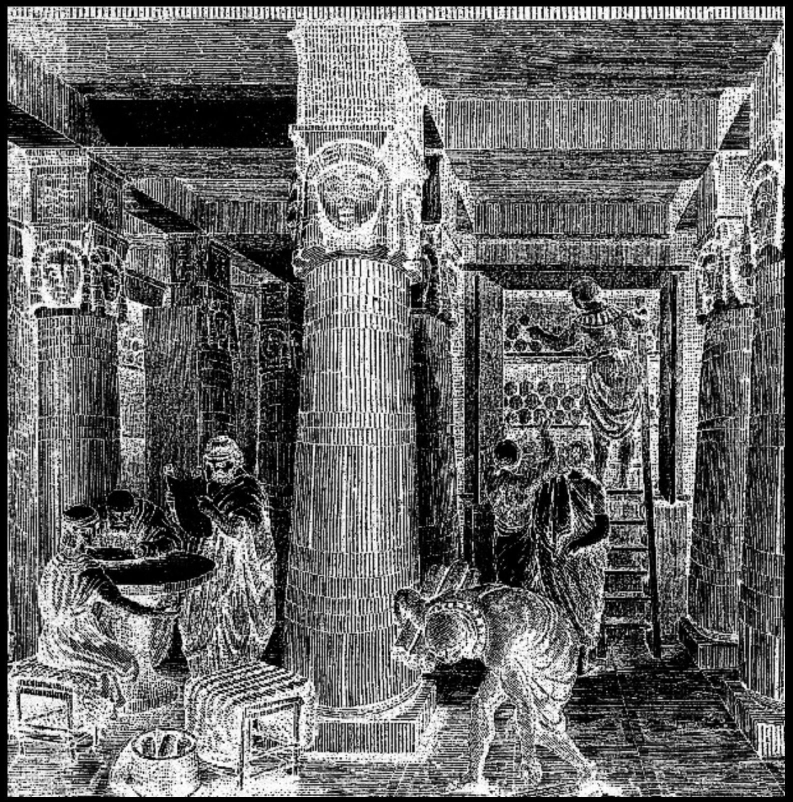

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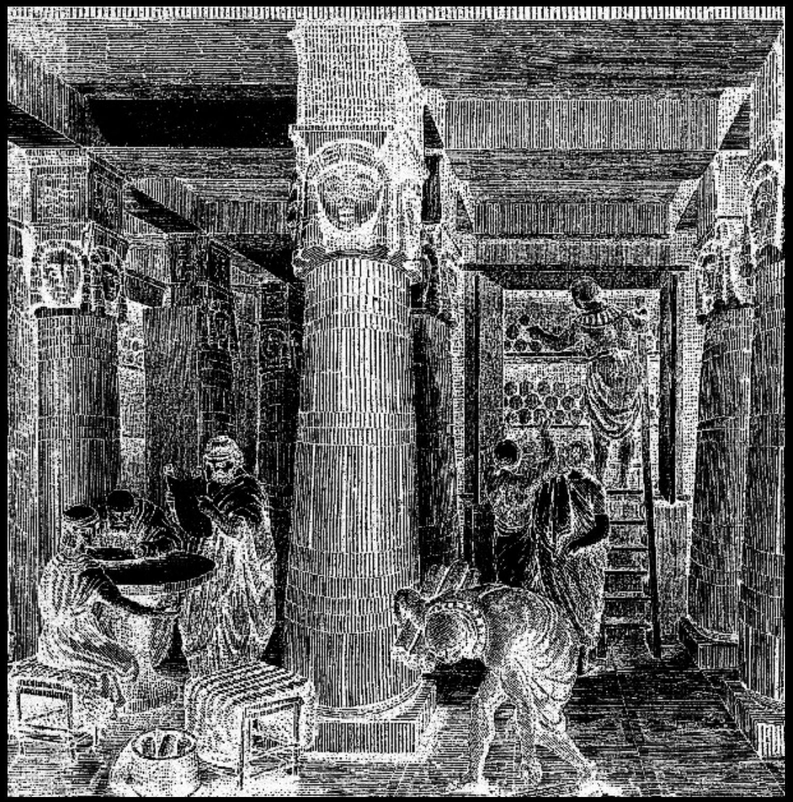

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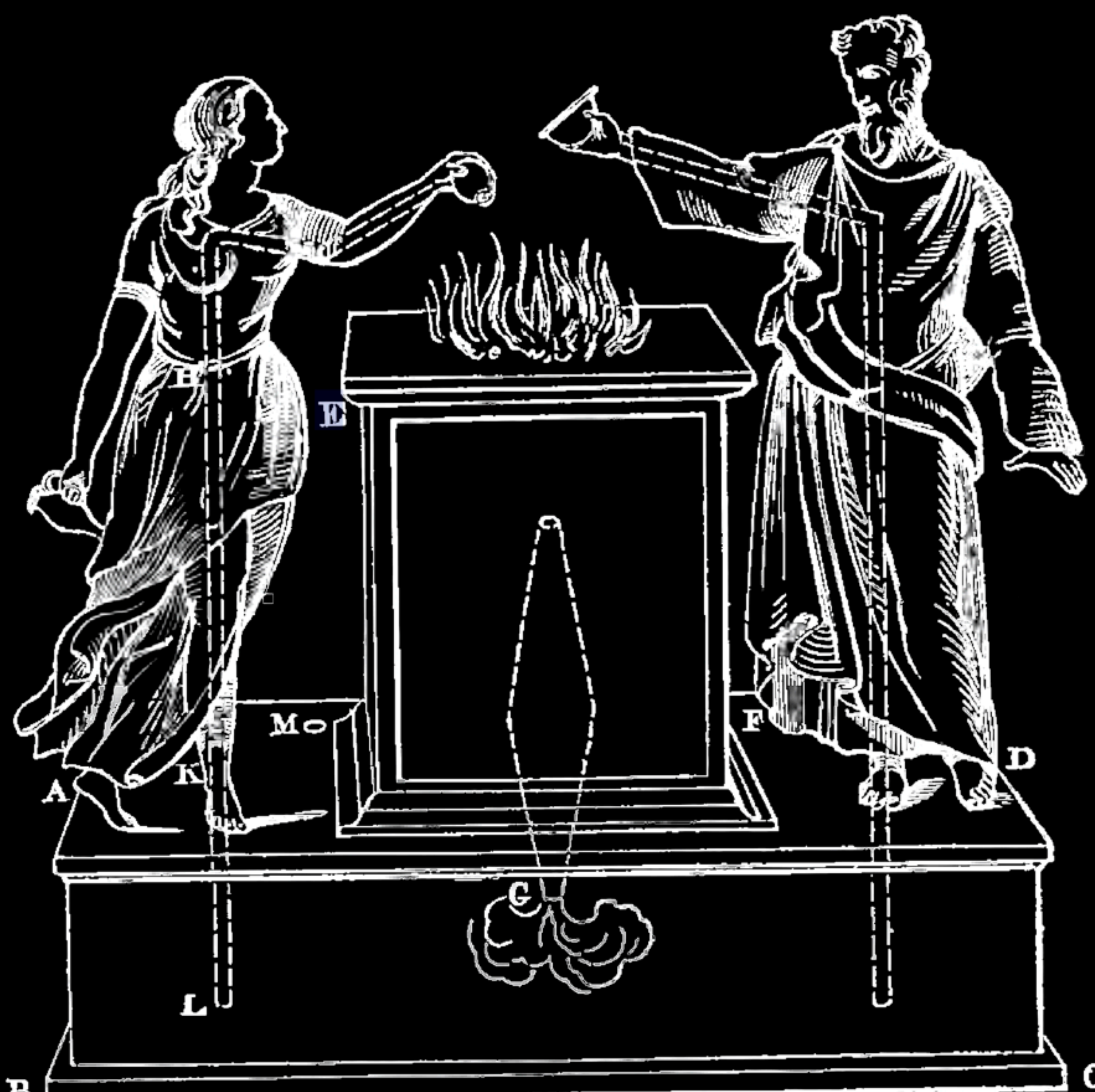

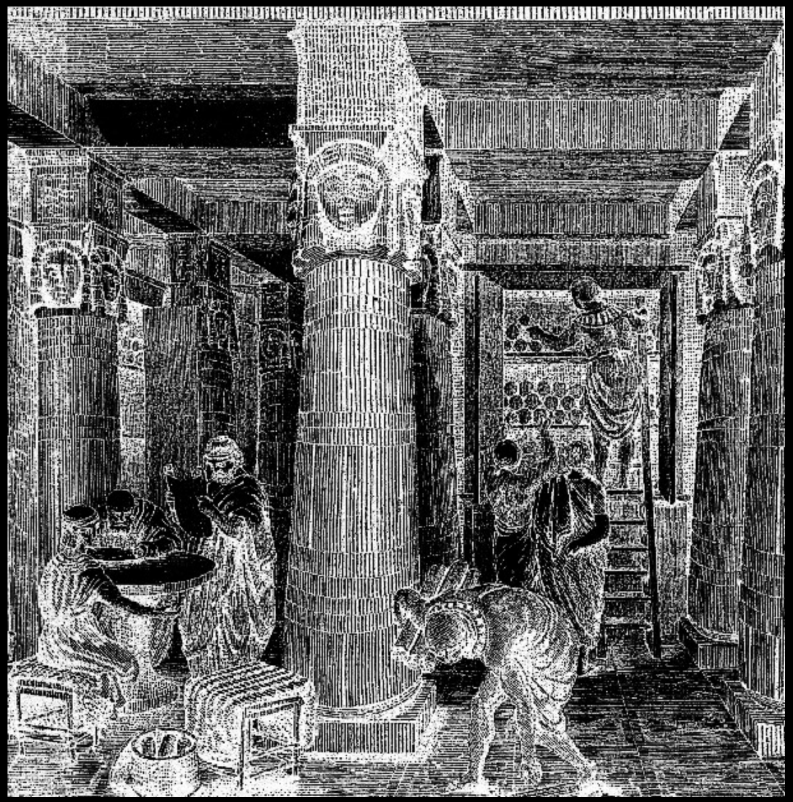

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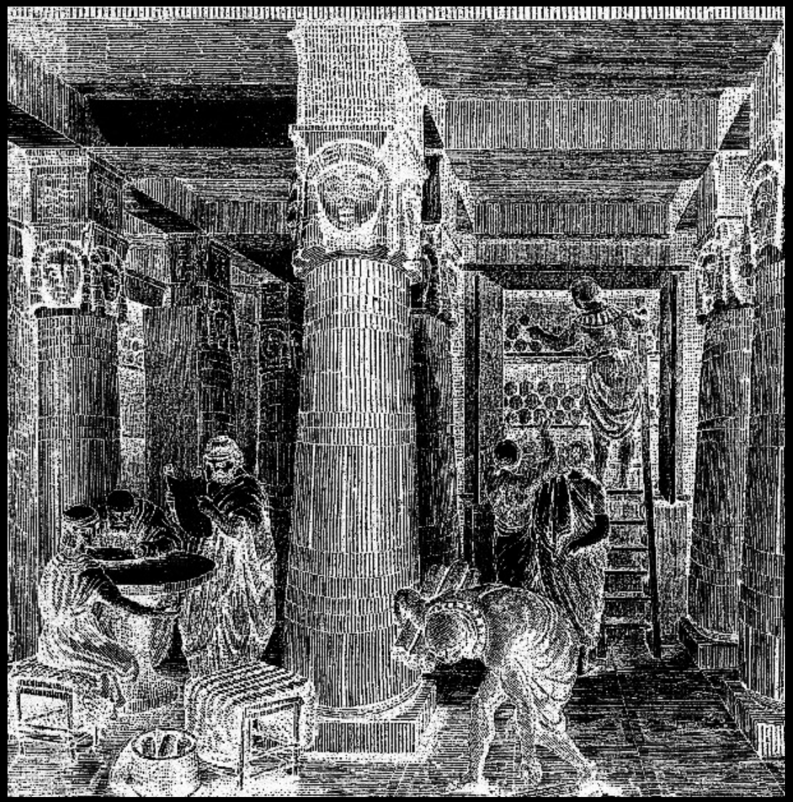

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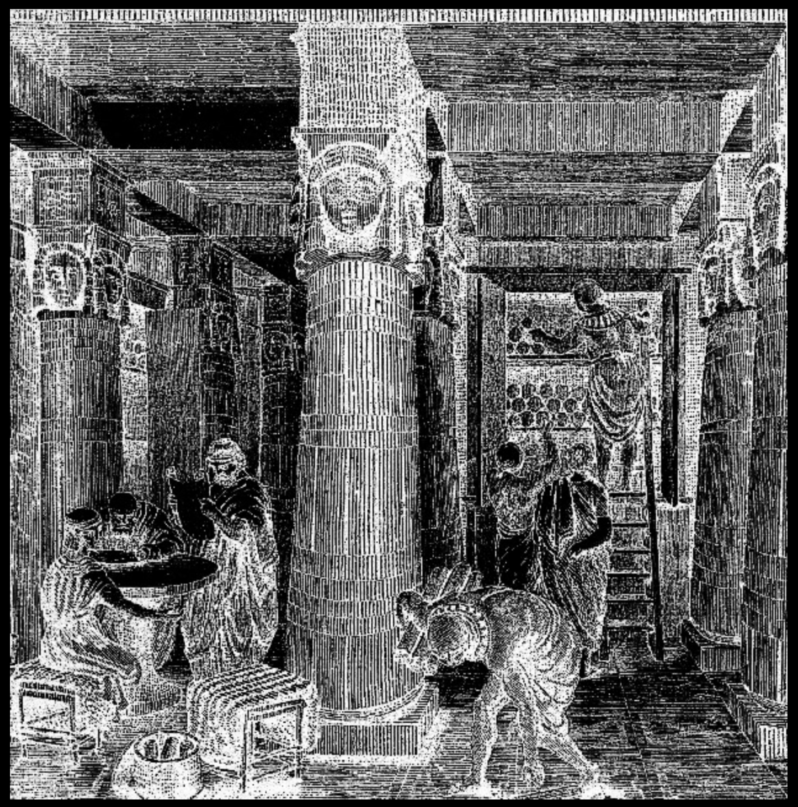

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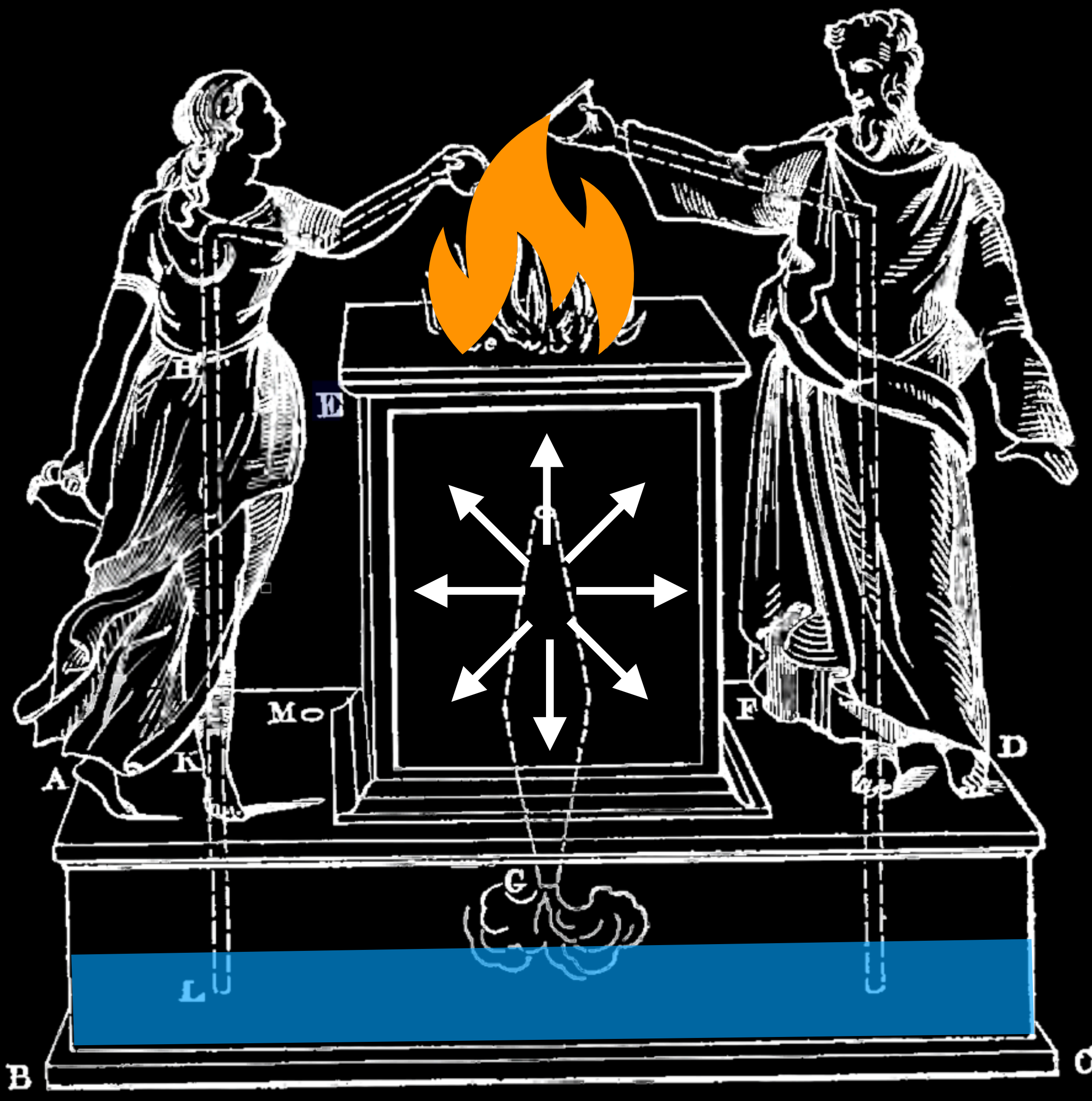

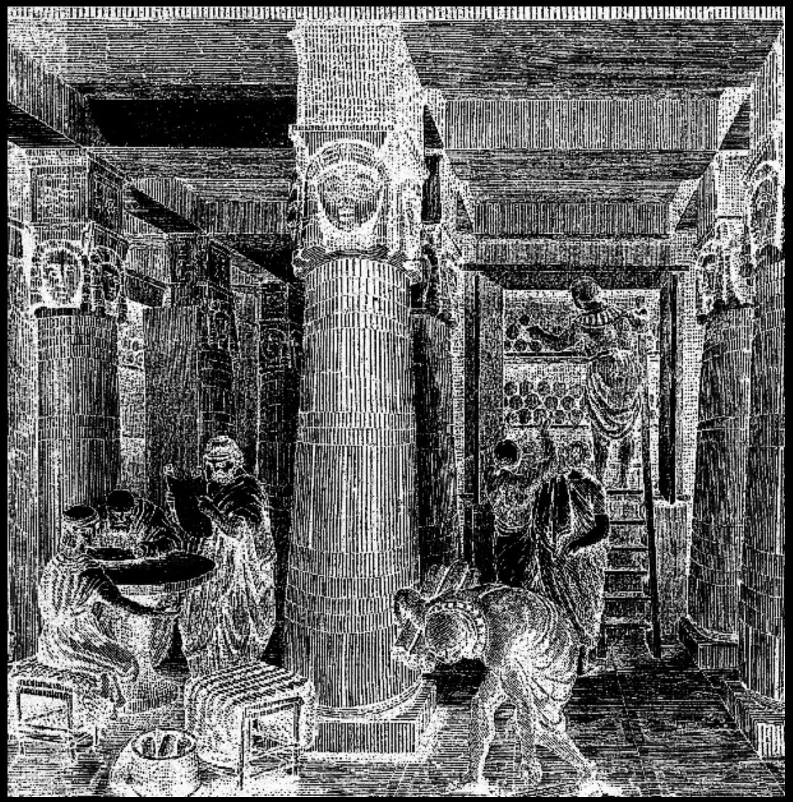

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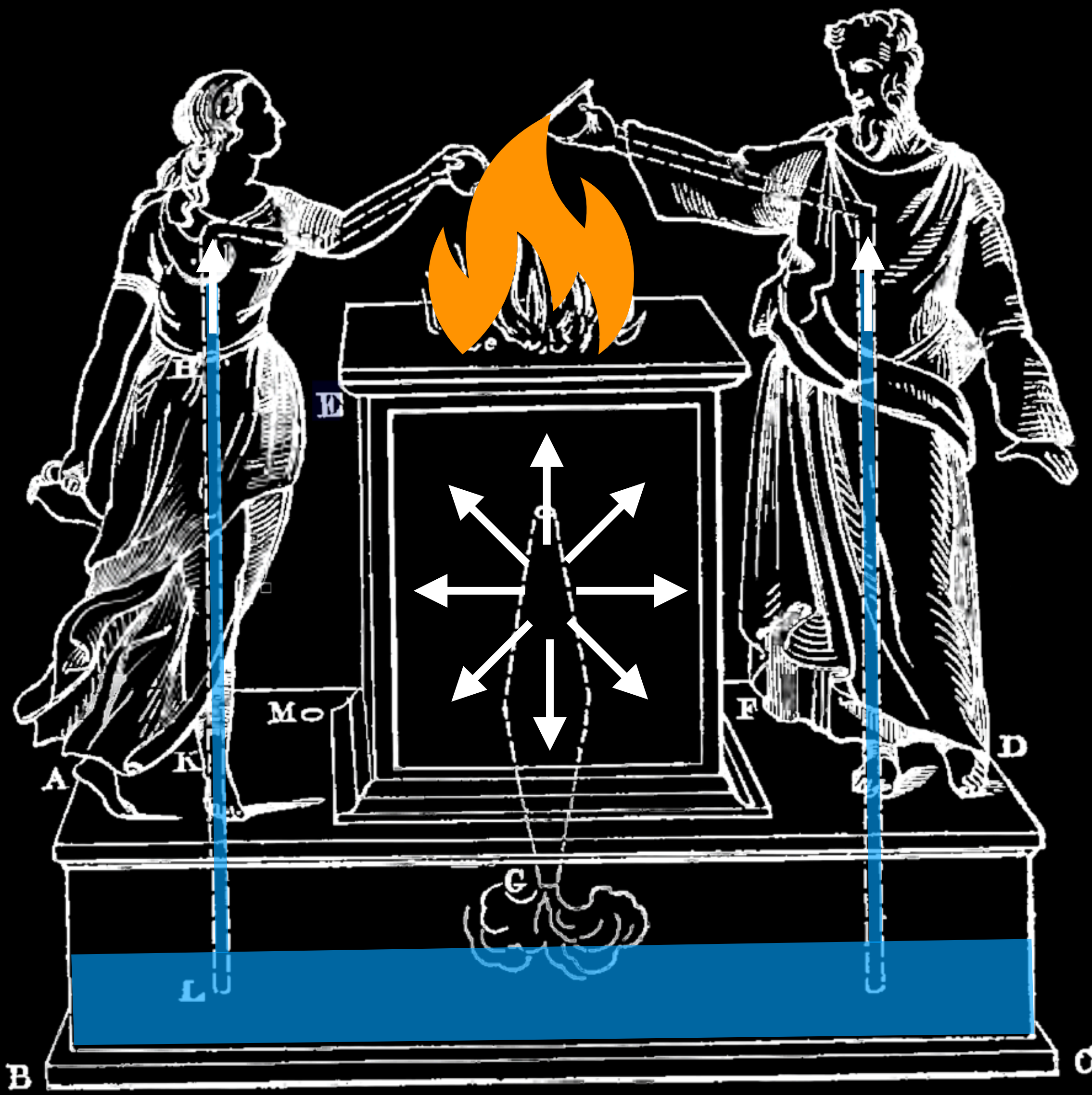

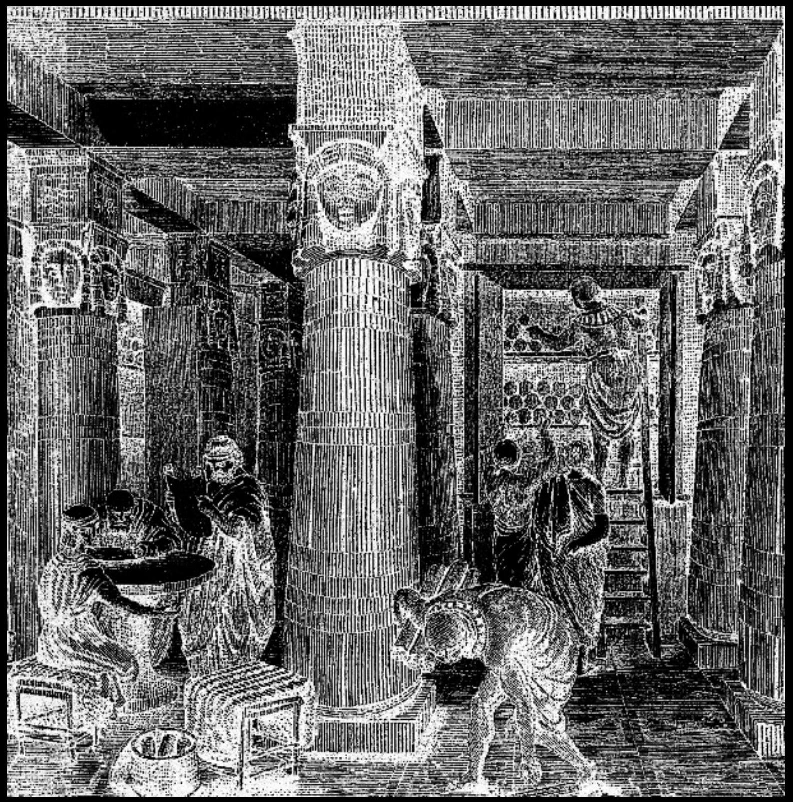

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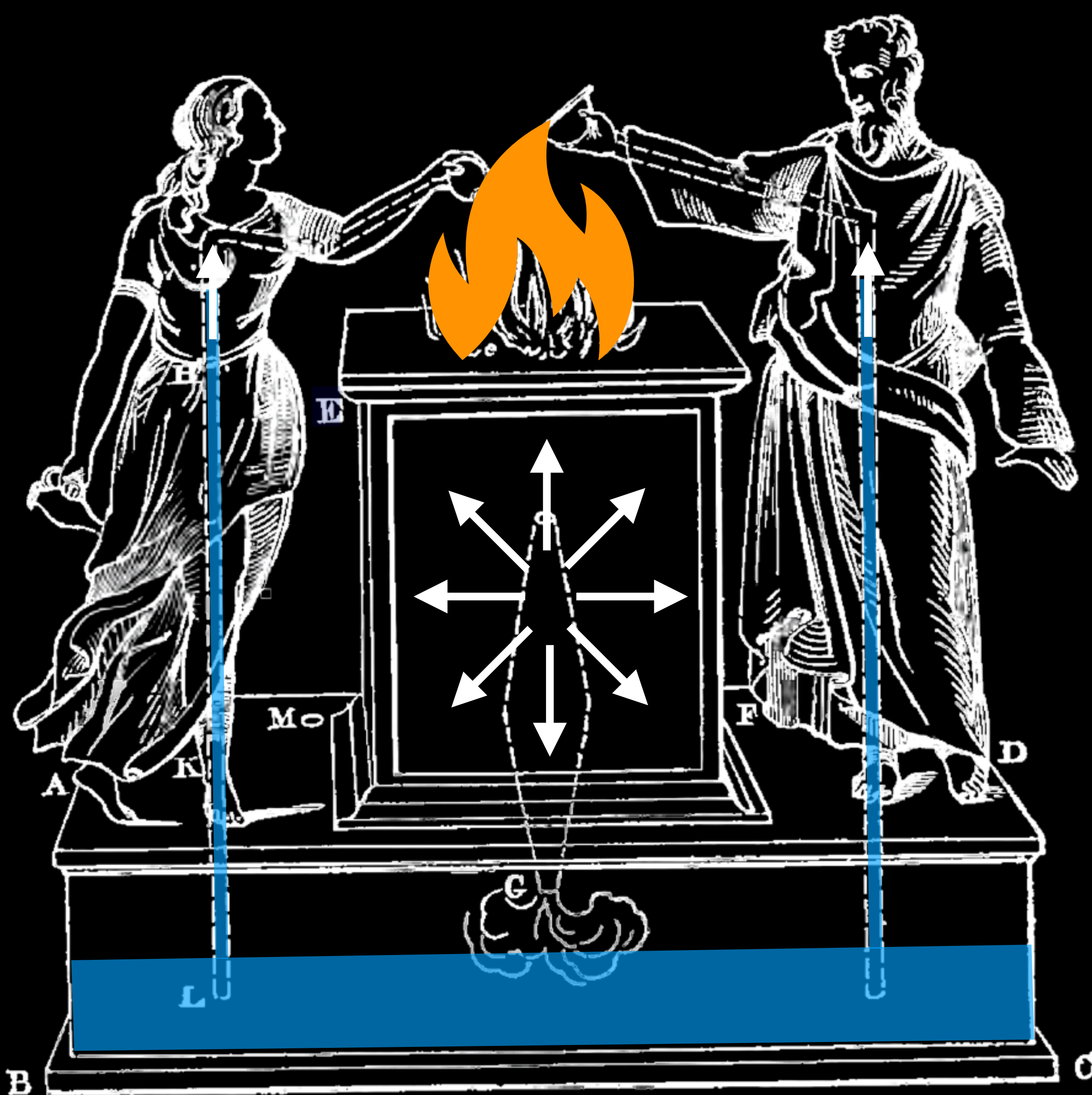
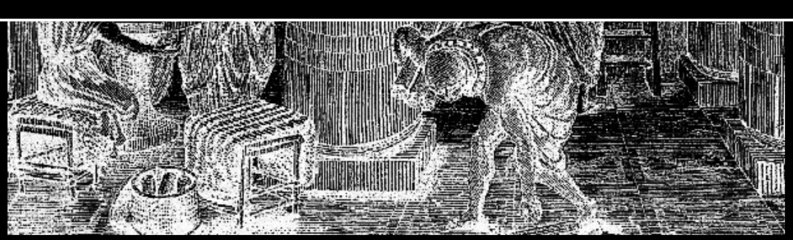


Hero’s explanation:

“The pipe through which the heat is to pass should be broader towards the middle, for it is requisite that the heat, or rather the vapor from it, should expand and act with greater force.”



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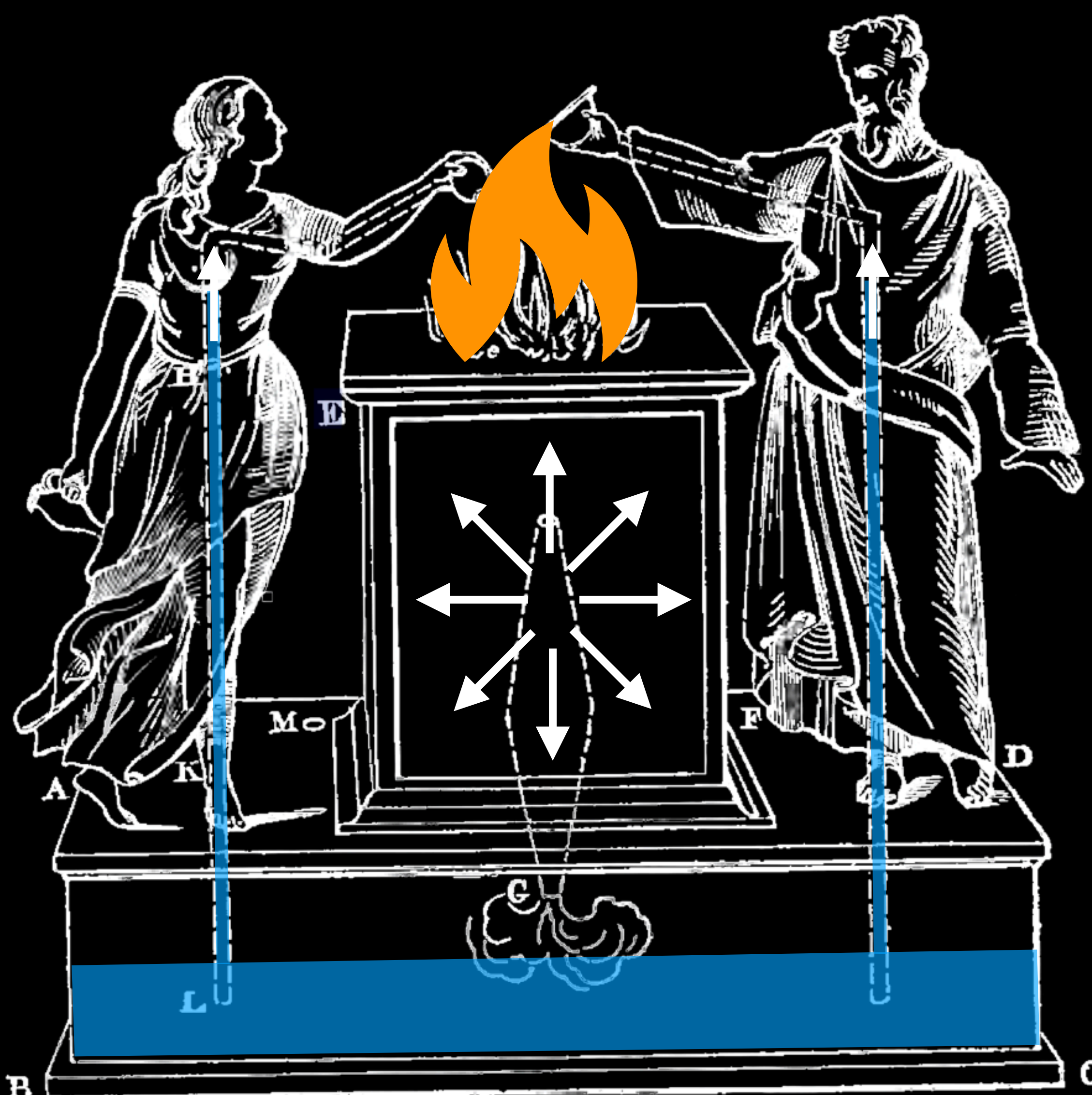

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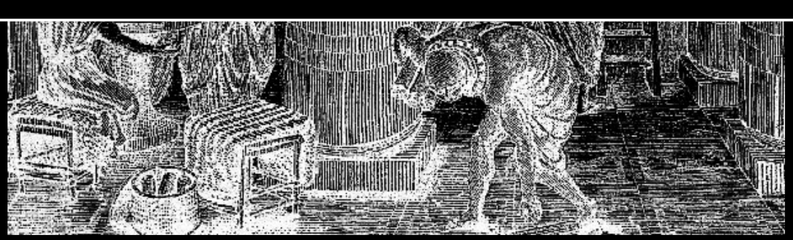
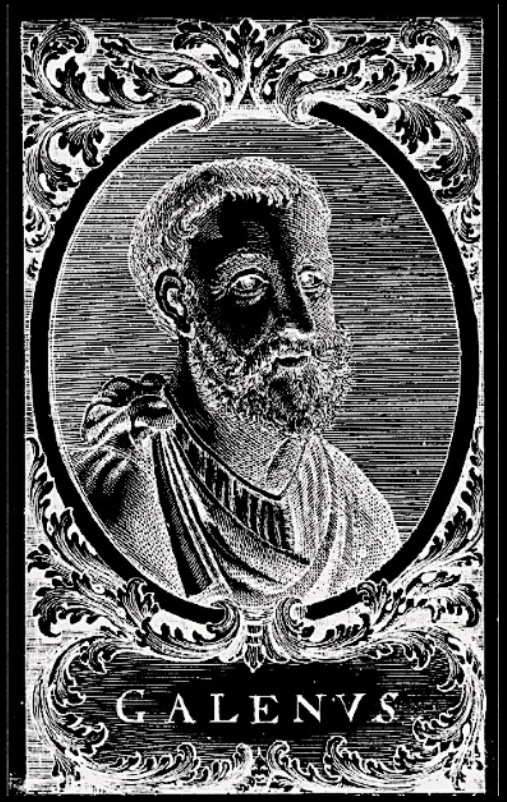


Mouseion of Alexandria

"Seat of the muses"

Temperature in antiquity

Galen of Pergamon *(ca. 140 AD)*



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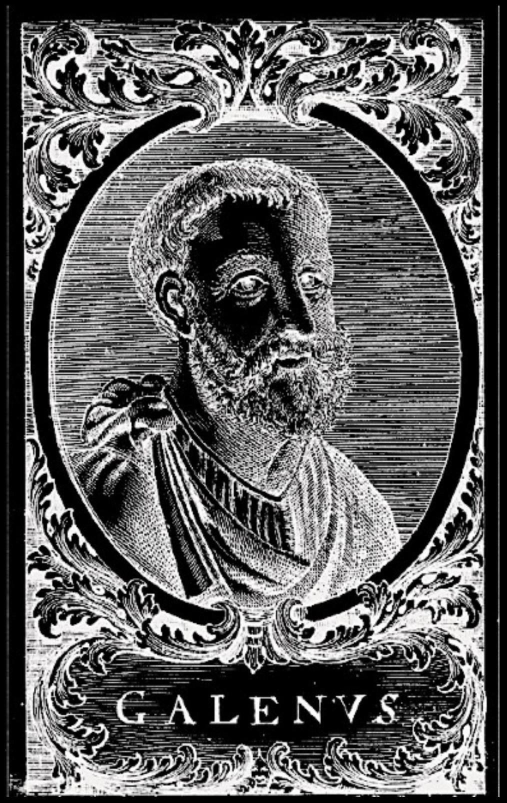
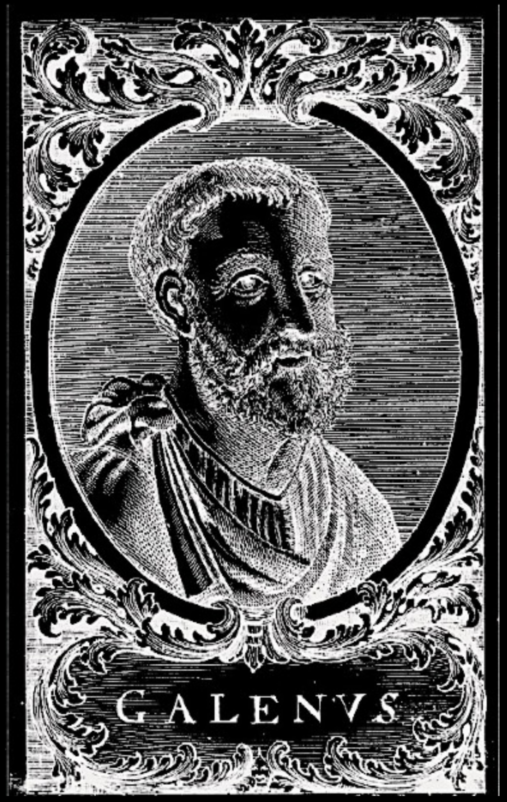


Coleric

("yellow bile")

Temperature in antiquity

Galen of Pergamon *(ca. 140 AD)*



Coleric
("yellow bile")

Blood

Temperature in antiquity

Galen of Pergamon *(ca. 140 AD)*

Coleric
("yellow bile")

Blood

Maelanc
("black bile")

Temperature in antiquity

Galen of Pergamon *(ca. 140 AD)*

Coleric
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Maelanc
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Phlegm

Temperature in antiquity

Galen of Pergamon *(ca. 140 AD)*

Coleric *("yellow bile")*	**Blood**	**Maelanc** *("black bile")*	**Phlegm**

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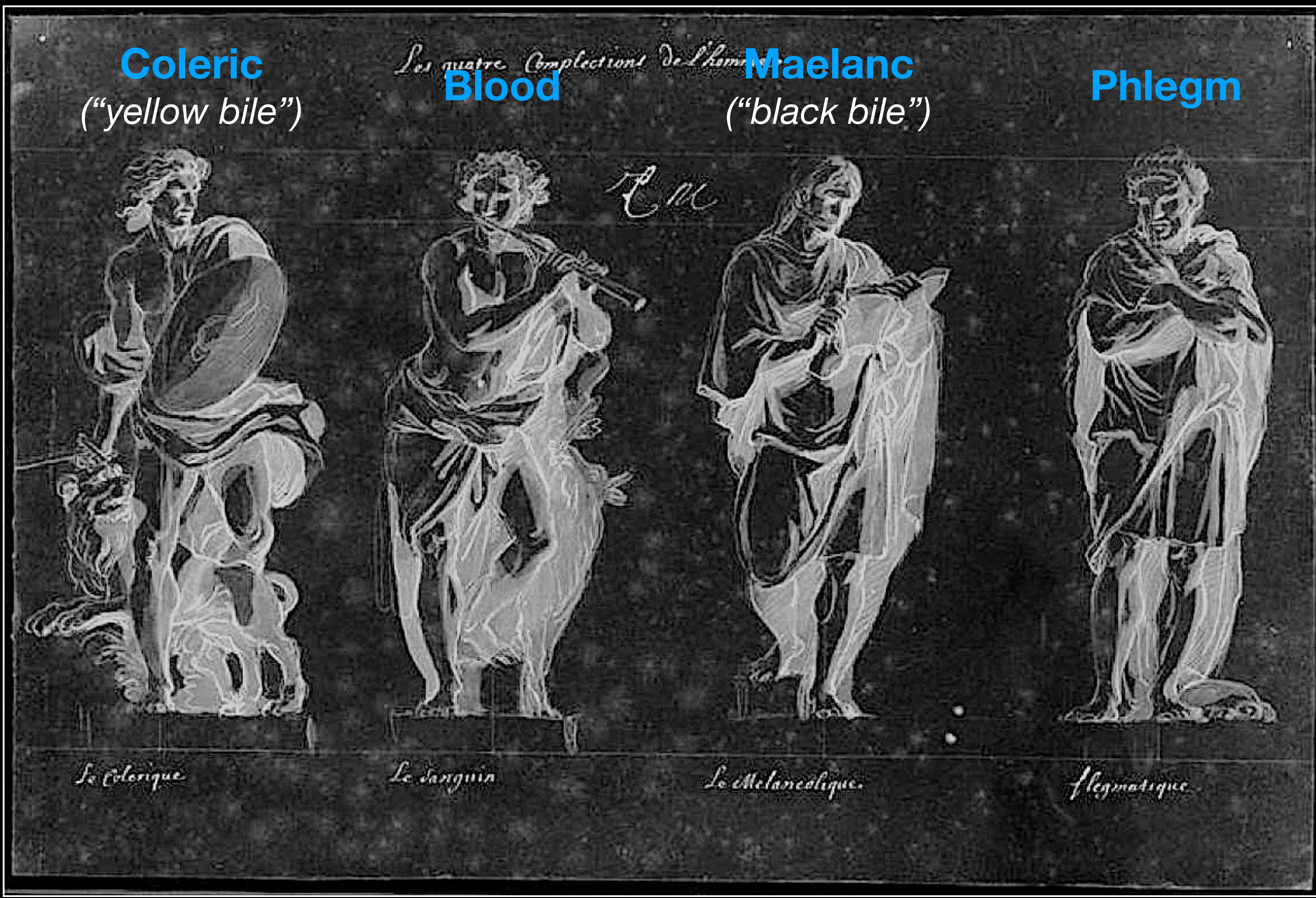

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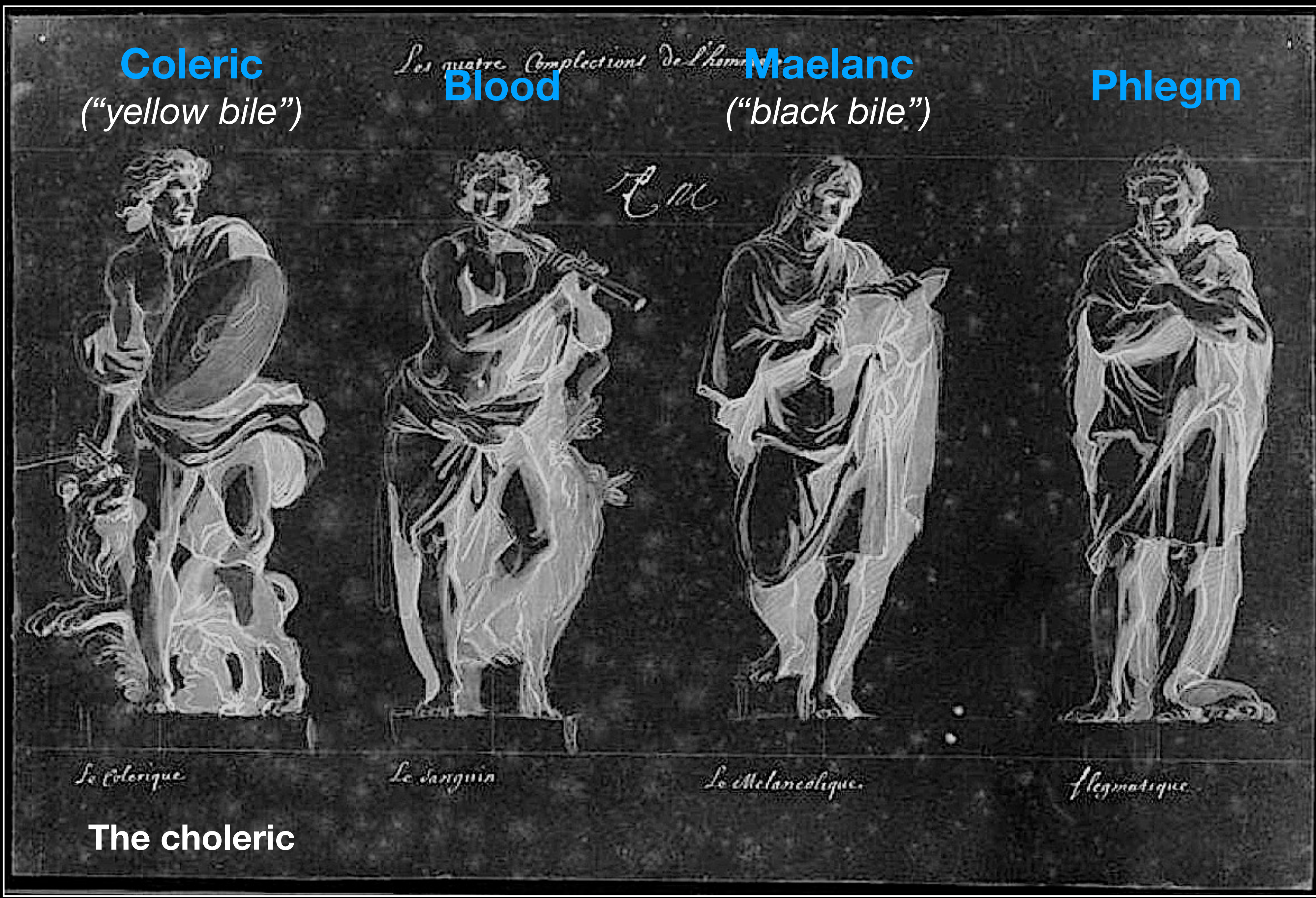

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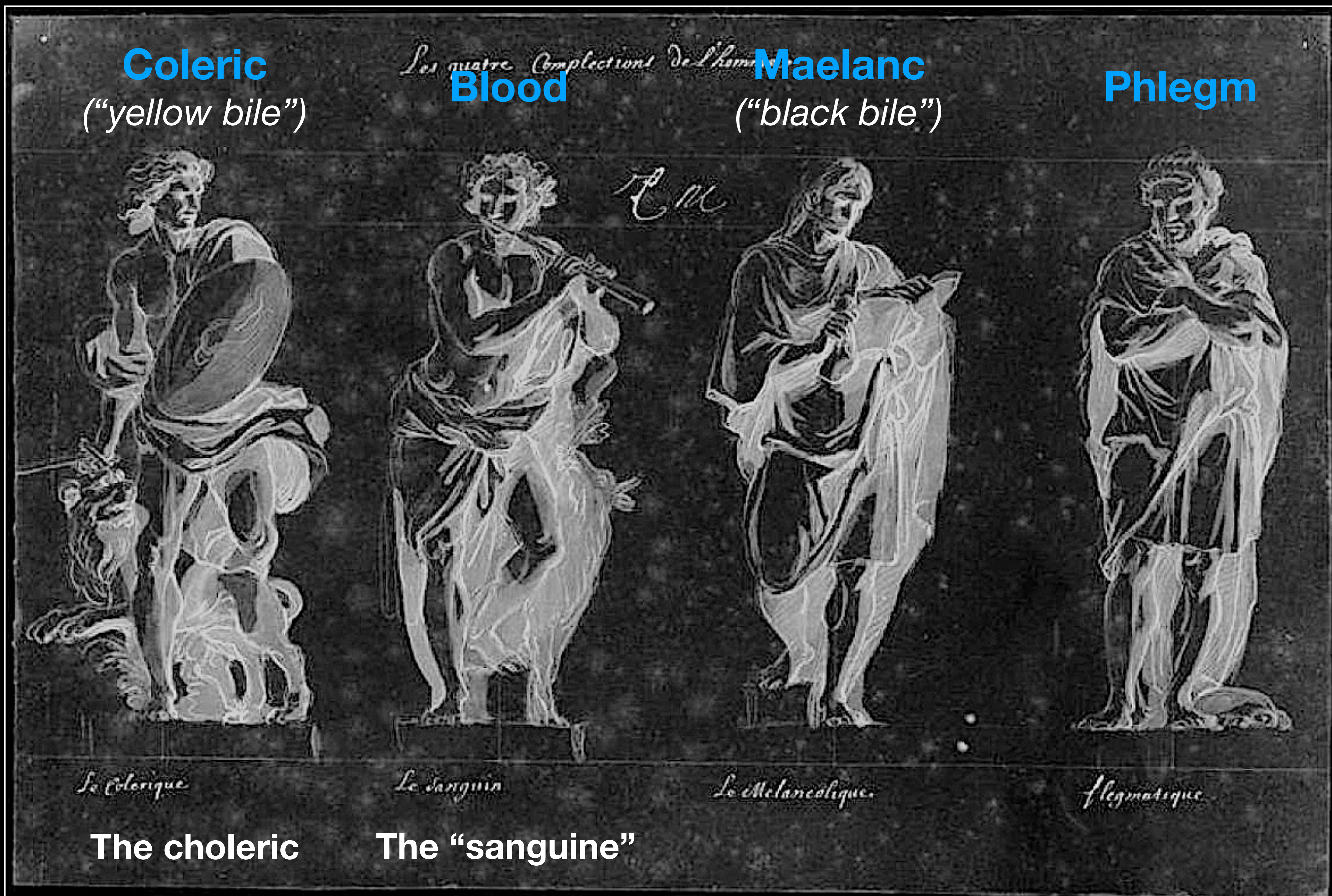

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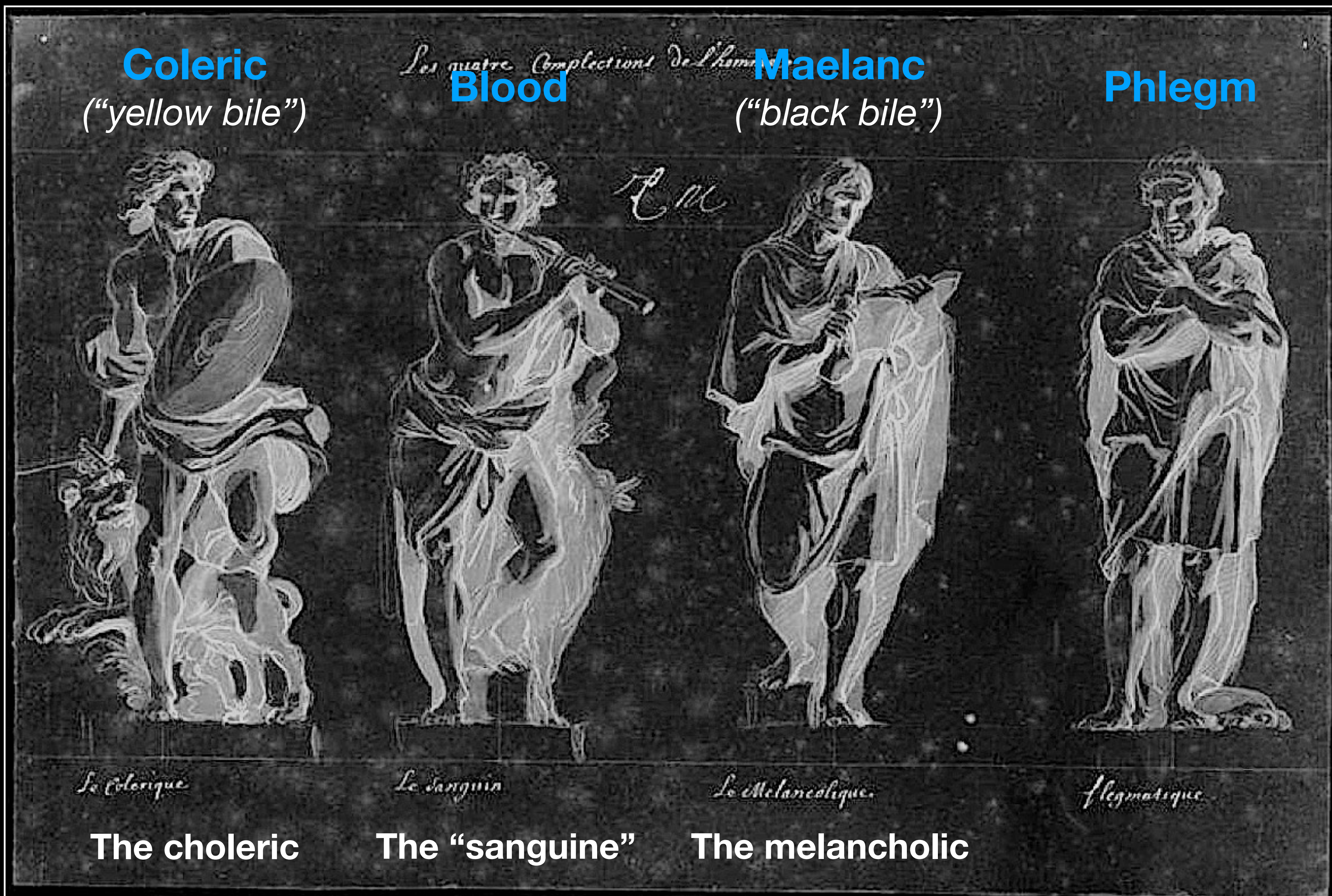

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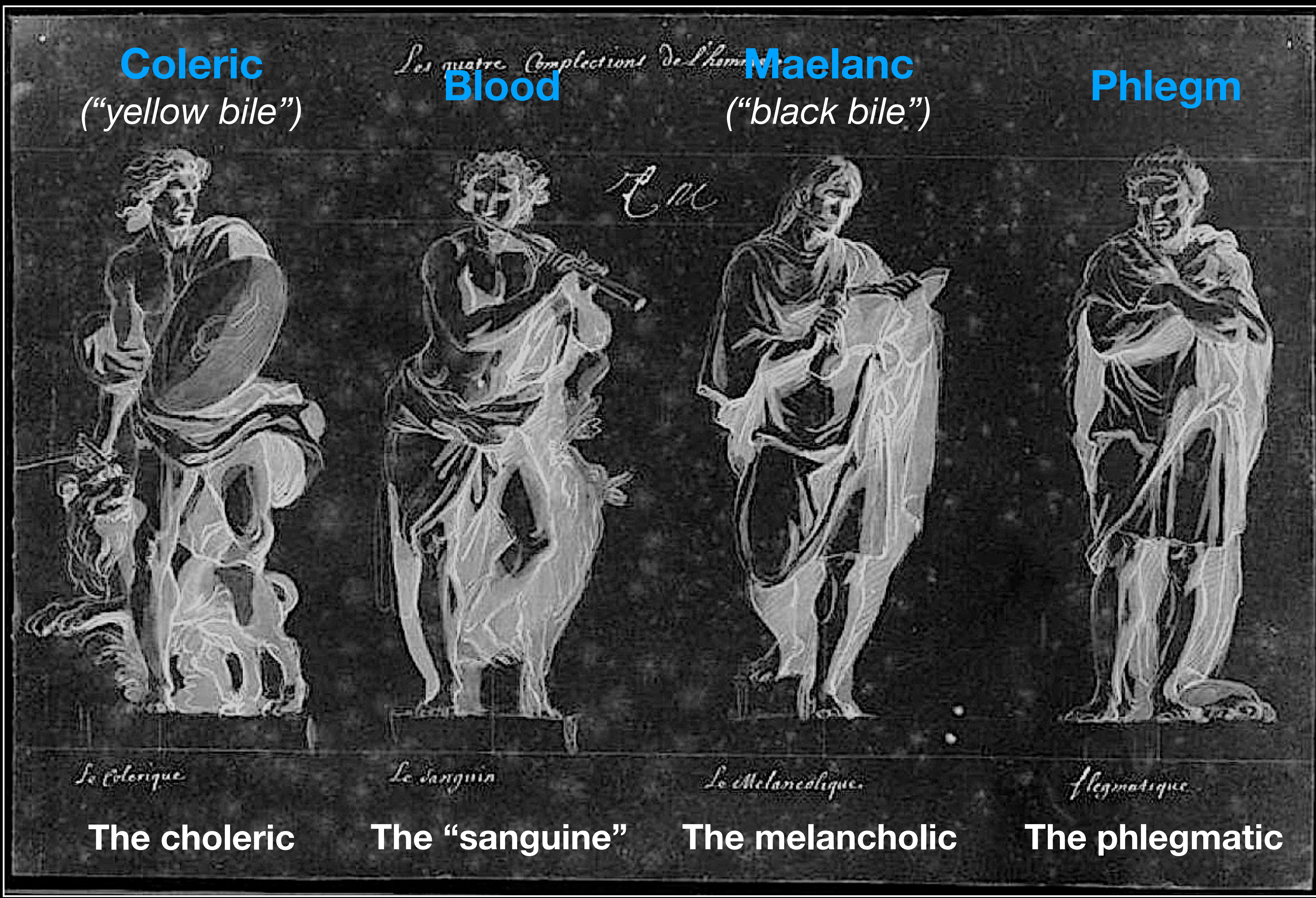

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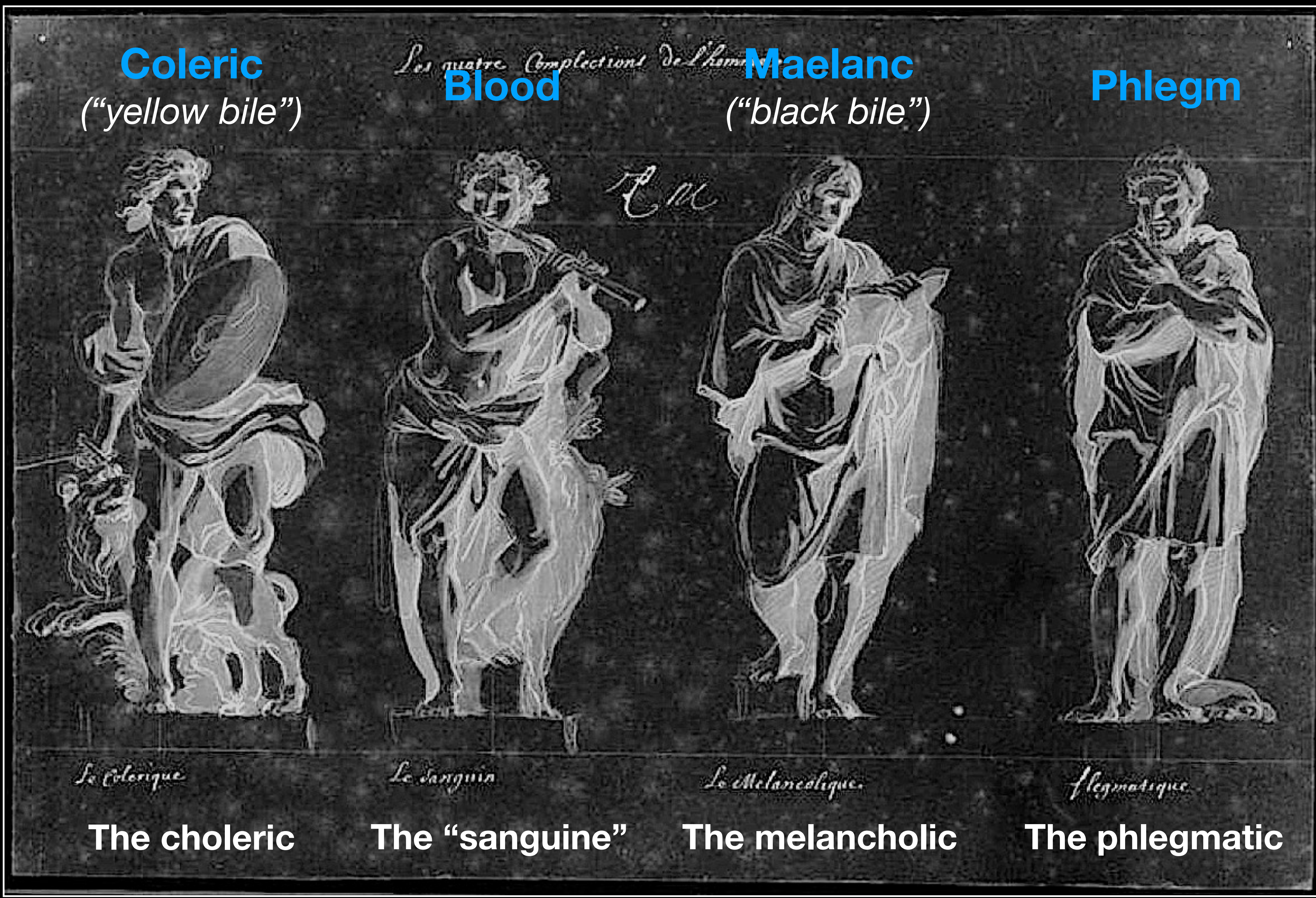


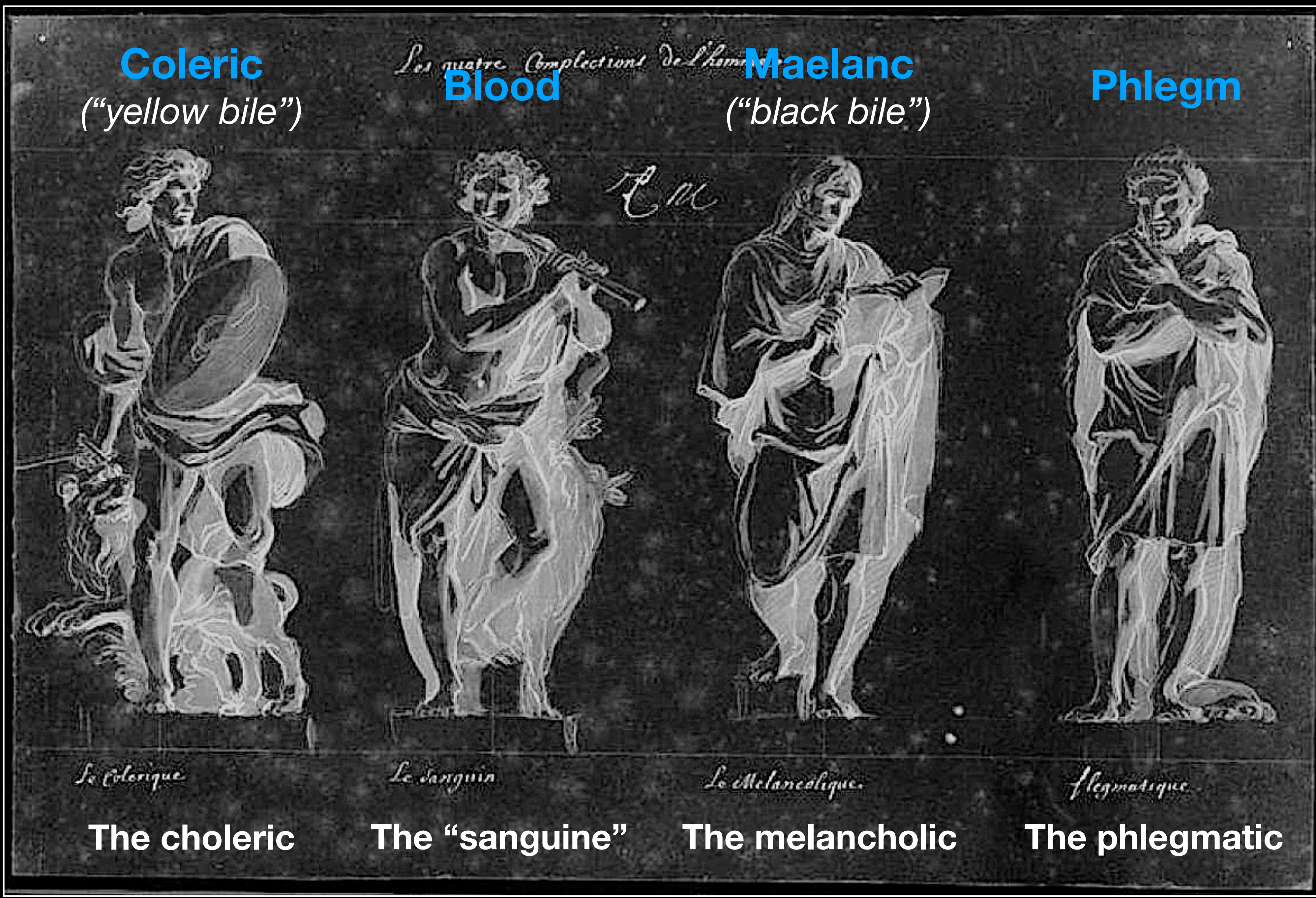
Bodily fluids

↓

Temperaments

Temperature in antiquity

Galen of Pergamon *(ca. 140 AD)*



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Temperaments

"Temperature"

Temperature in antiquity

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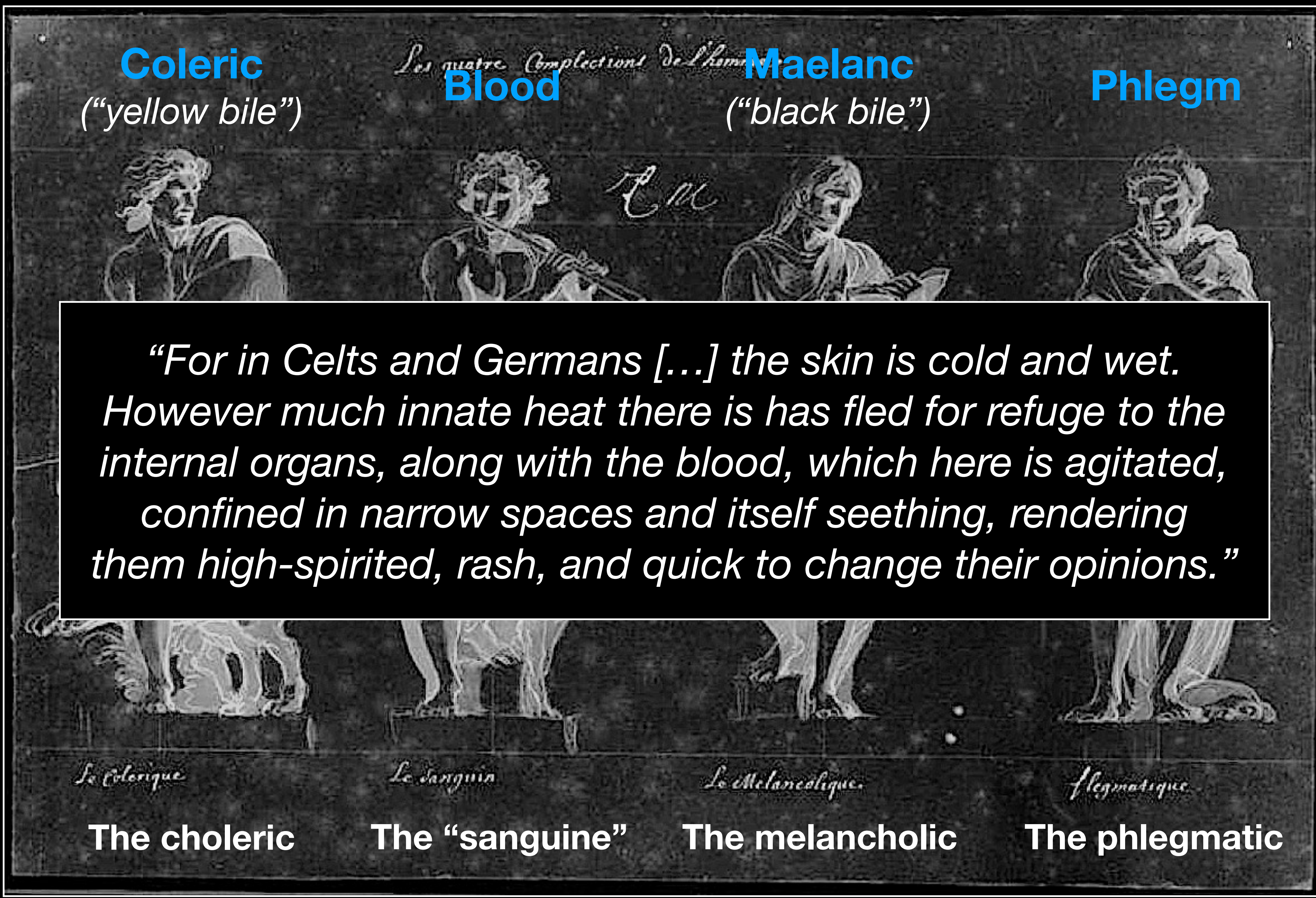

“For in Celts and Germans […] the skin is cold and wet. However much innate heat there is has fled for refuge to the internal organs, along with the blood, which here is agitated, confined in narrow spaces and itself seething, rendering them high-spirited, rash, and quick to change their opinions.”

Bodily fluids

↓

Temperaments

“Temperature”

Galen’s temperature scale

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“Proceeding from the hottest of all those coming to perception
(for example, either fire or boiling water)

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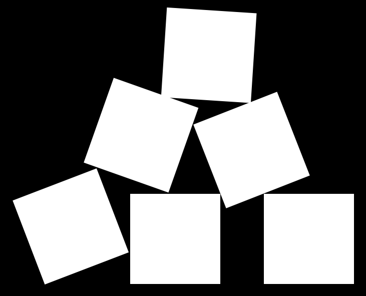
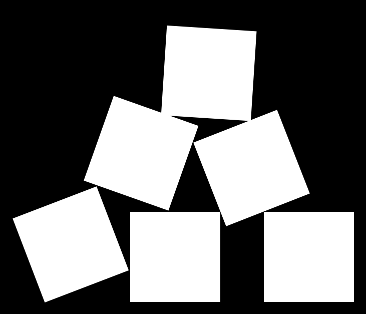


Galen's temperature scale

"Proceeding from the hottest of all those coming to perception (for example, either fire or boiling water)

to the very coldest of all things we know (for example, either ice or snow) …"

"We divide this precisely in the middle, discovering the moderate which is equally removed from each of the extremes."



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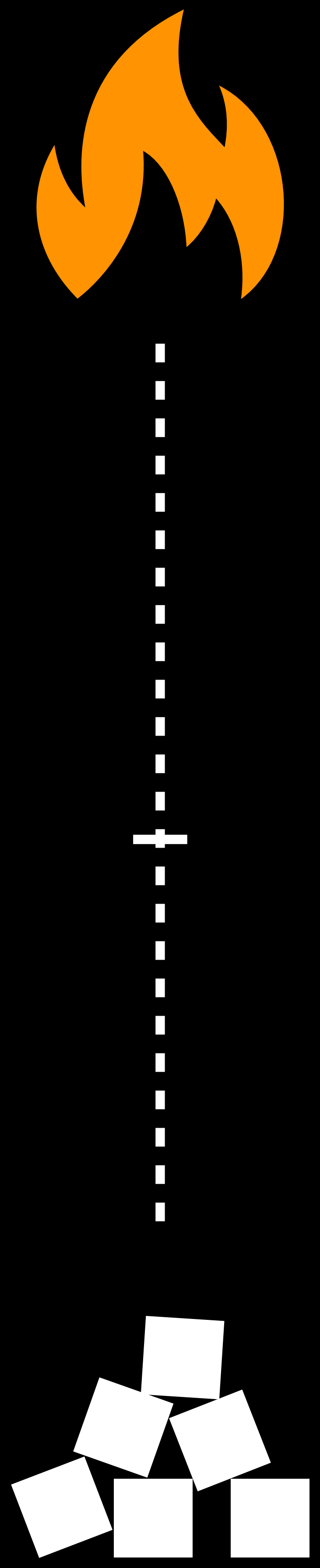

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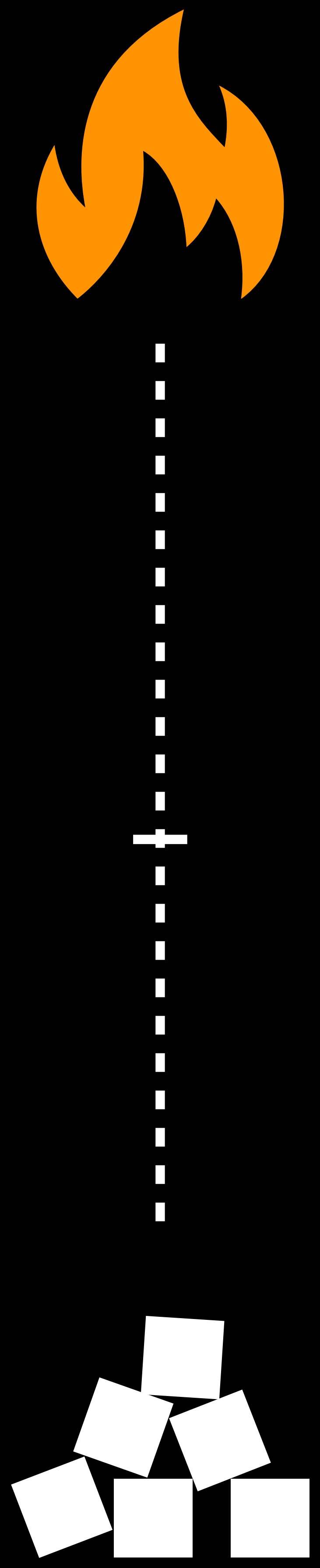
"But we are also able to prepare this in a certain way when we mix an equal mass of ice with boiling water."



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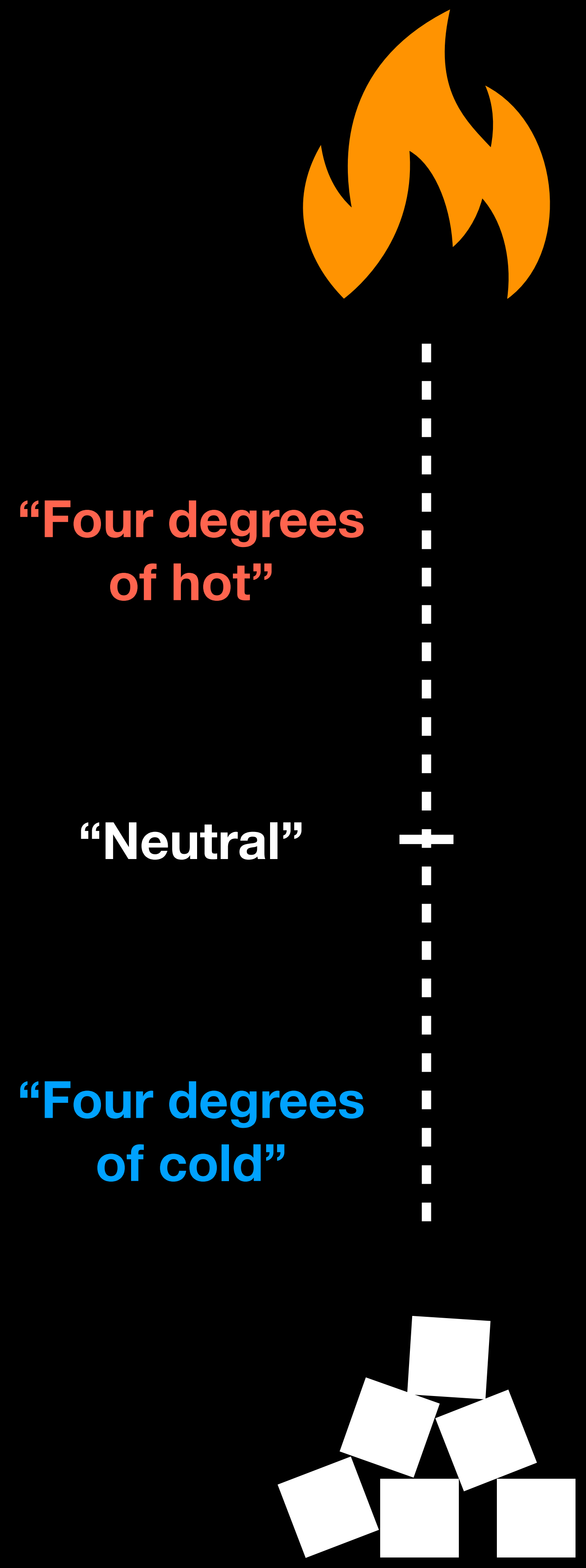

Nothing changed for 1500 years!

Johannis Hasler of Berne:
"Of medical practice" (1578)

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Problem 1:

Nothing changed for 1500 years!

Johannis Hasler of Berne:
“Of medical practice” (1578)

Problem 1:

“To find the natural degree of temperature of each man, as determined by his age, the time of year, the elevation of the pole, and other influences.”

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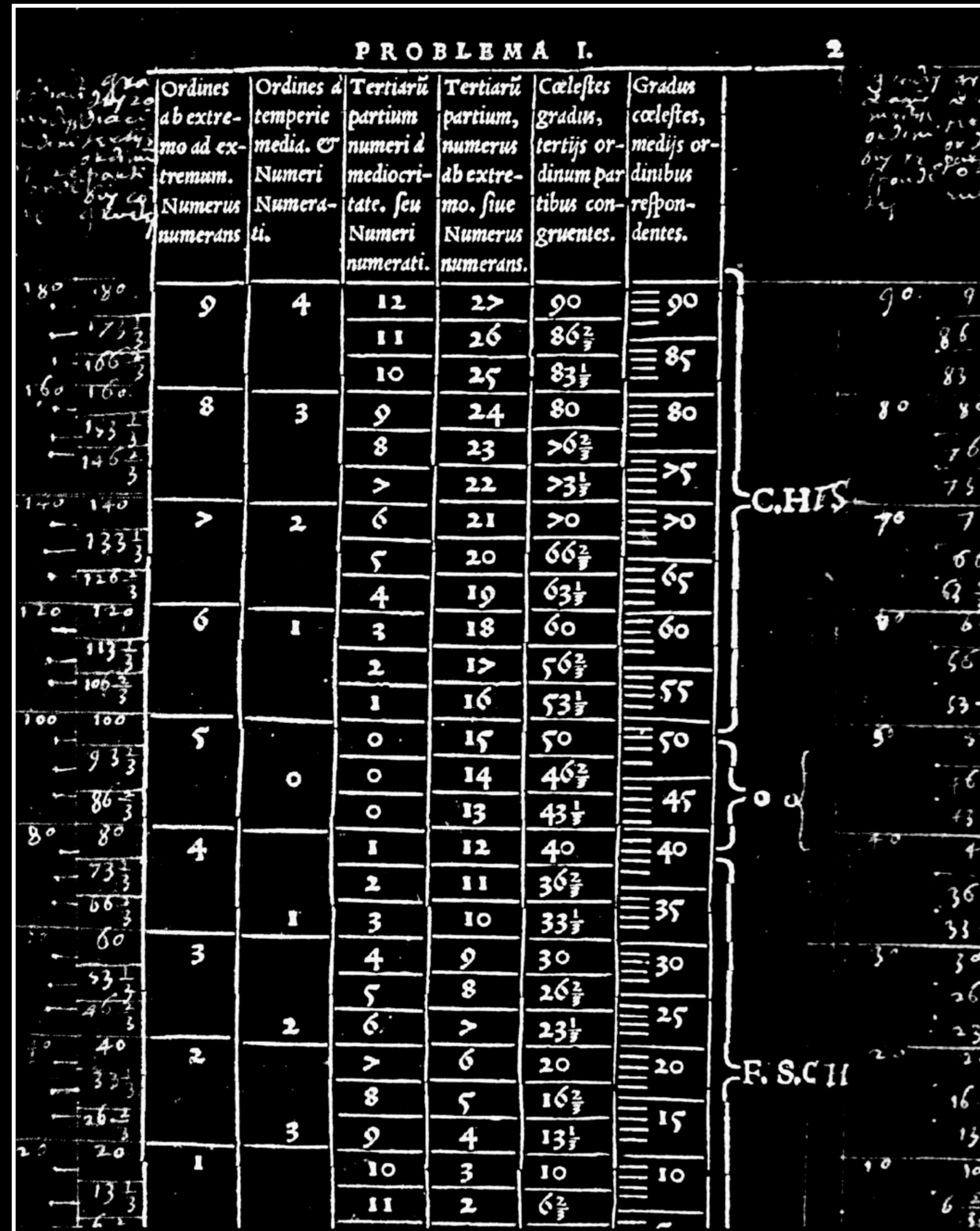

PROBLEMA I. 2

Ordines ab extremo ad extremum. Numerus numerans	Ordines à temperie media. & Numeri Numeranti.	Tertiarũ partium numeri à mediocritate, seu Numeri numerati.	Tertiarũ partium, numerus ab extremo, siue Numerus numerans.	Cœlestes gradus, tertijs ordinum partibus congruentes.	Gradus cœlestes, medijs ordinibus respondentes.
9	4	12	27	90	90
		11	26	86⅔	
		10	25	83⅓	85
8	3	9	24	80	80
		8	23	76⅔	
		7	22	73⅓	75
7	2	6	21	70	70
		5	20	66⅔	
		4	19	63⅓	65
6	1	3	18	60	60
		2	17	56⅔	
		1	16	53⅓	55
5		0	15	50	50
	0	0	14	46⅔	
		0	13	43⅓	45
4		1	12	40	40
		2	11	36⅔	
	1	3	10	33⅓	35
3		4	9	30	30
		5	8	26⅔	
	2	6	7	23⅓	25
2		7	6	20	20
		8	5	16⅔	
	3	9	4	13⅓	15
1		10	3	10	10
		11	2	6⅔	

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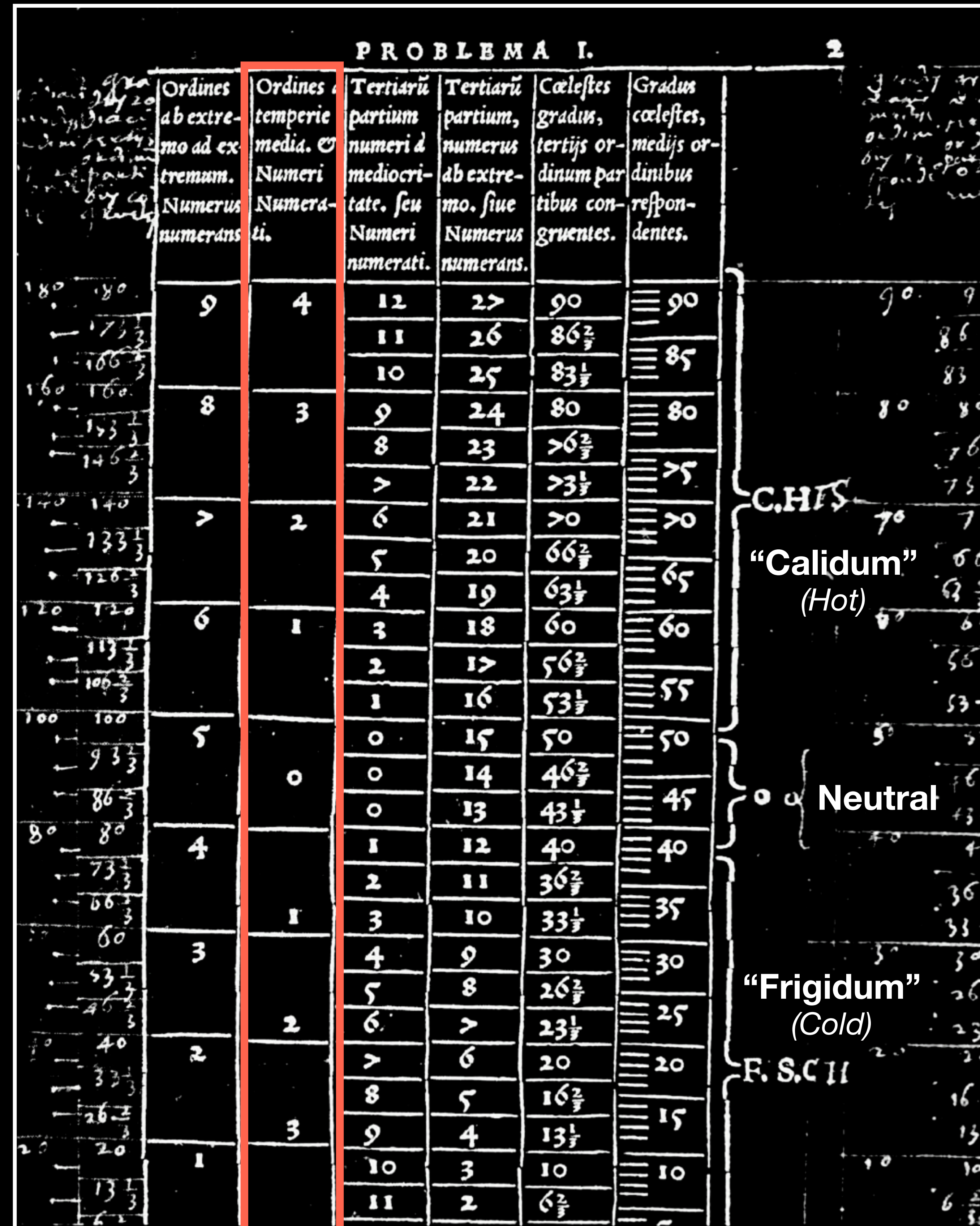
Relating Galen's temperature scale …



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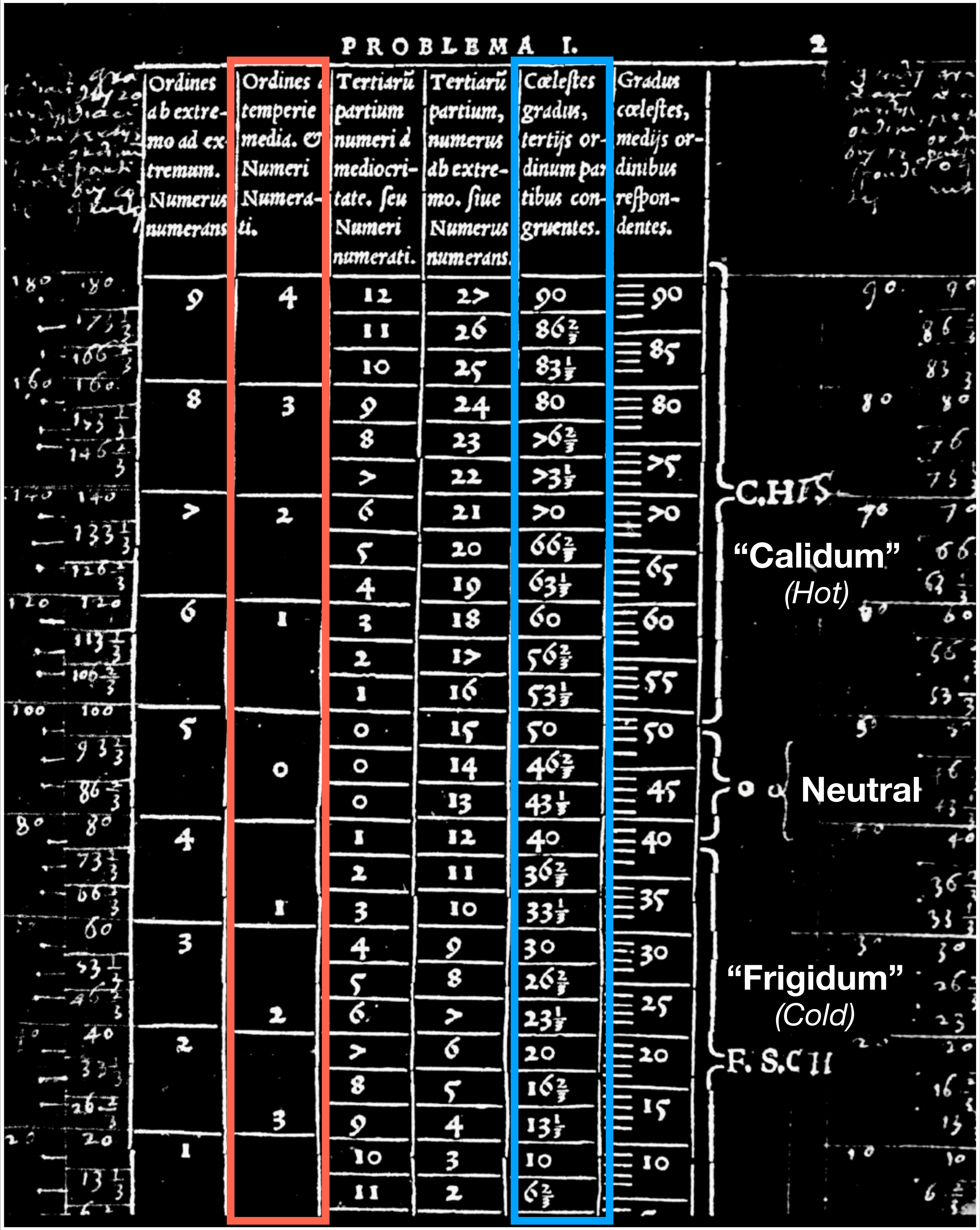
Relating Galen’s temperature scale …

… to the latitude of the patient.



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2		7	6	20	20
		8	5	16⅔	
	3	9	4	13⅓	15
1		10	3	10	10
		11	2	6⅔	

The first "thermoscopes"

Letters from Giovanni Sagredo to Galileo:

Giovanni Francesco Sagredo

Mathematician in Venice, diplomat and spy
in Syria, treasurer in Palmanova,
close friend of Galileo's

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In today’s terminology:
“air thermometer”

Trapped air expands when warmed, contracts when cooled

Cooler

Warmer

Trapped air

Water line

Water bucket

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"The instrument for measuring heat has been reduced to me to various very elegant and convenient forms.

With these, I have found various marvelous things, as, for example, that in winter the air may be colder than ice or snow; that the water just now appears colder than the air, and similar subtle matters."

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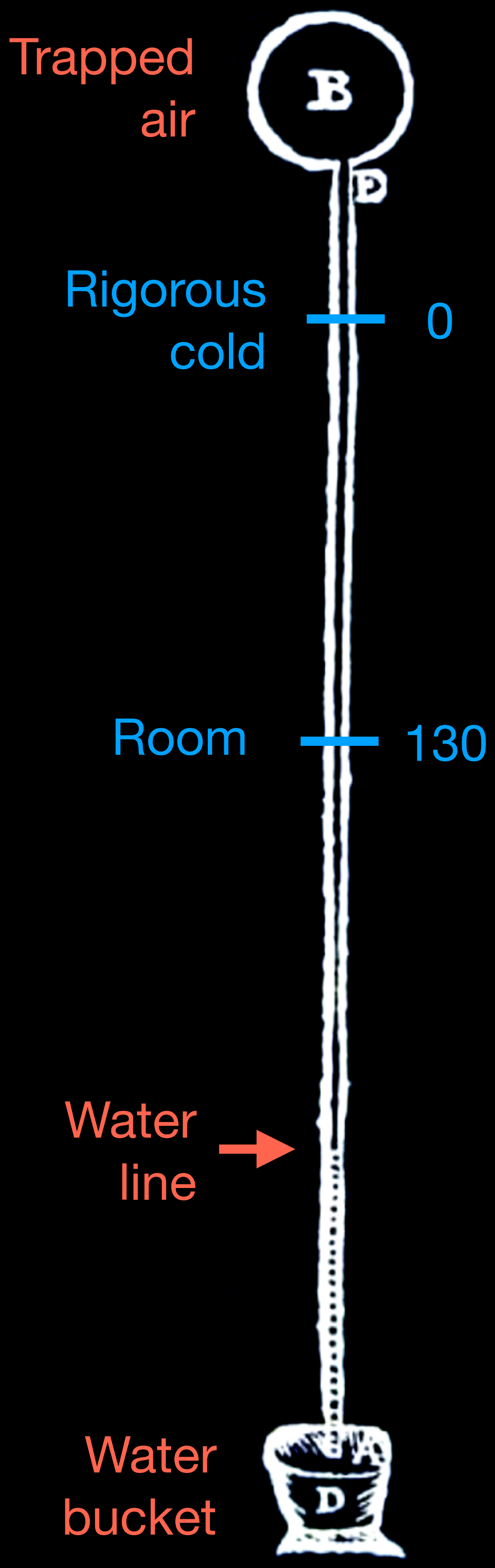

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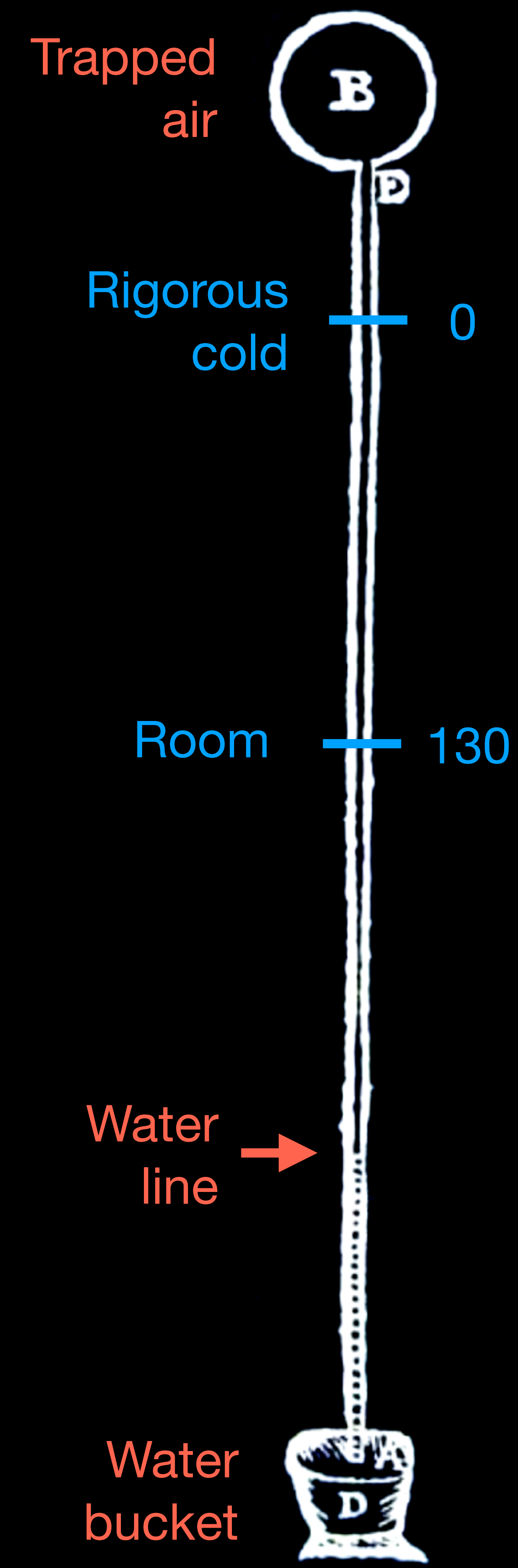

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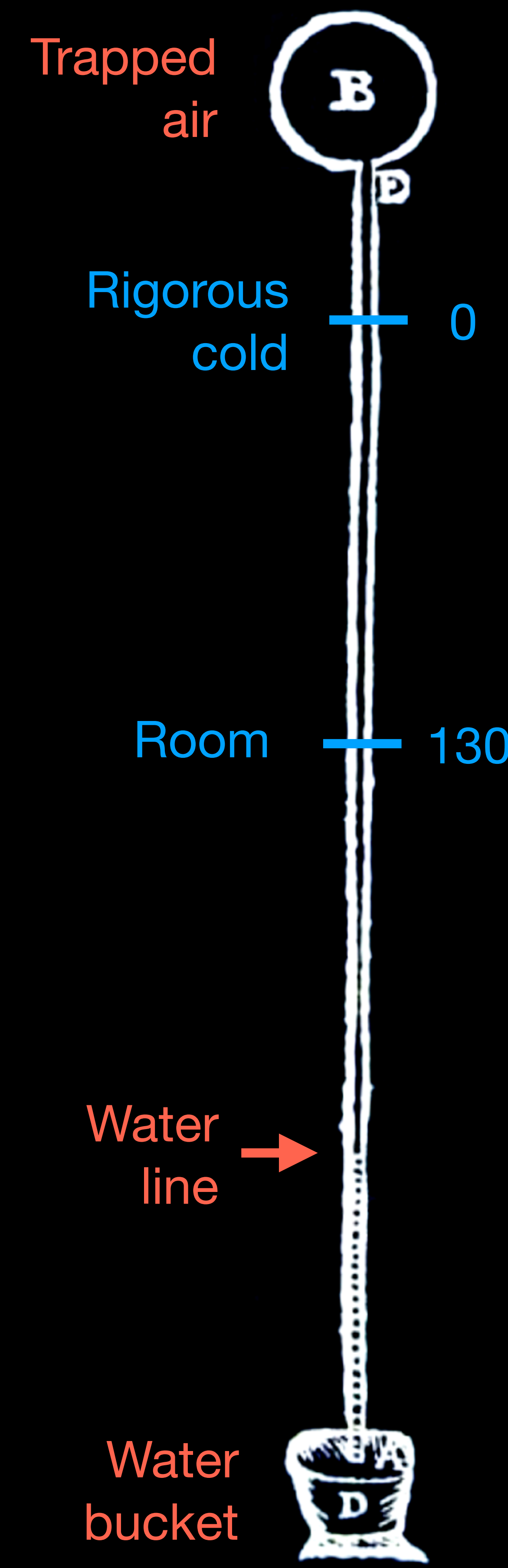

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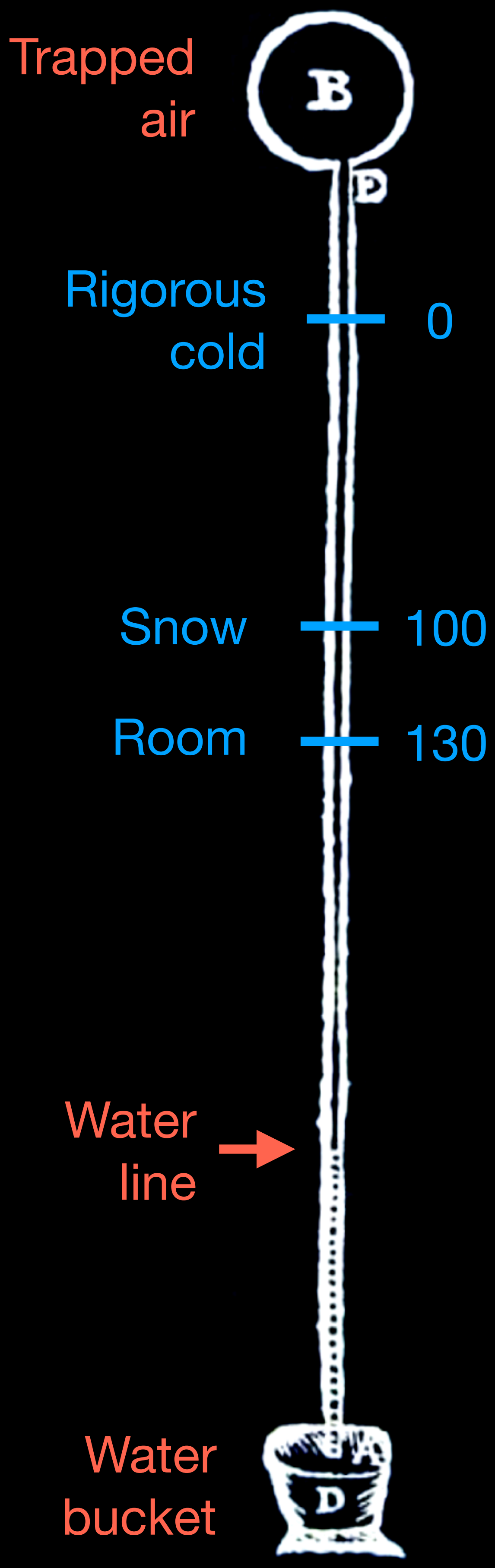

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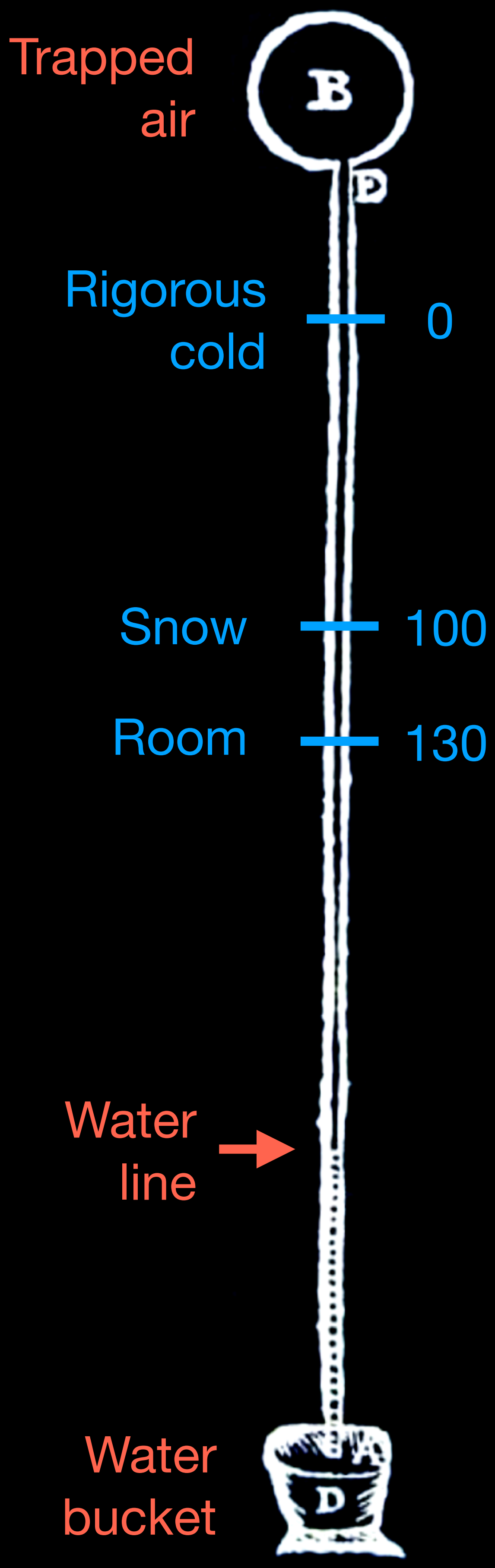

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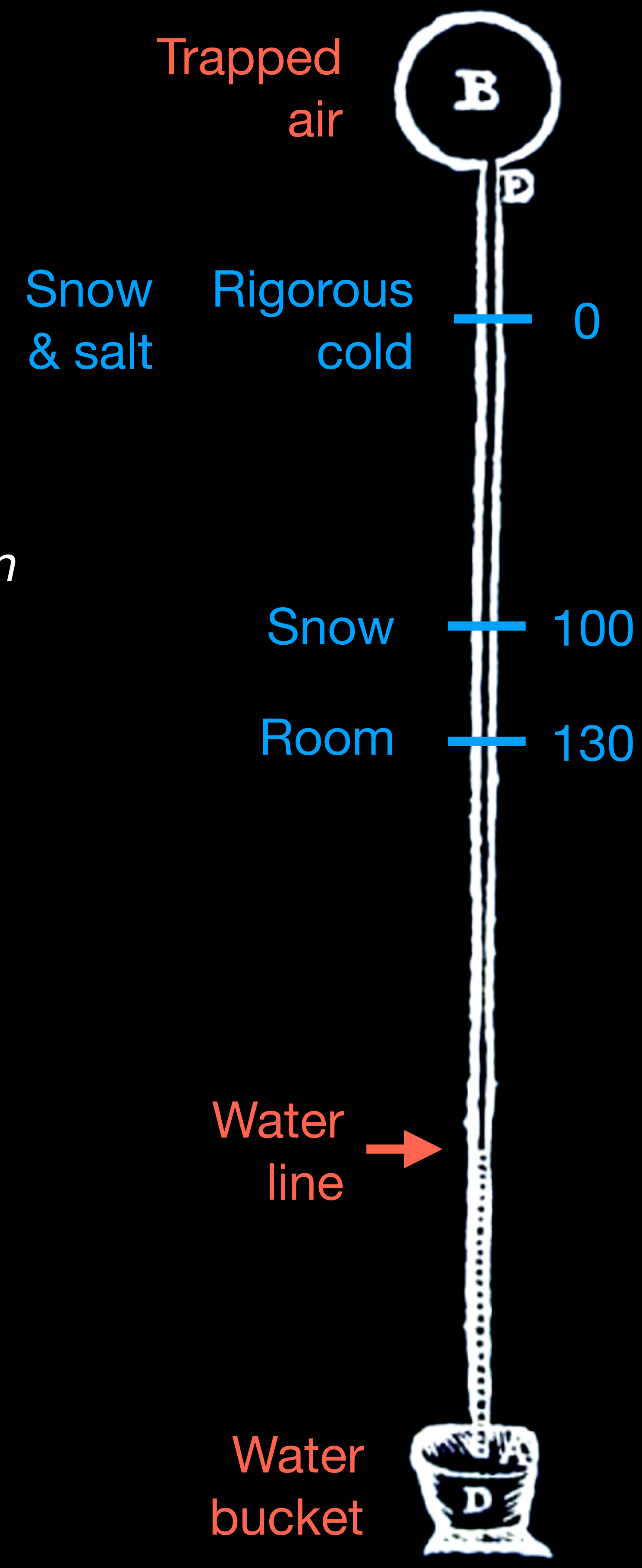

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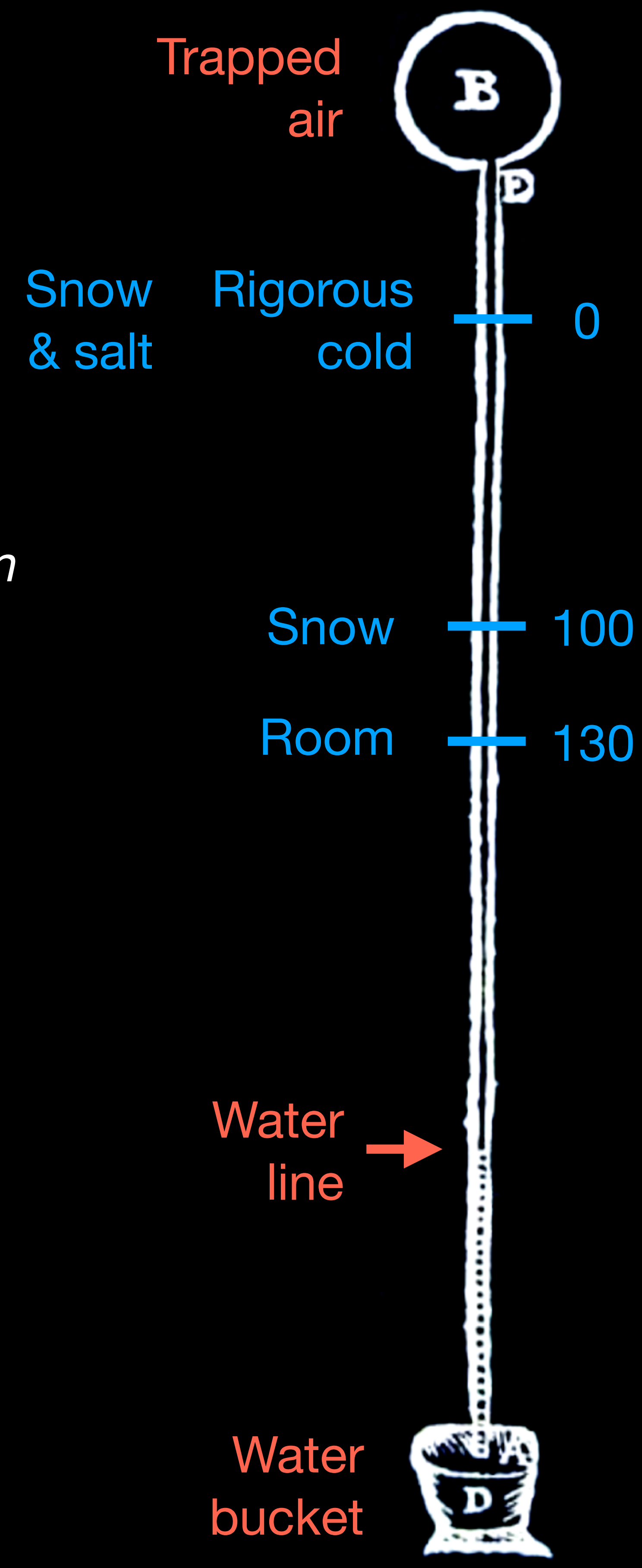

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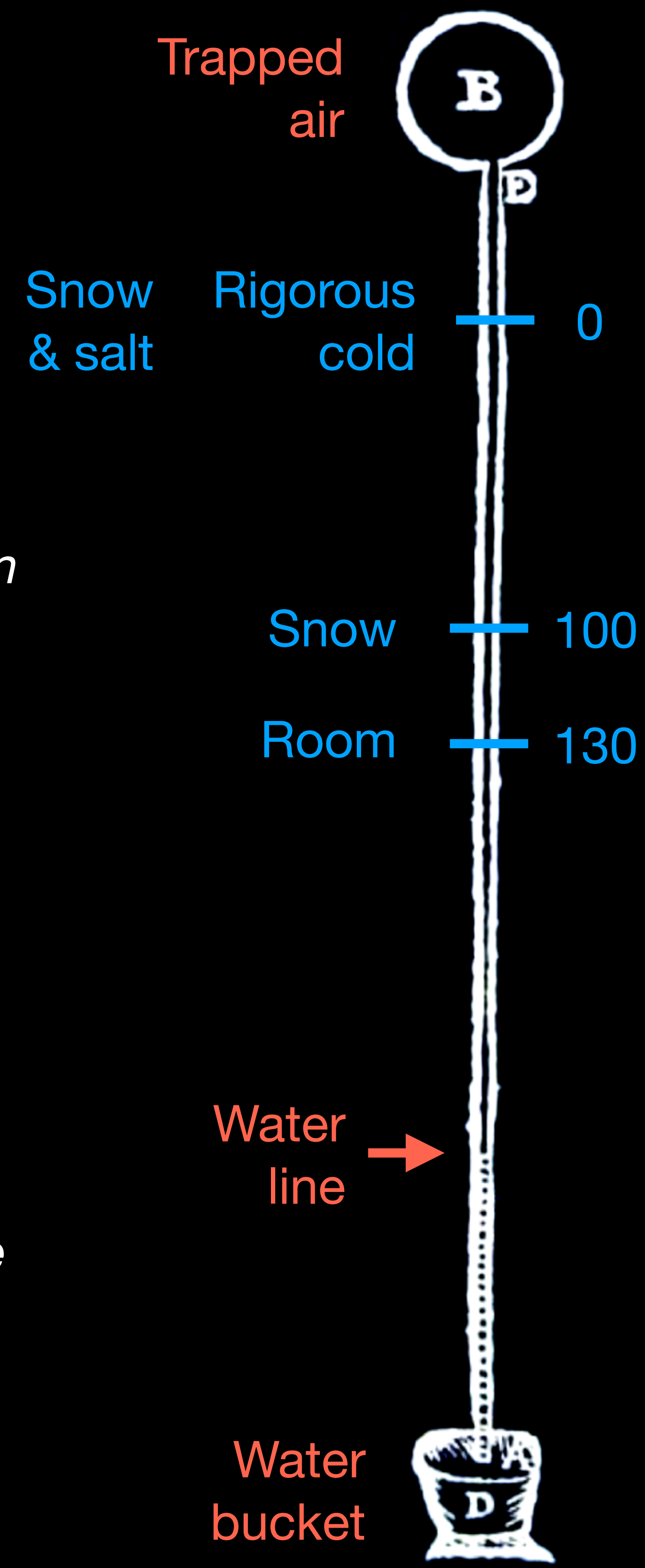

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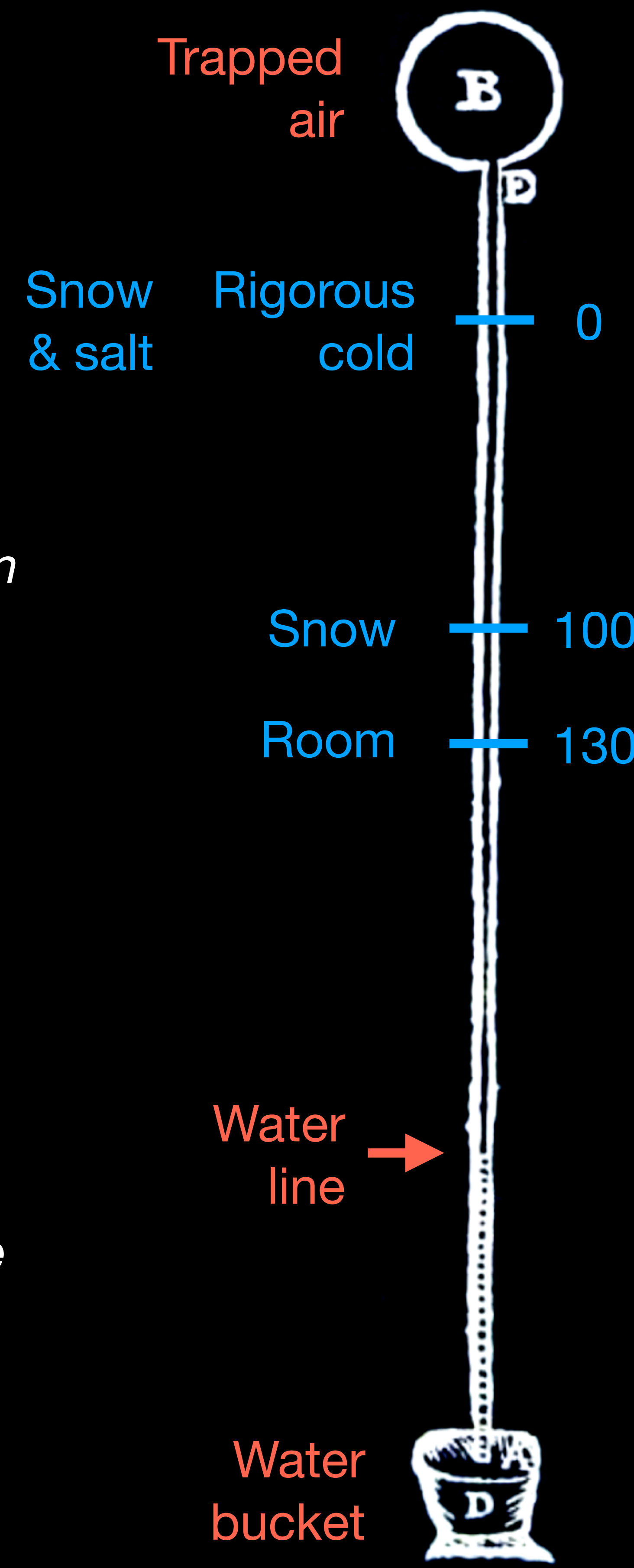

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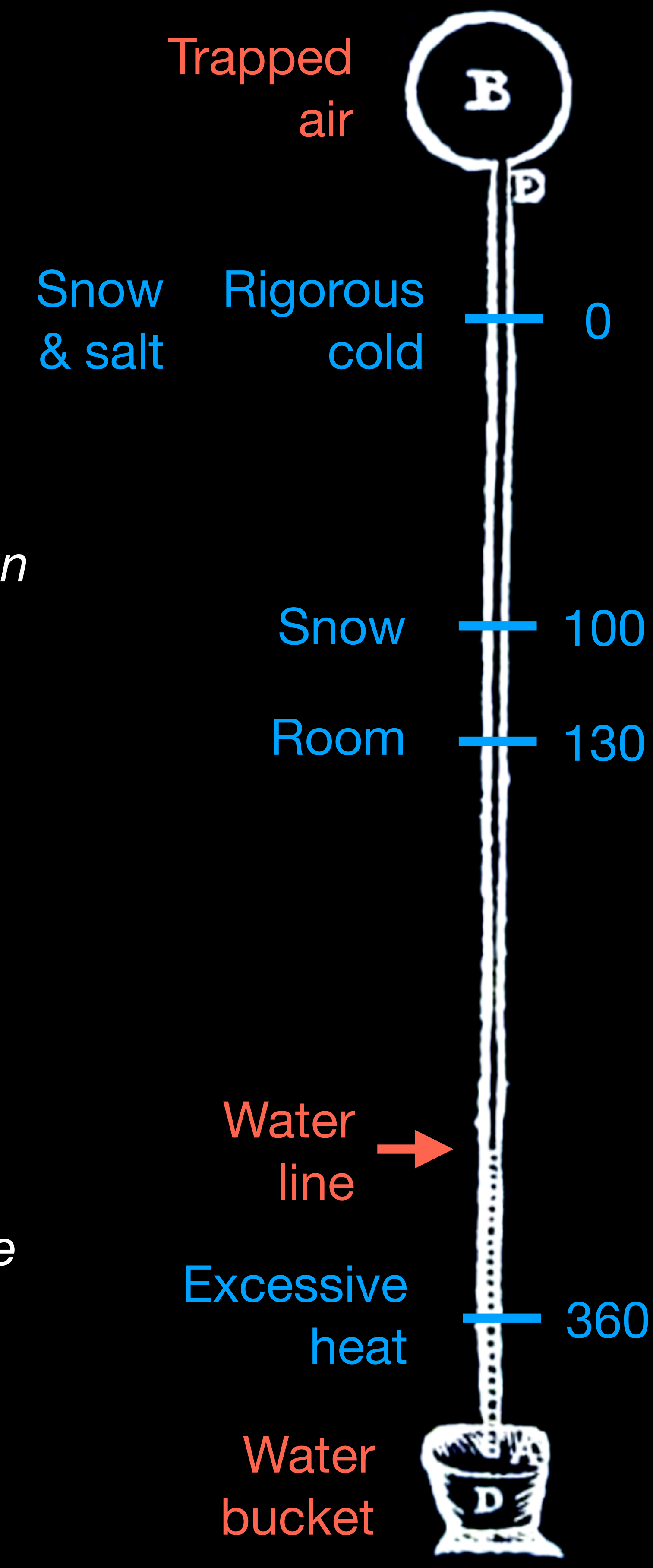
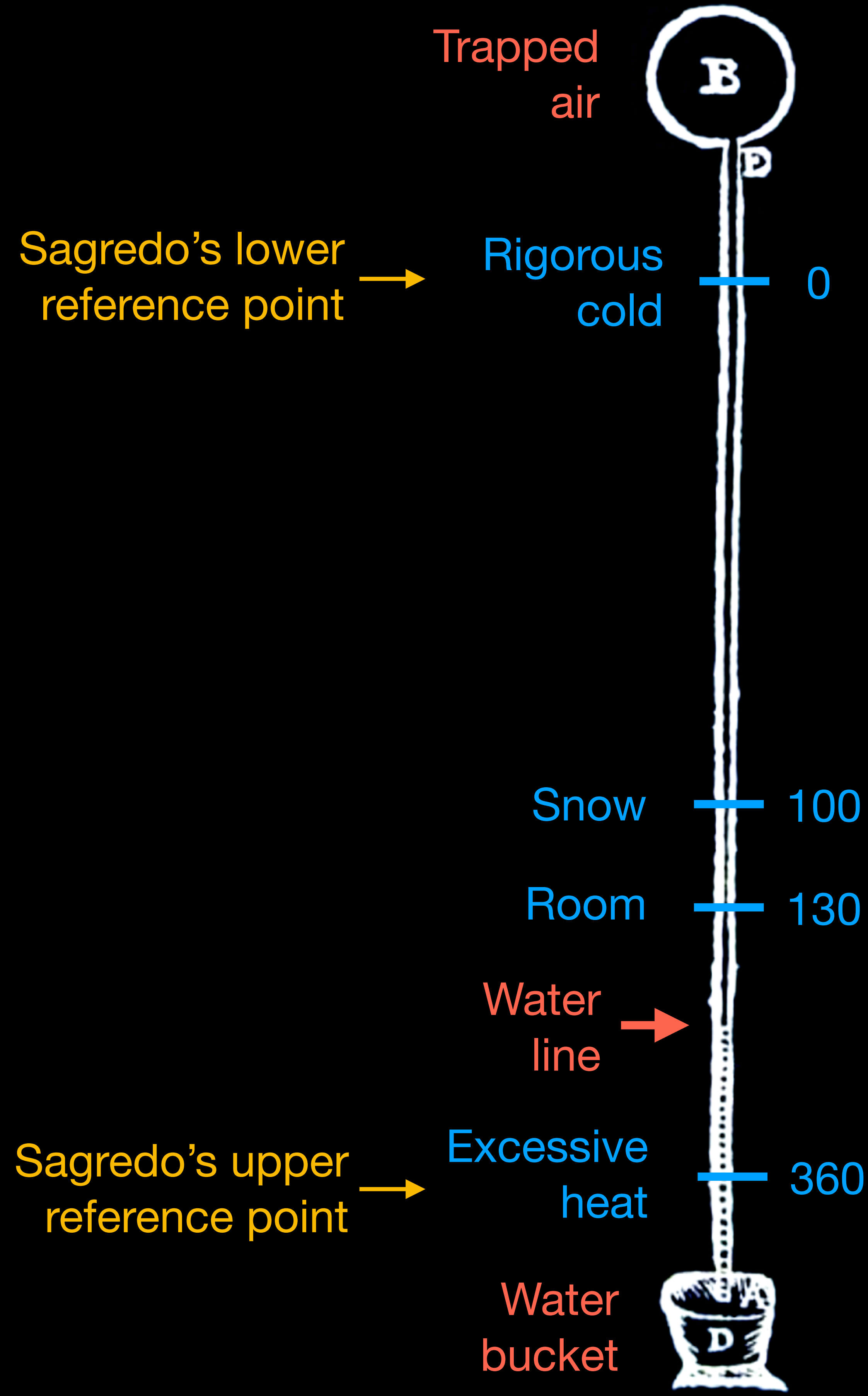
—a thing so wonderful, that I can provide no credible reason for it."



Measuring temperature

This is how (most) temperature scales are defined even today!

Pick two reference points, divide the space in between into an arbitrary number of "degrees".



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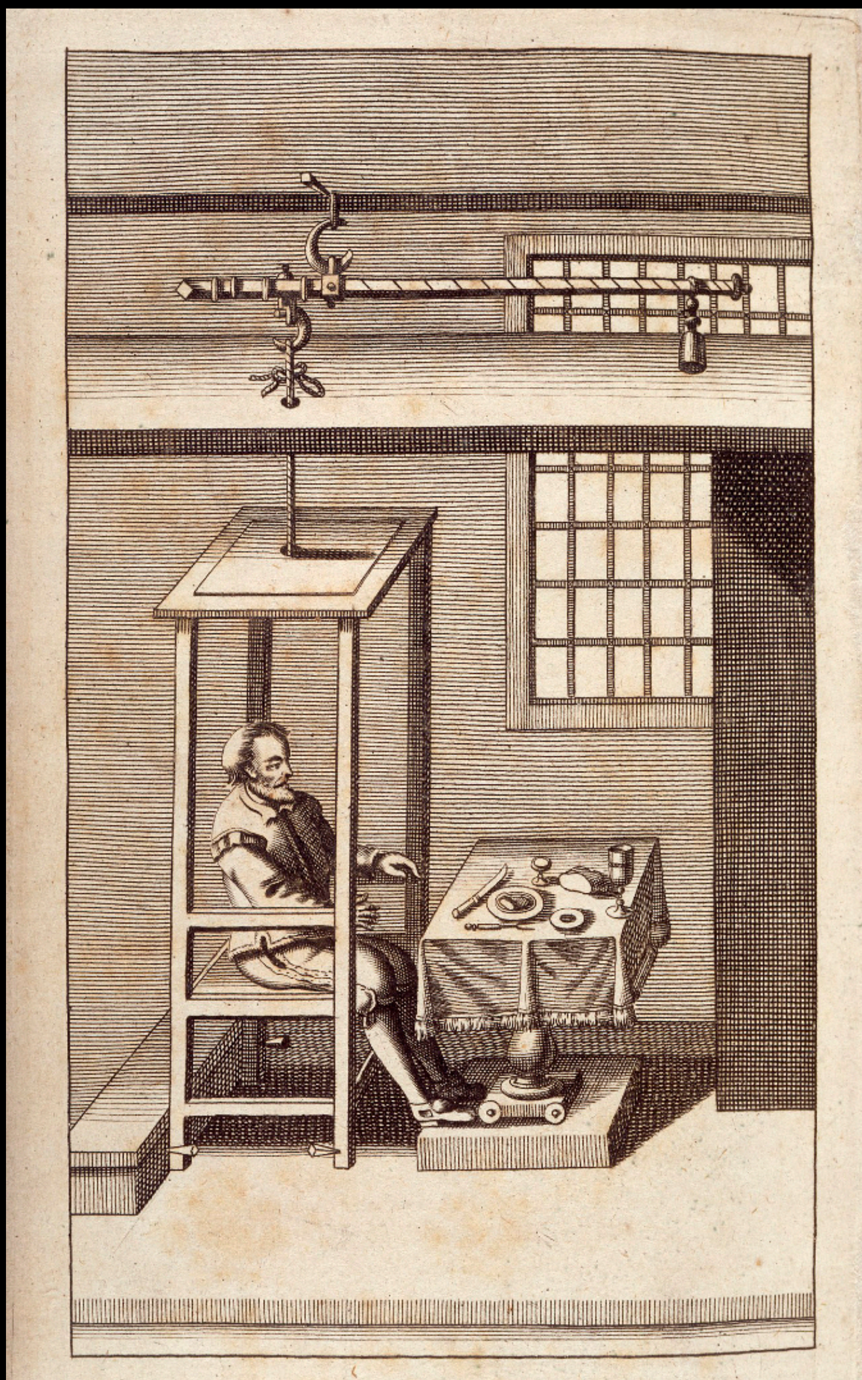

← "Weighing chair" to study his own metabolism for 30 years!

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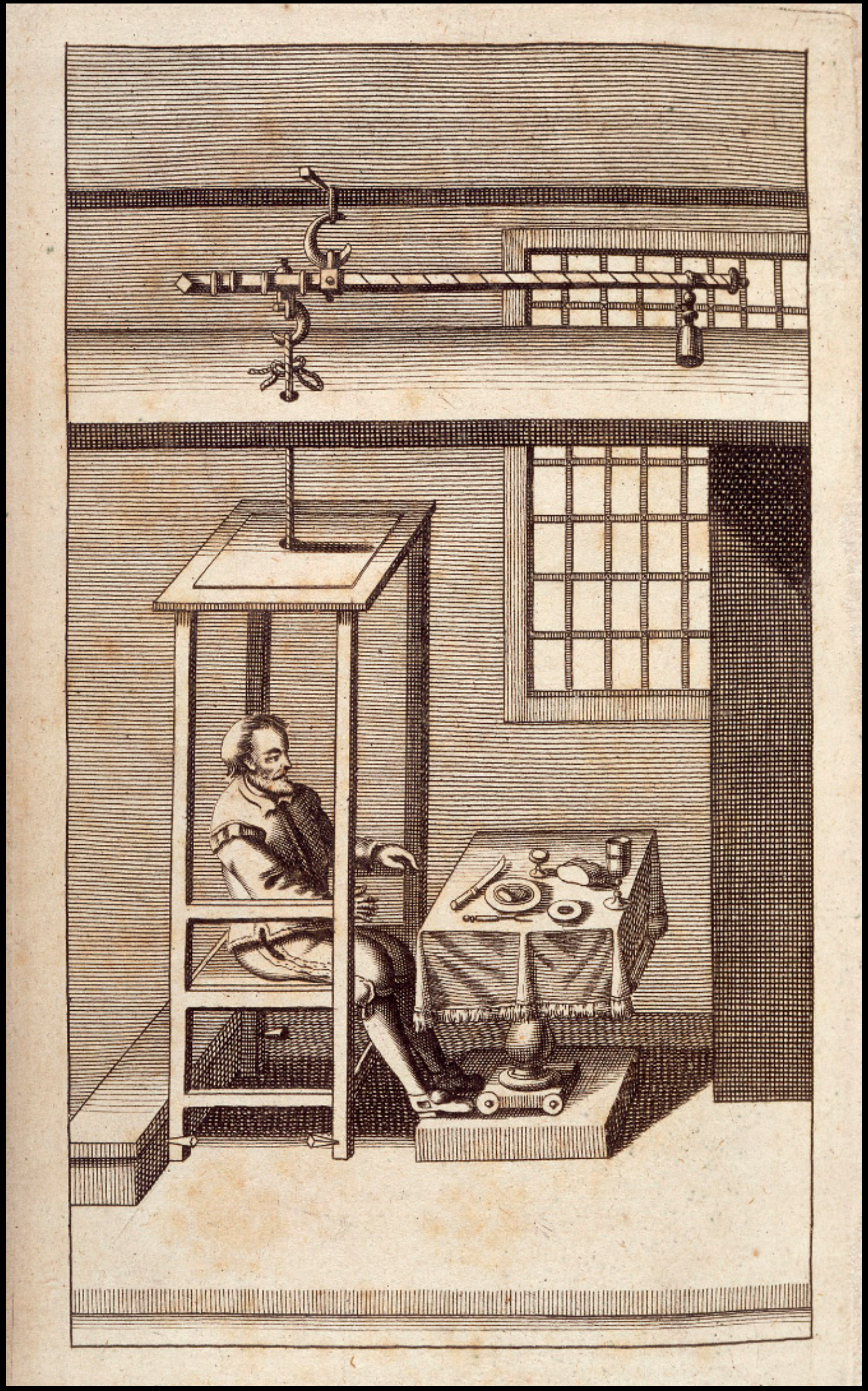

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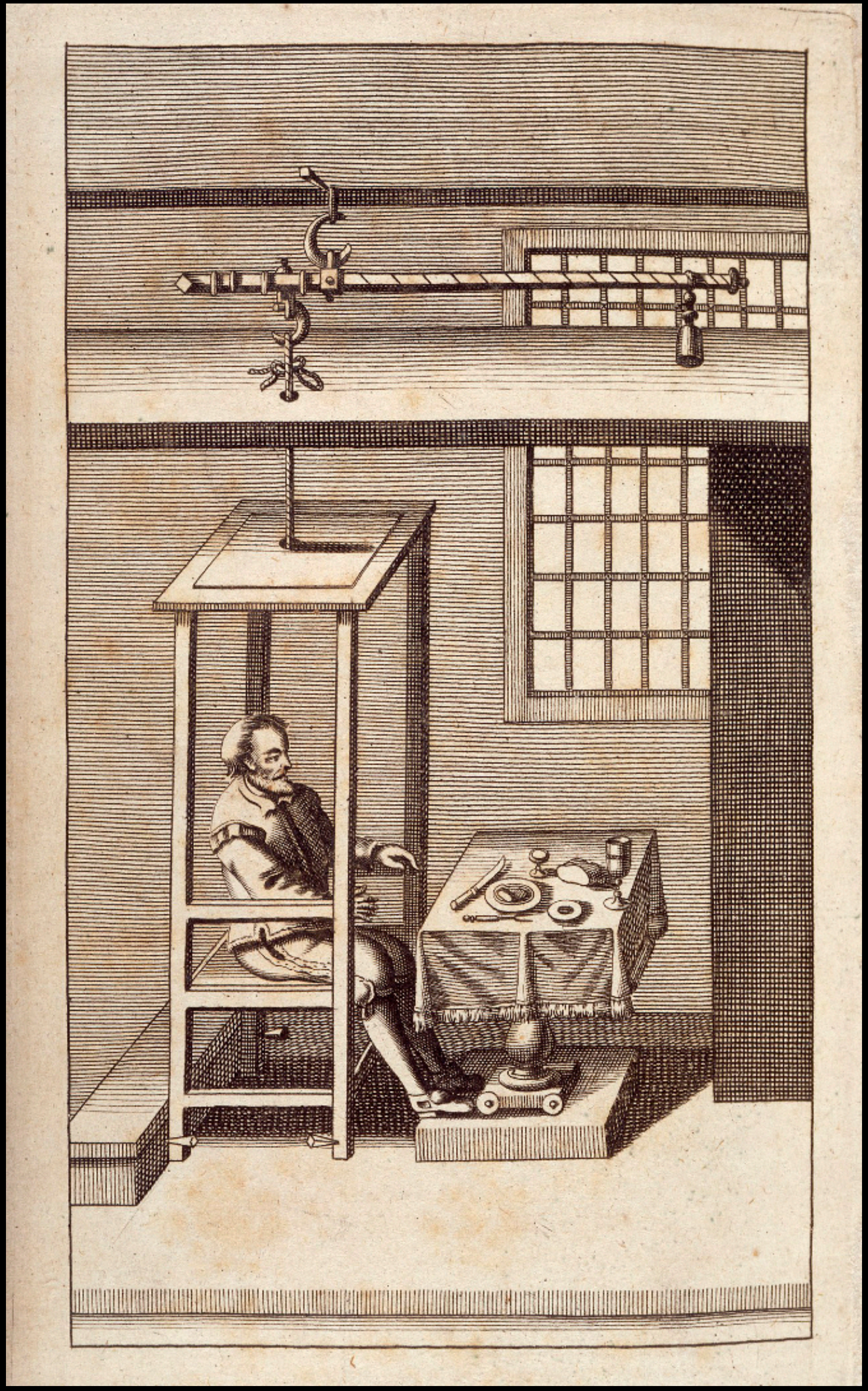

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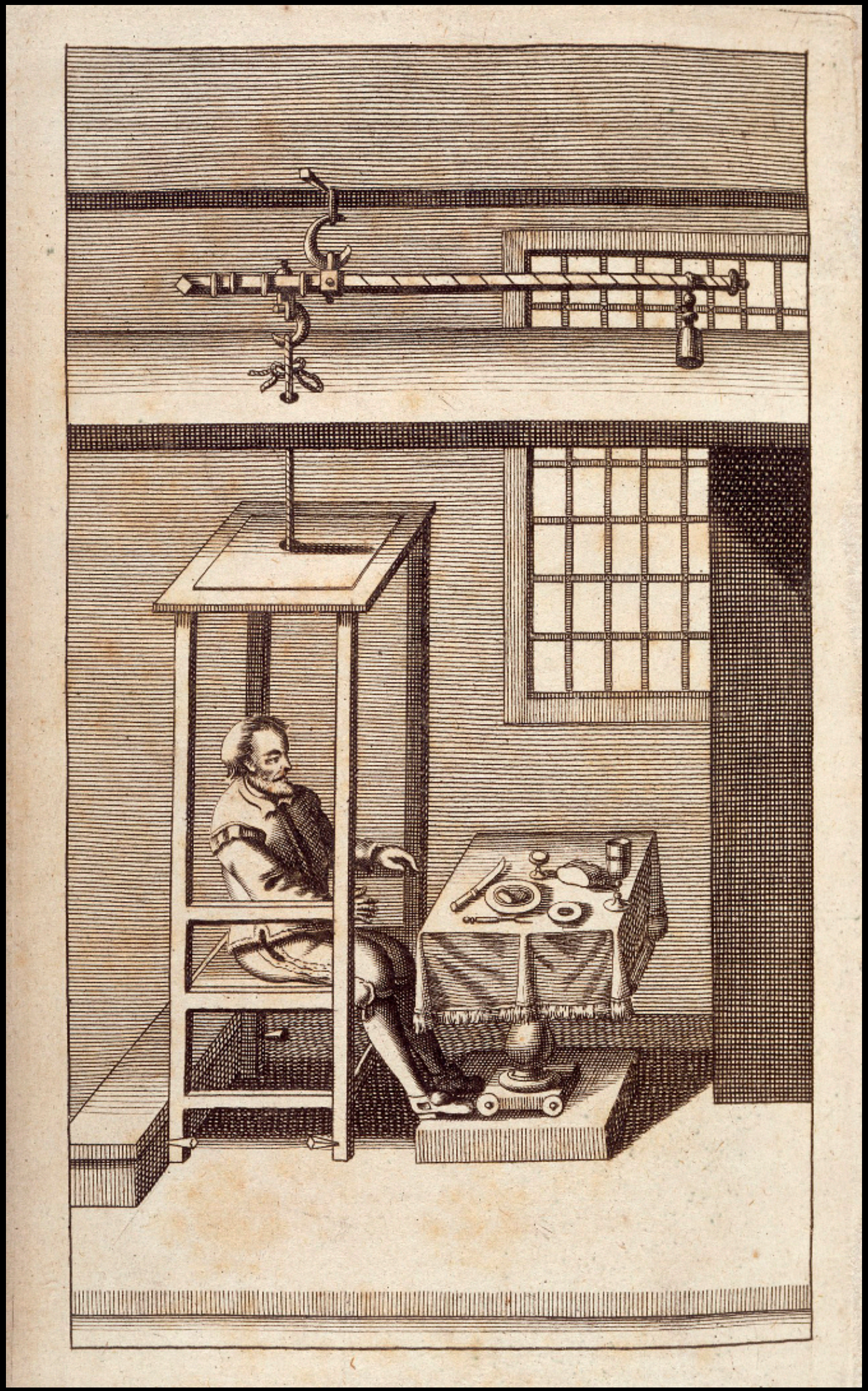

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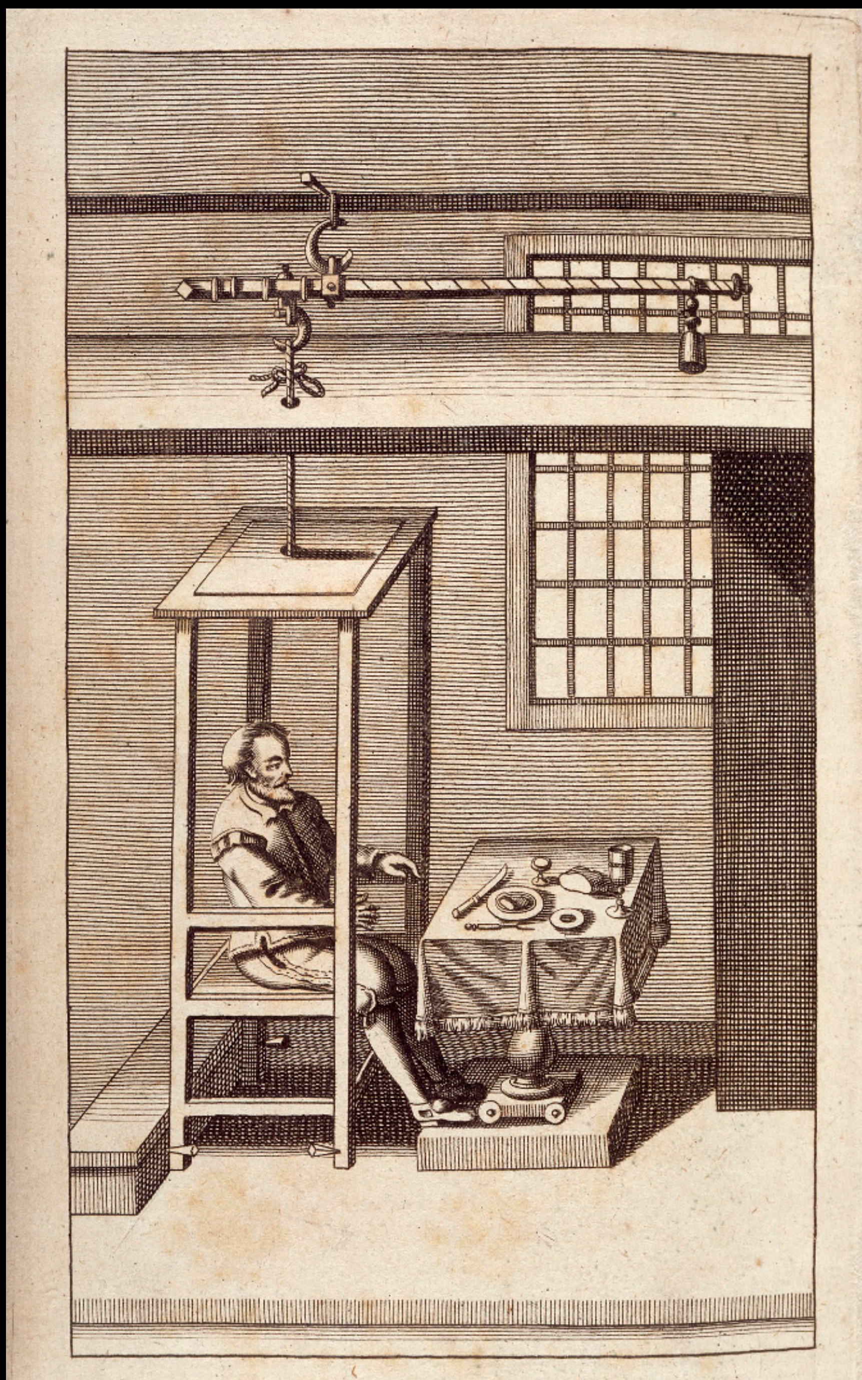

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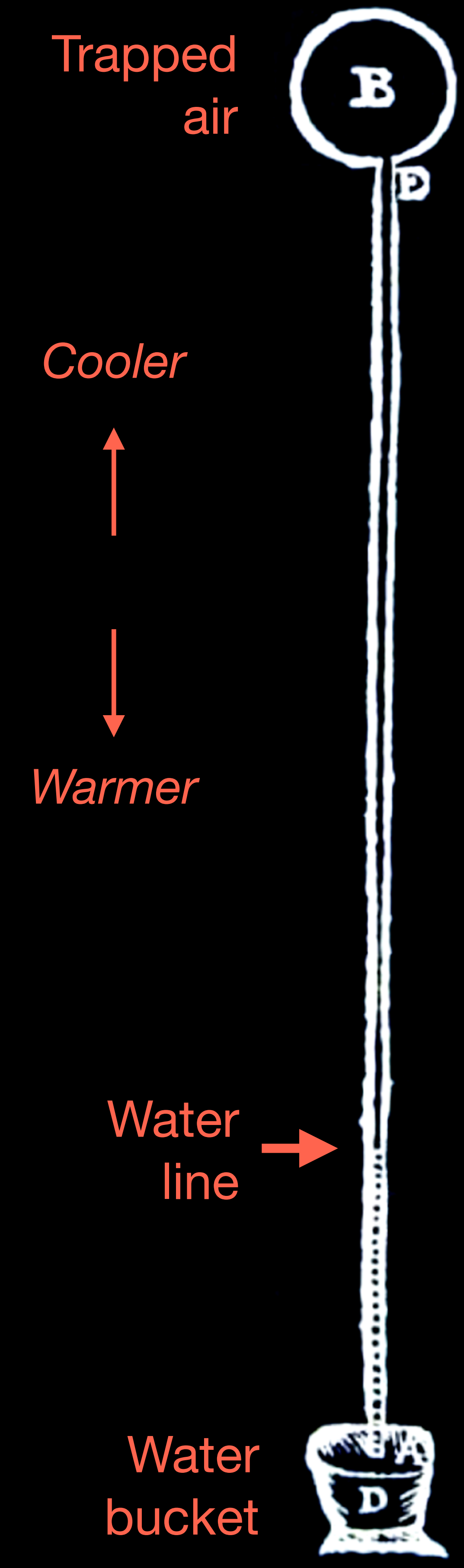
We promise that a book about medical instruments that are not well-known will shortly appear, in which we shall give an illustration of this instrument and describe its construction and use."

A serious problem

The air thermometer is also a barometer!

The water bucket is open!

Atmospheric pressure also affects the water level, in the opposite direction that temperature does!



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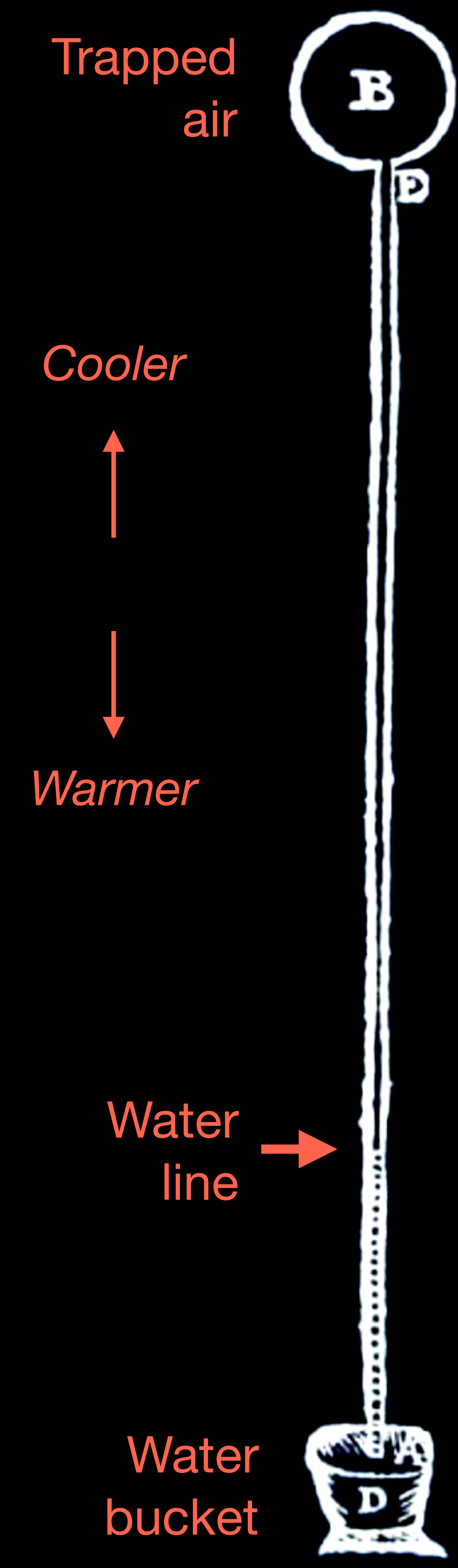

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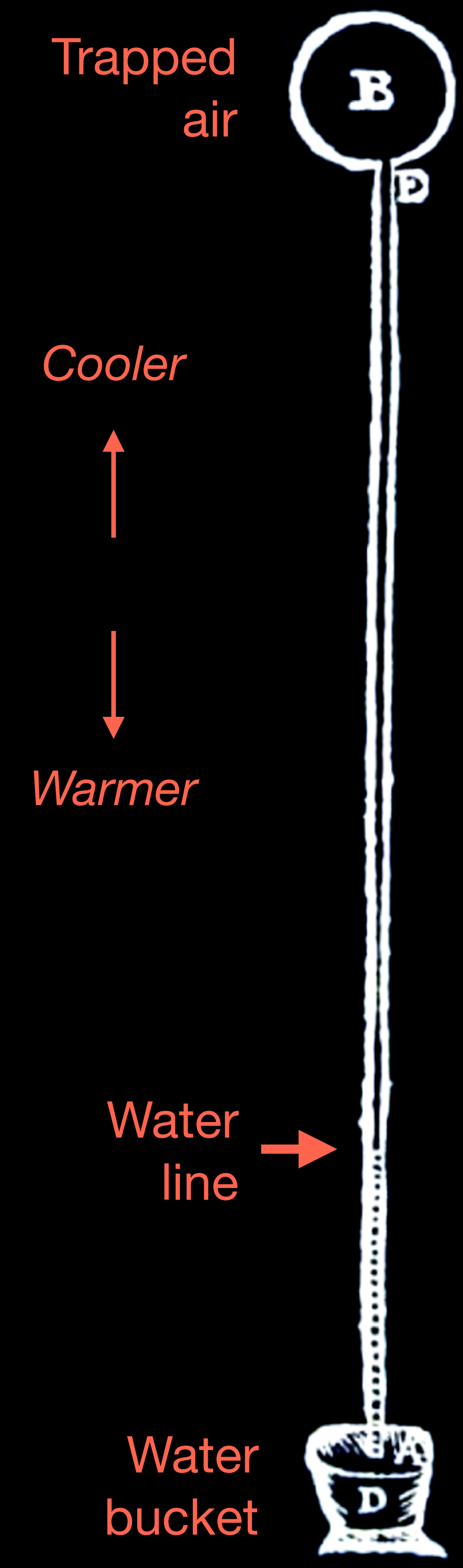

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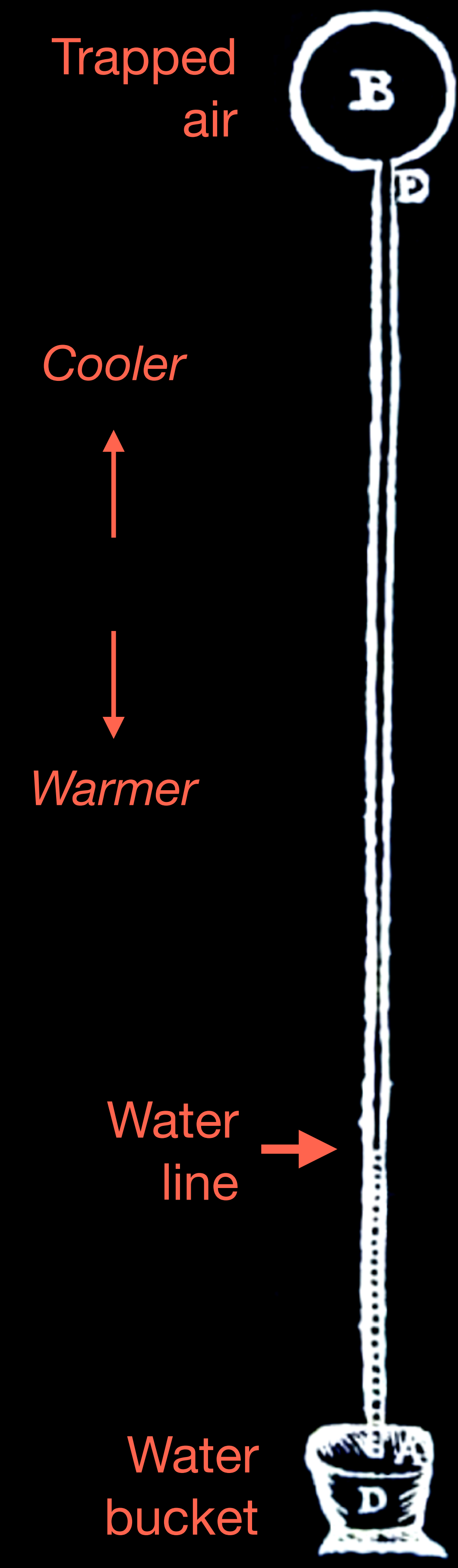

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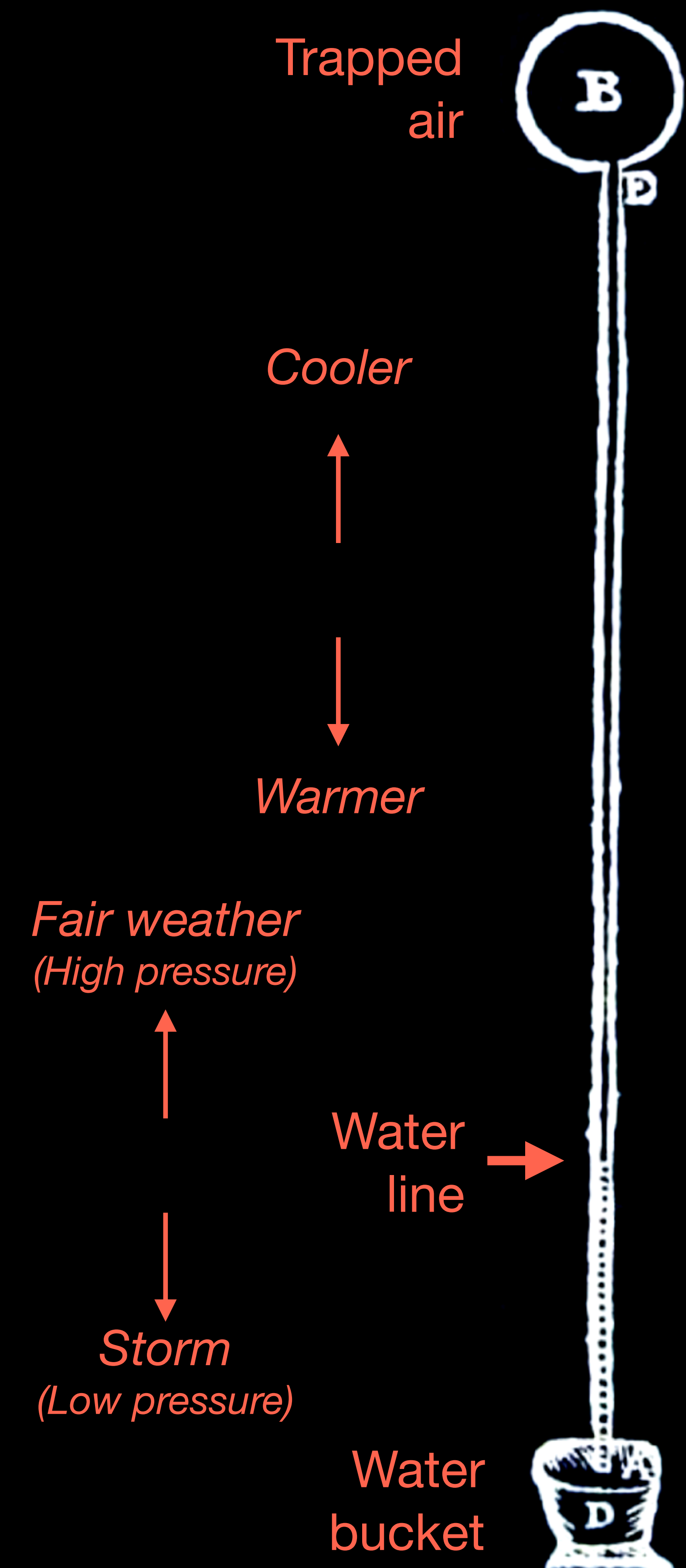

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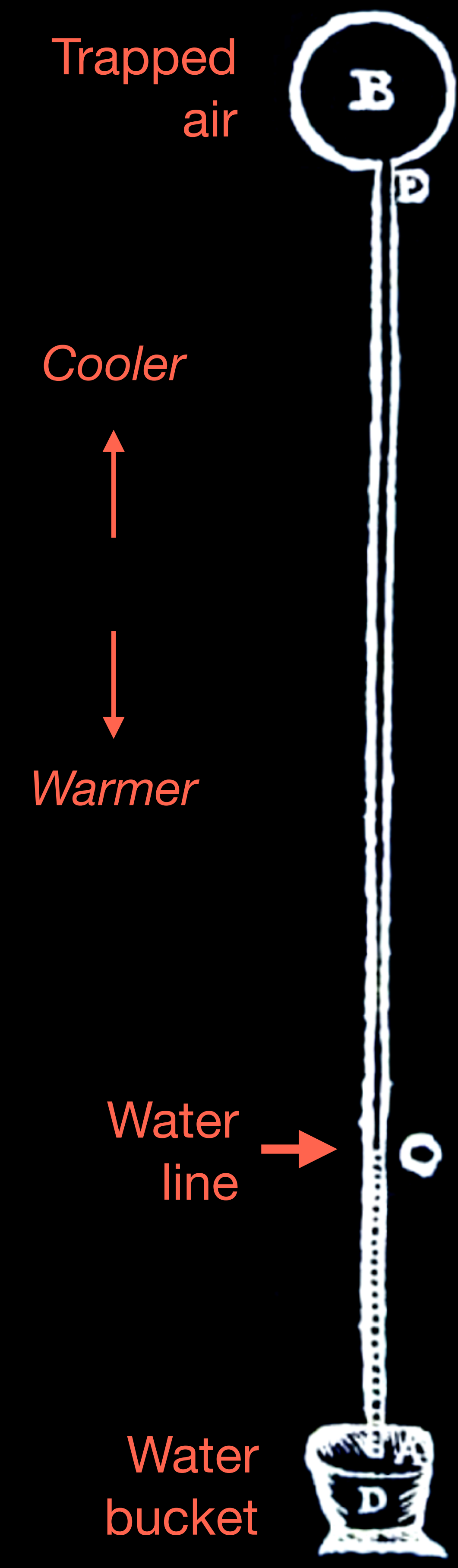
A physician in the French countryside



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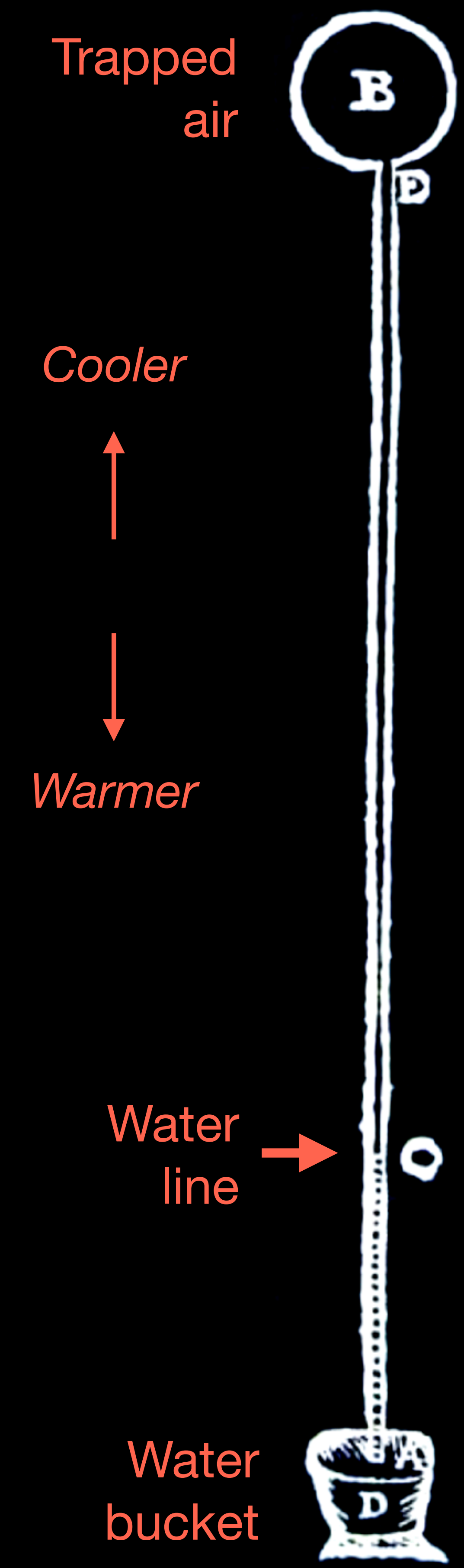

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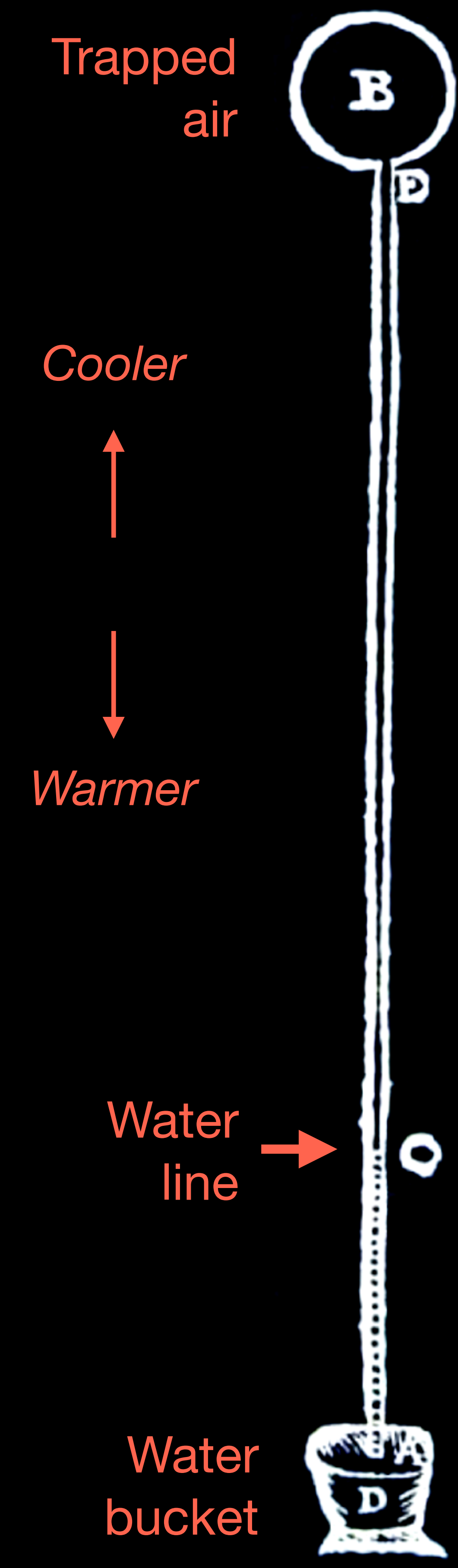

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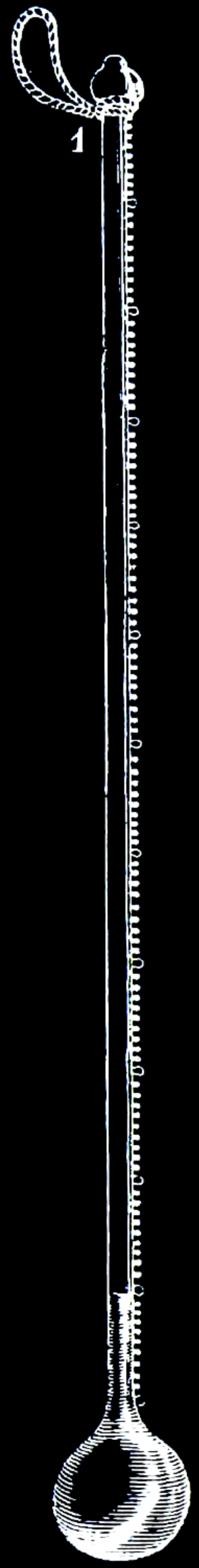

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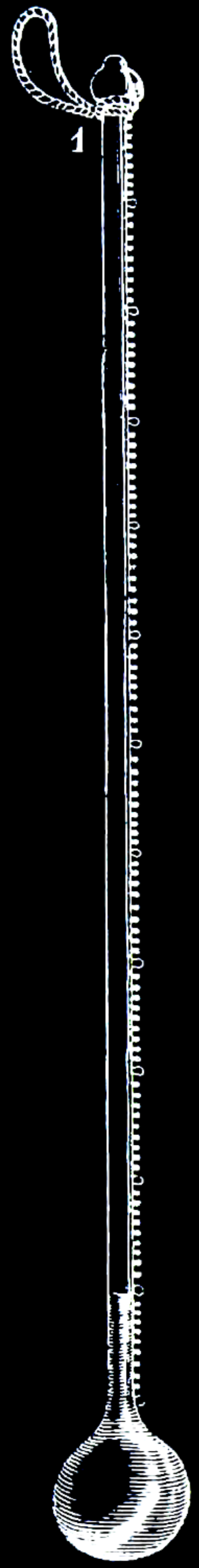

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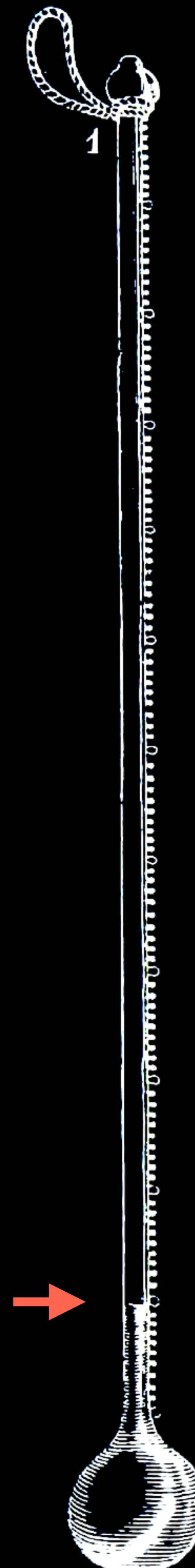

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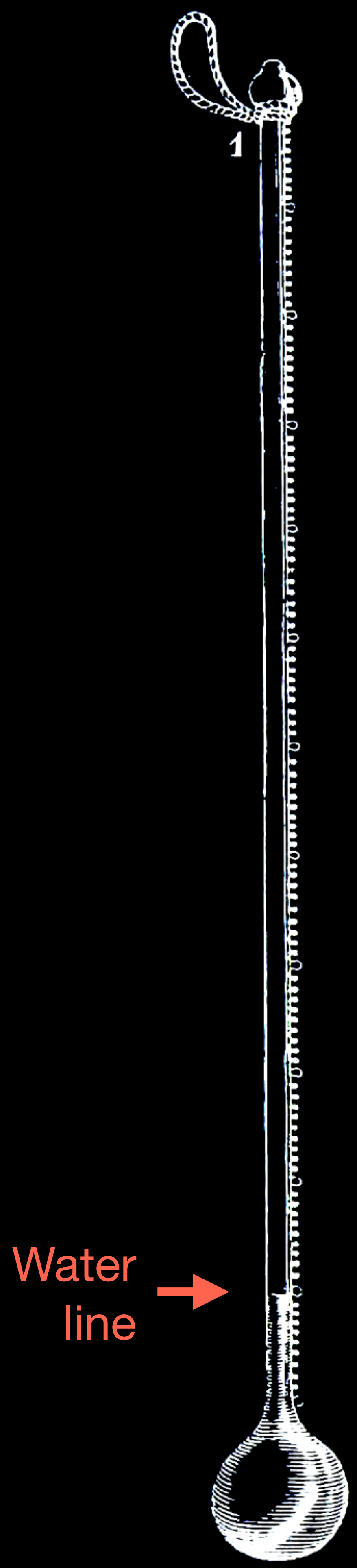
The heat, expanding the water, makes it rise more or less according to whether the heat is great or small."



A silent inventor: Jean Rey

A physician in the French countryside

Marin Mersenne (a monk from Paris) to Jean Rey:
September 31, 1631

"Then the thermoscope, making the liquid descend by the rarefaction of its air, bears witness that heat makes air more subtle […]"

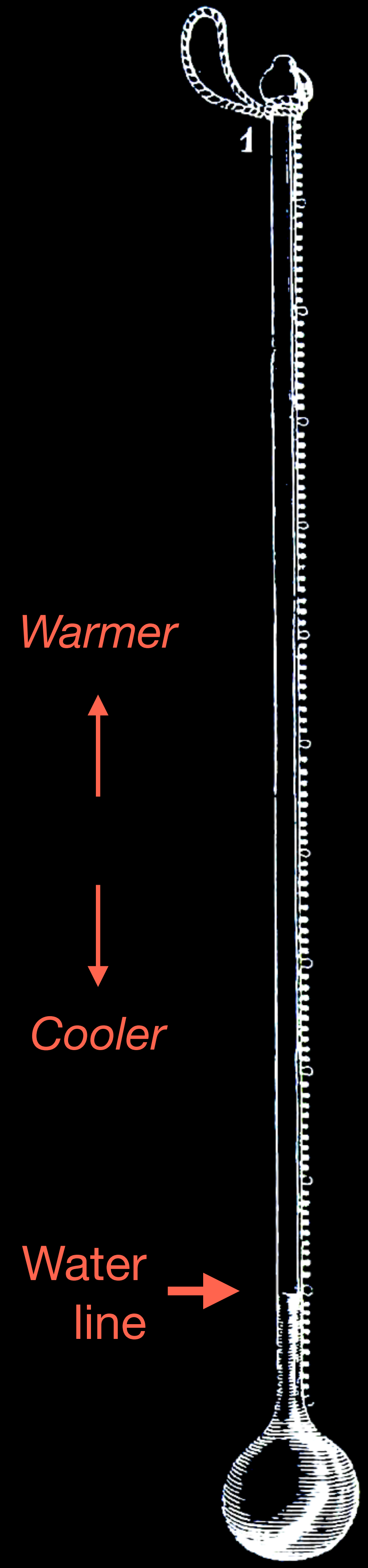
Jean Rey, in his reply:
January 1, 1632 (before Pascal!)

"There are a variety of thermoscopes, or so it appears.

What you say cannot agree with mine, which is nothing more than a little round phial with a very long and slender neck.

To use it, I fill all but the neck with water.

The heat, expanding the water, makes it rise more or less according to whether the heat is great or small."



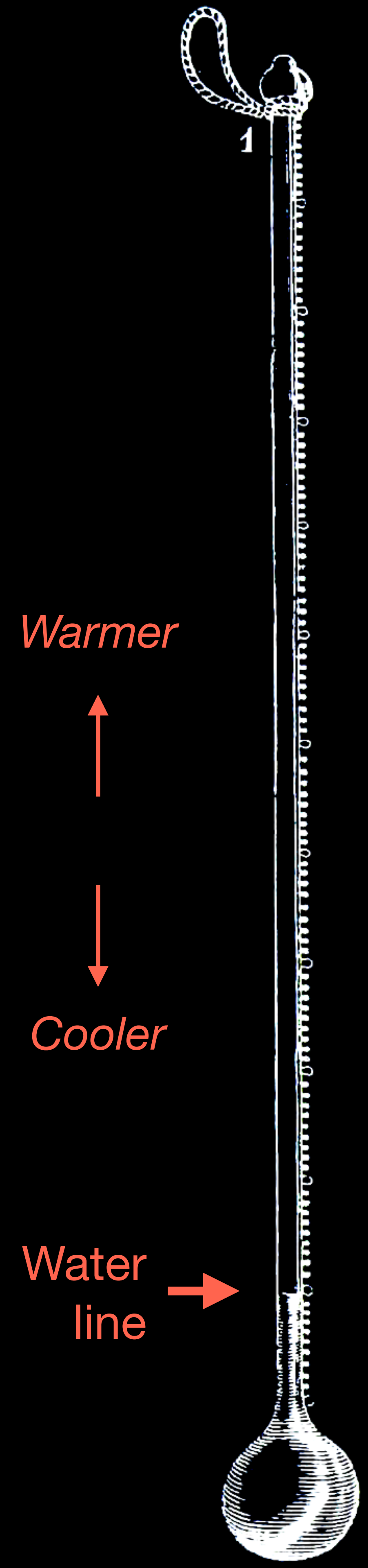
A silent inventor: Jean Rey

A physician in the French countryside

Rey's thermometer is hermetically sealed

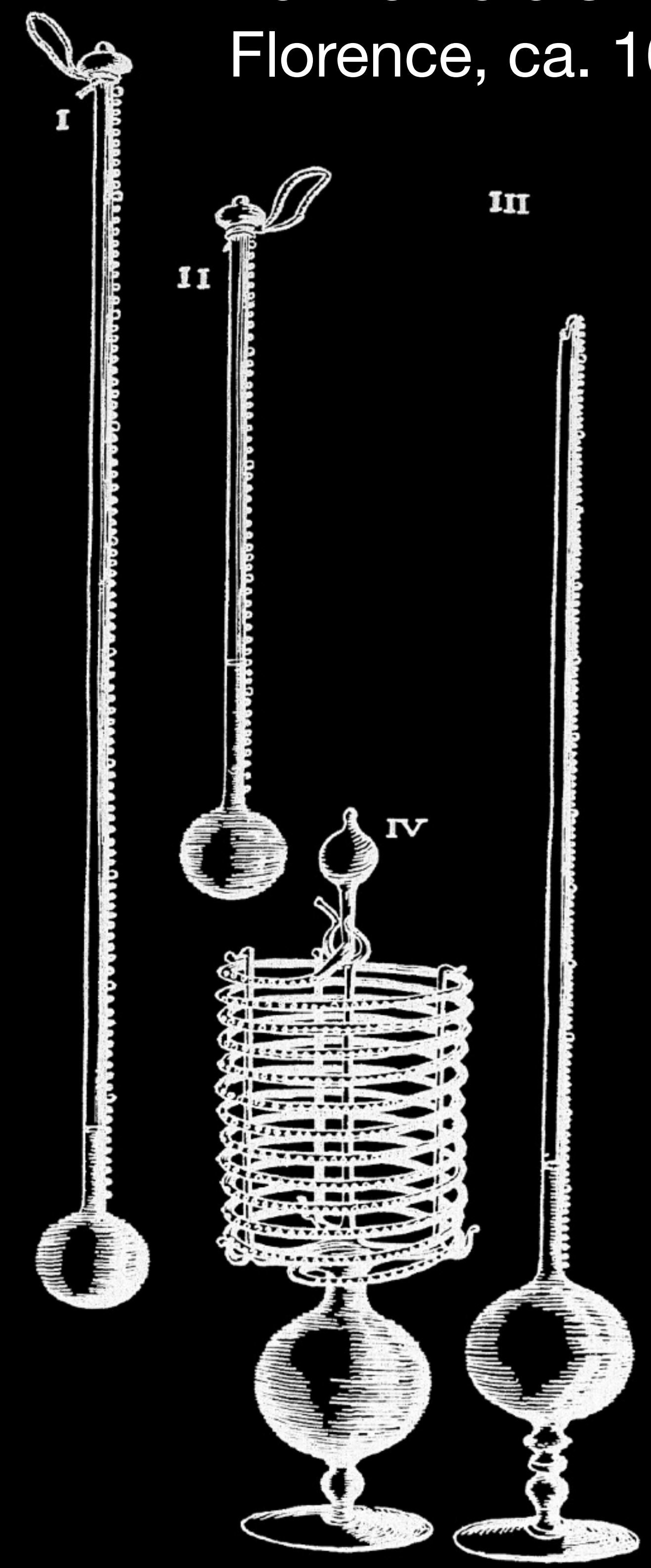
Changes in air pressure
<u>do not</u> affect the temperature reading

He did not know of that advantage!



Thermometry as a precision science

Thermometers from Florence, ca. 1660



Thermometry as a precision science

But which scale and which reference points to use?

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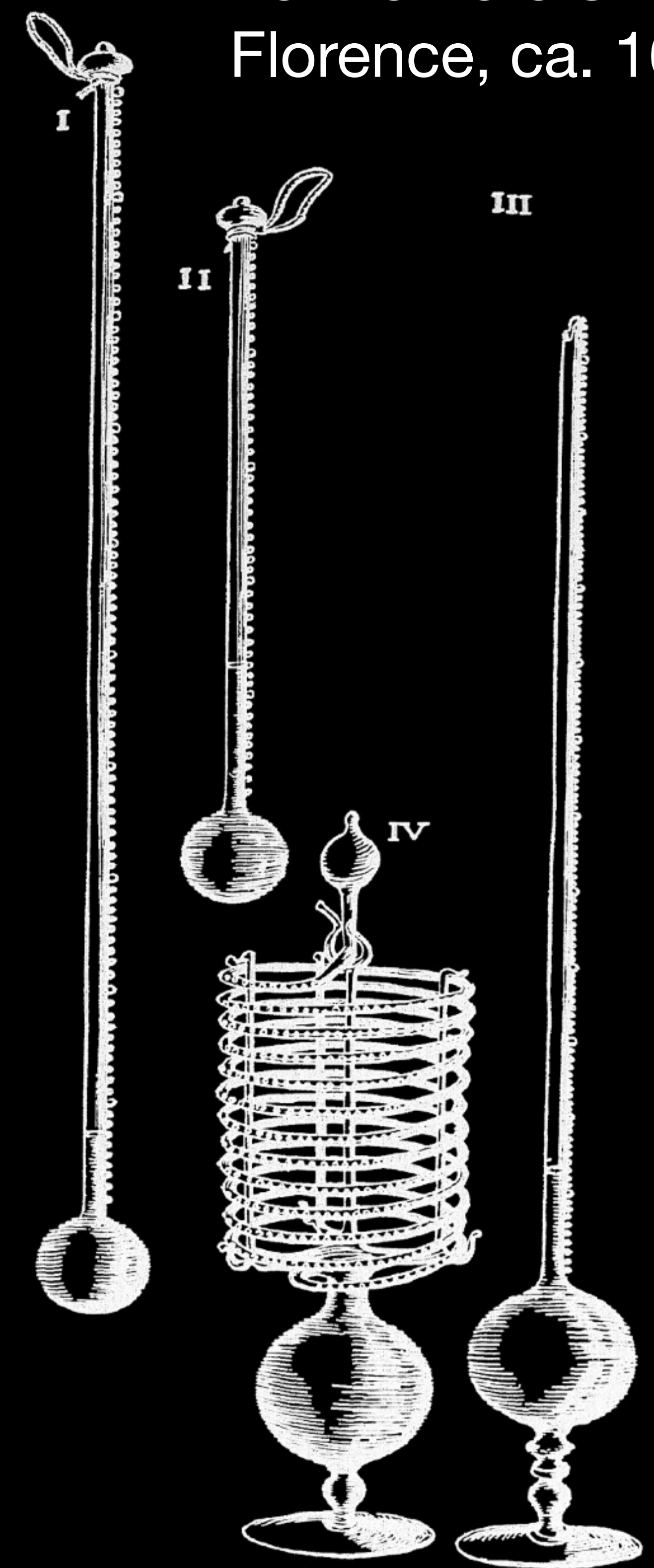

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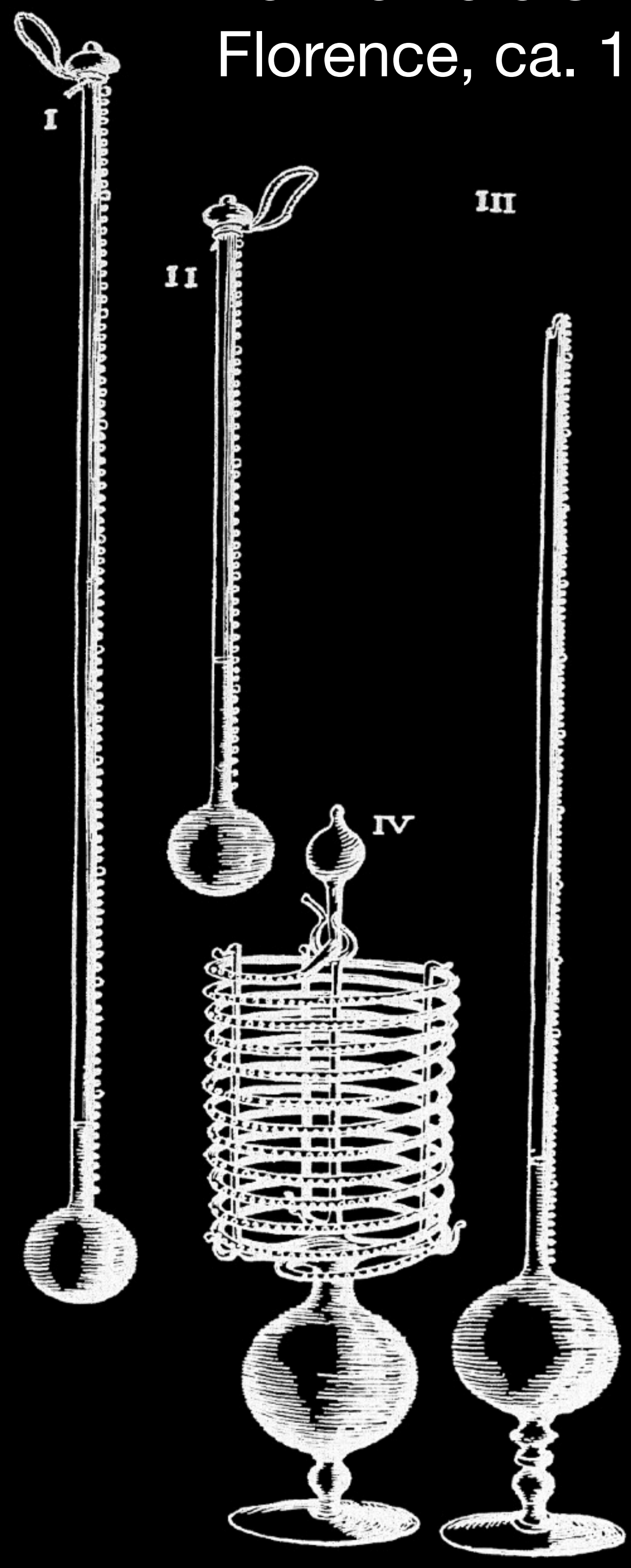

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Florence (1669)	Melting snow	“The greatest summer heat”

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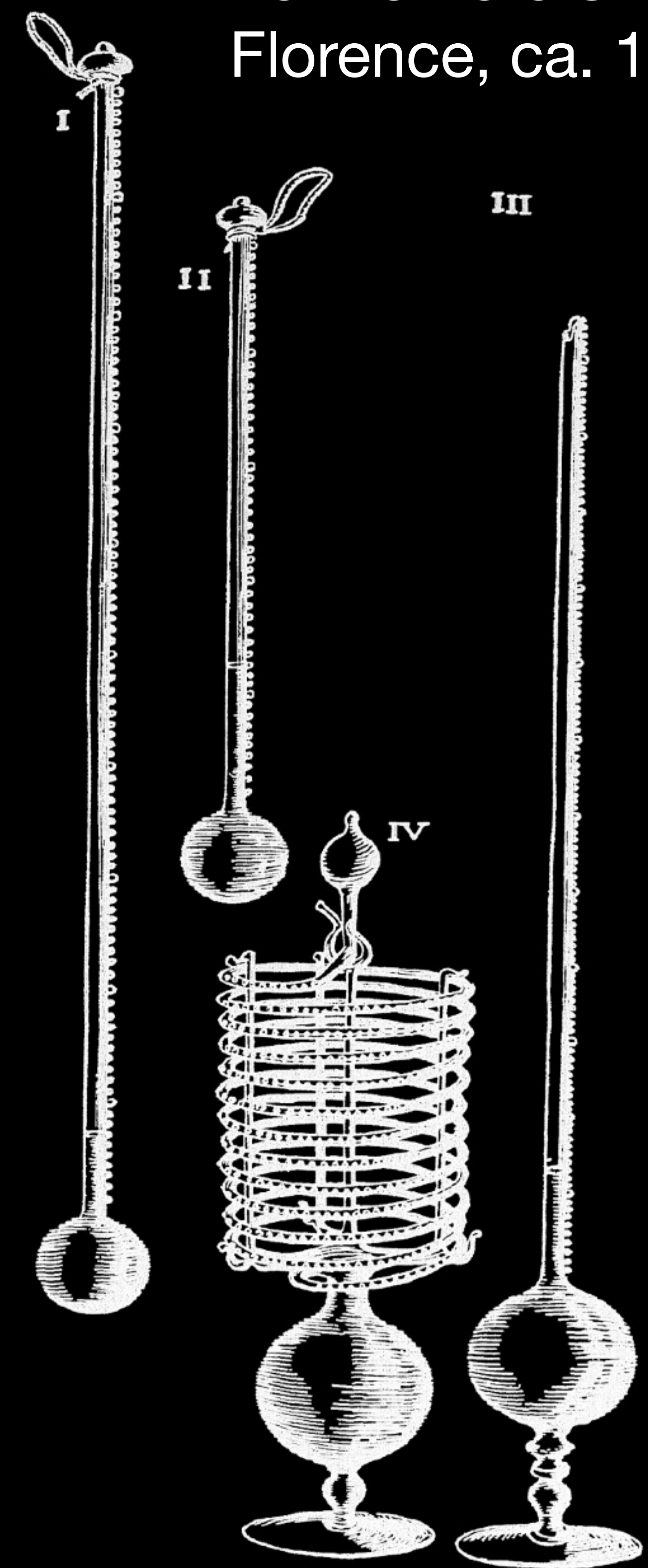

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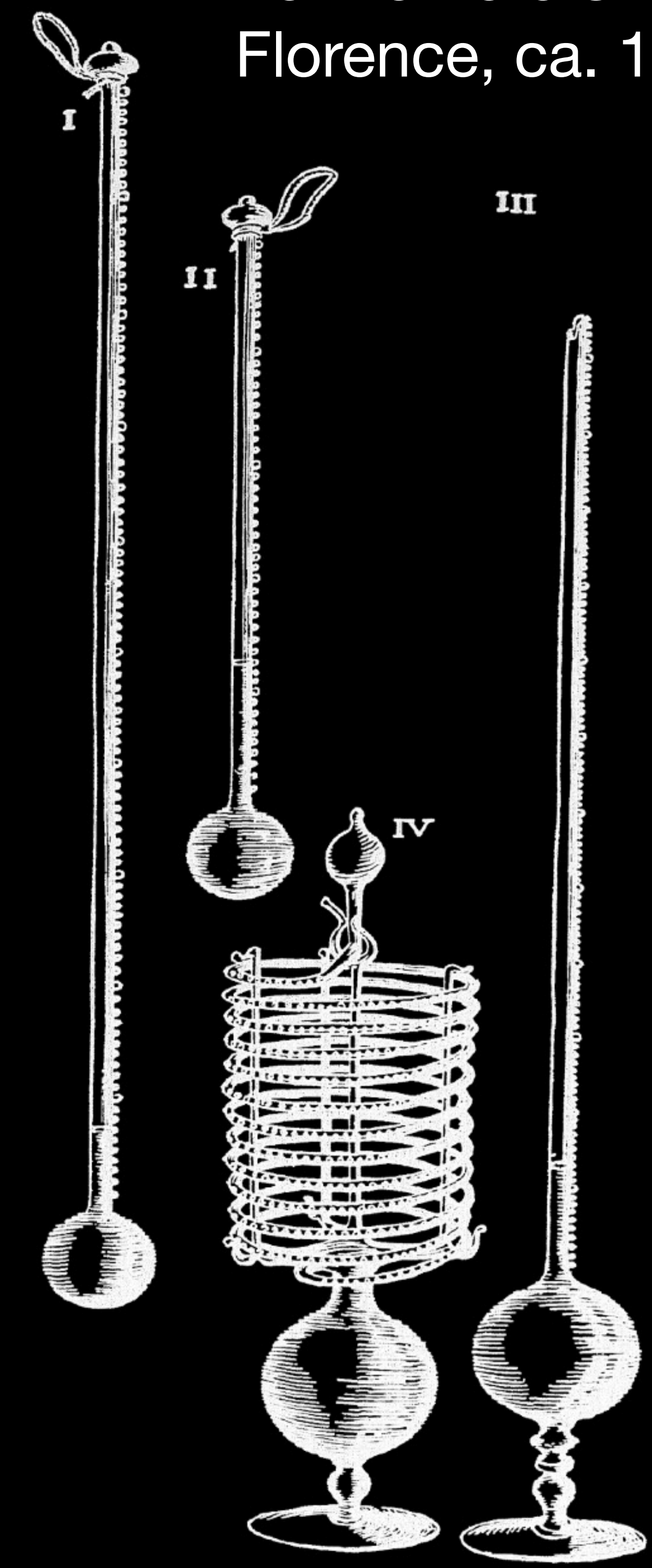

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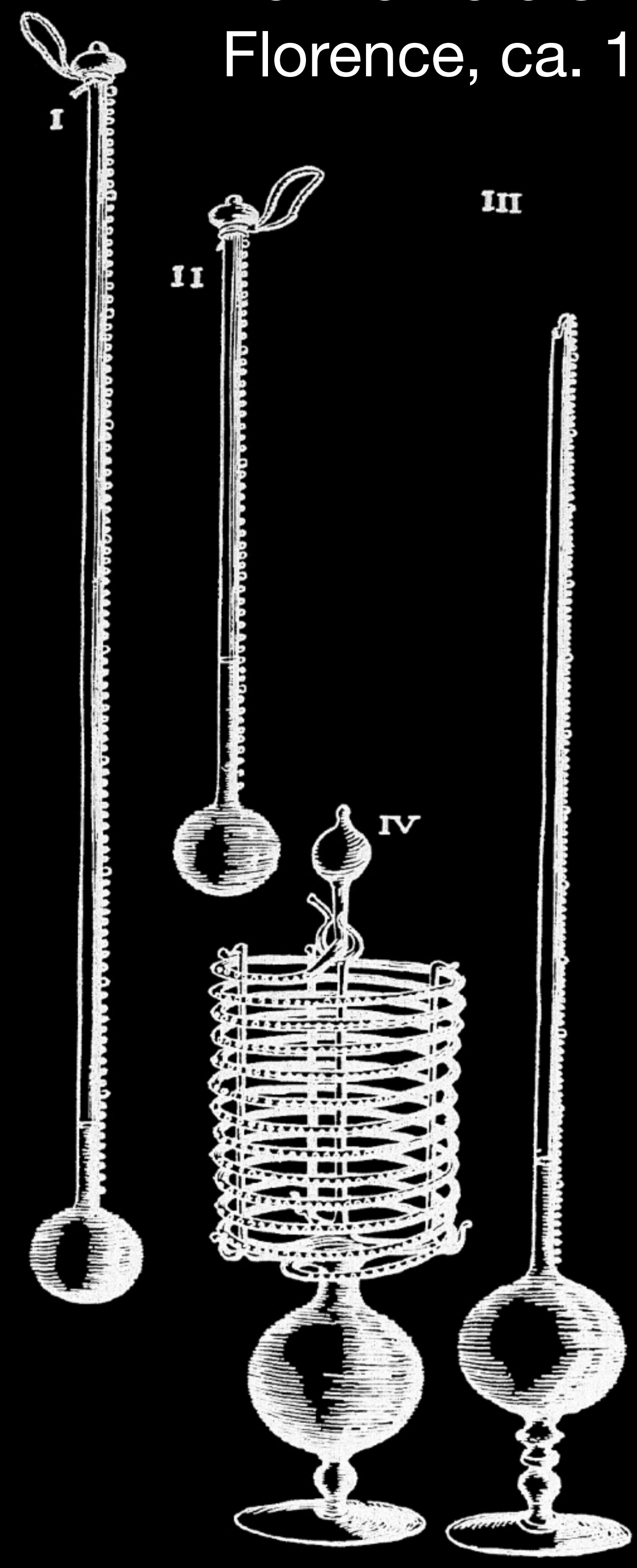

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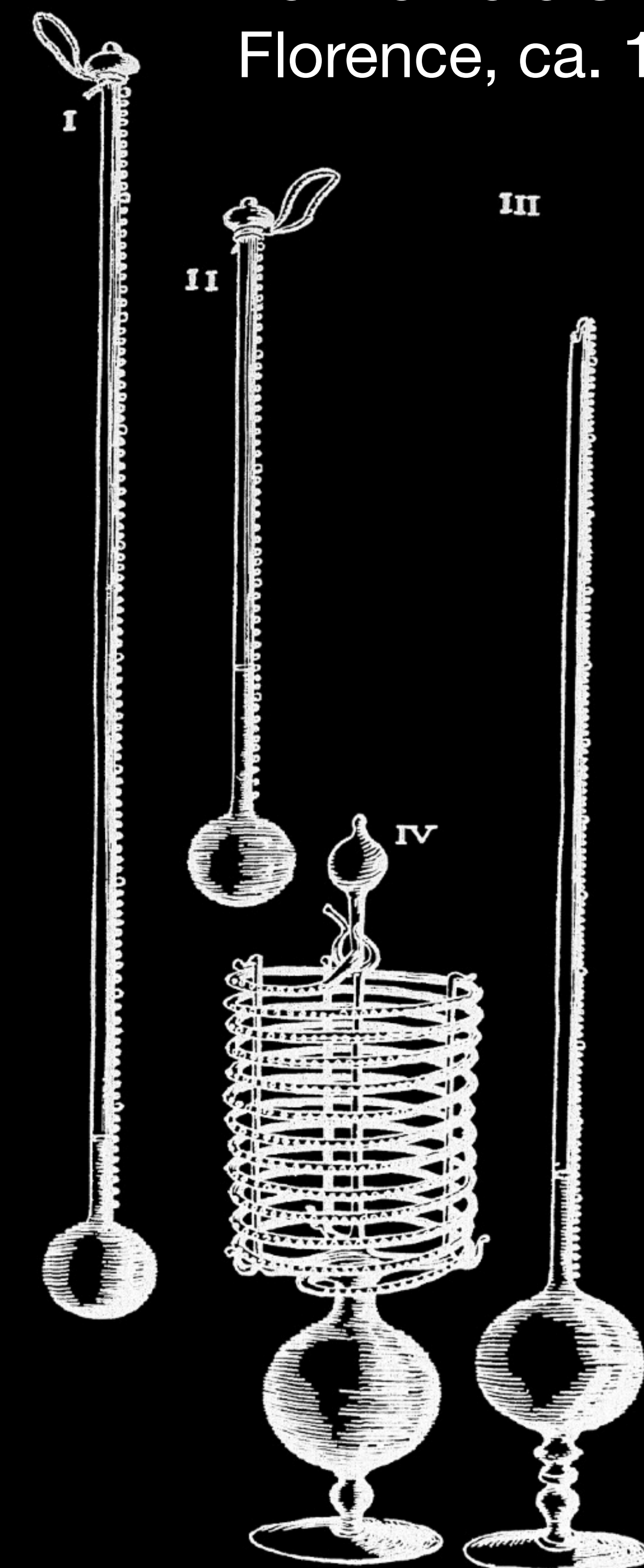

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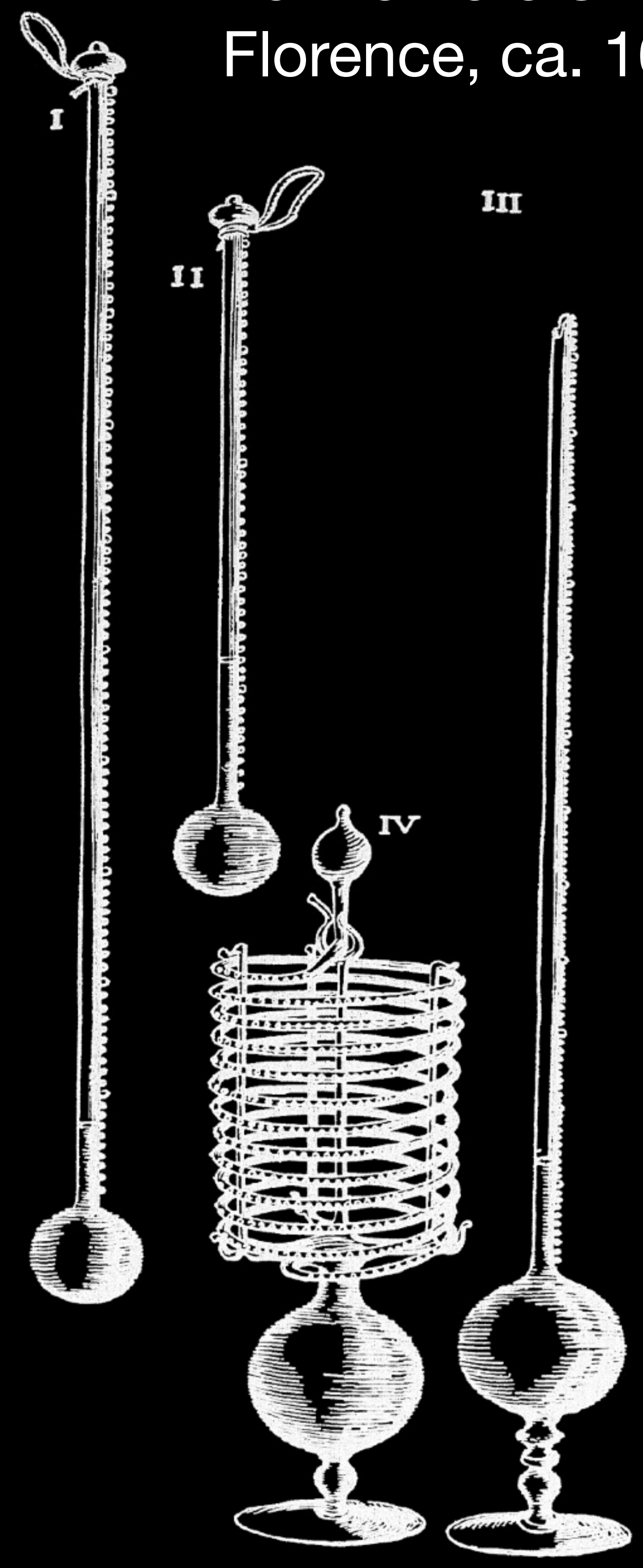

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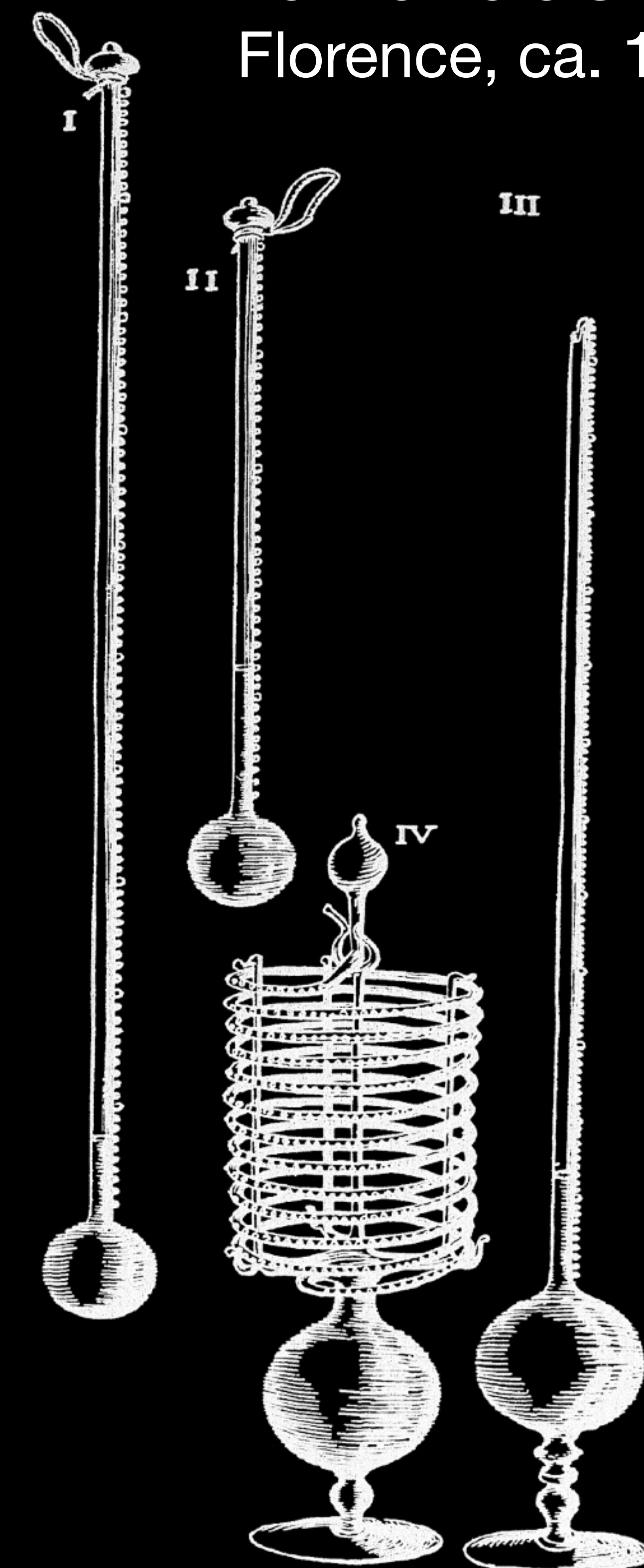


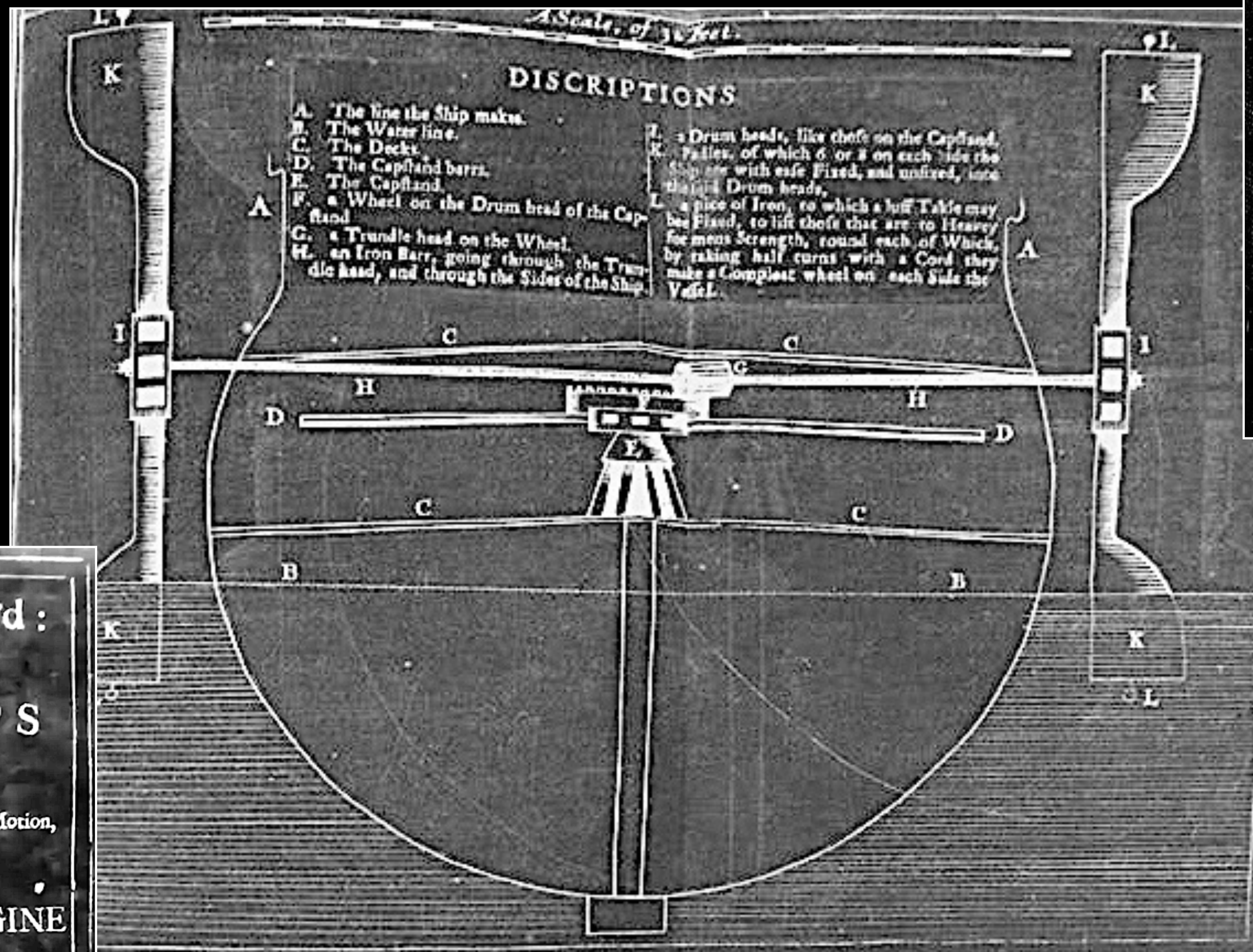
Science

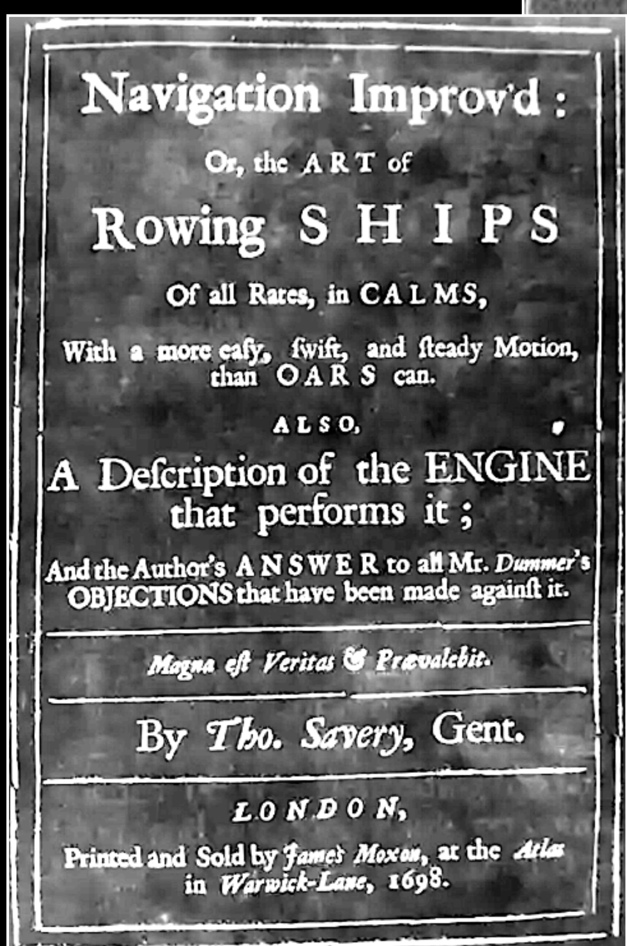
Science

Engineering

Captain Thomas Savery

Military engineer, trench-master, hobbyist





Navigation Improv'd:

Or, the ART of

Rowing SHIPS

Of all Rates, in CALMS,

With a more easy, swift, and steady Motion, than OARS can.

ALSO,

A Description of the ENGINE that performs it;

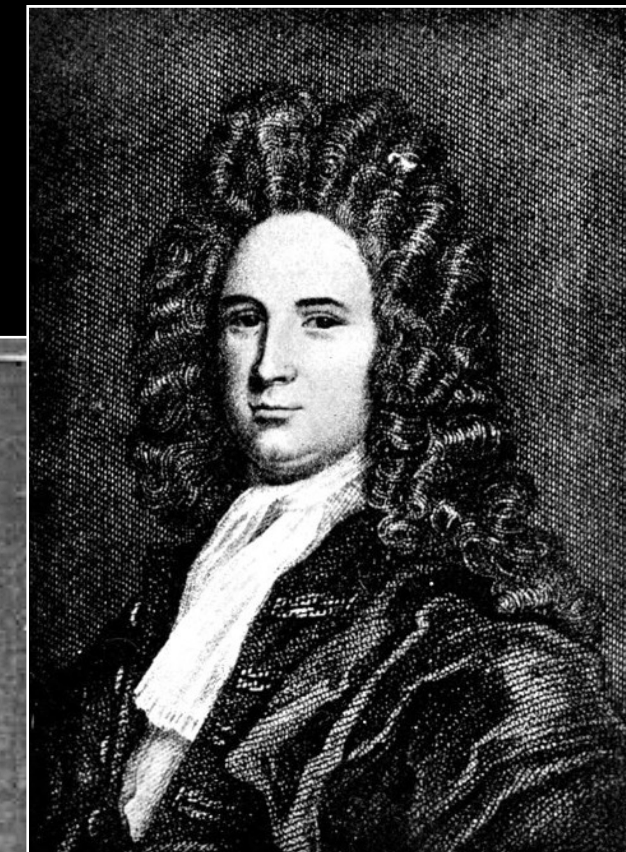
And the Author's ANSWER to all Mr. *Dummer's* OBJECTIONS that have been made against it.

Magna est Veritas & Prævalebit.

By *Tho. Savery*, Gent.

LONDON,

Printed and Sold by *James Moxon*, at the *Atlas* in *Warwick-Lane*, 1698.



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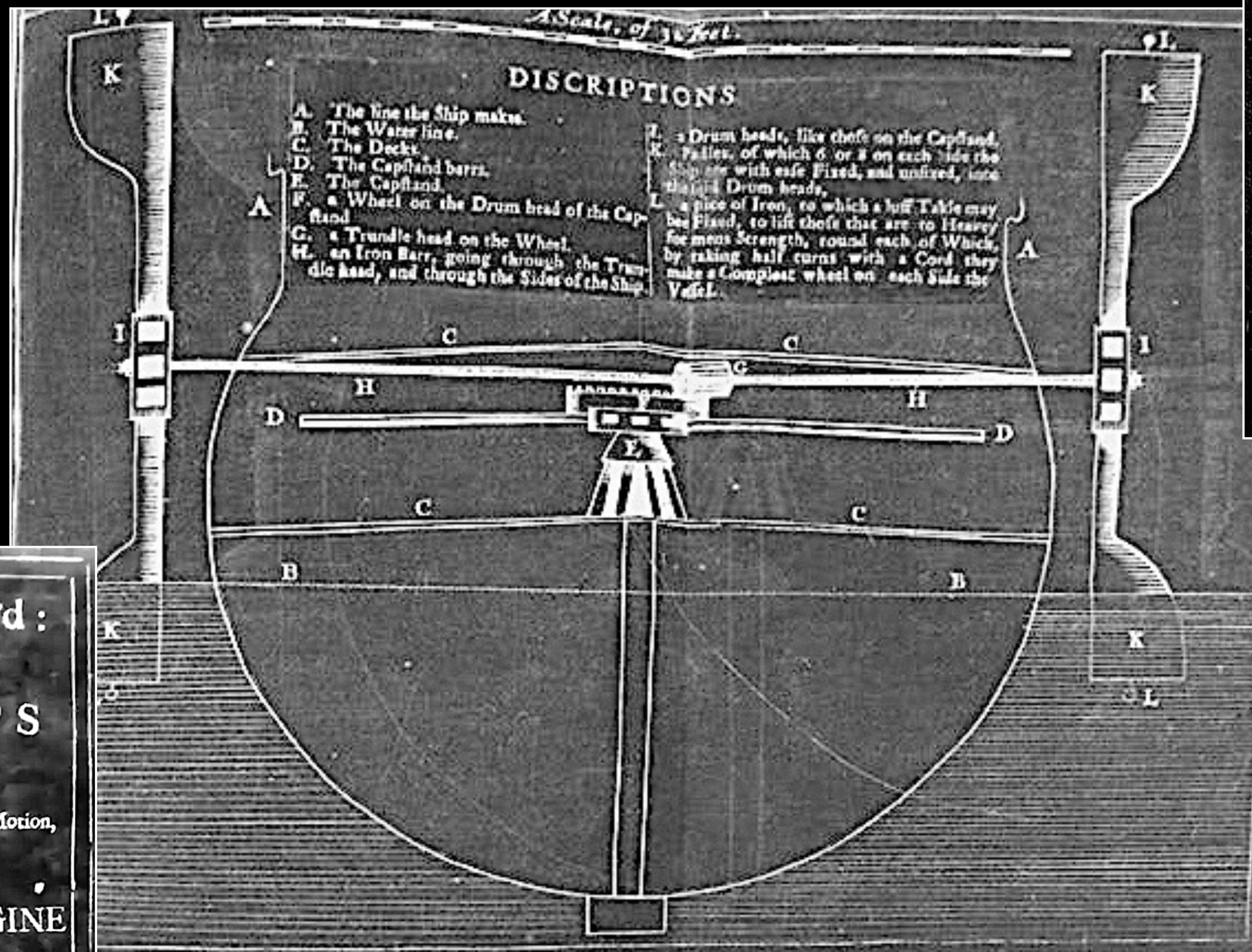

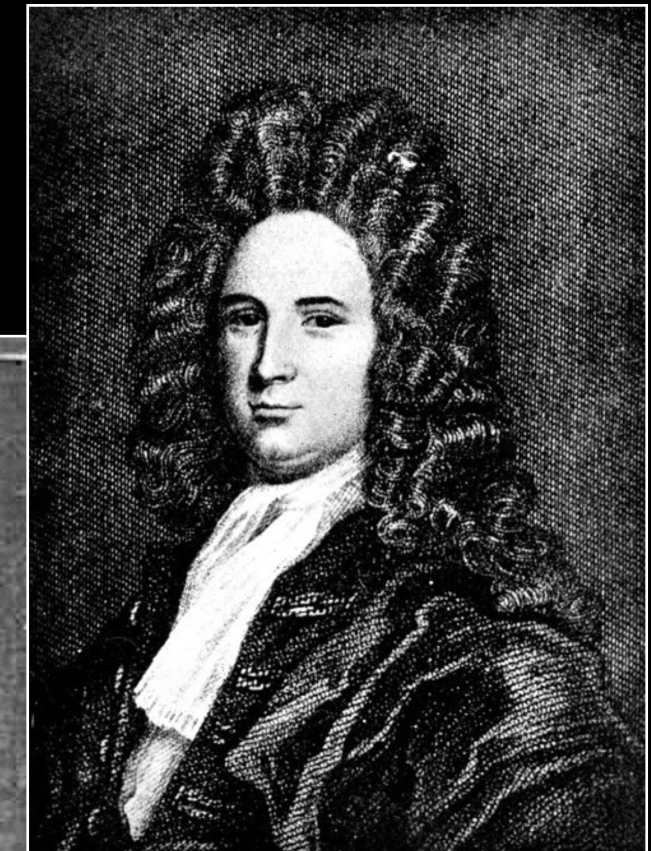

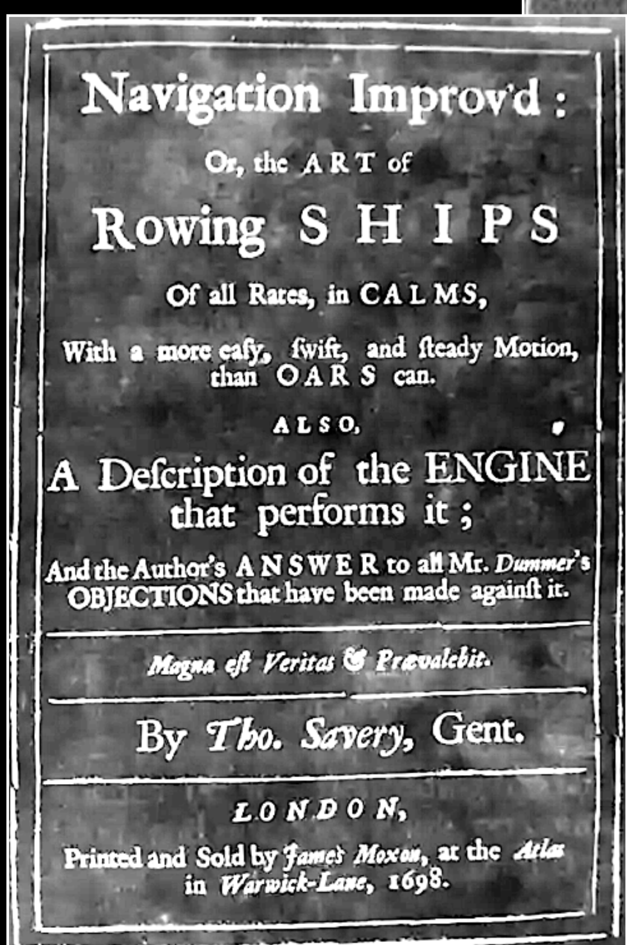

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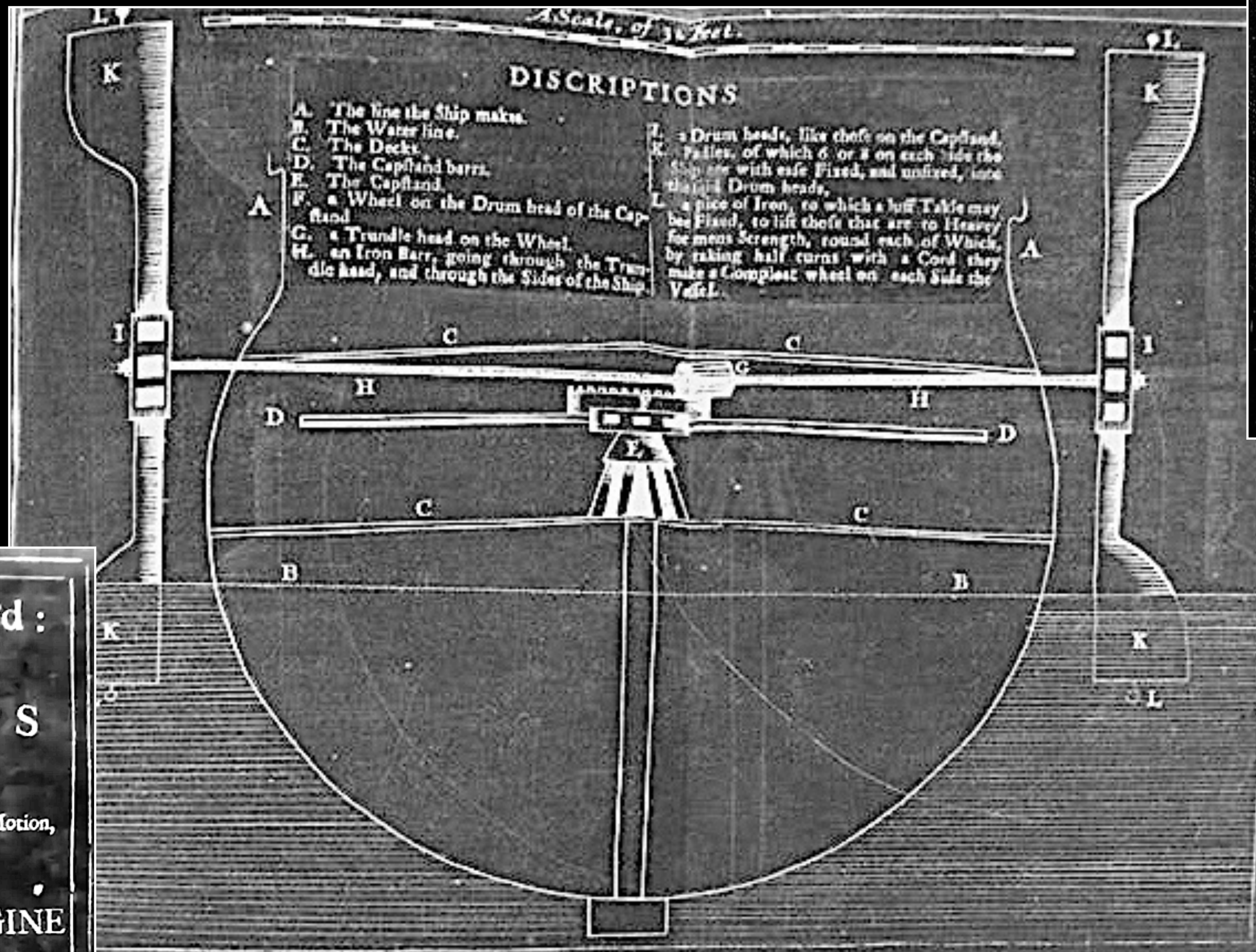

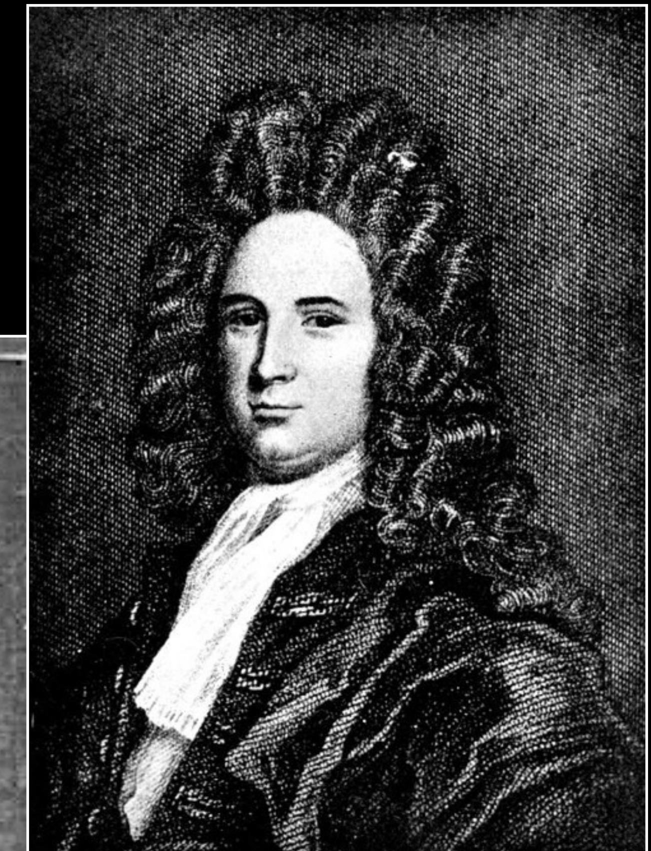

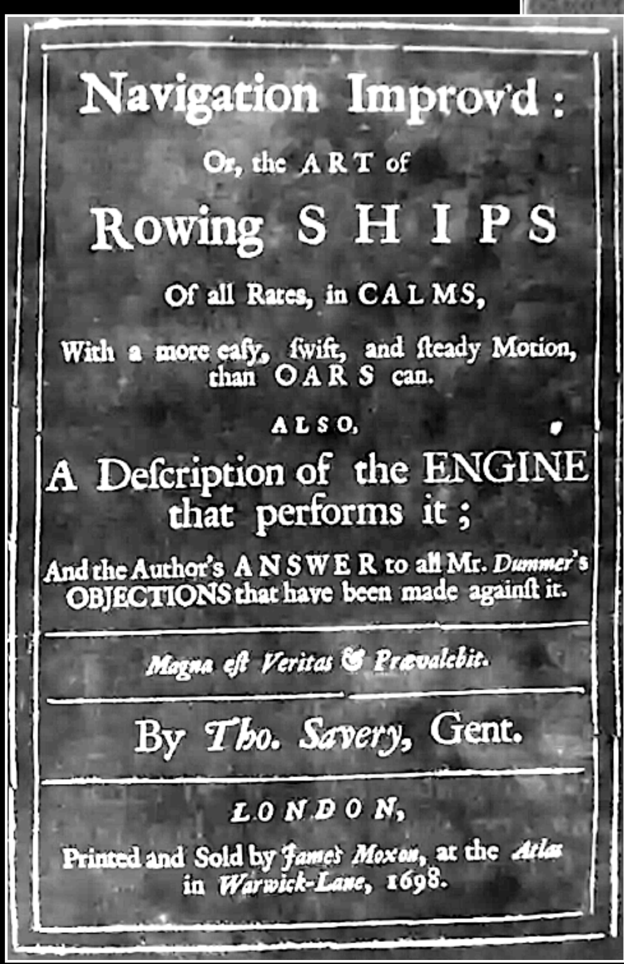

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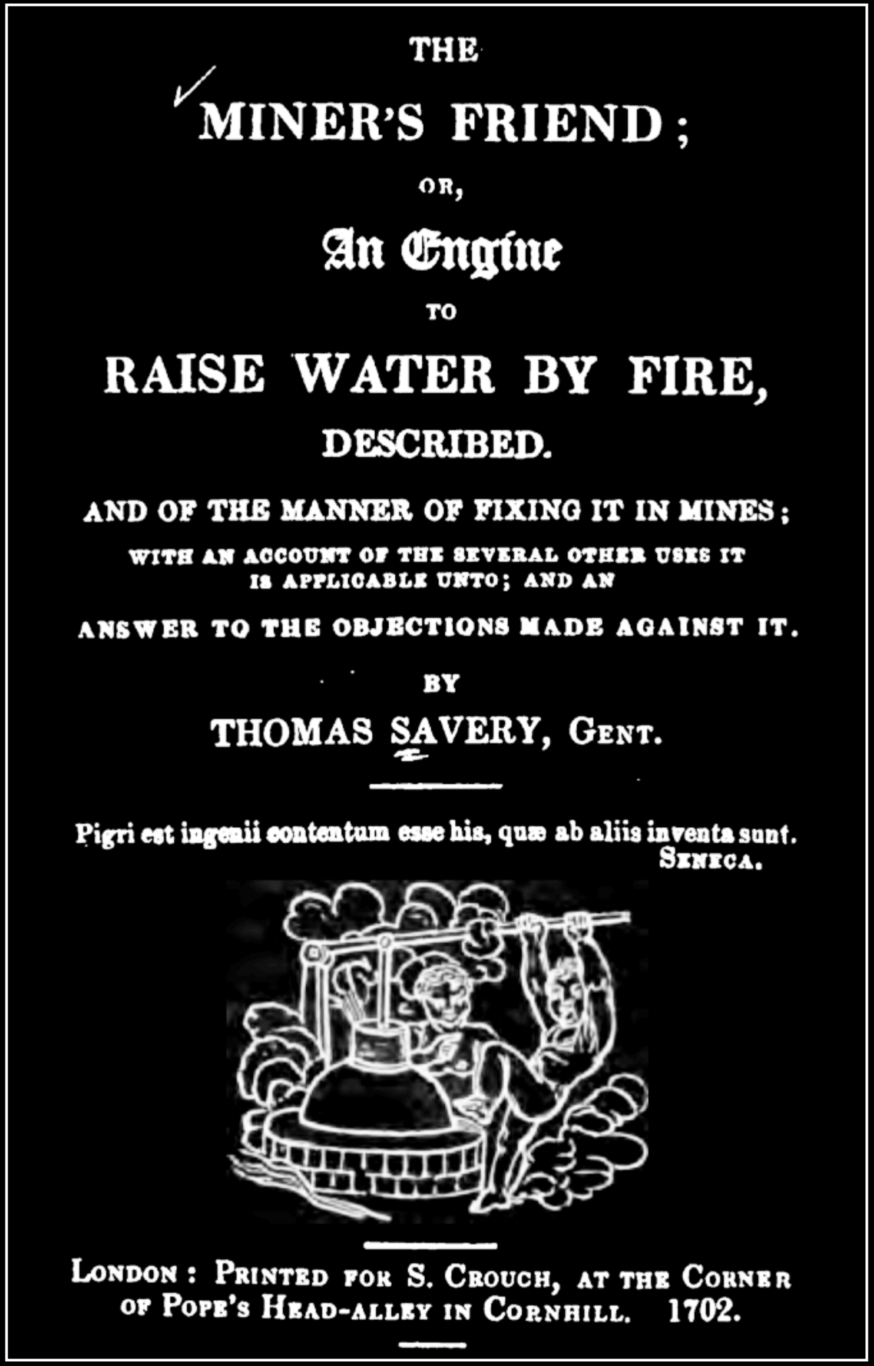
Surveyor of the Royal British Navy: "And have interloping people, that have no concern with us, pretend to contrive or invent things for us?"

His second try: a steam pump

Patented on 2 July 1698:

"A new Invention for Raiseing of Water and occasioning Motion to all Sorts of Mill Work by the Impellent Force of Fire, which will be of great use and Advantage for Drayning Mines, serveing Towns with Water, and for the Working of all Sorts of Mills where they have not the benefitt of Water nor constant Windes;

to hold for 14 years; with usual clauses"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OR,

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AND OF THE MANNER OF FIXING IT IN MINES;

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SENECA.

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(Published right around Rømer's proposal for his temperature scale)

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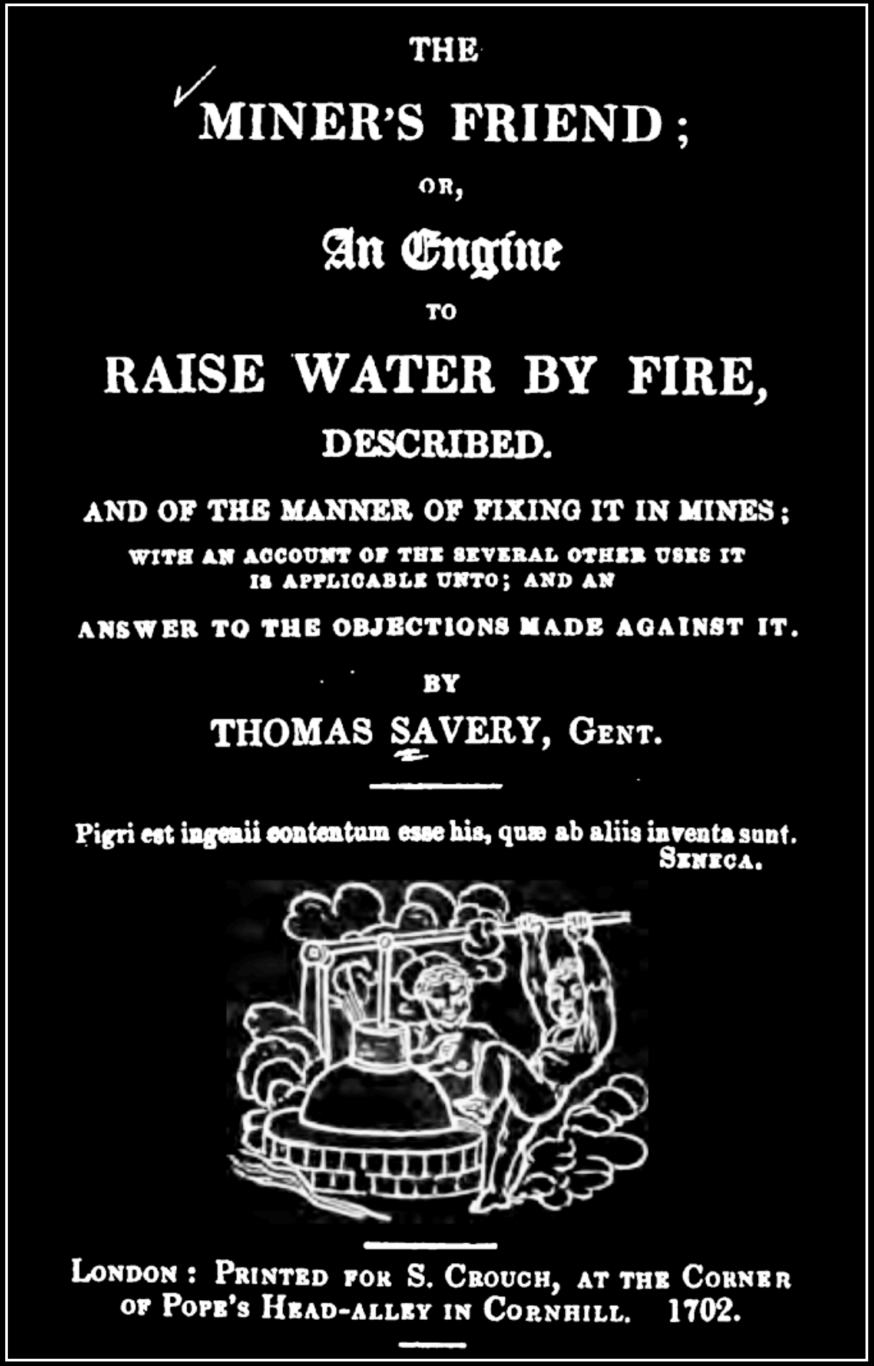

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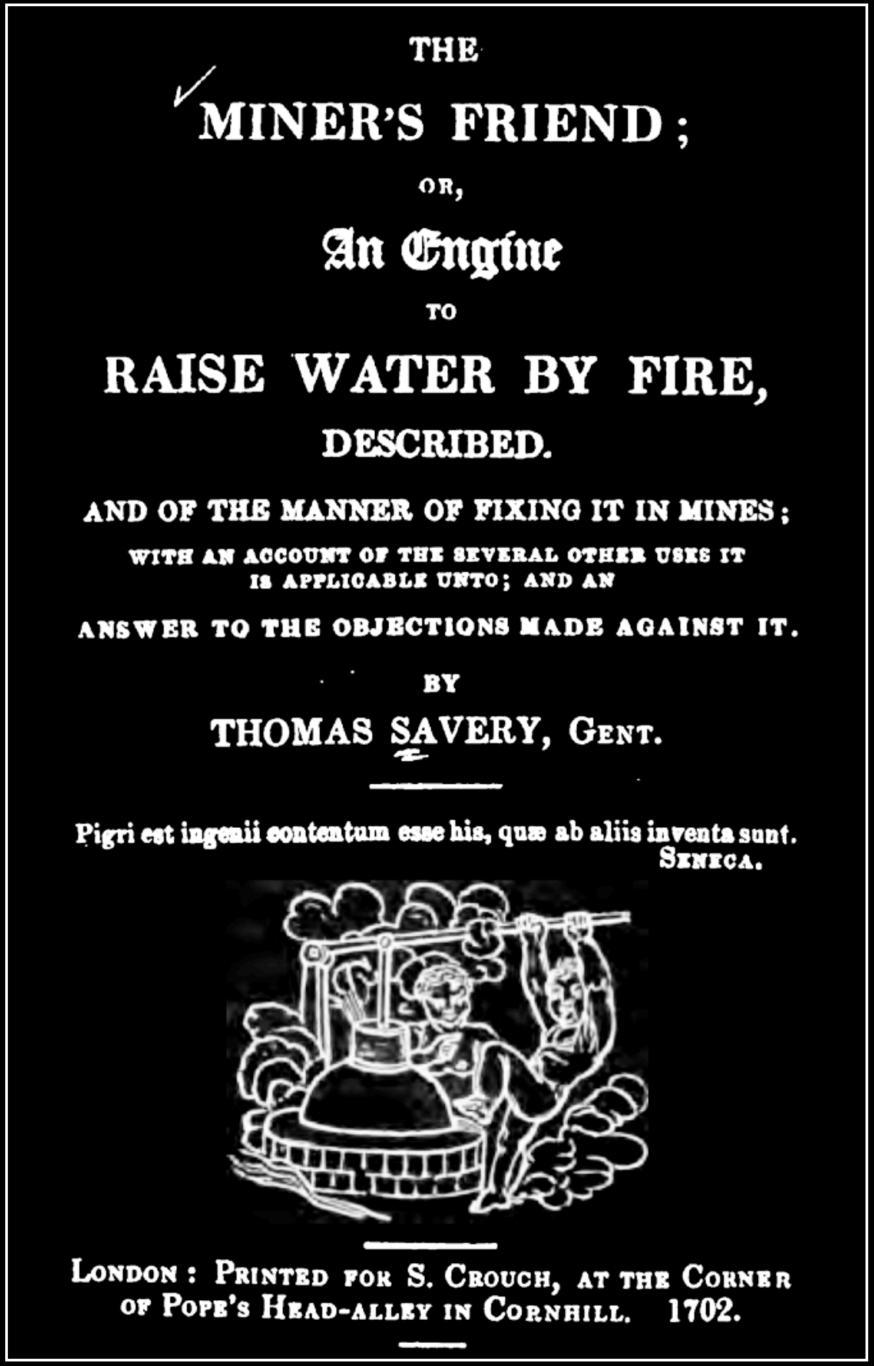

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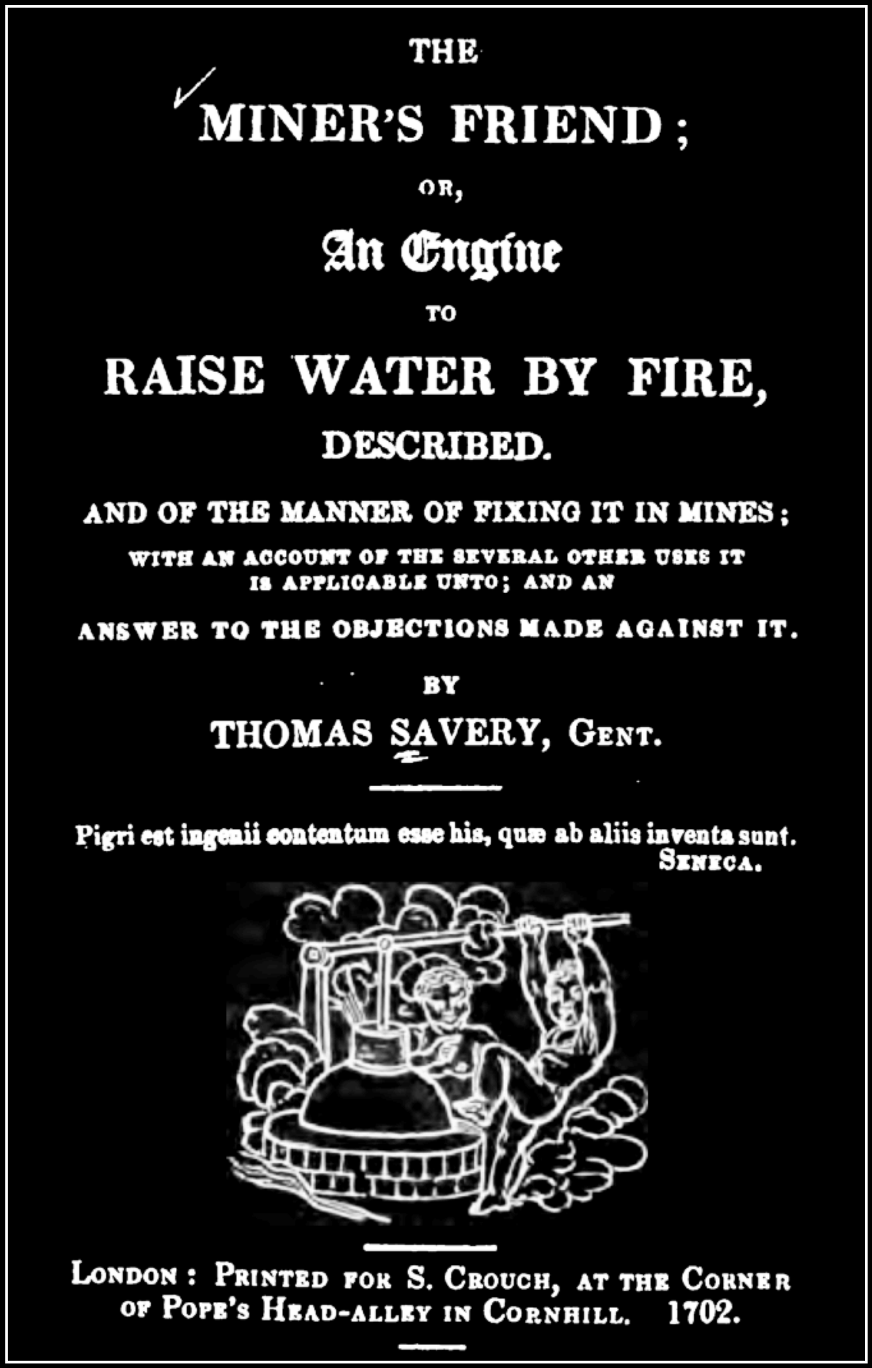

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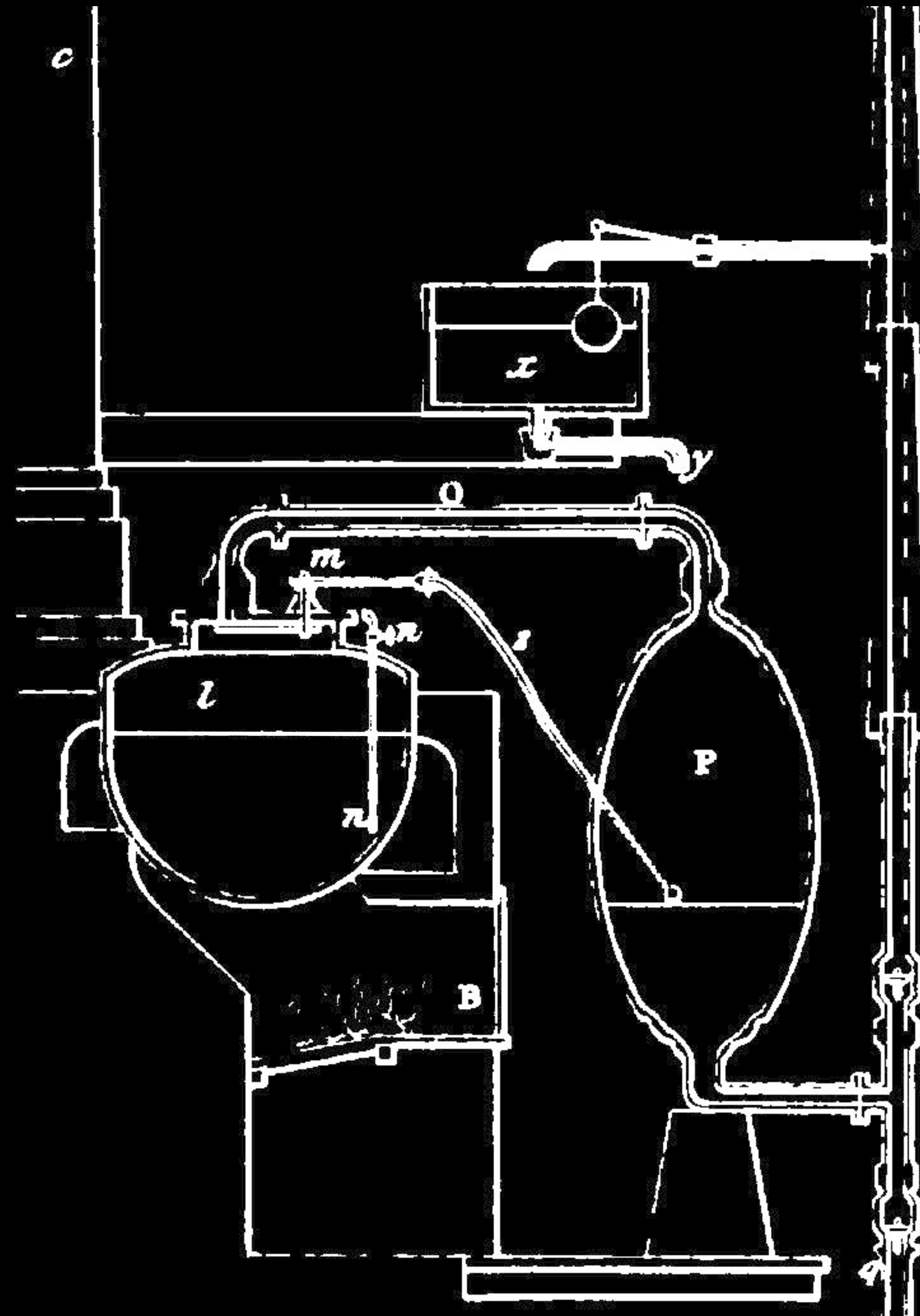
“It will raise your water five hundred or one thousand feet high, were any pit so deep.”

The “Savery Engine”



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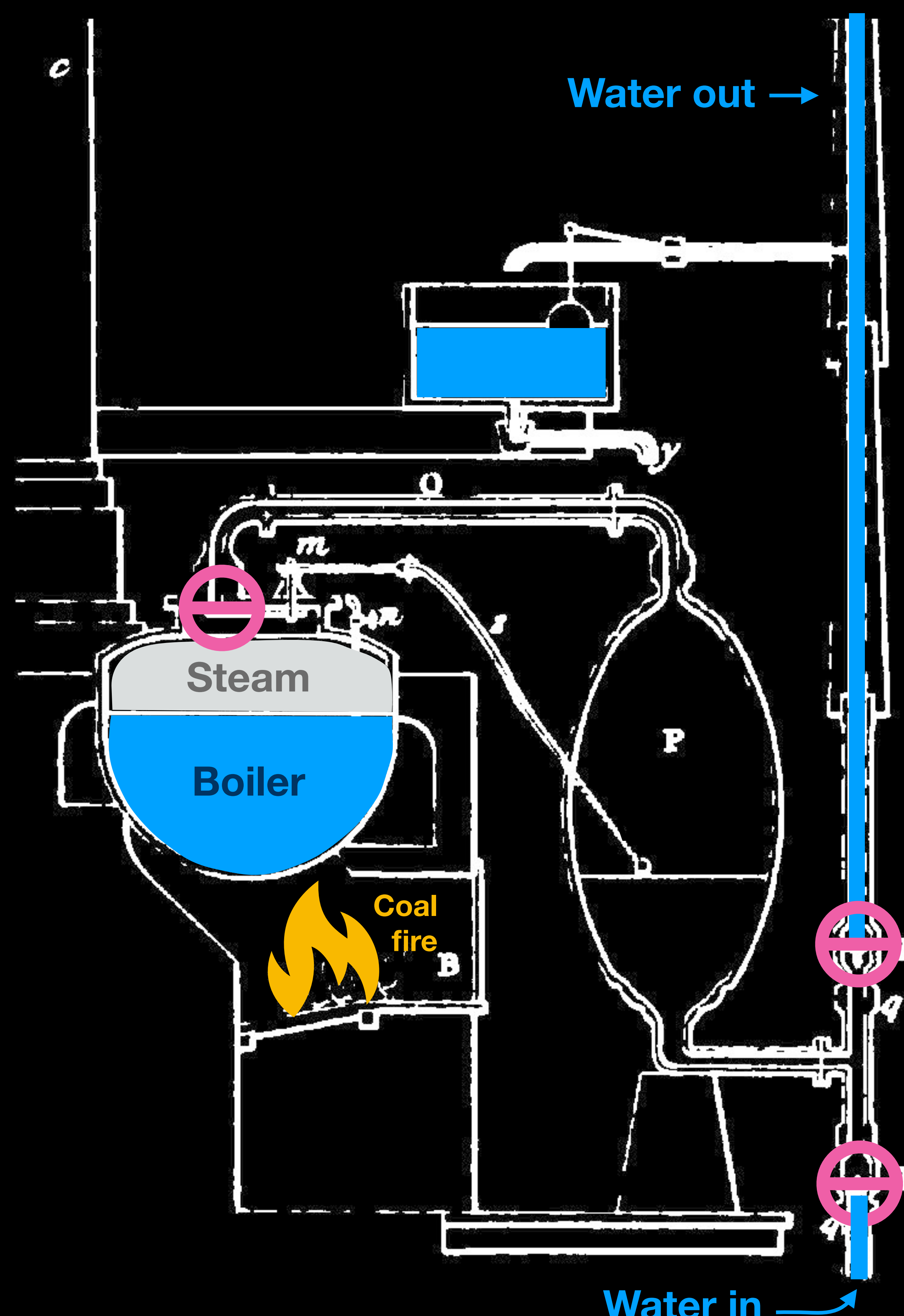
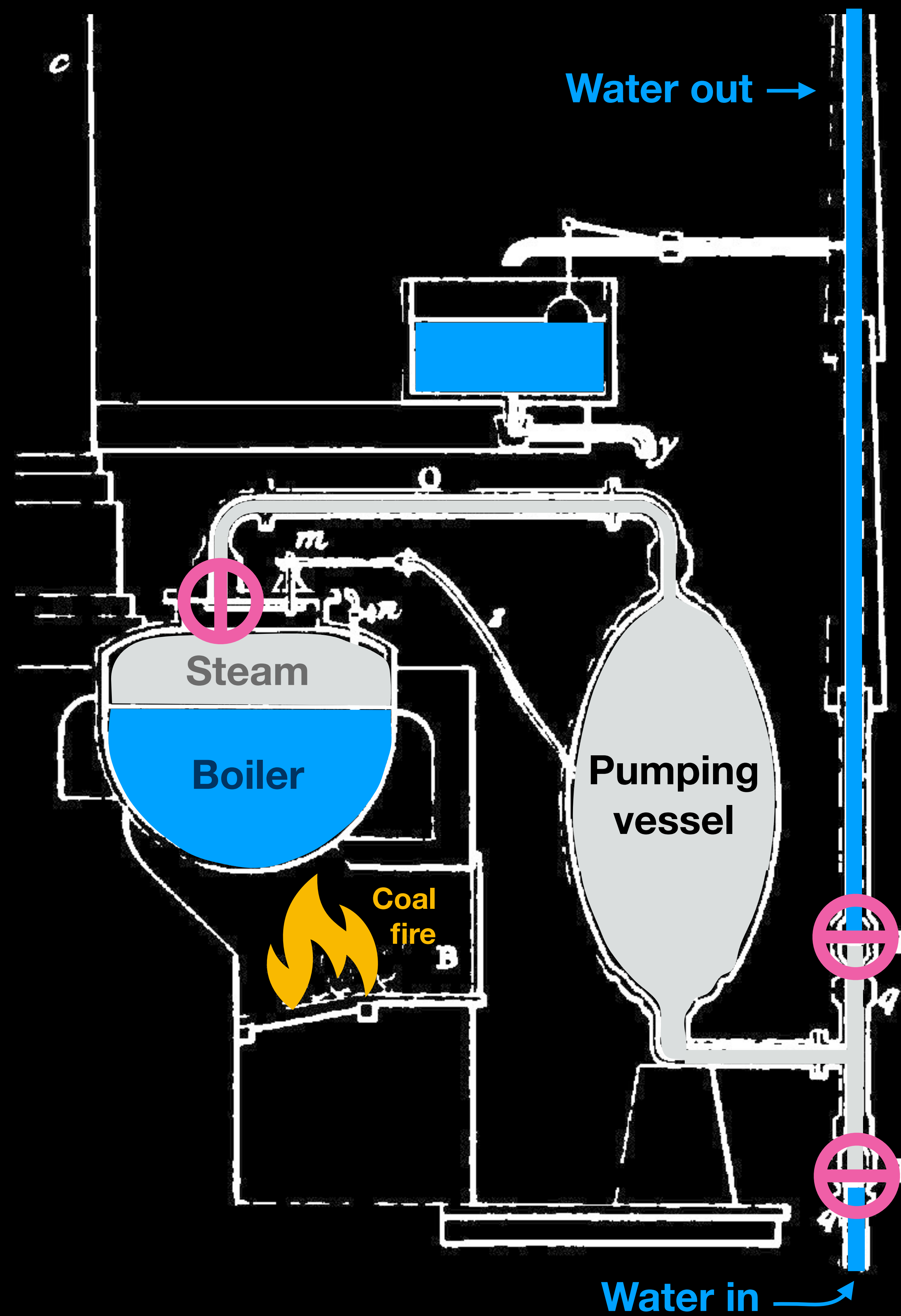


The "Savery Engine"

Pumping cycle:

1.) Pumping vessel connected to boiler; filled with steam



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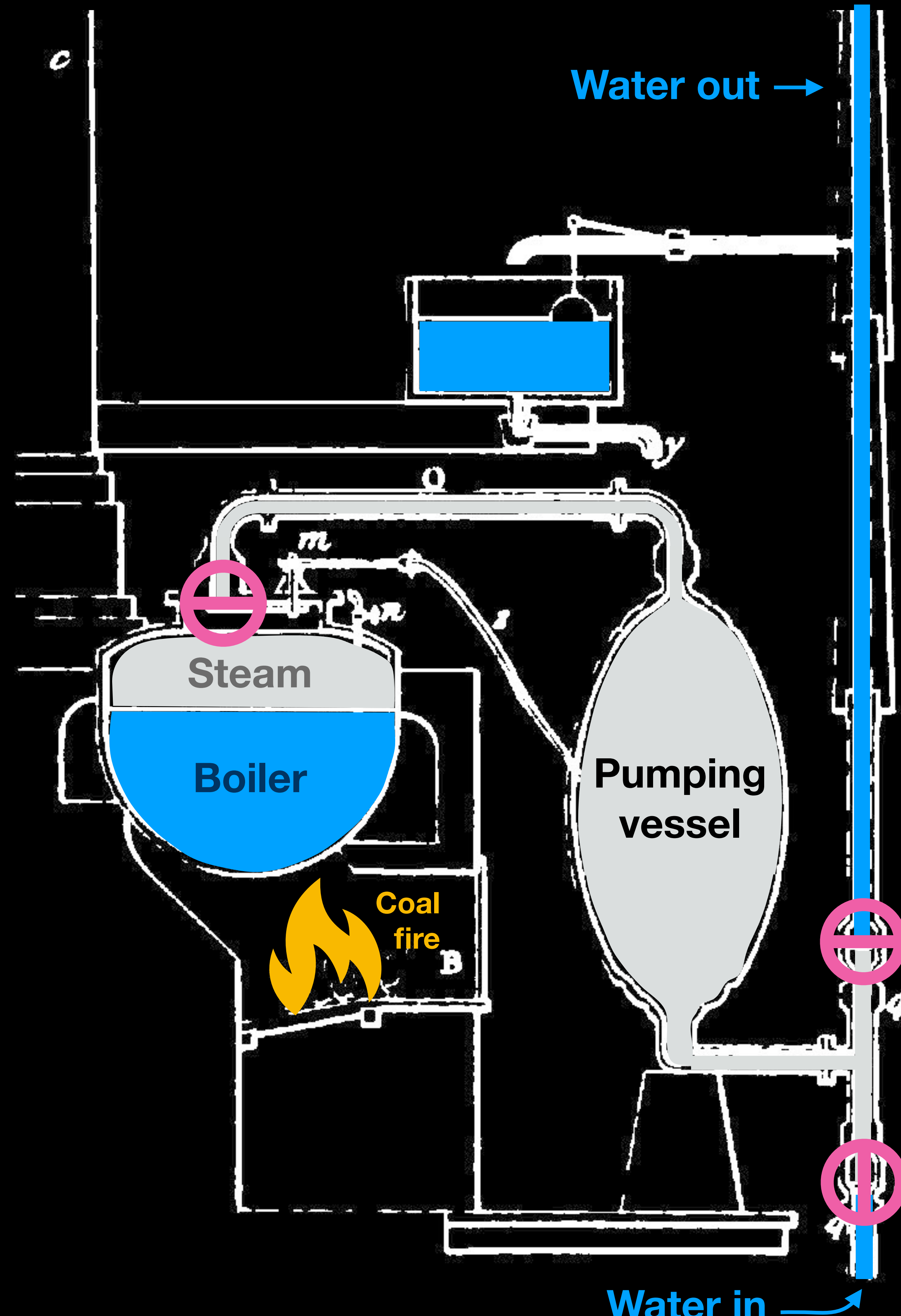
2.) Pumping vessel isolated from boiler; connected to intake



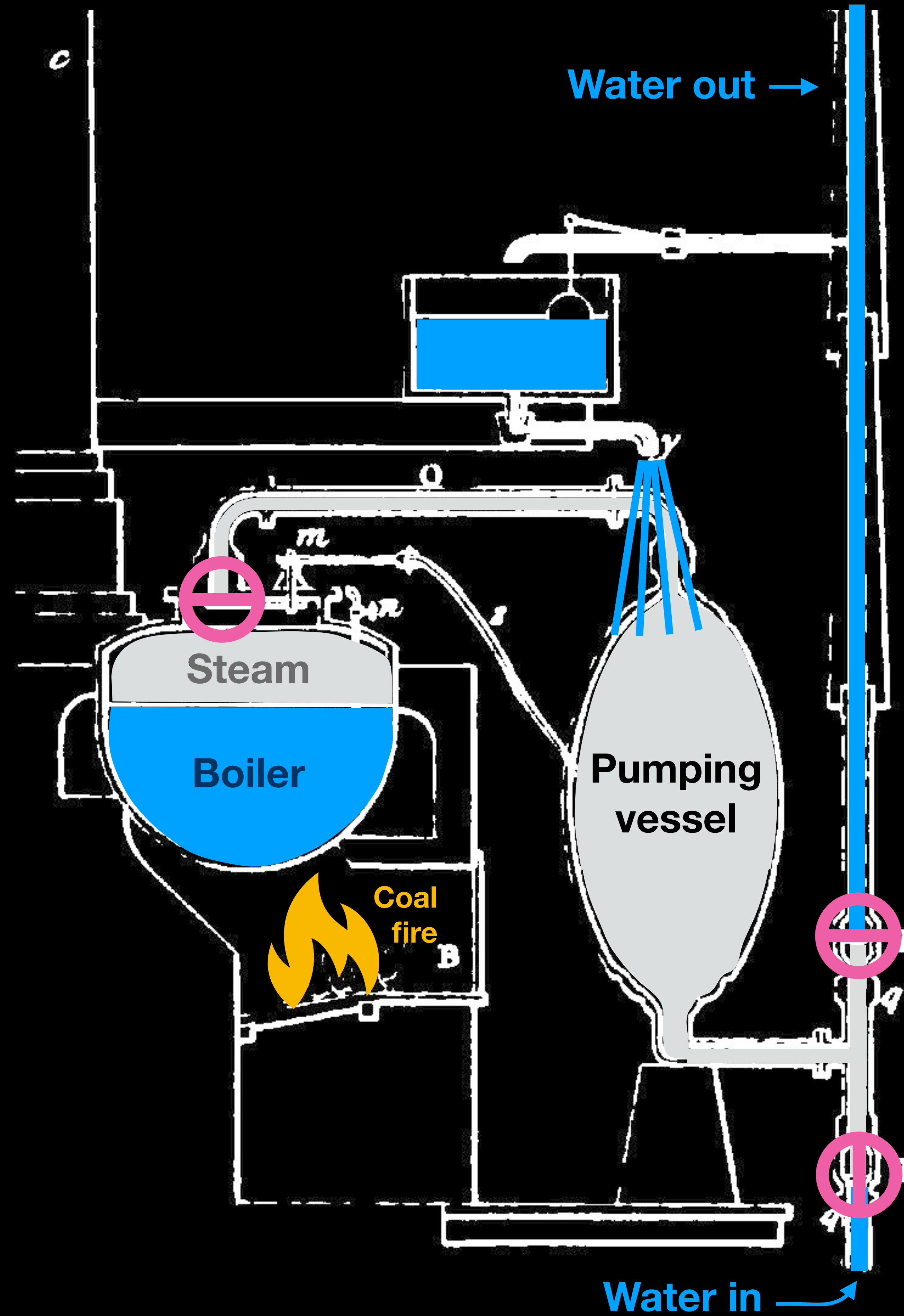
The “Savery Engine”

Pumping cycle:

1.) **Pumping vessel connected to boiler; filled with steam**

2.) **Pumping vessel isolated from boiler; connected to intake**

3.) **Pumping vessel doused with water and cooled down**



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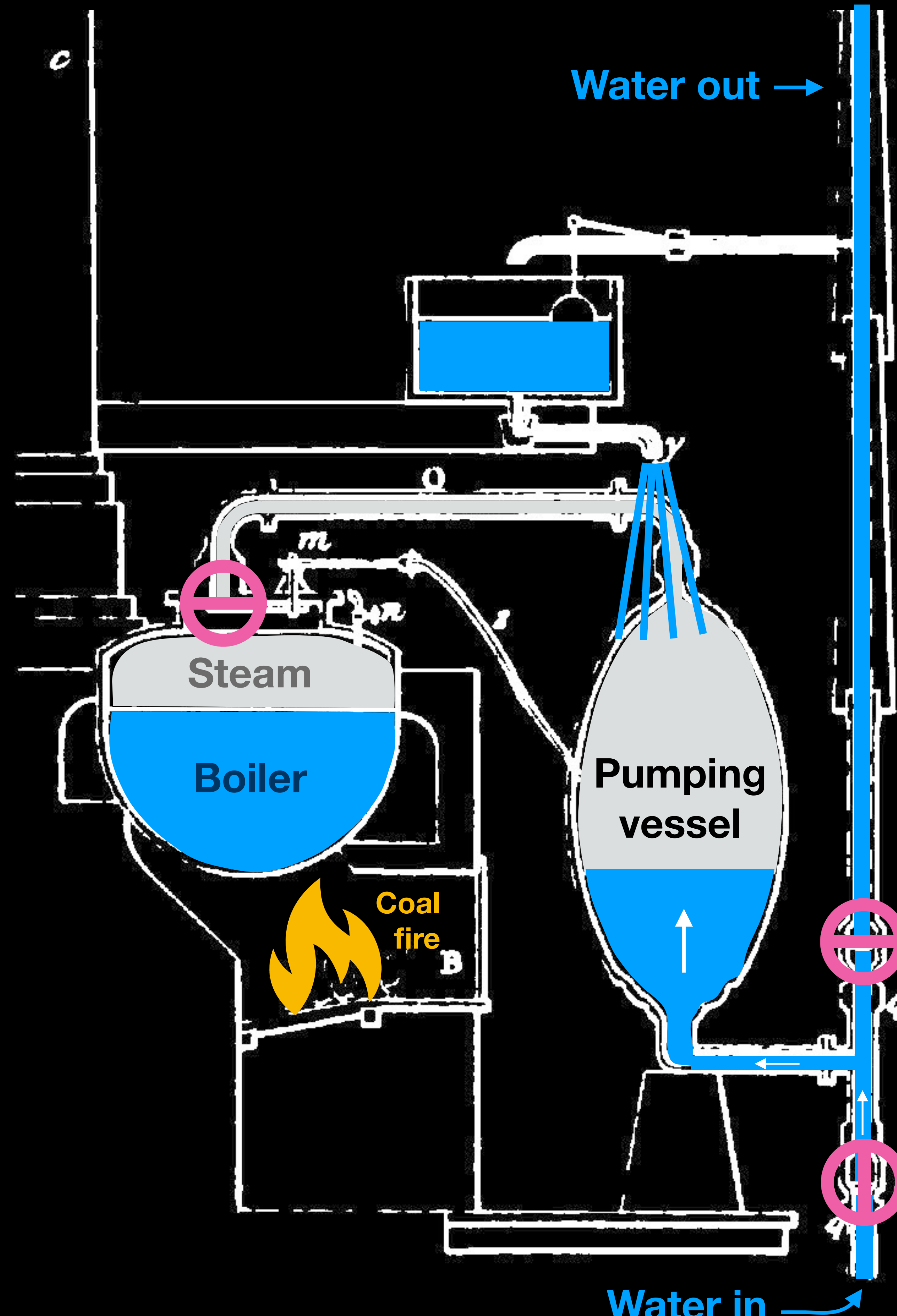
→ Steam condenses and contracts, water sucked into pumping vessel



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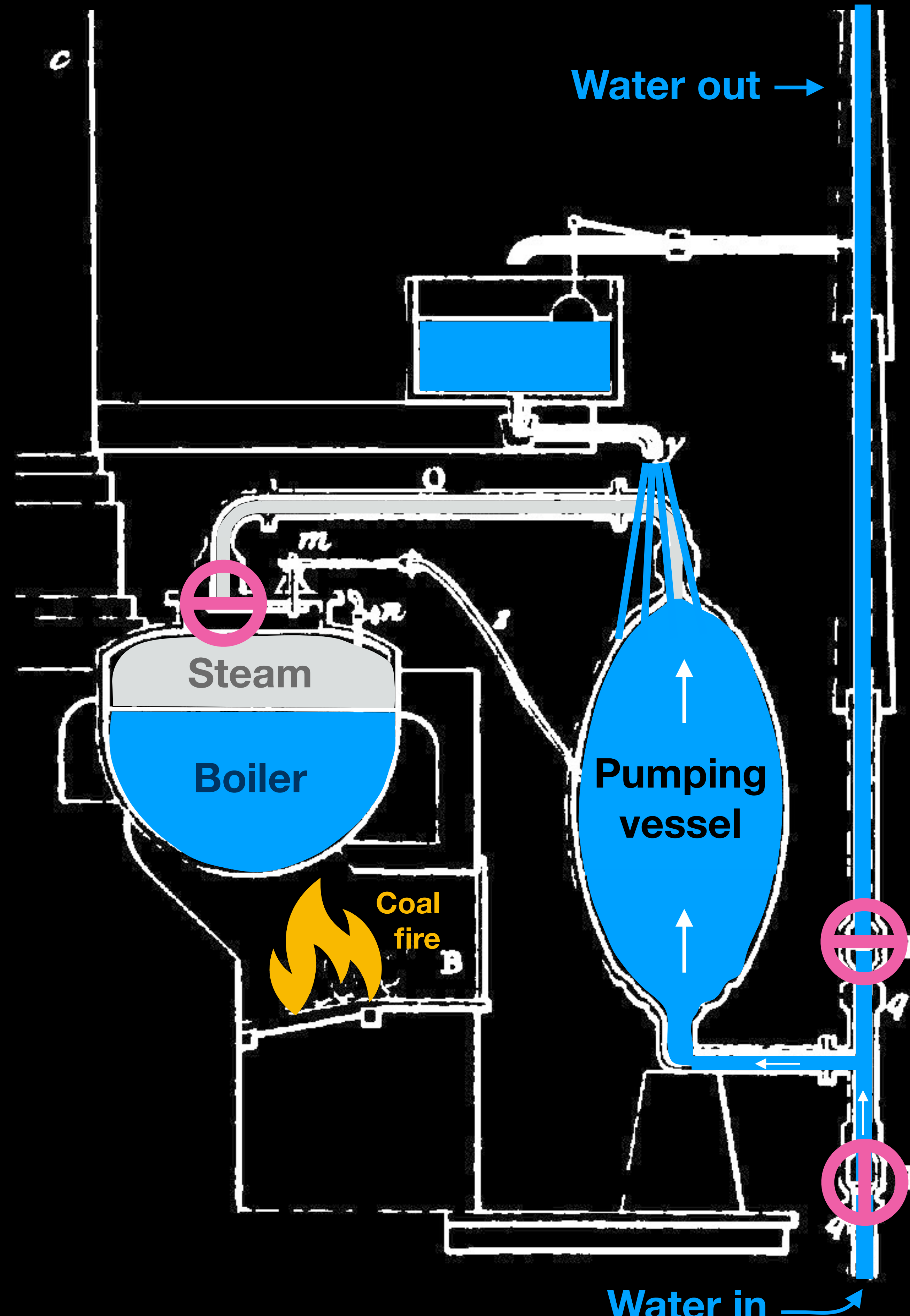

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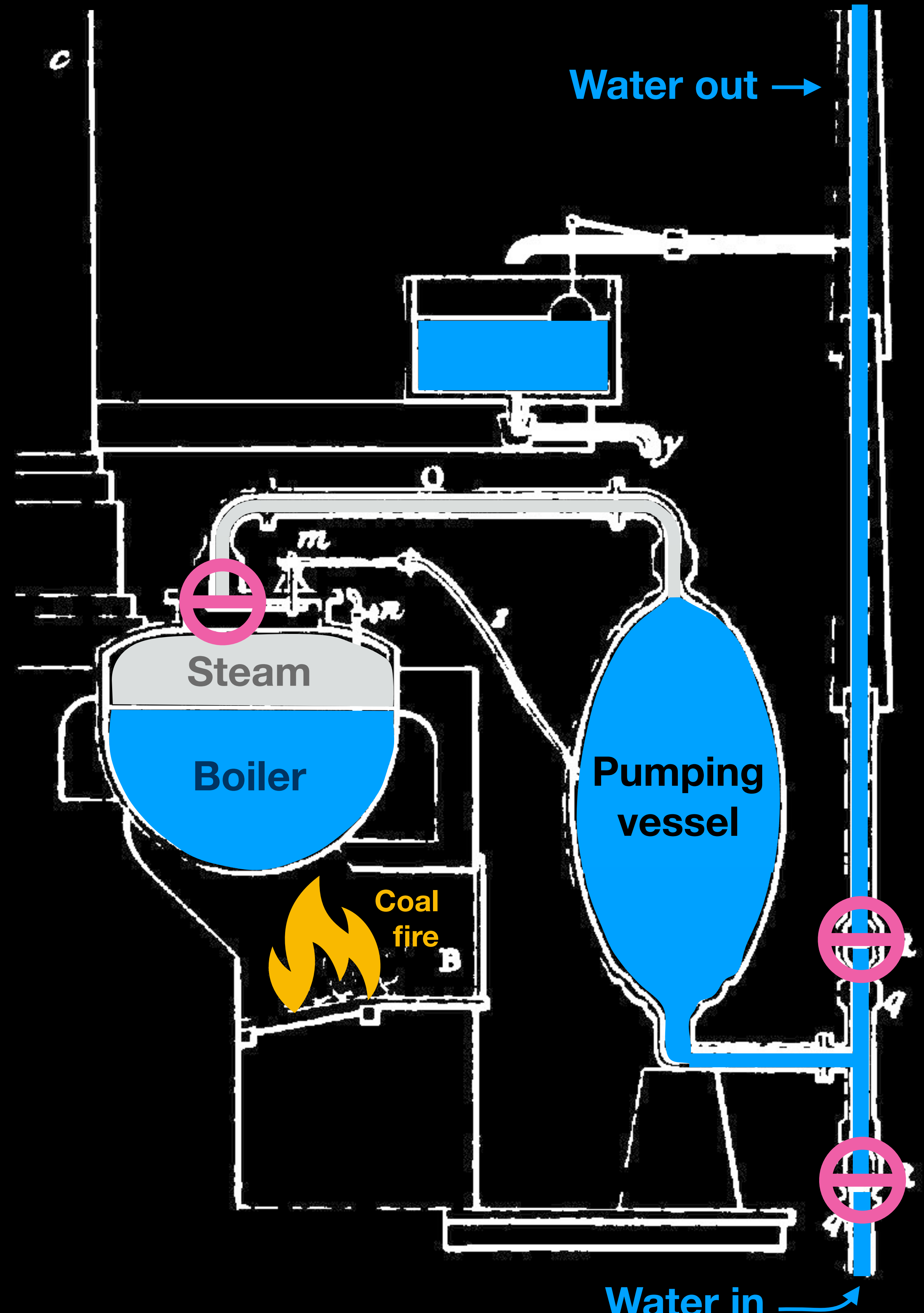

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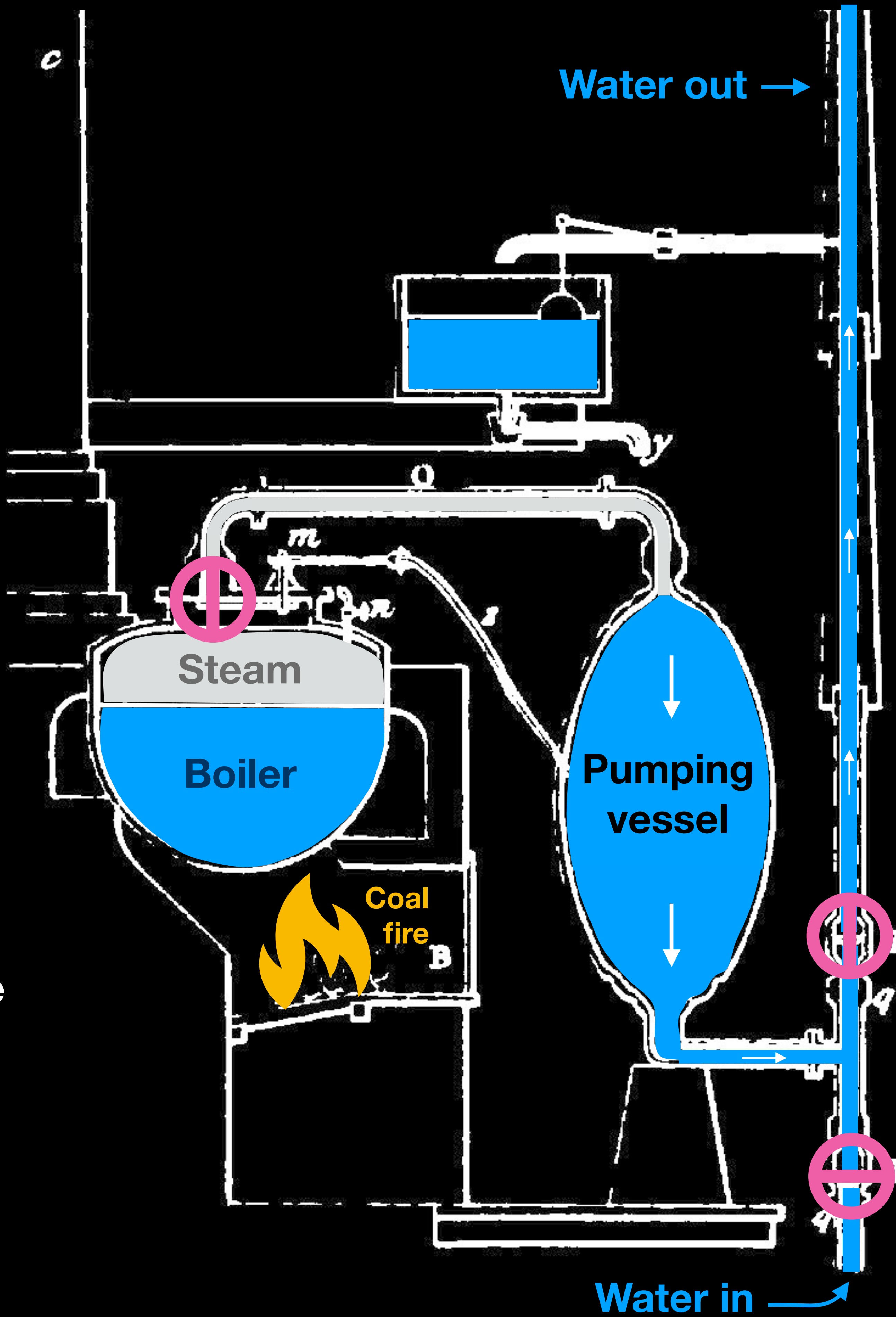
→ **Steam condenses and contracts, water sucked into pumping vessel**

4.) **Dousing water turned off, pumping vessel reconnected to boiler and to outflow pipe**



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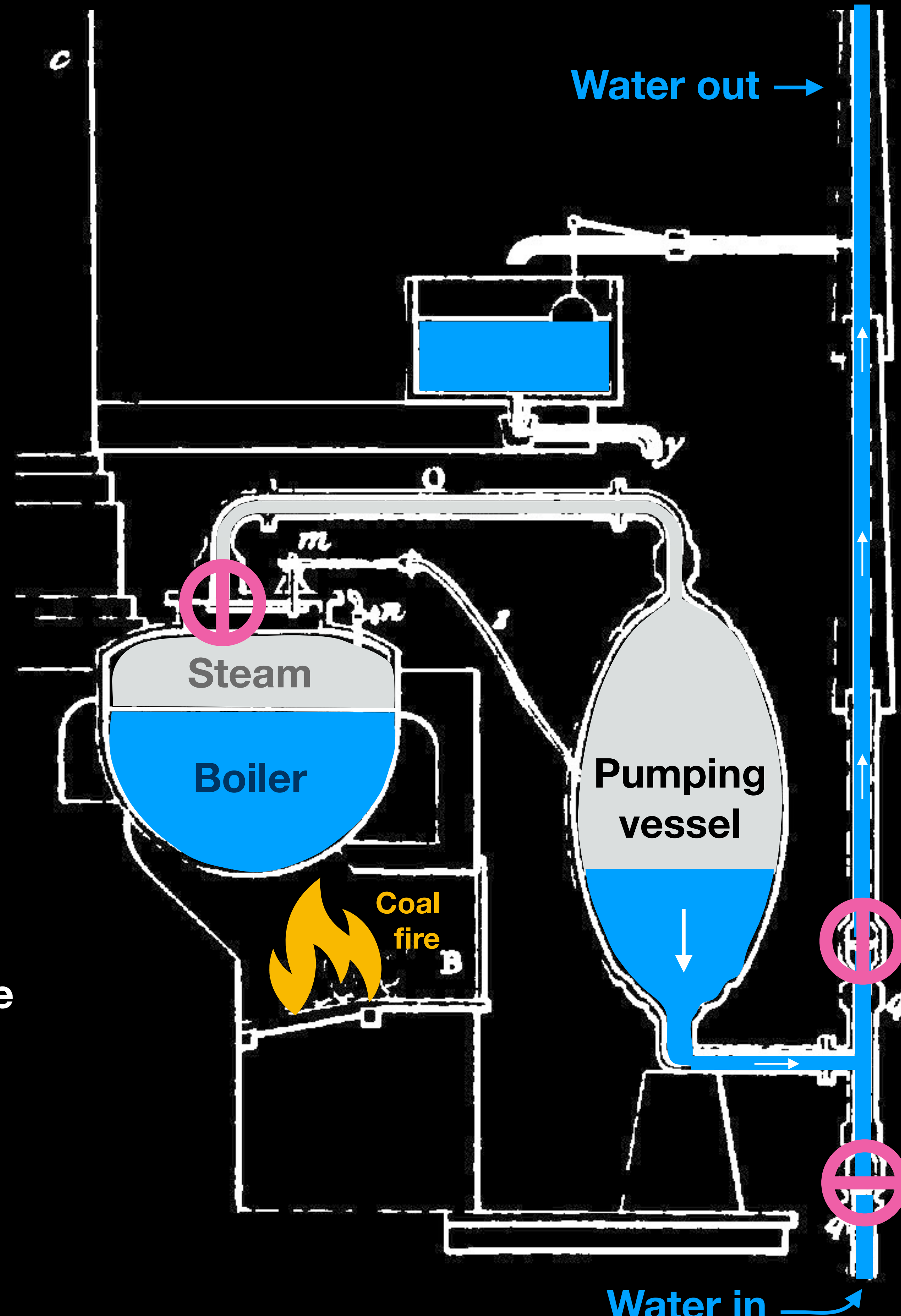
4.) Dousing water turned off, pumping vessel reconnected to boiler and to outflow pipe

→ Steam pressure pushes water out of the pumping vessel



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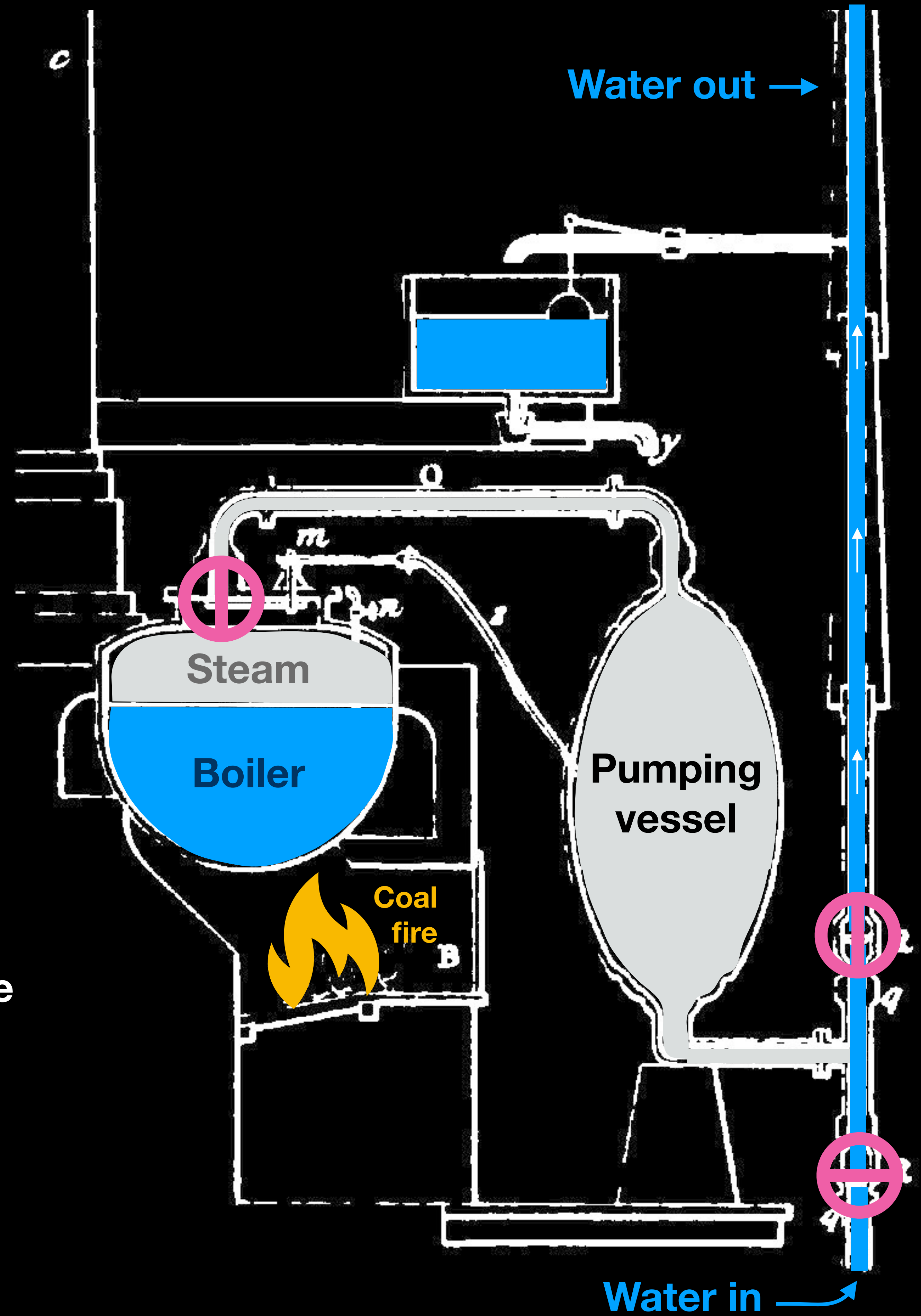


The Savery Engine in action

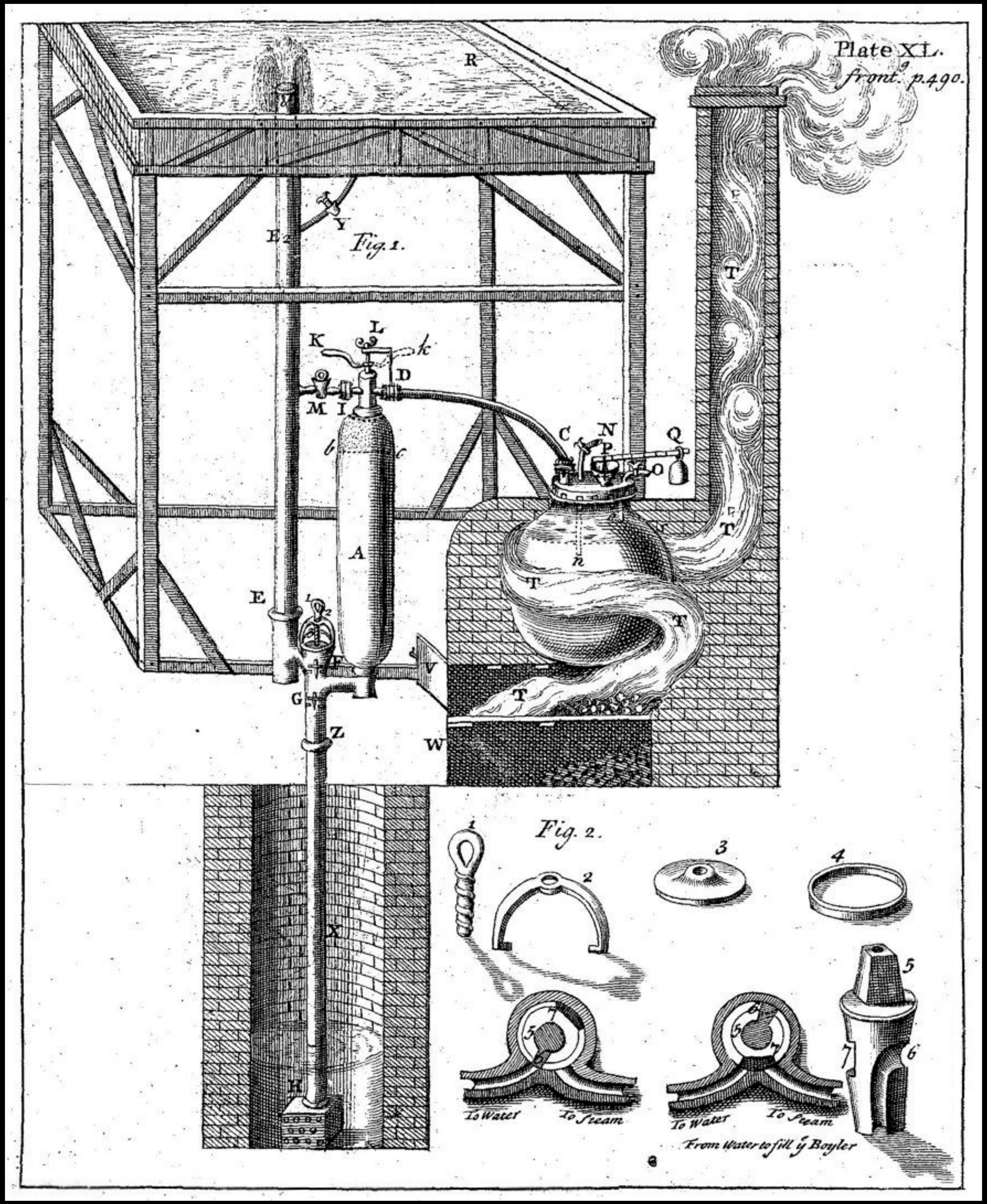
Never became the "Miner's friend"

High-pressure steam

↕

boiler explosions

Used in two London waterworks



Thomas Newcomen

Ironmonger in Devonshire, phantom

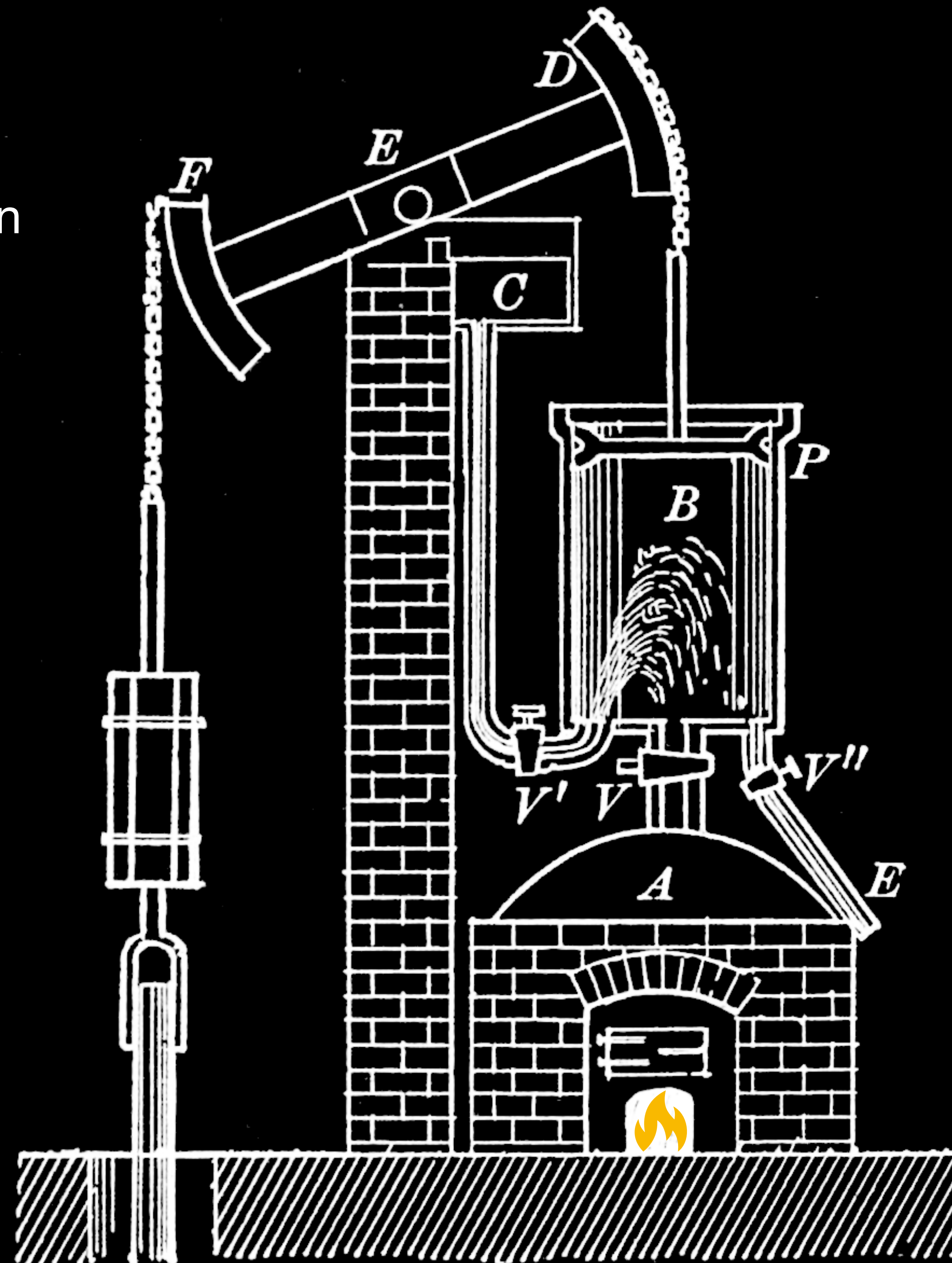
“A man from Dartmouth, without any knowledge whatever of the speculations of Captain Savery, had also made up his mind to invent a fire-machine for drawing water from the English tin mines.”

From the records of Marten Triewald

Newcomen's "atmospheric engine"

"For ten consecutive years Mr. Newcomen worked at this fire-machine …"

Marten Triewald



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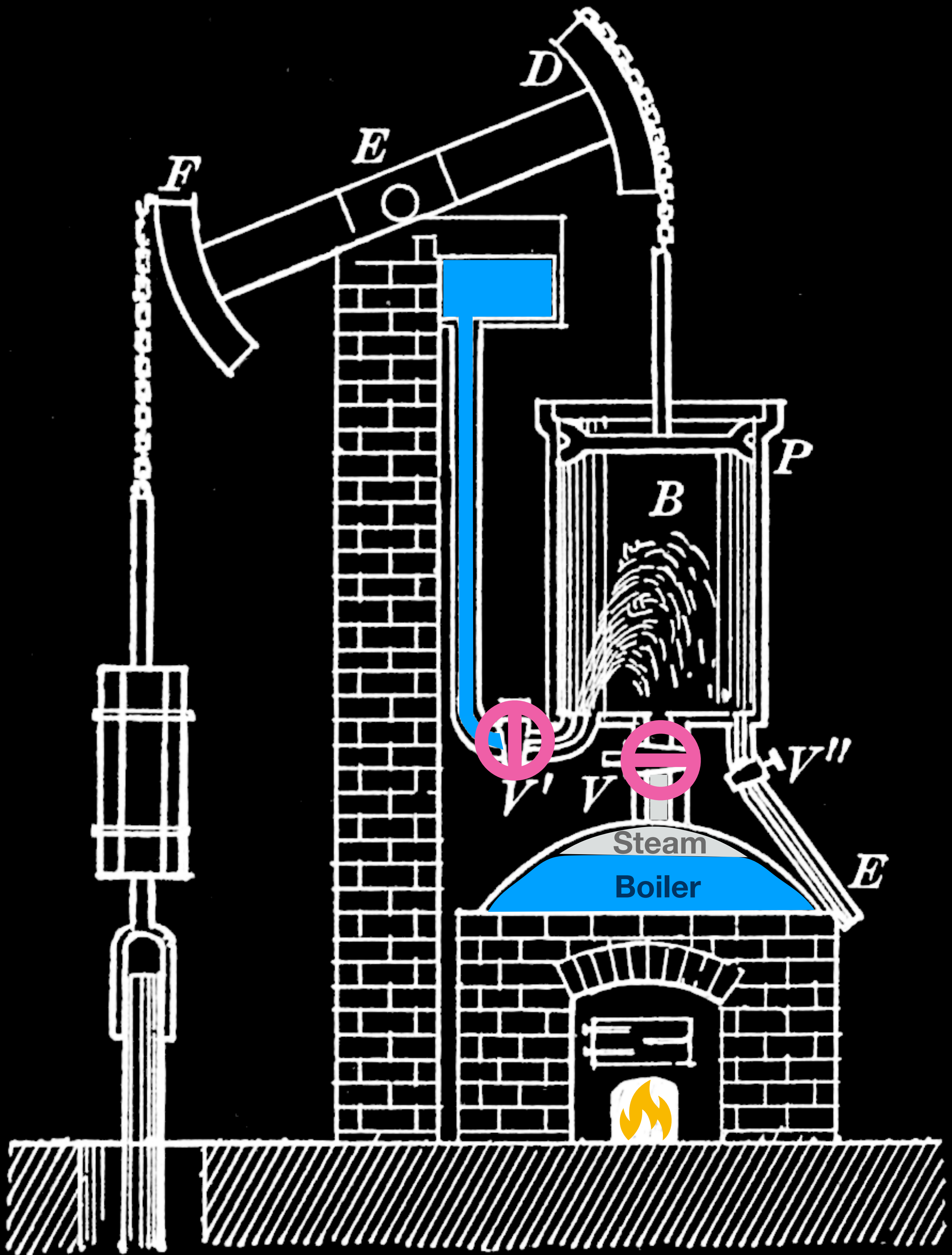
Pumping cycle:



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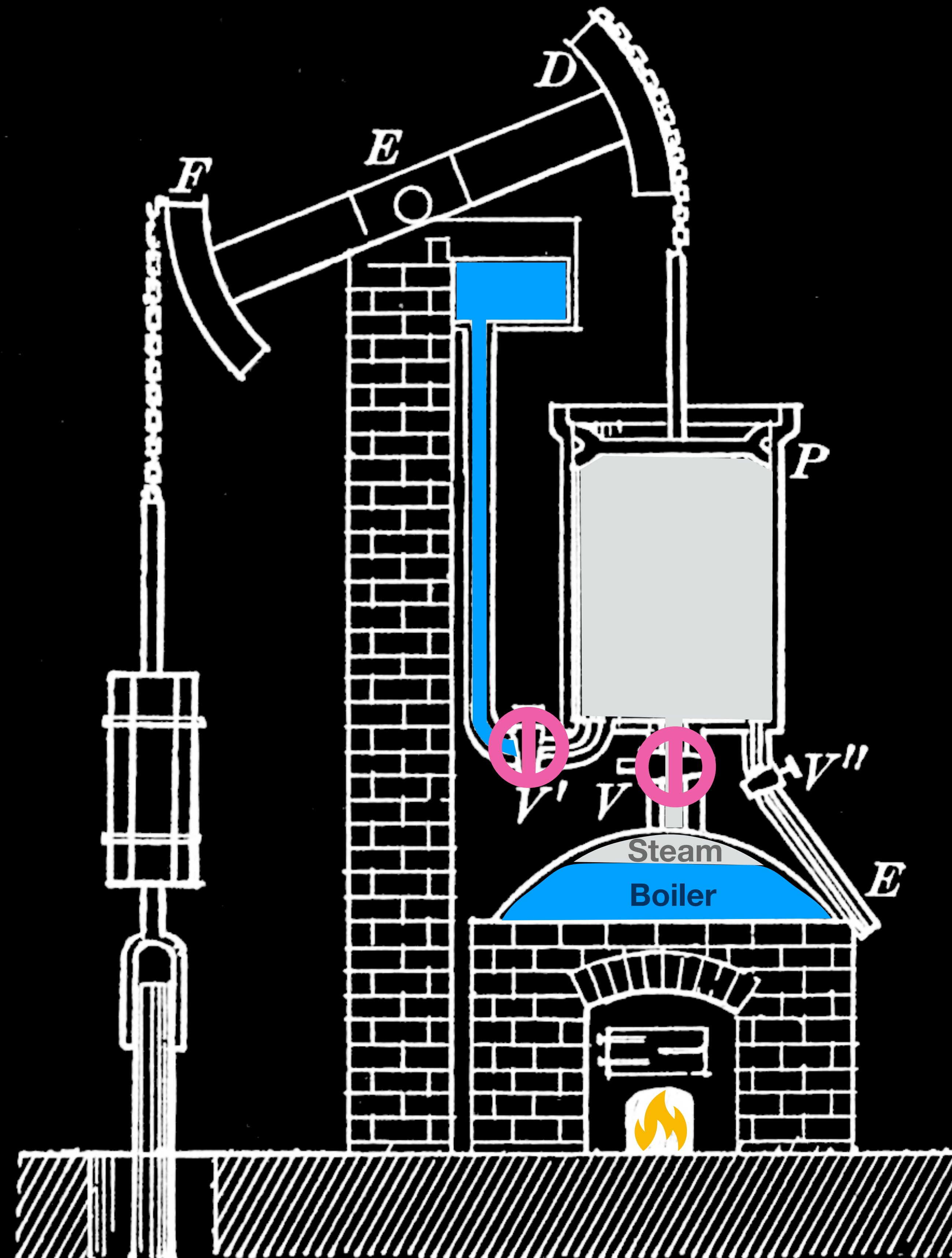
Pumping cycle:

1.) Piston connected with boiler, filled with steam

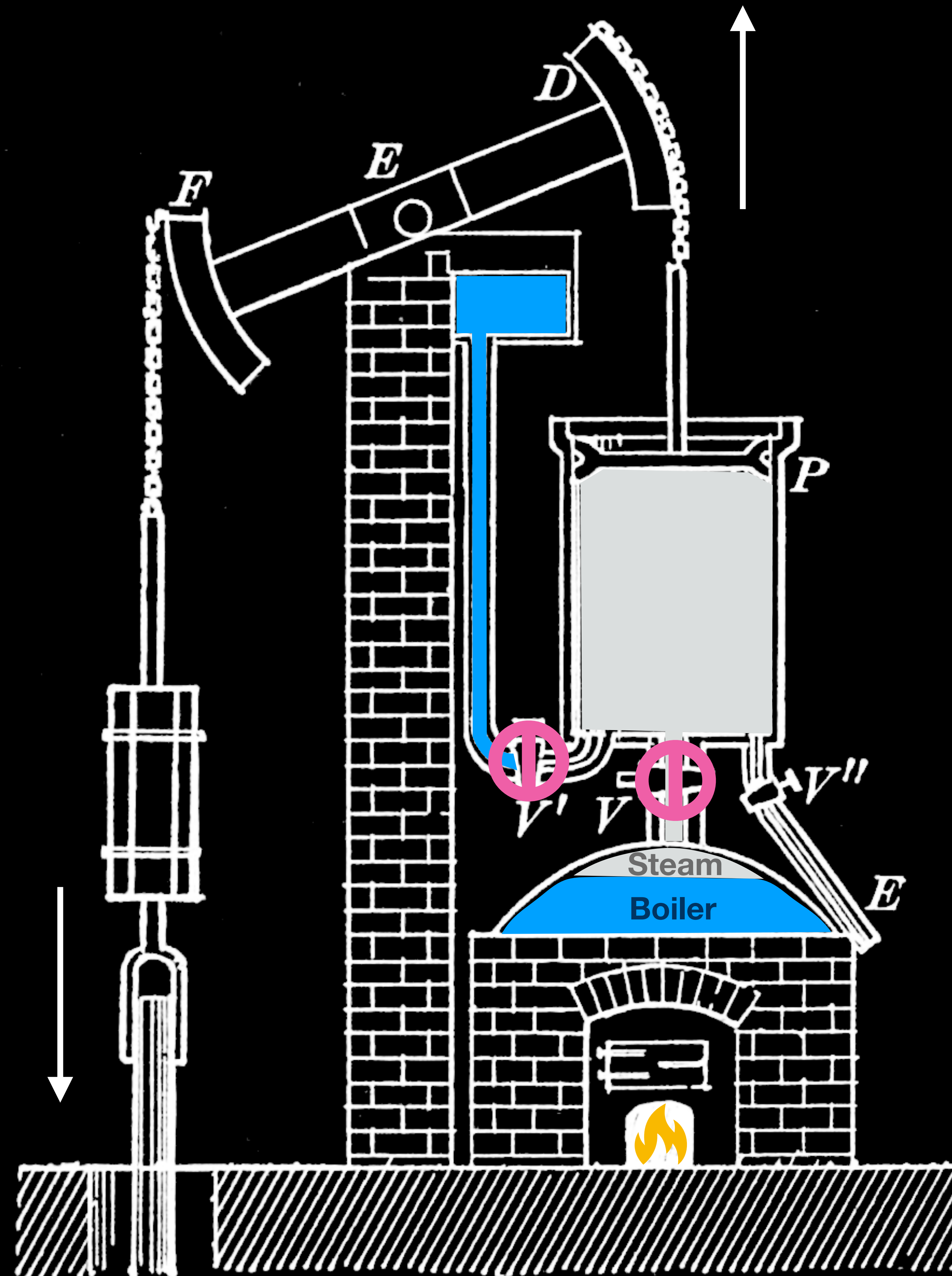


Newcomen's "atmospheric engine"

Pumping cycle:

1.) Piston connected with boiler, filled with steam

→ Piston extends, counterweight is lowered



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Pumping cycle:

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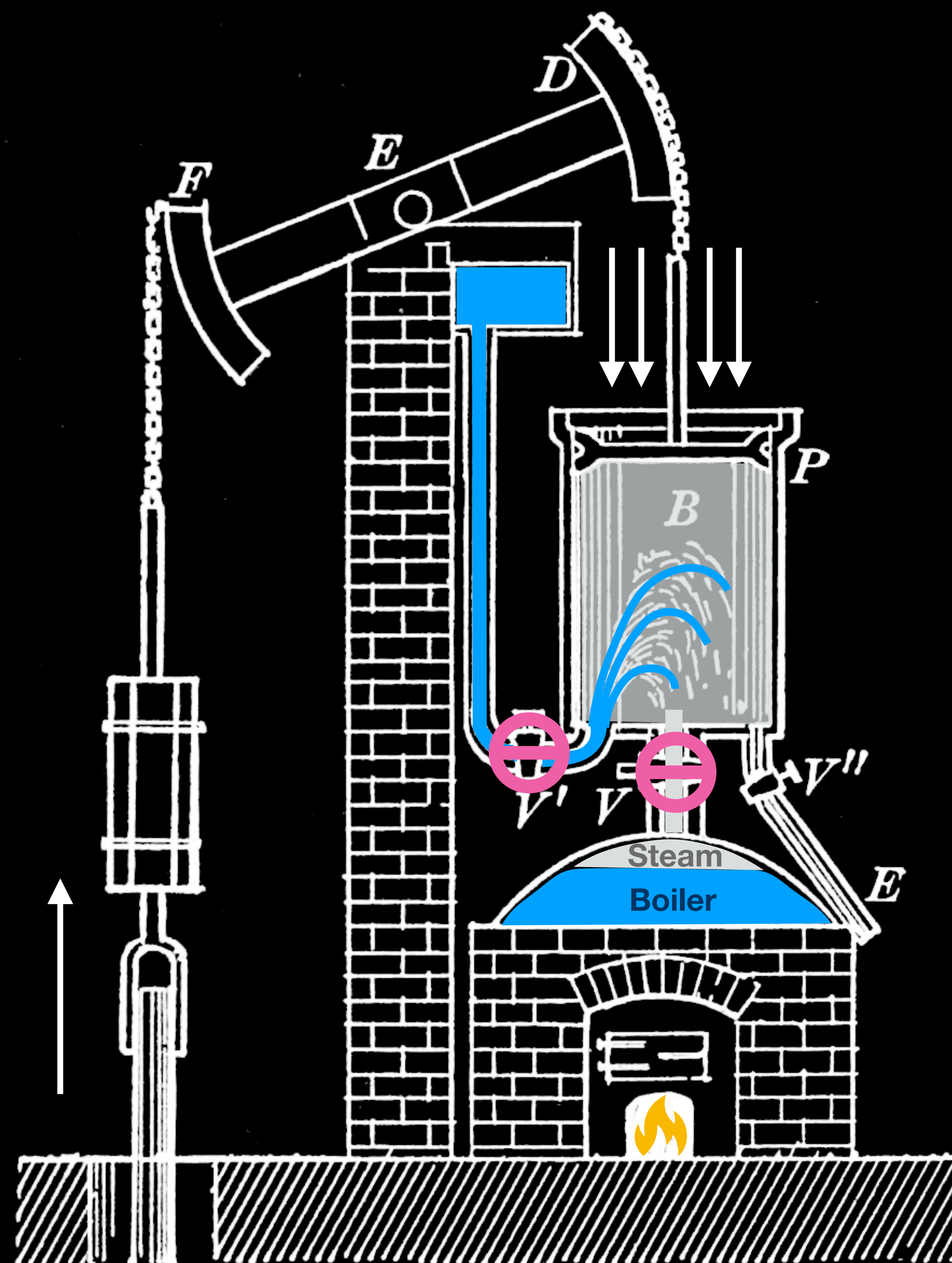
→ Piston extends, counterweight is lowered

2.) Piston disconnected from boiler, cold water injected



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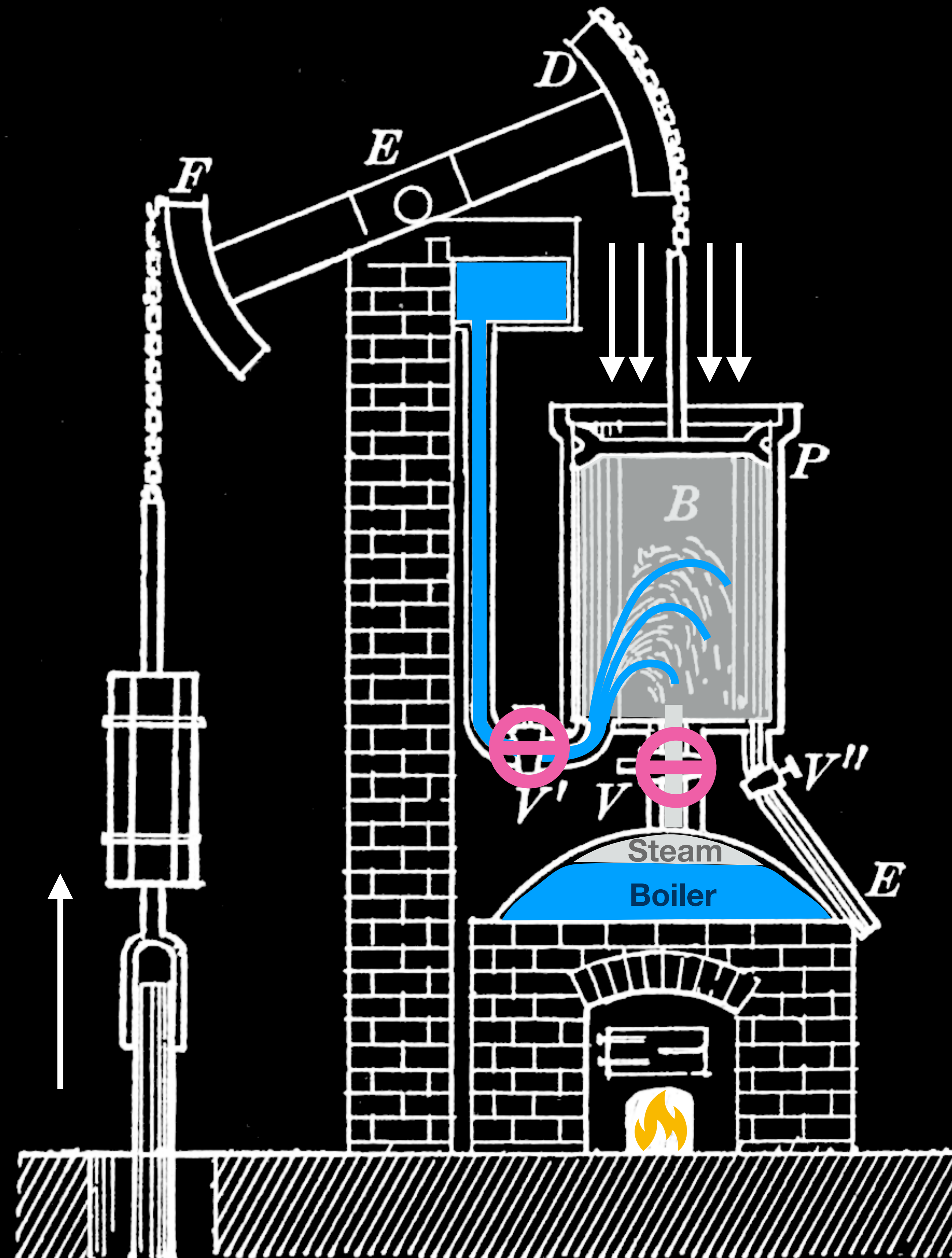
→ Piston extends, counterweight is lowered

2.) Piston disconnected from boiler, cold water injected

→ Steam condenses, atmospheric pressure pushes piston back in, counterweight is raised



Newcomen's "atmospheric engine"

Pumping cycle:

1.) Piston connected with boiler, filled with steam

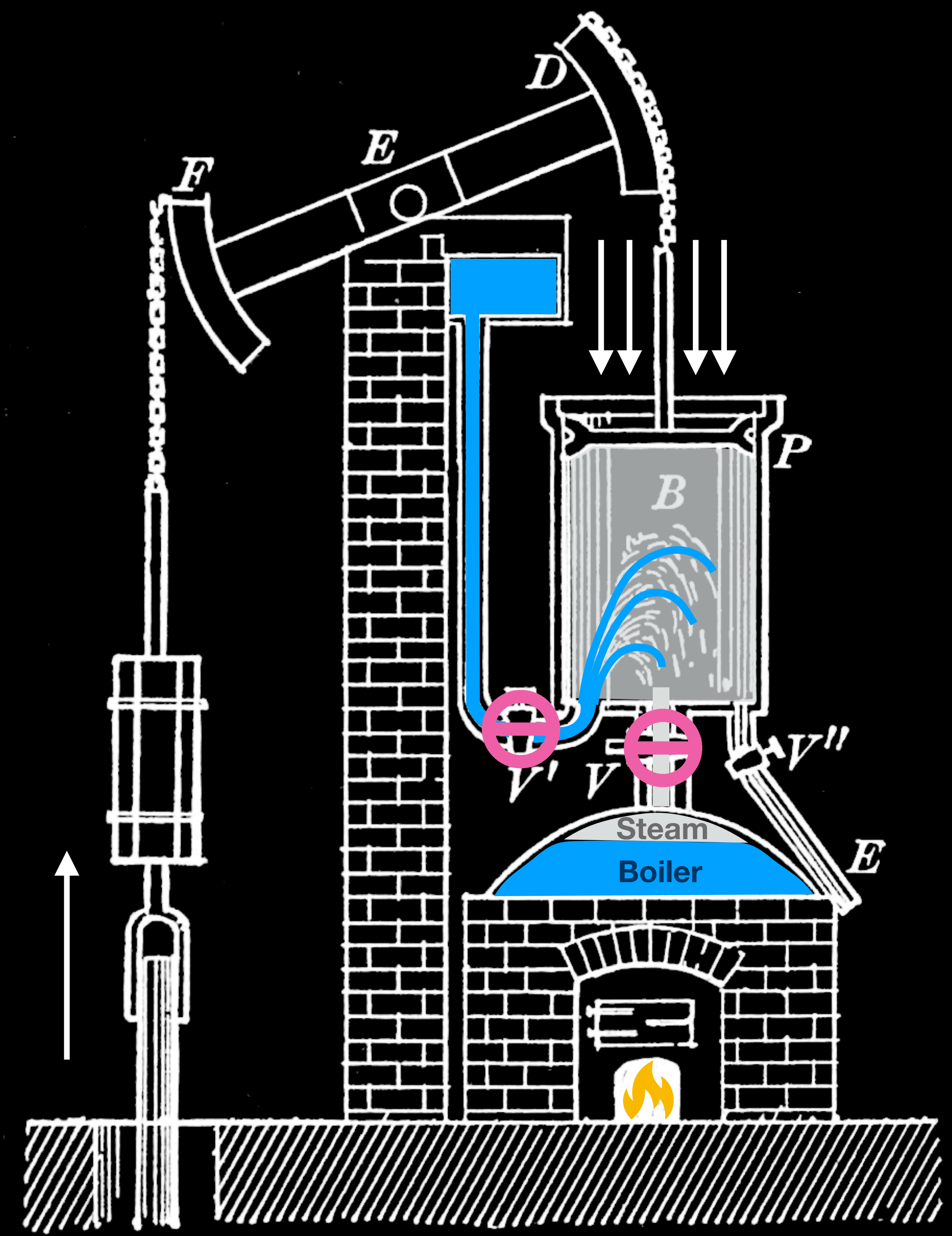
→ Piston extends, counterweight is lowered

2.) Piston disconnected from boiler, cold water injected

→ Steam condenses, atmospheric pressure pushes piston back in, counterweight is raised

Up- and downward movement of shaft drives pump

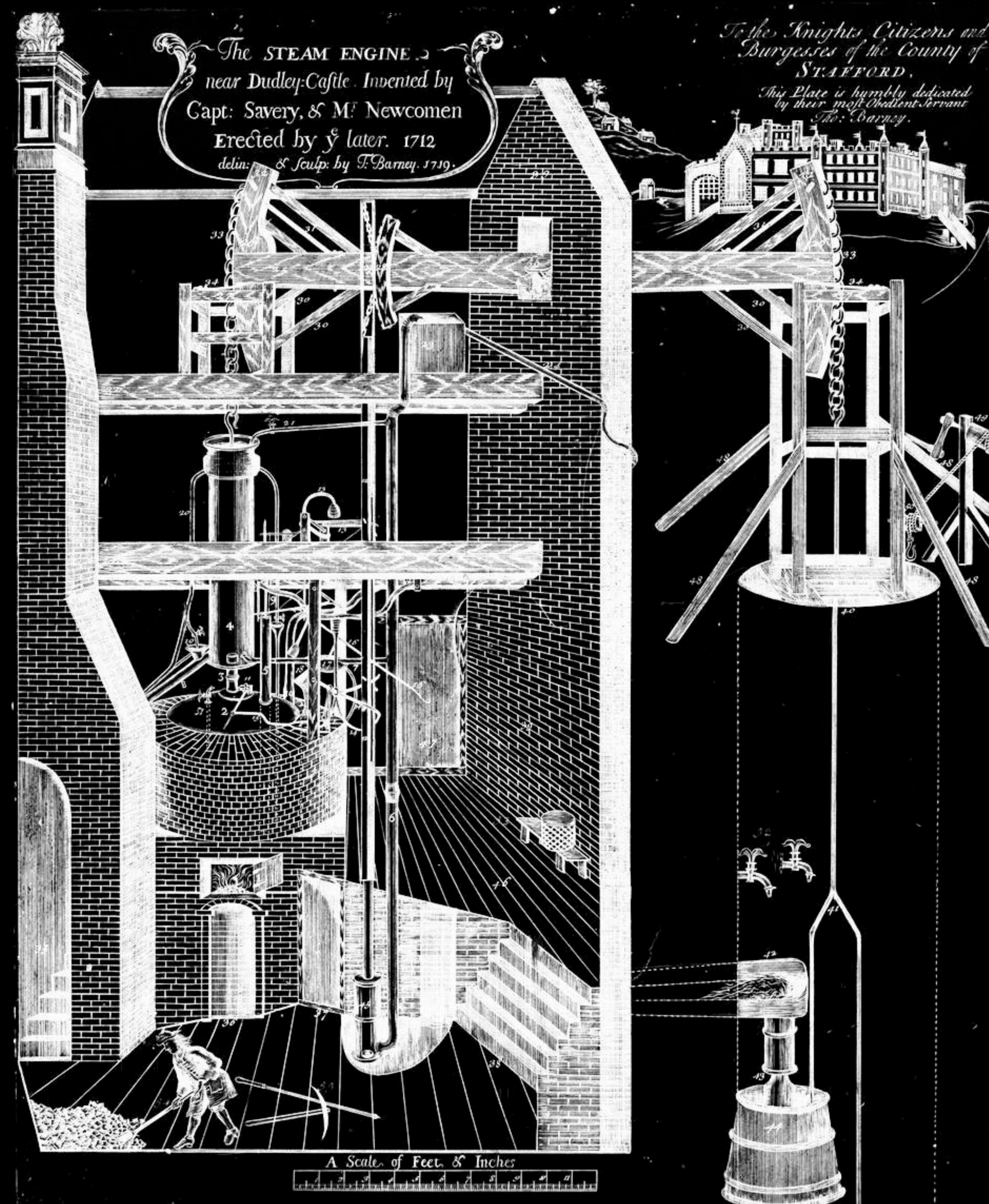
No need for high-pressure steam
→ more reliable



The first Newcomen engine in operation

"The steam engine
near Dudley castle.

Invented by Capt. Savery
& Mr. Newcomen,
Erected by ye later 1712"



The Newcomen engine spreads …

… under Savery's patent!

Bernissart, Belgium
(built 1781)

Landgoed Groenendaal,
Netherlands
(shown in 1780s)

"Fairbottom Bobs" at a coal mine in
Lancashire, England
(operating 1760-1827)

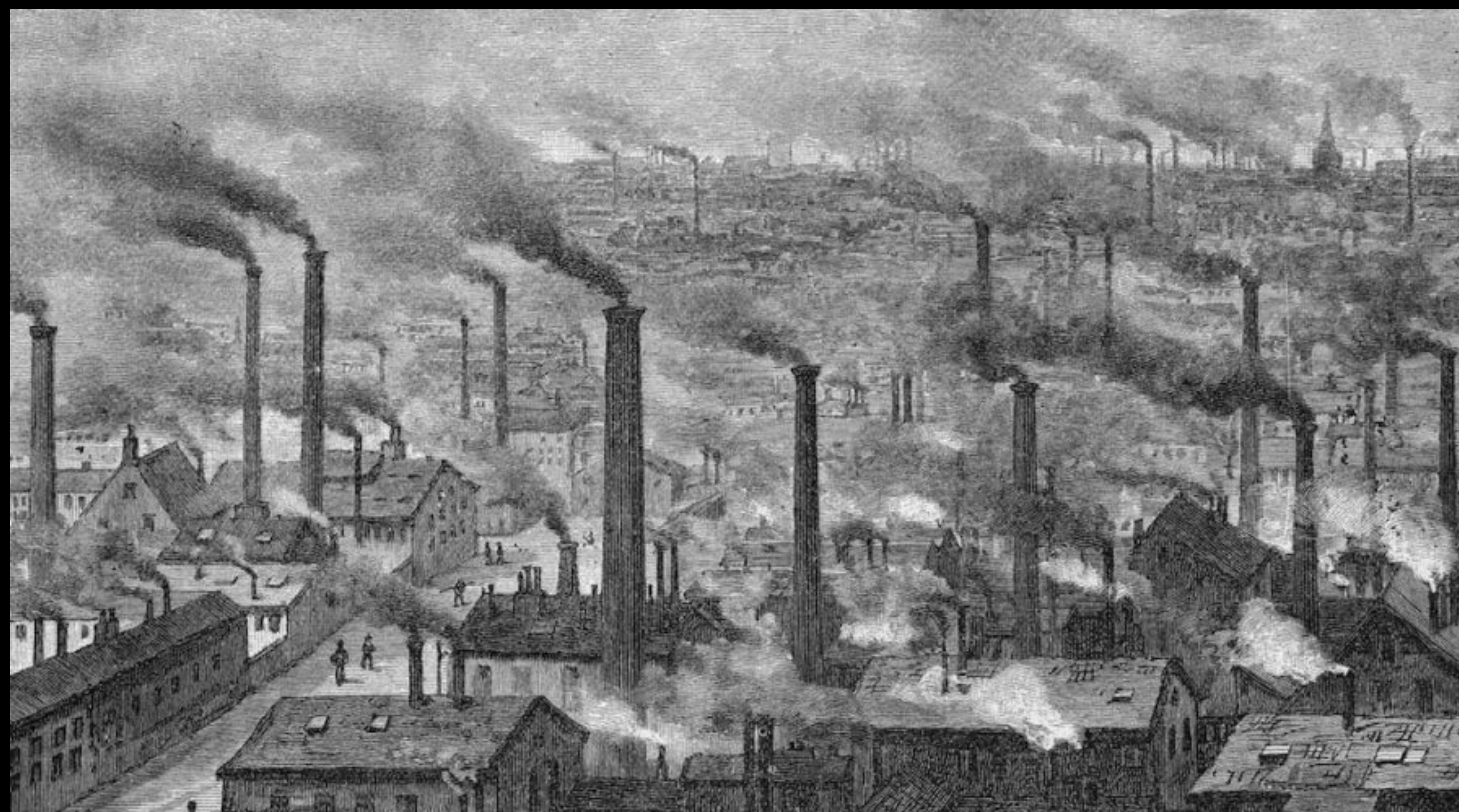
Now at Henry Ford museum in Dearborn, MI

~1500 Newcomen engines had been built by 1800

The Newcomen engine spreads …

patent!

Extremely inefficient workhorse of the early industrial revolution:
deep coal mines, blast furnaces, …



And did the Countenance Divine,
Shine forth upon our clouded hills?
And was Jerusalem builded here,
Among these dark Satanic Mills?

"And did those feet in ancient time",
William Blake, 1804

al mine in
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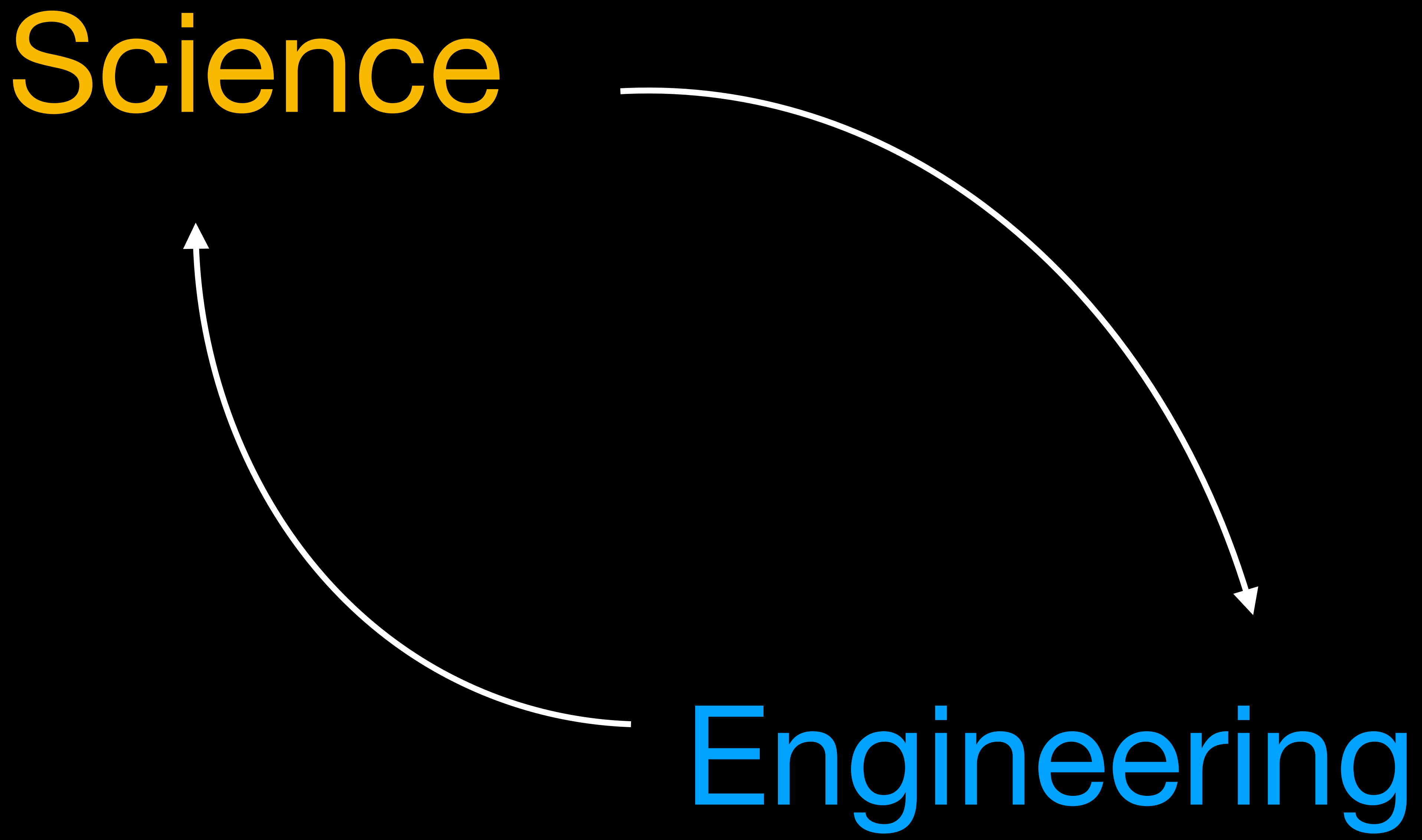
earborn, MI

B

800

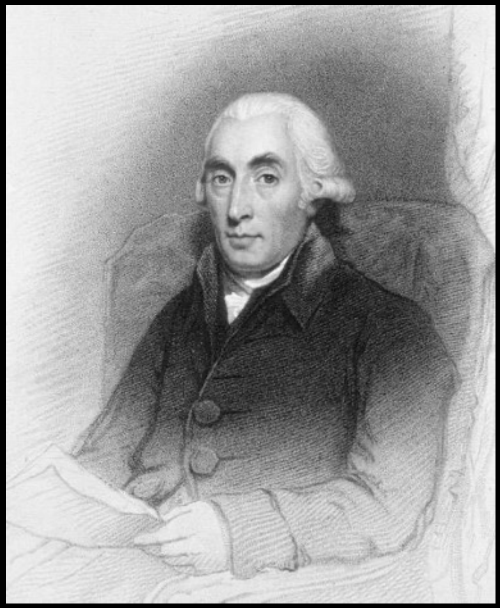
Science

Engineering


Science
Engineering

Joseph Black

Professor of anatomy and chemistry in Glasgow



University of Glasgow (1756–1766)

Newcomen's machine already well-established!

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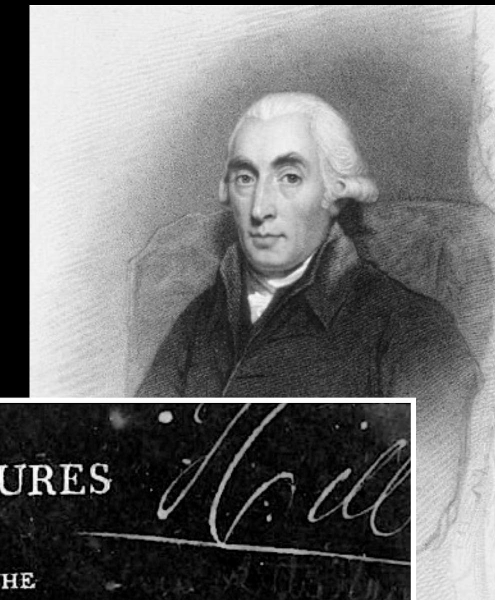
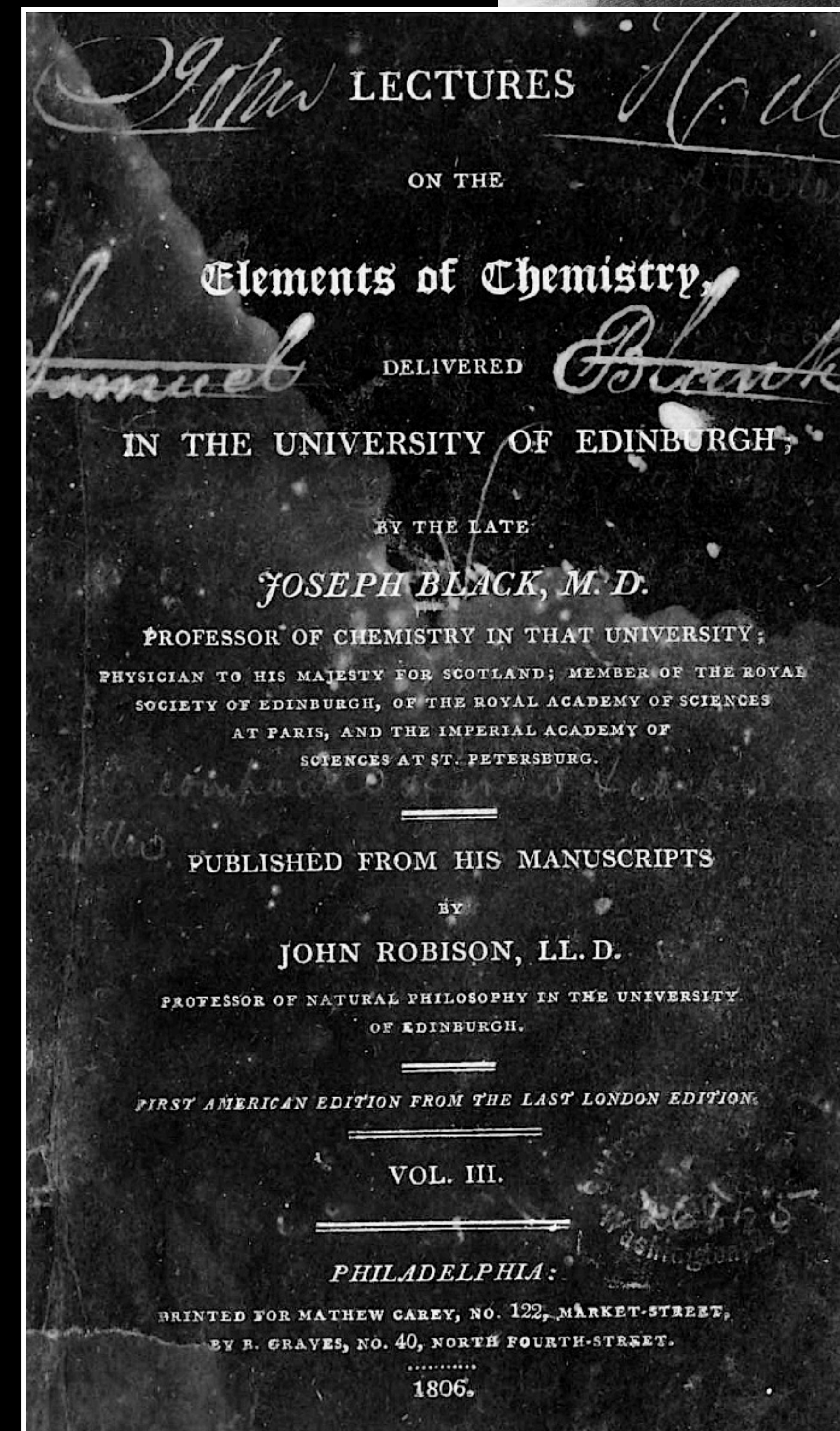


University of Glasgow (1756–1766)

Newcomen's machine already well-established!

Lecture notes:
published posthumously by his friend John Robison



LECTURES
ON THE
Elements of Chemistry,
DELIVERED
IN THE UNIVERSITY OF EDINBURGH;
BY THE LATE
JOSEPH BLACK, M.D.
PROFESSOR OF CHEMISTRY IN THAT UNIVERSITY;
PHYSICIAN TO HIS MAJESTY FOR SCOTLAND; MEMBER OF THE ROYAL SOCIETY OF EDINBURGH, OF THE ROYAL ACADEMY OF SCIENCES AT PARIS, AND THE IMPERIAL ACADEMY OF SCIENCES AT ST. PETERSBURG.

PUBLISHED FROM HIS MANUSCRIPTS
BY
JOHN ROBISON, LL.D.
PROFESSOR OF NATURAL PHILOSOPHY IN THE UNIVERSITY OF EDINBURGH.

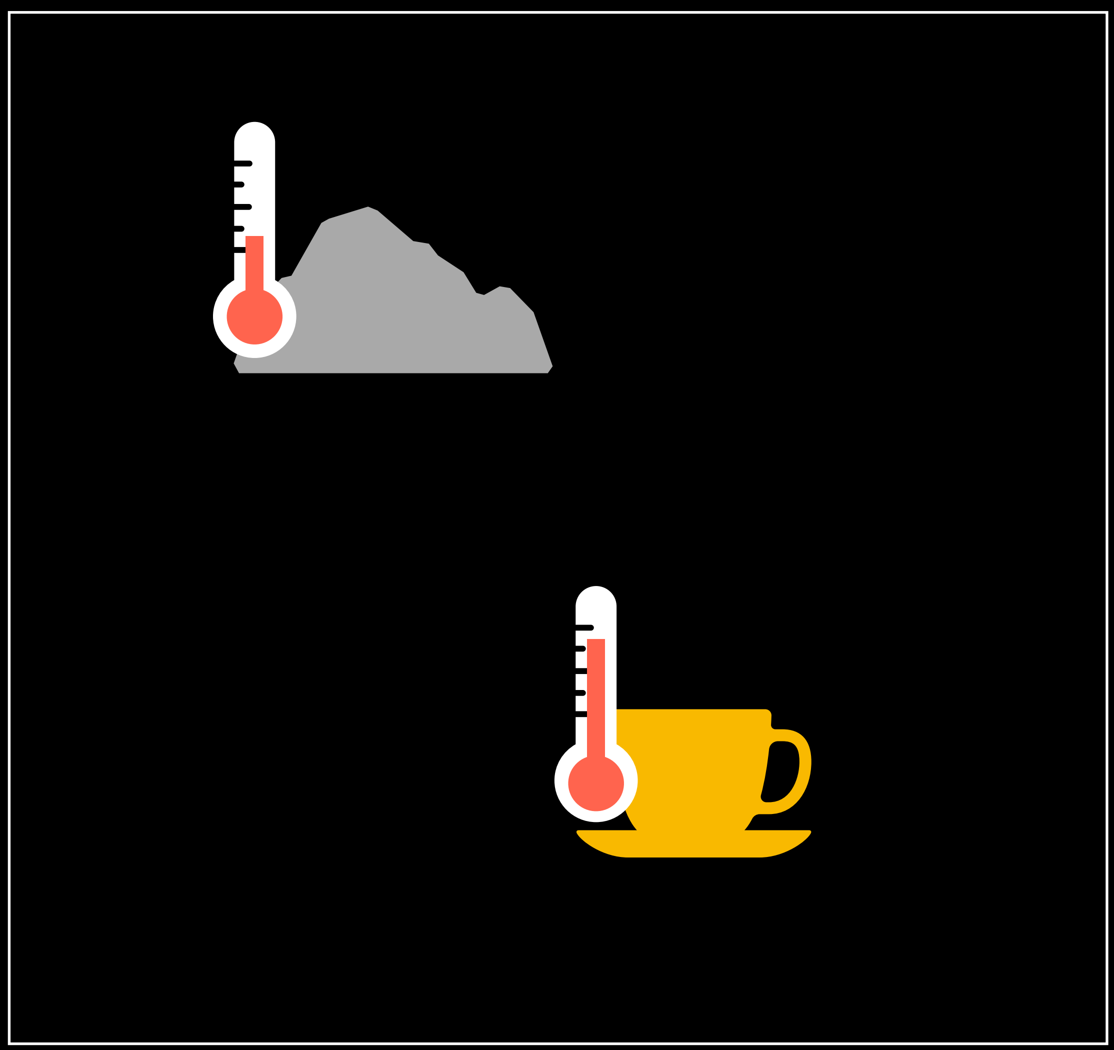
FIRST AMERICAN EDITION FROM THE LAST LONDON EDITION.

VOL. III.

PHILADELPHIA:
PRINTED FOR MATHEW CAREY, NO. 122, MARKET-STREET,
BY B. GRAVES, NO. 40, NORTH FOURTH-STREET.
1806.

Black's "equilibrium"

"If we take a thousand different kinds of matter and put them together in a room without a fire …"



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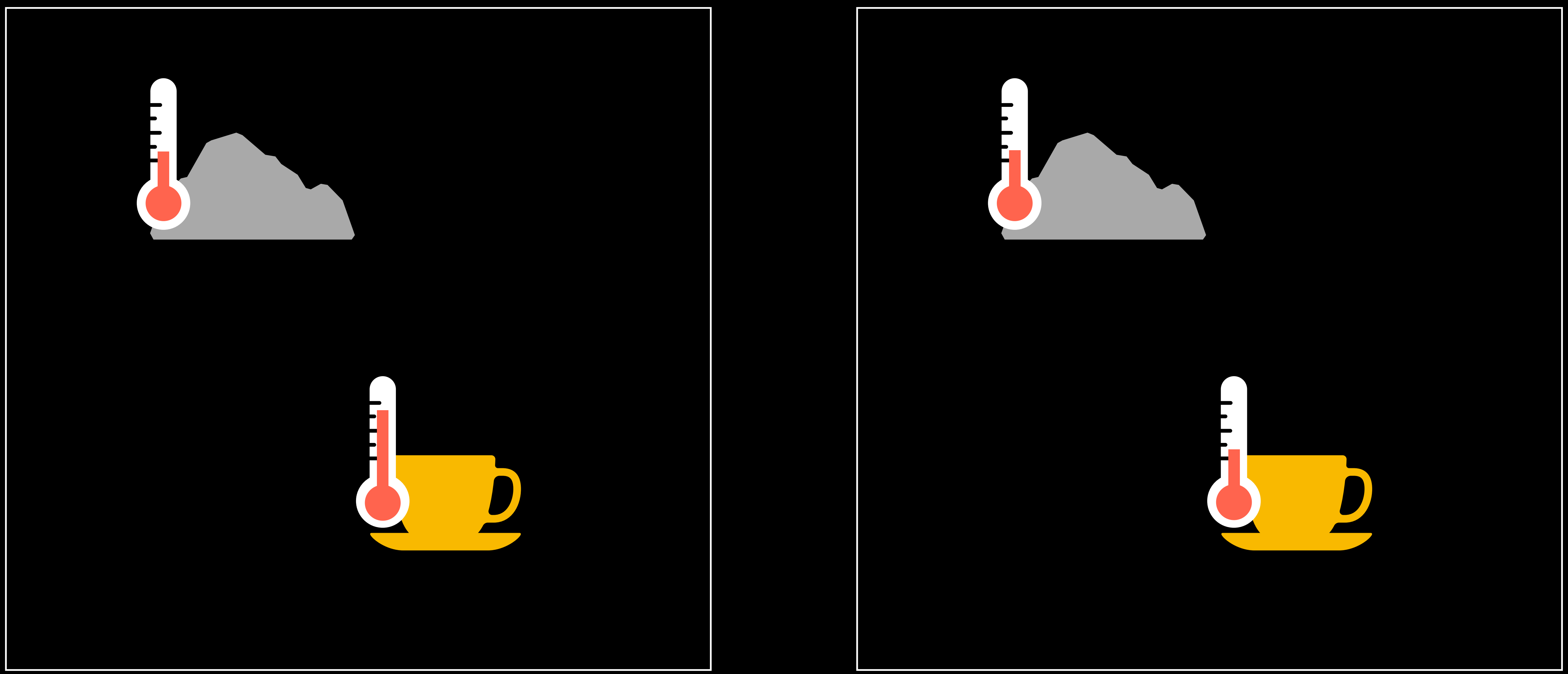

"… if we apply a thermometer to them all in succession, it will give precisely the same reading."

Black's "equilibrium"

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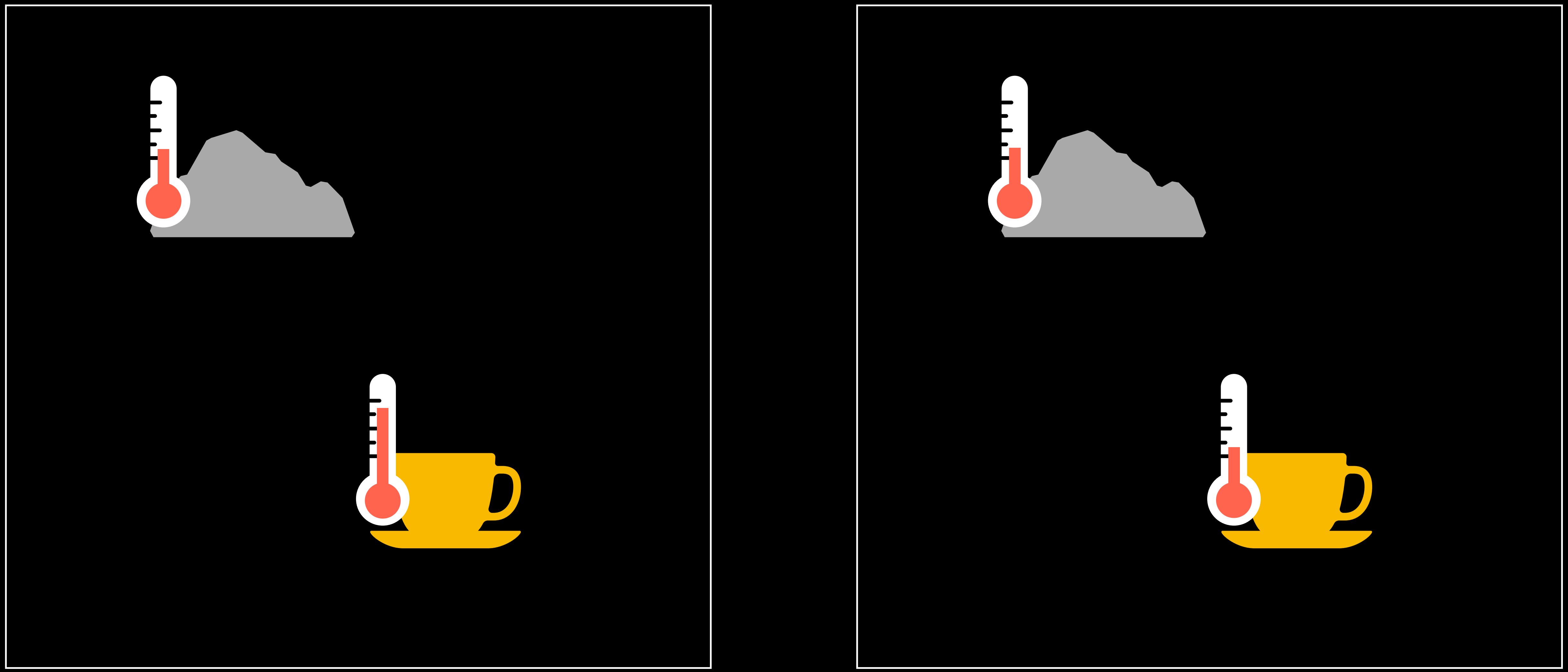
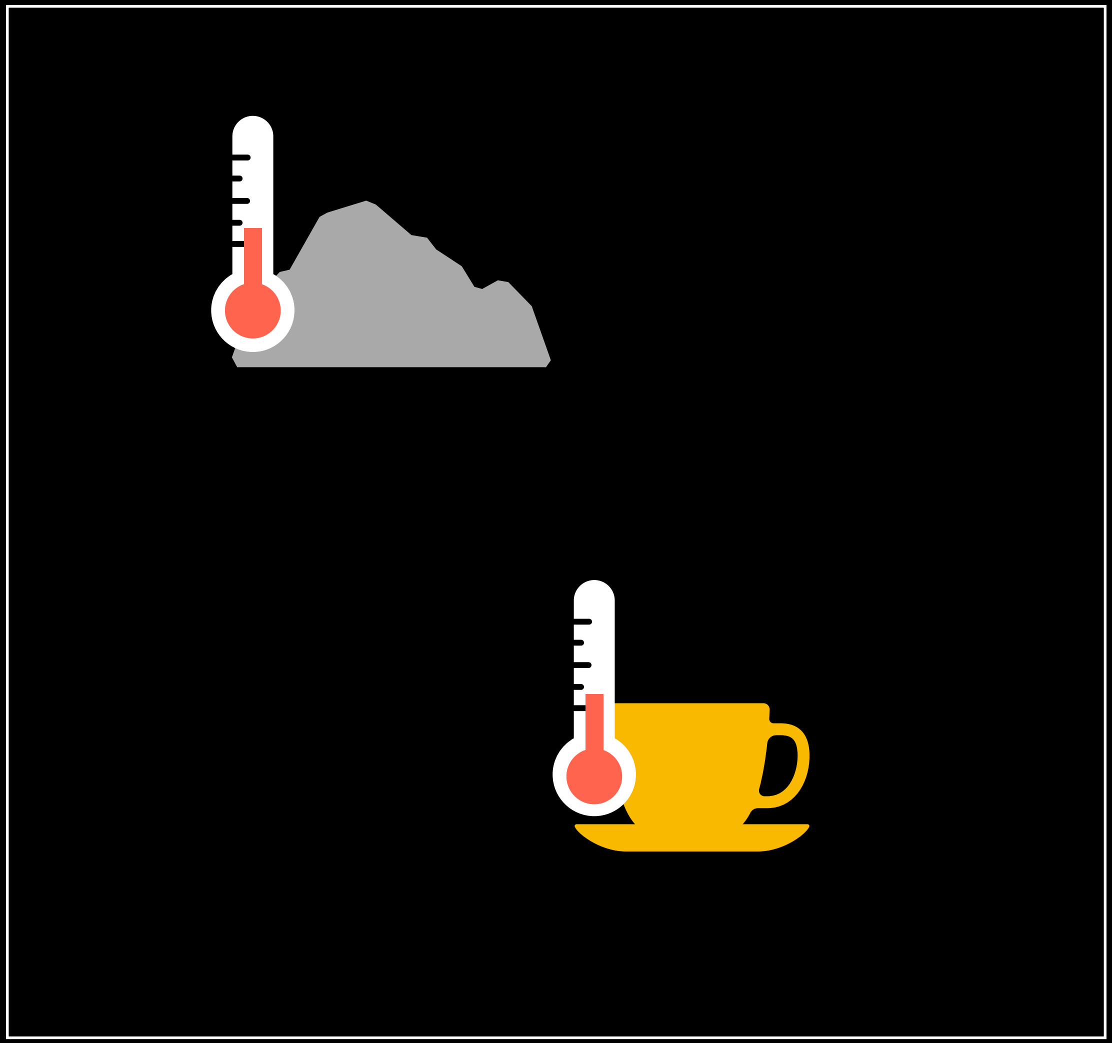


The thermometer has been critical for this observation to be made!

A piece of metal and feathers at the same temperature feel very different

Black's "equilibrium"

"I call it the equilibrium of heat.
Its nature was not well understood until I pointed out a method of investigating it."



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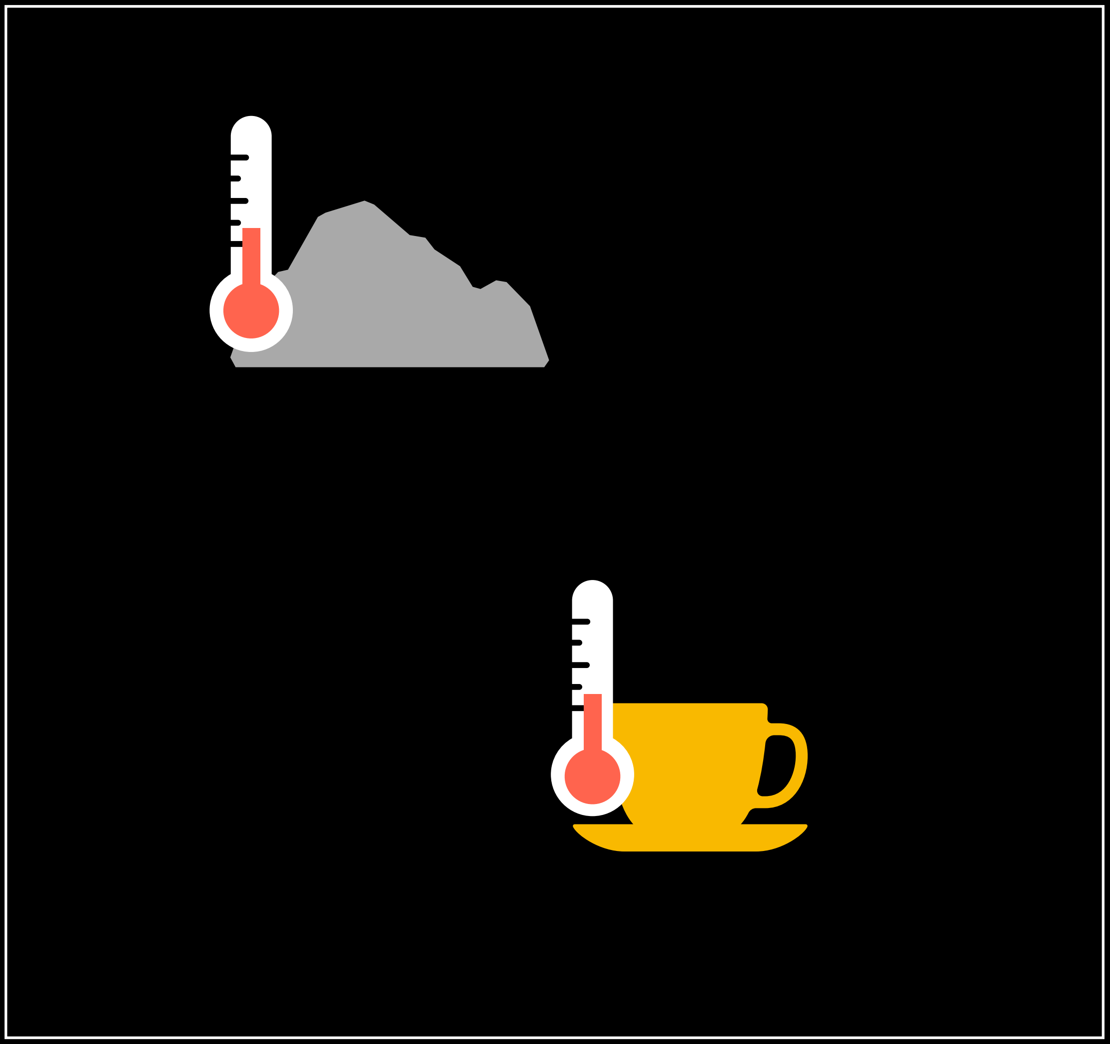

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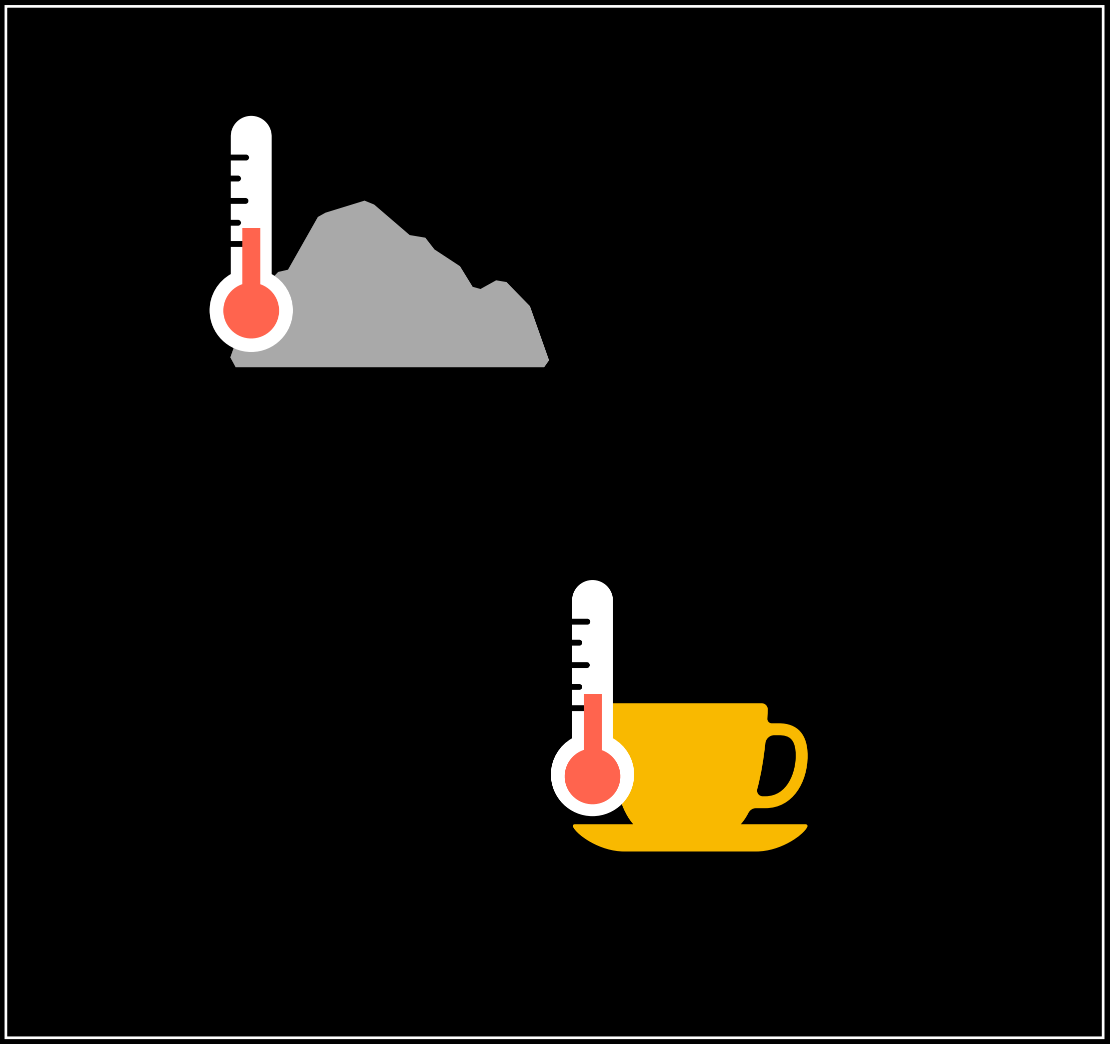

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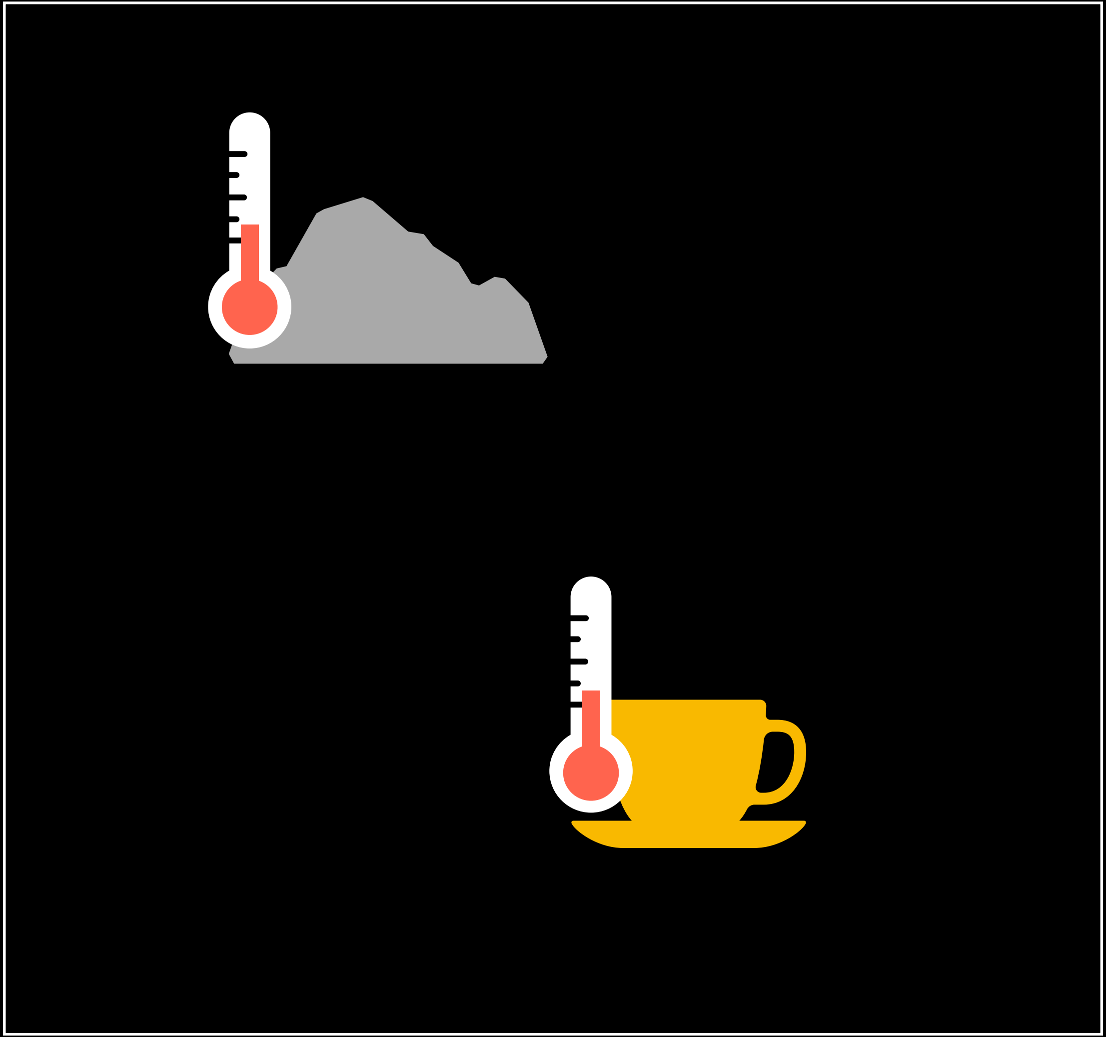

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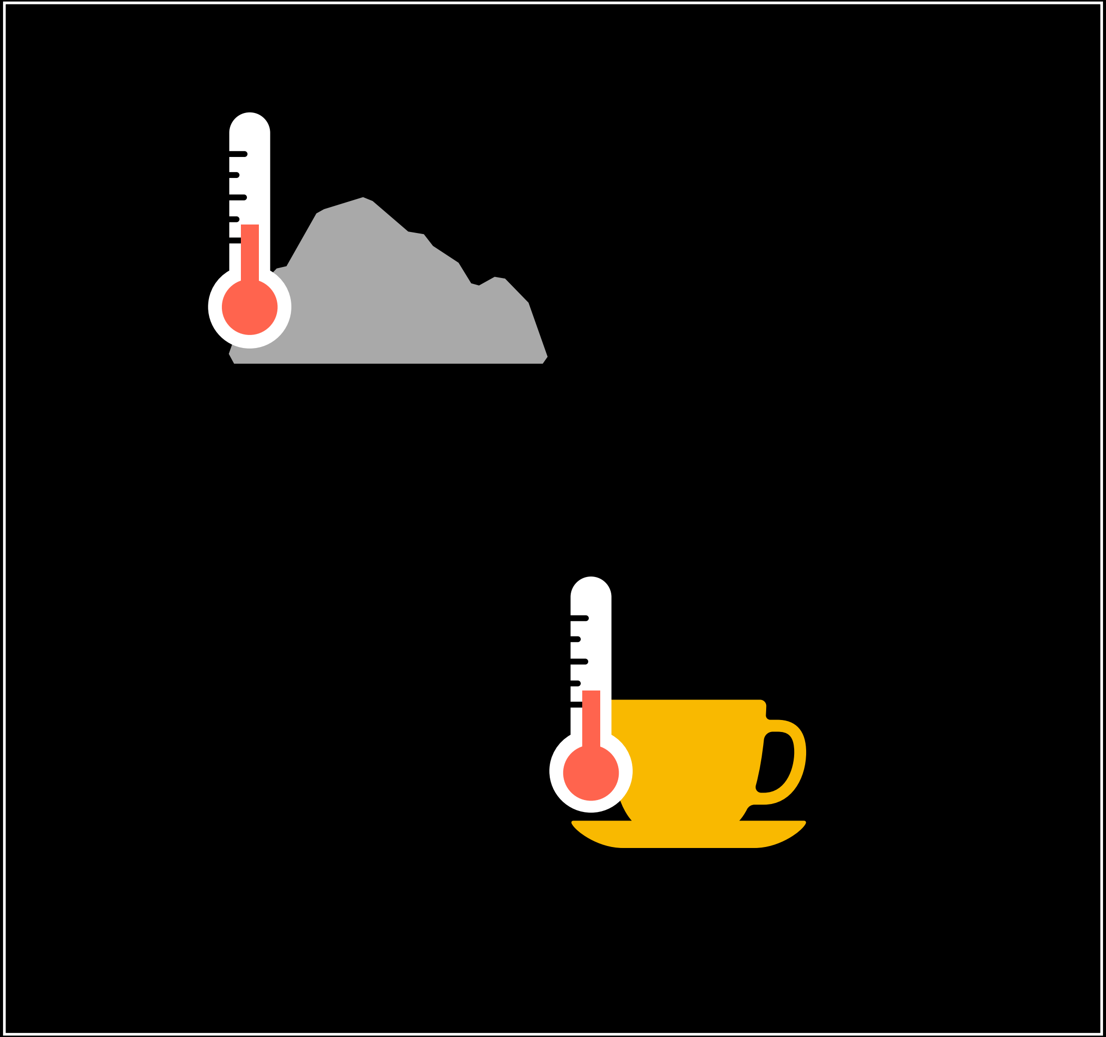

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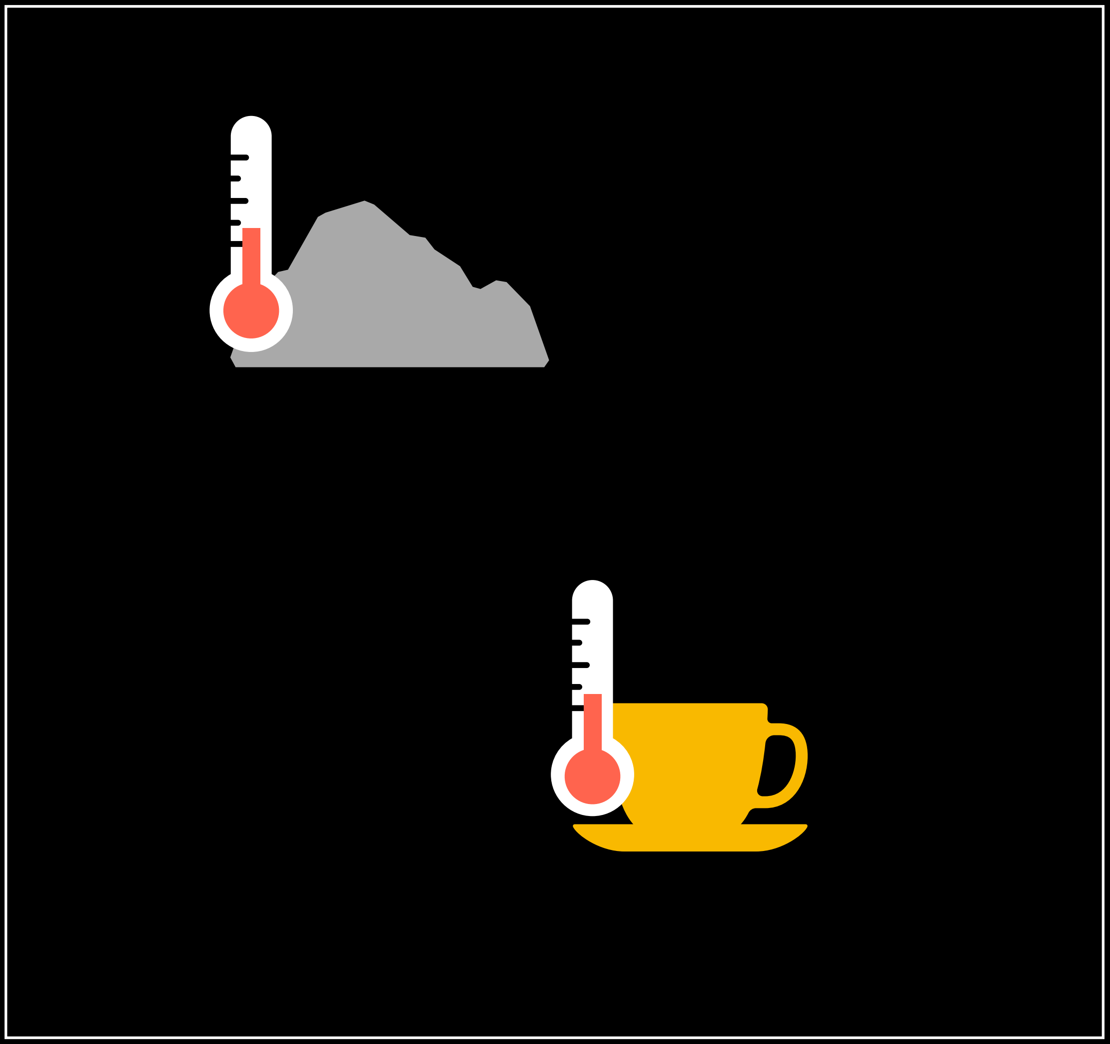
"The reason is that, to whichever of these bodies the thermometer be applied, it gives the same reading."



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"In equilibr
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however

"The reas
bodies the

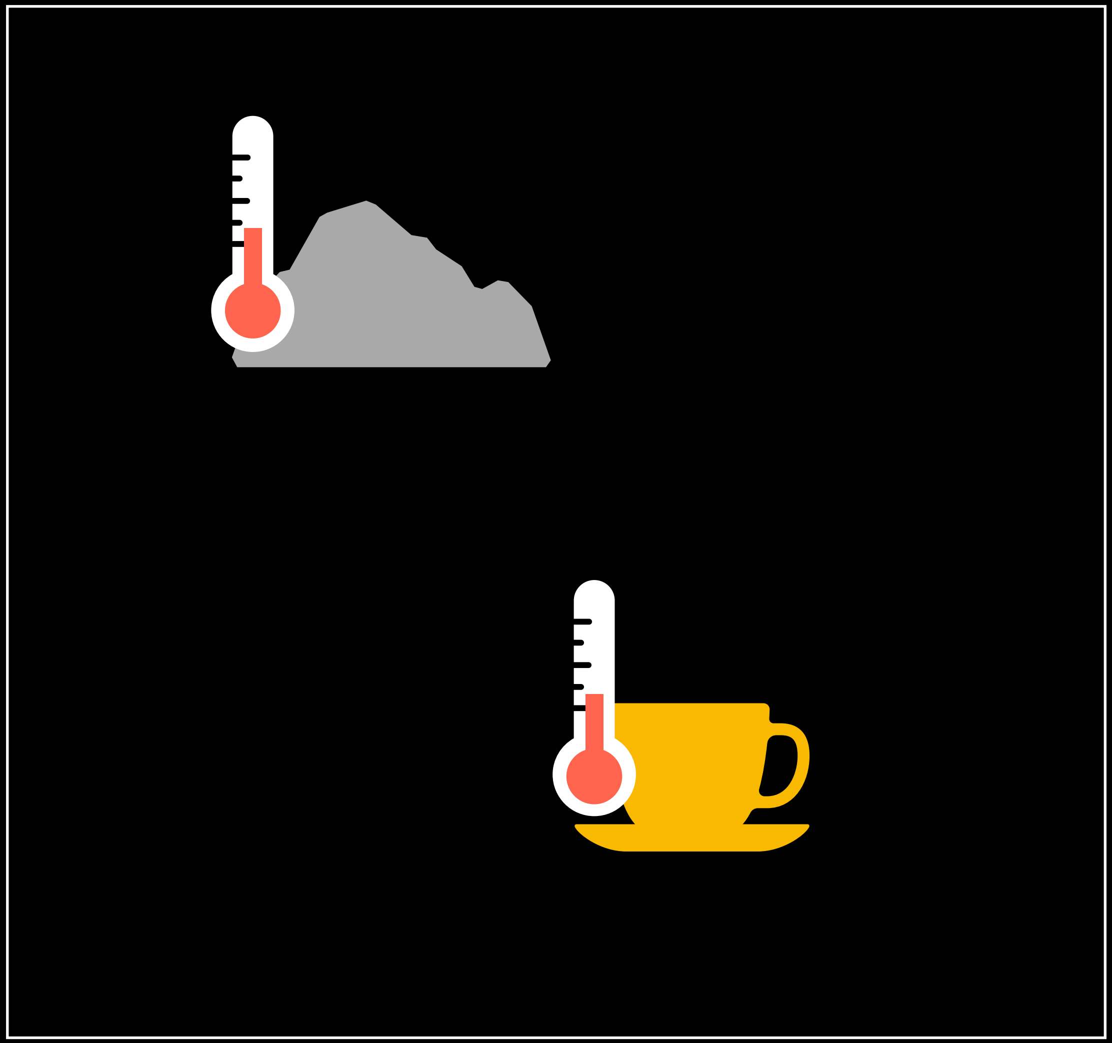
Herman Boerhaave

Dutch physician, chemist, and botanist
(1668–1738)

"Father of physiology" together with Santorio

Black's "equilibrium"

"But [Boerhaave] is taking a very hasty view of the subject."



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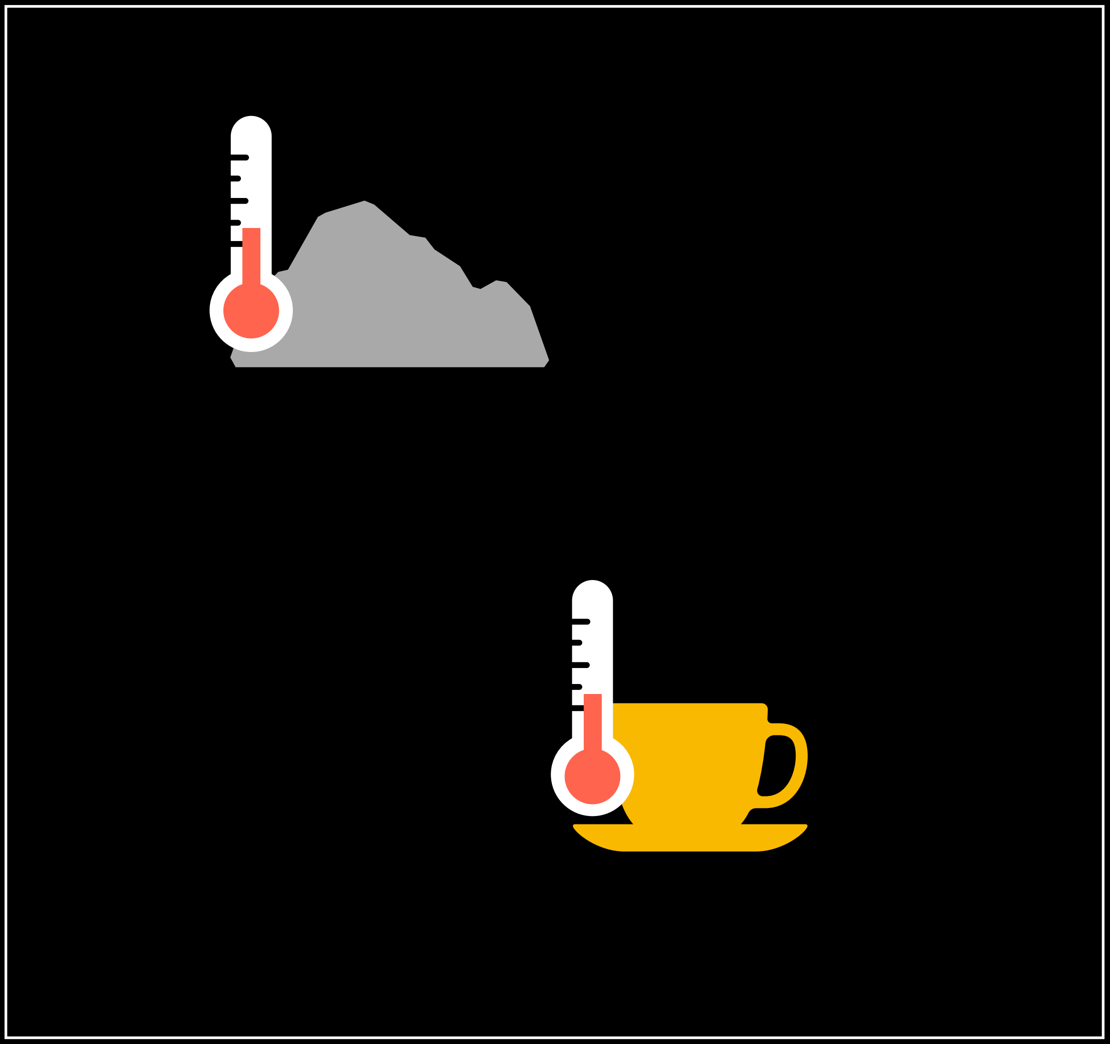
"But [Boerhaave] is taking a very hasty view of the subject."

"He is confounding the quantity of heat in different bodies with its intensity [temperature], though it is plain that these are two different things, and should always be distinguished."



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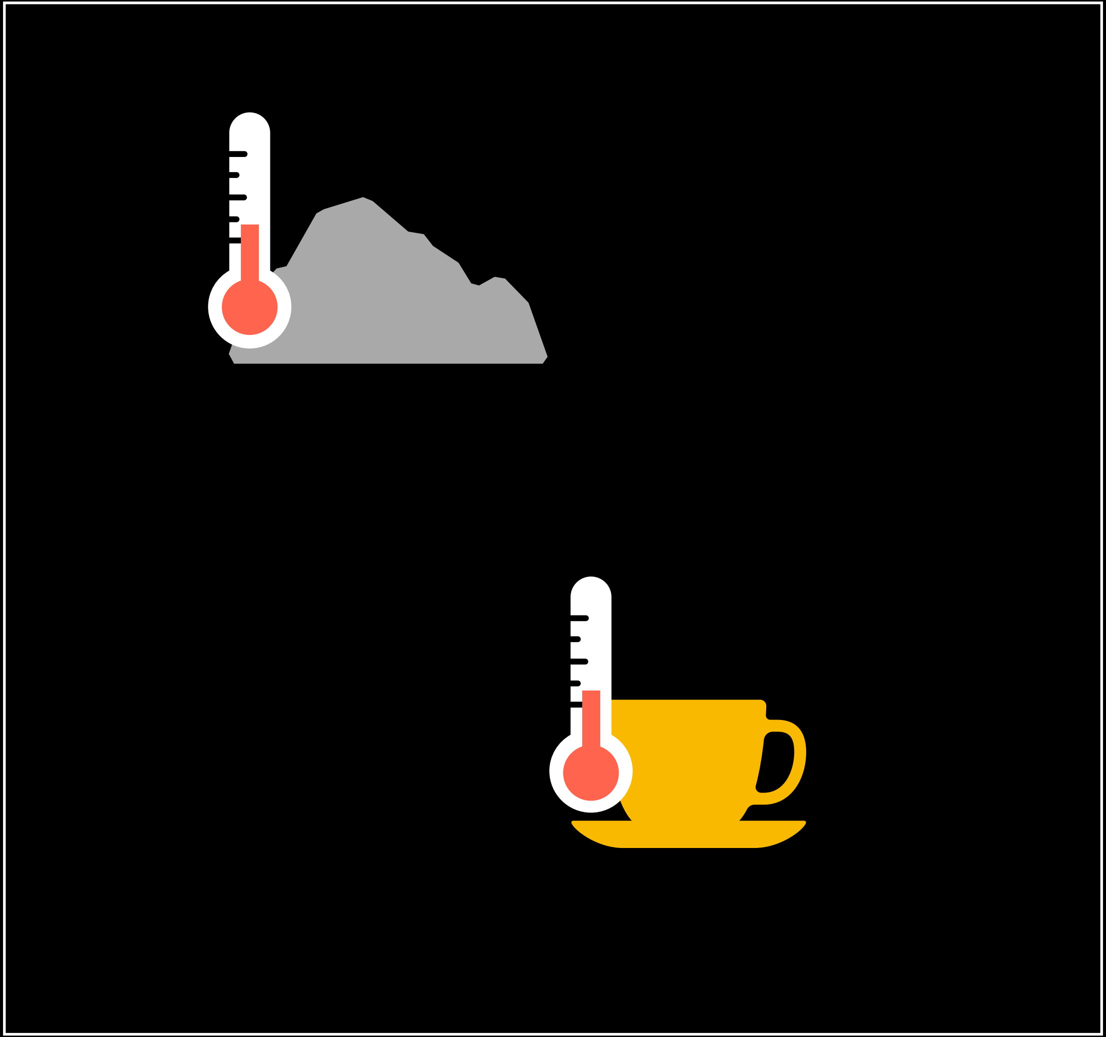

Is it really "plain"?

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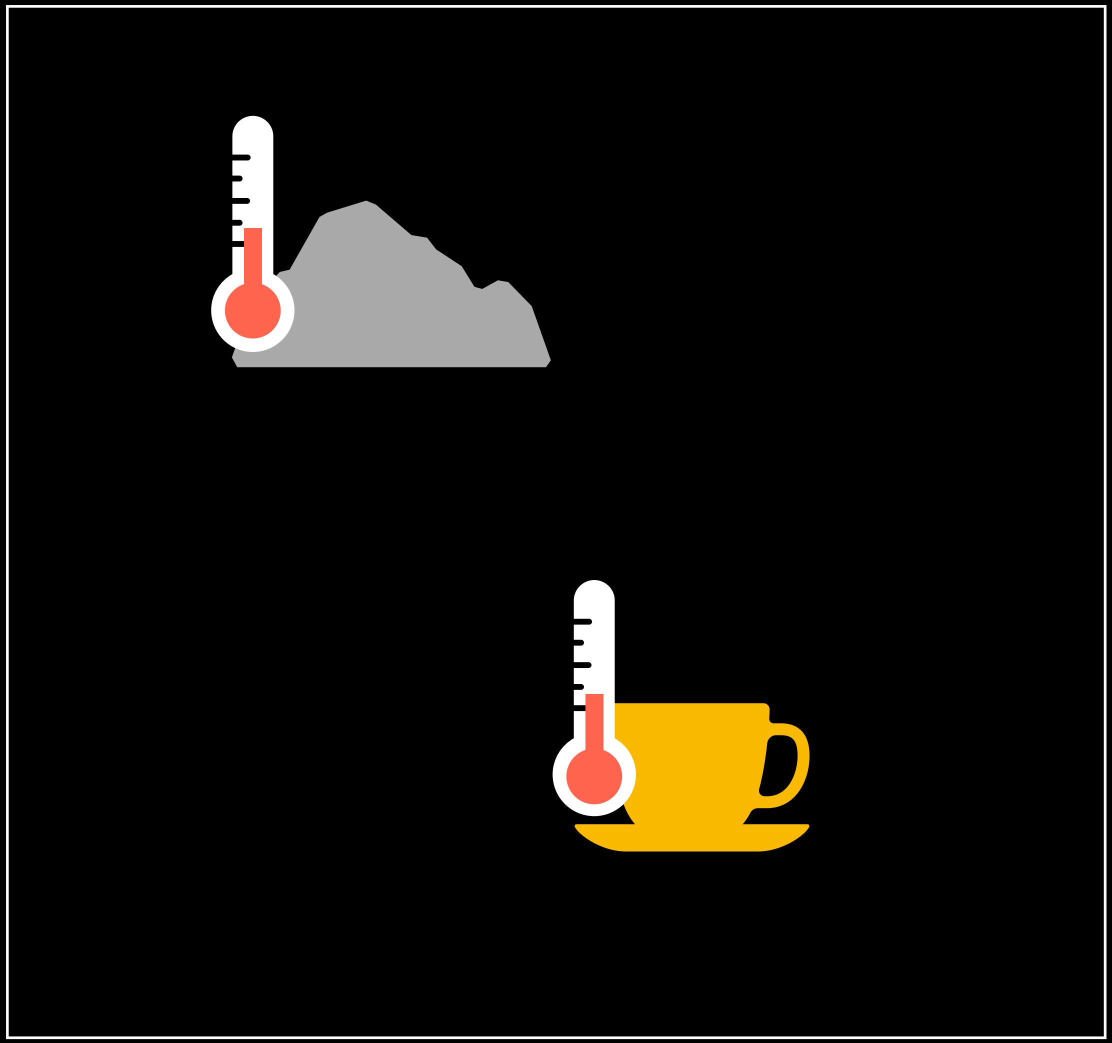

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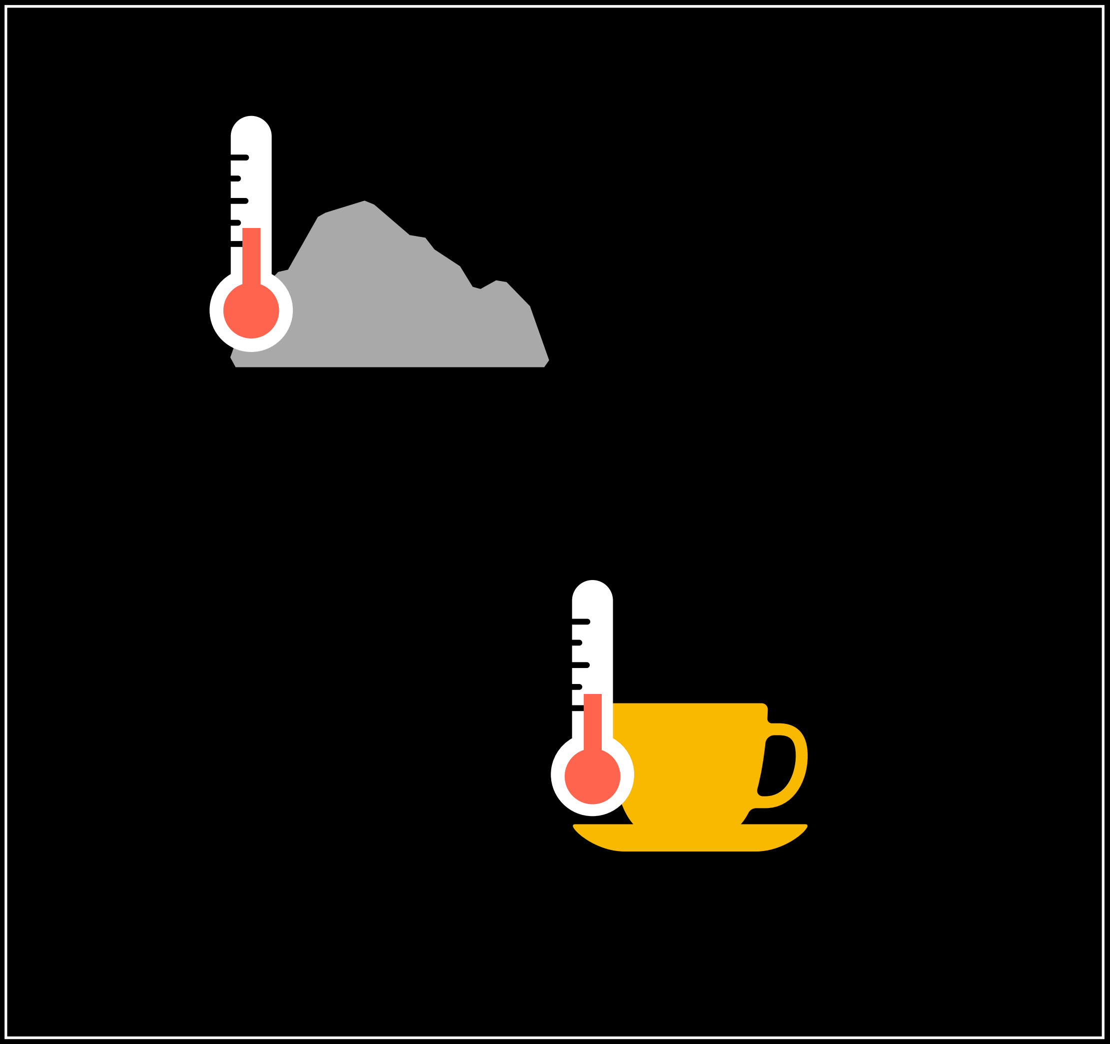


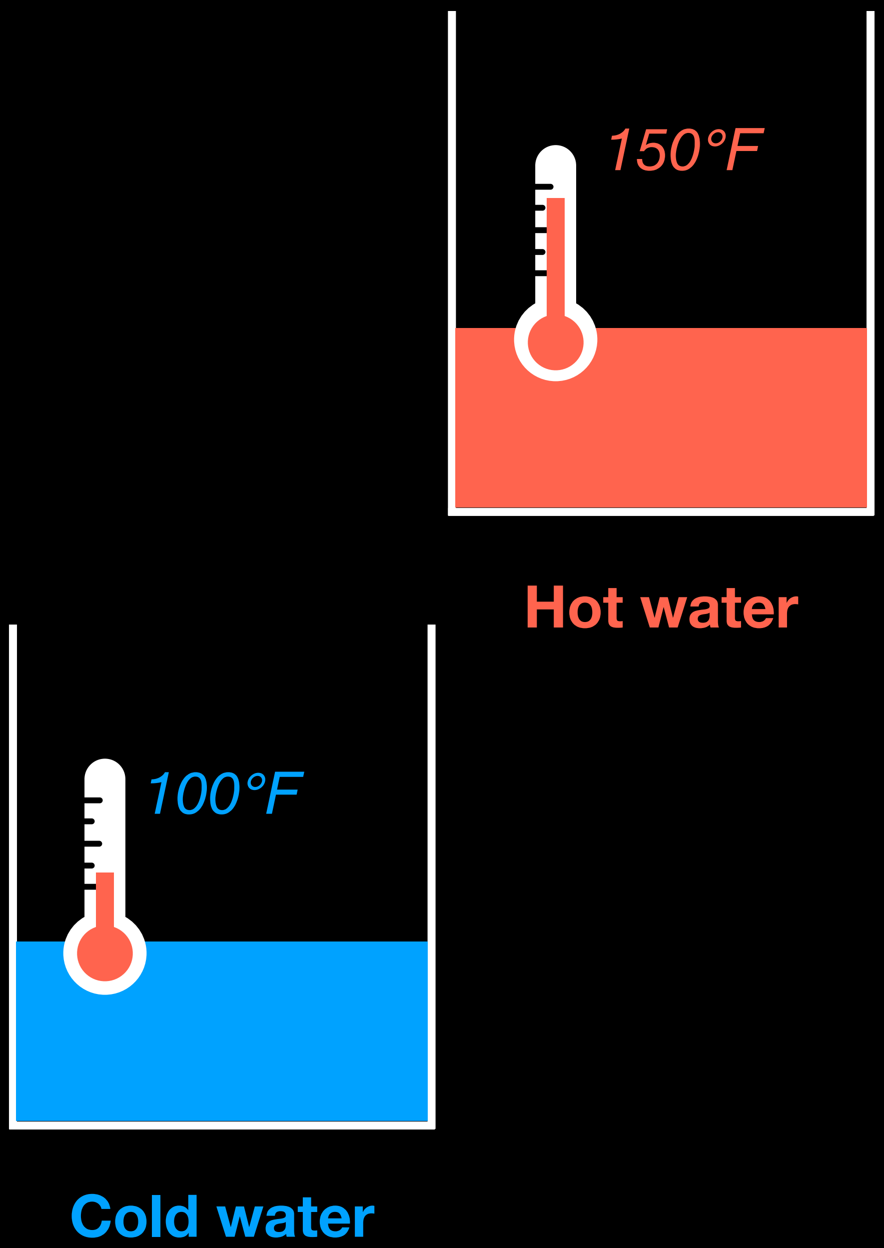
Is it really "plain"?

Temperature is measured by a thermometer, but ***heat*** flows between bodies.

Interpreting second-hand experiments

Experiment performed by Fahrenheit, described by Boerhaave, analyzed by Black

Mixing warm water with cold water



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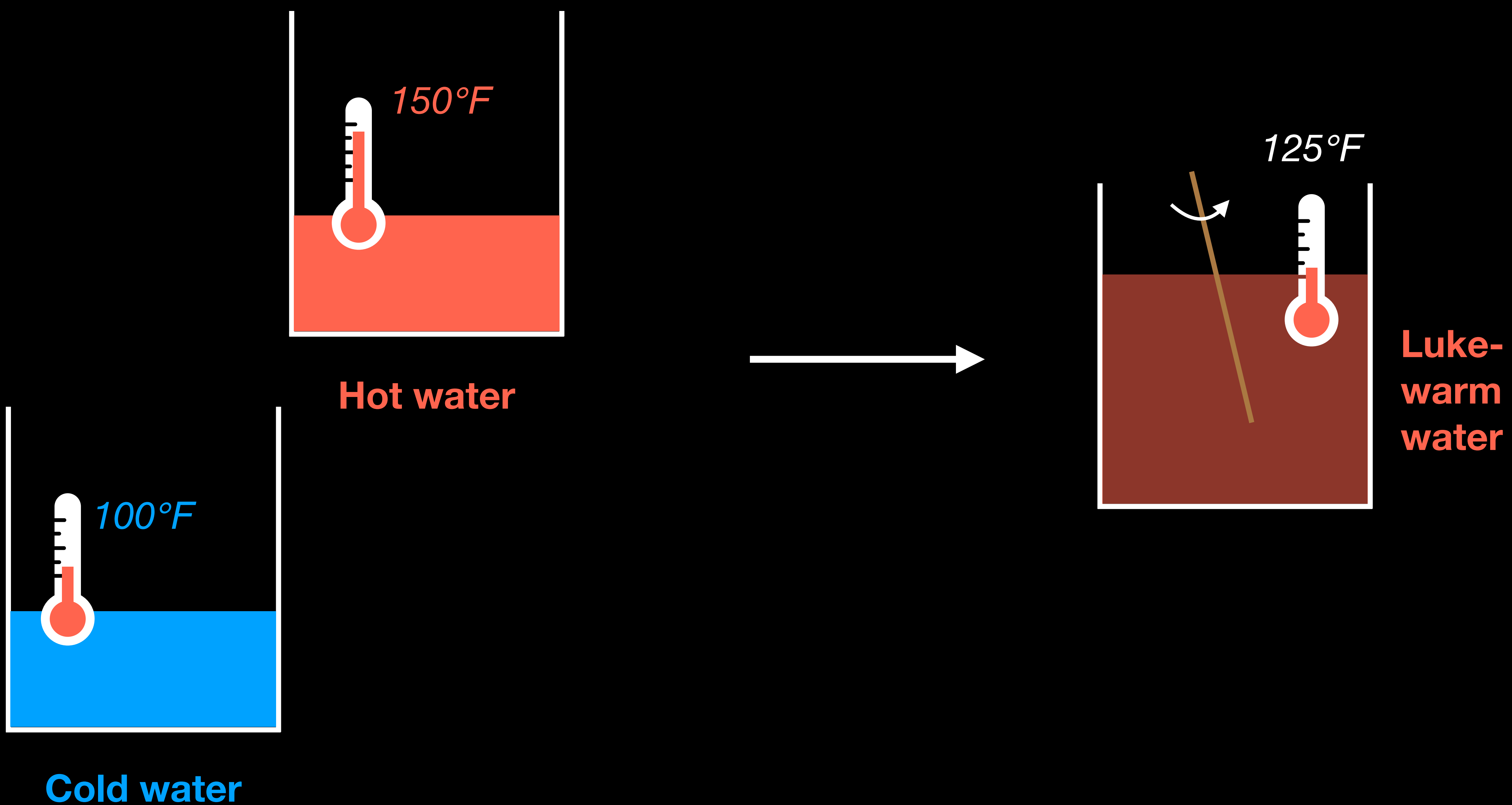

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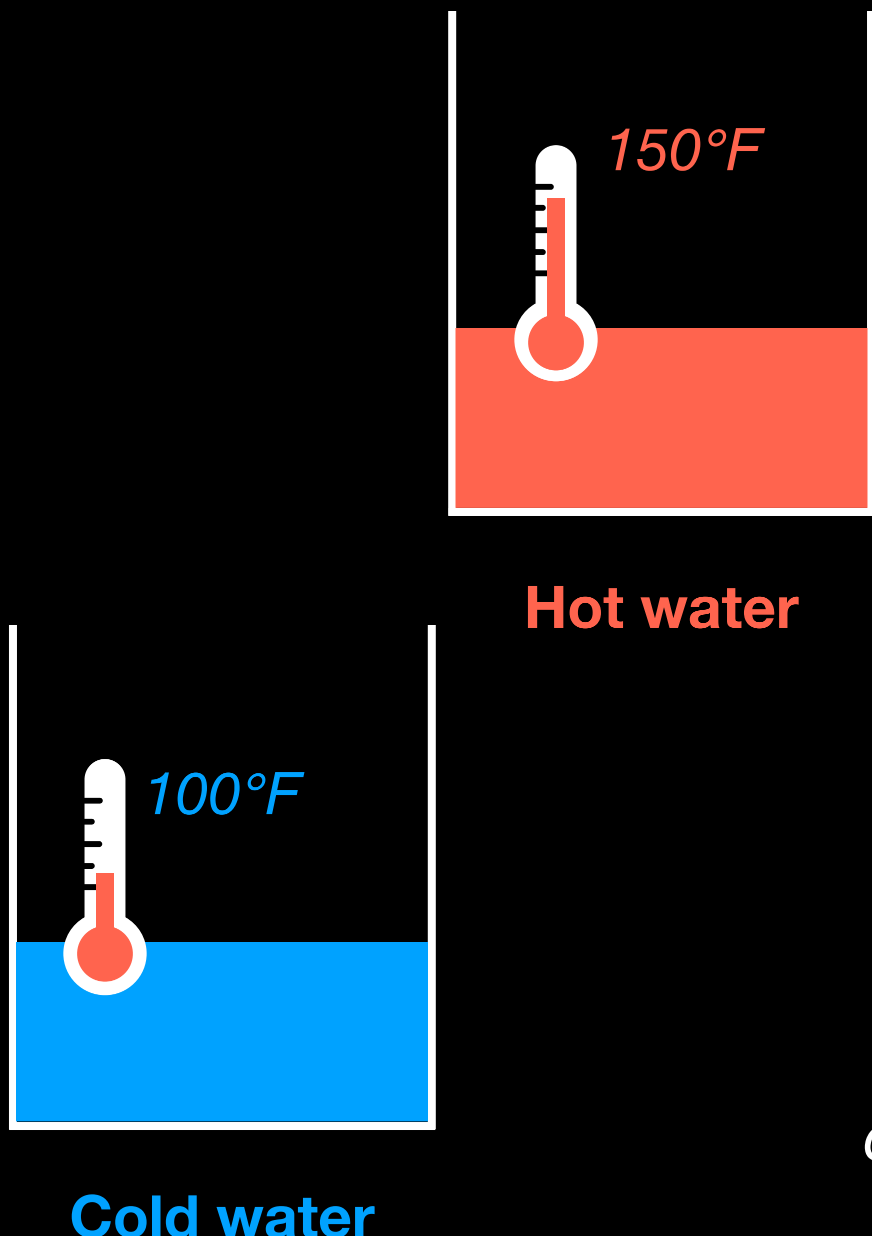
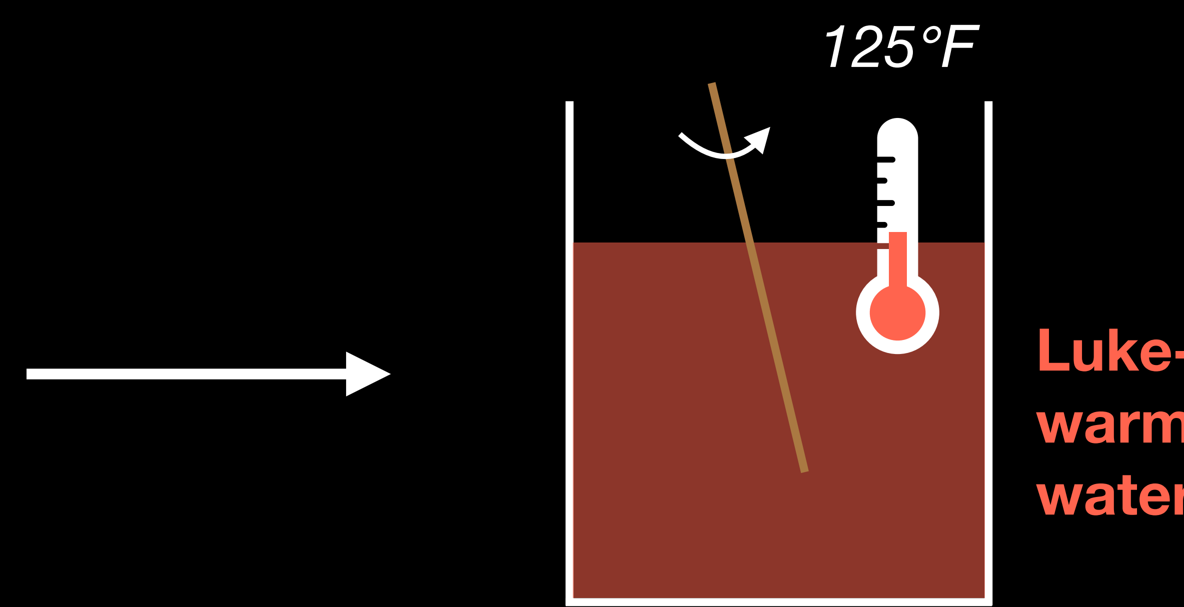


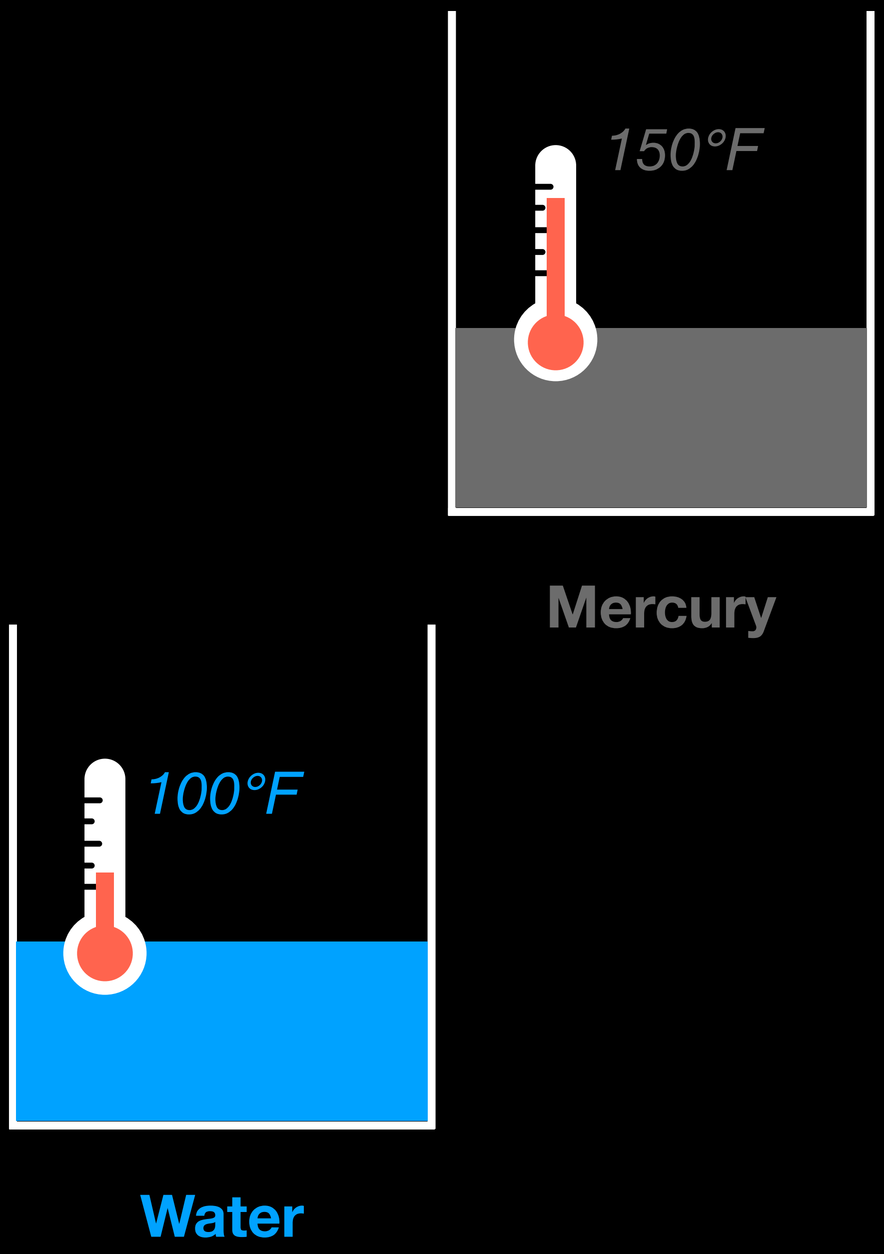


"The temperature of the warm water is lowered by 25 degrees while that of the cold is raised just as much."

Interpreting second-hand experiments

Experiment performed by Fahrenheit, described by Boerhaave, analyzed by Black

Mixing warm mercury with cold water



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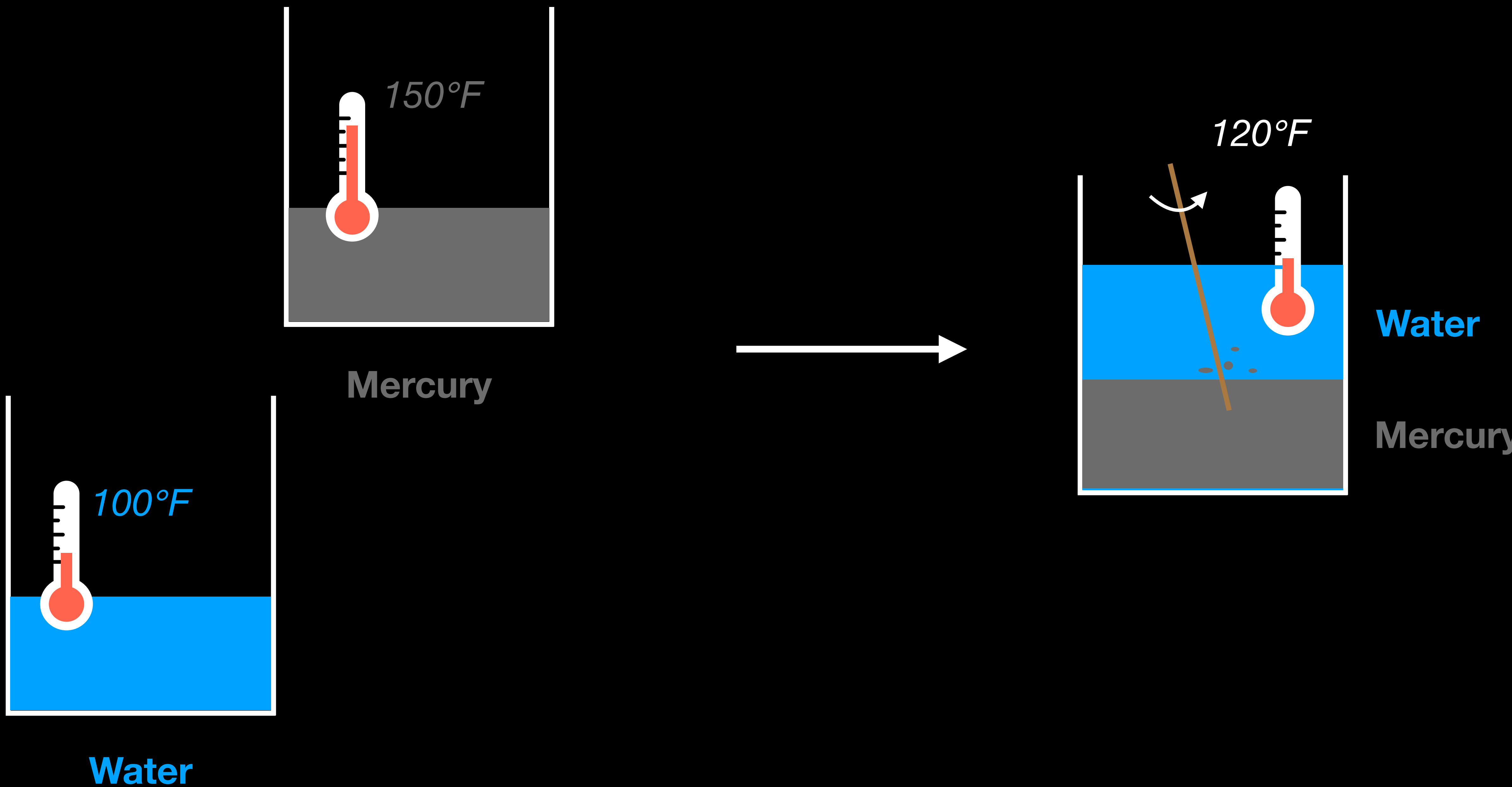

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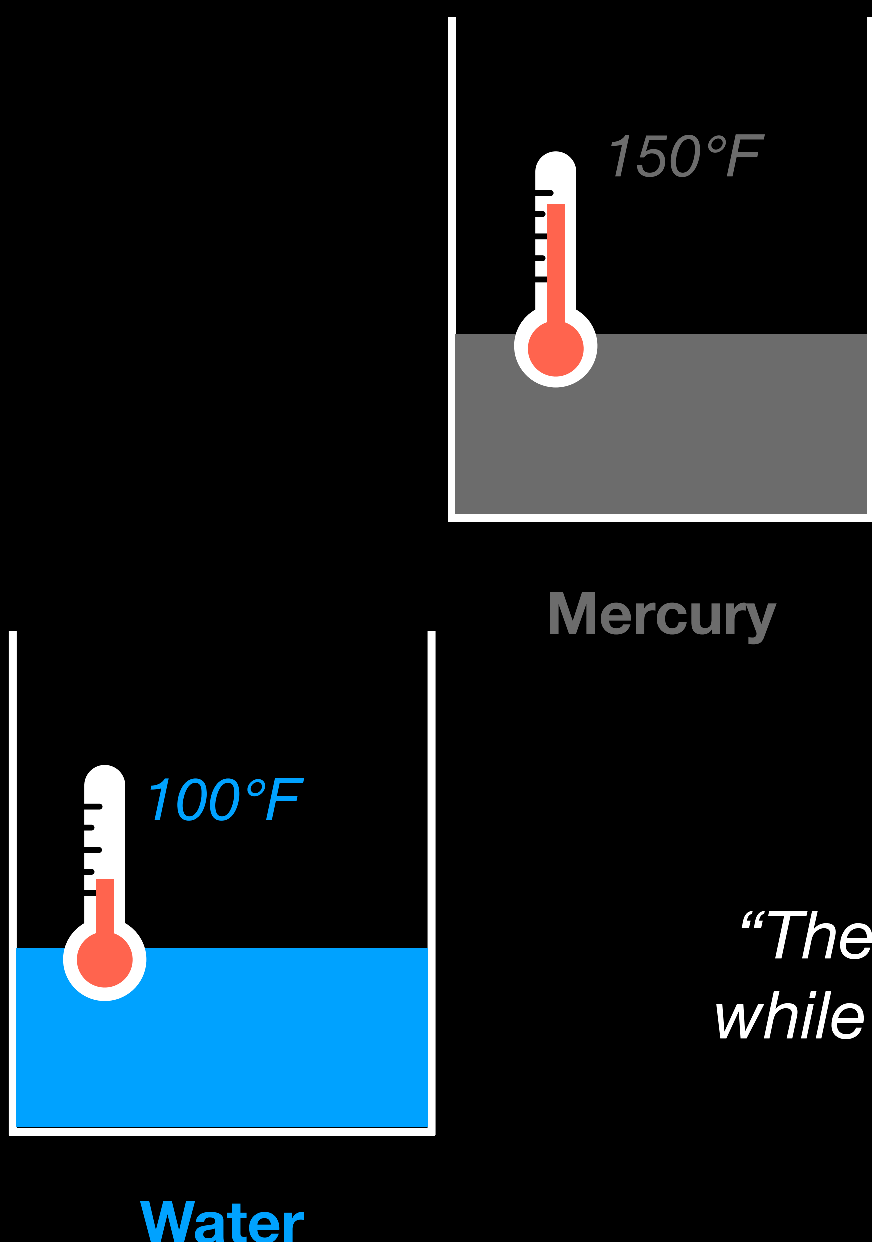

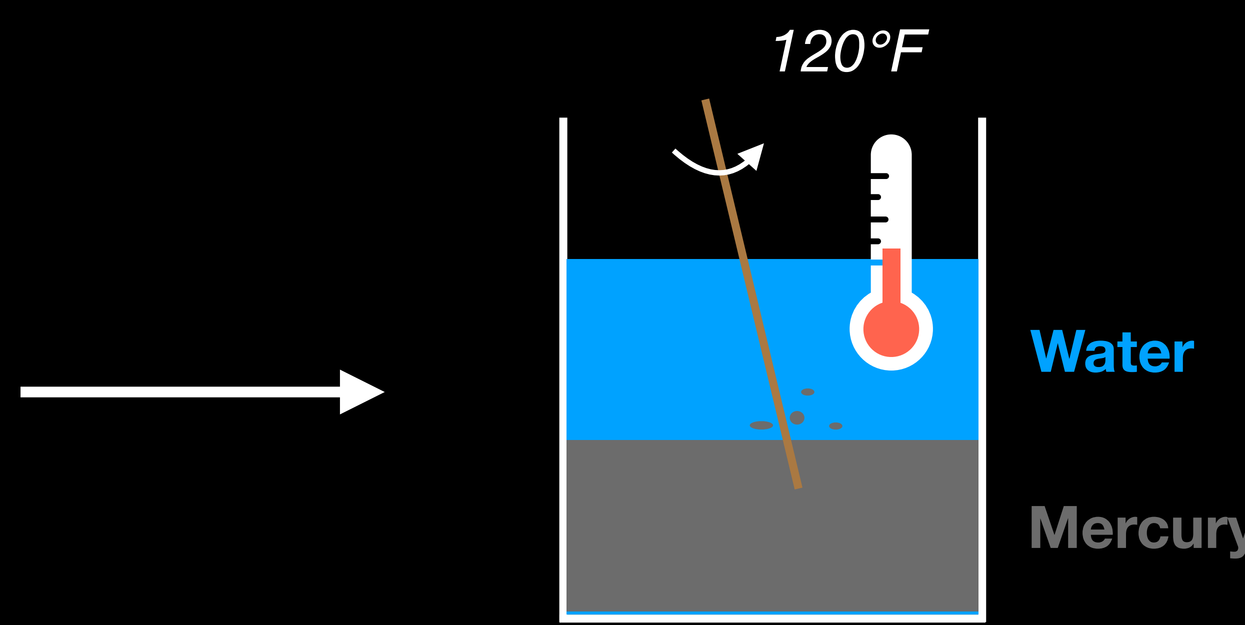

"The quicksilver, therefore, has cooled through 30 degrees, while the water has become warmer by 20 degrees only …"

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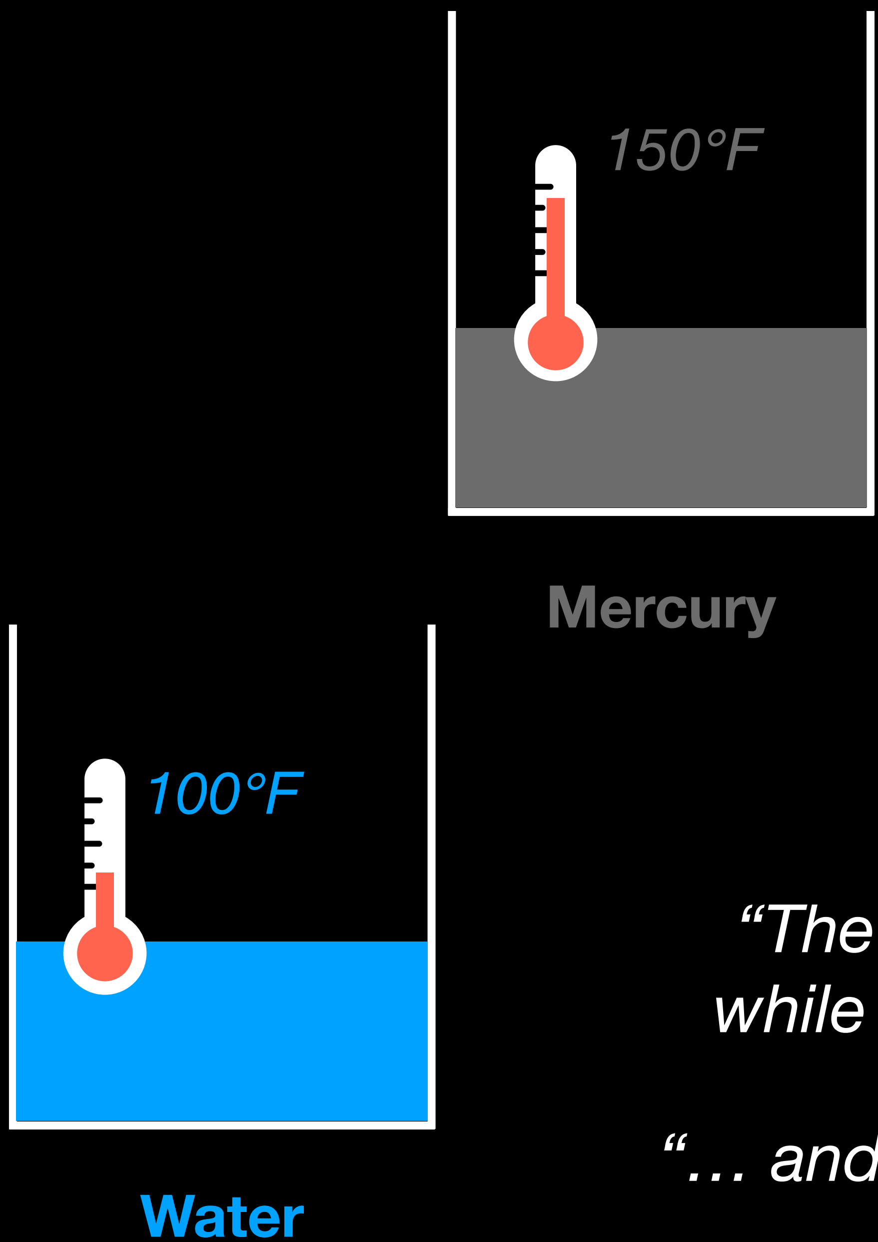
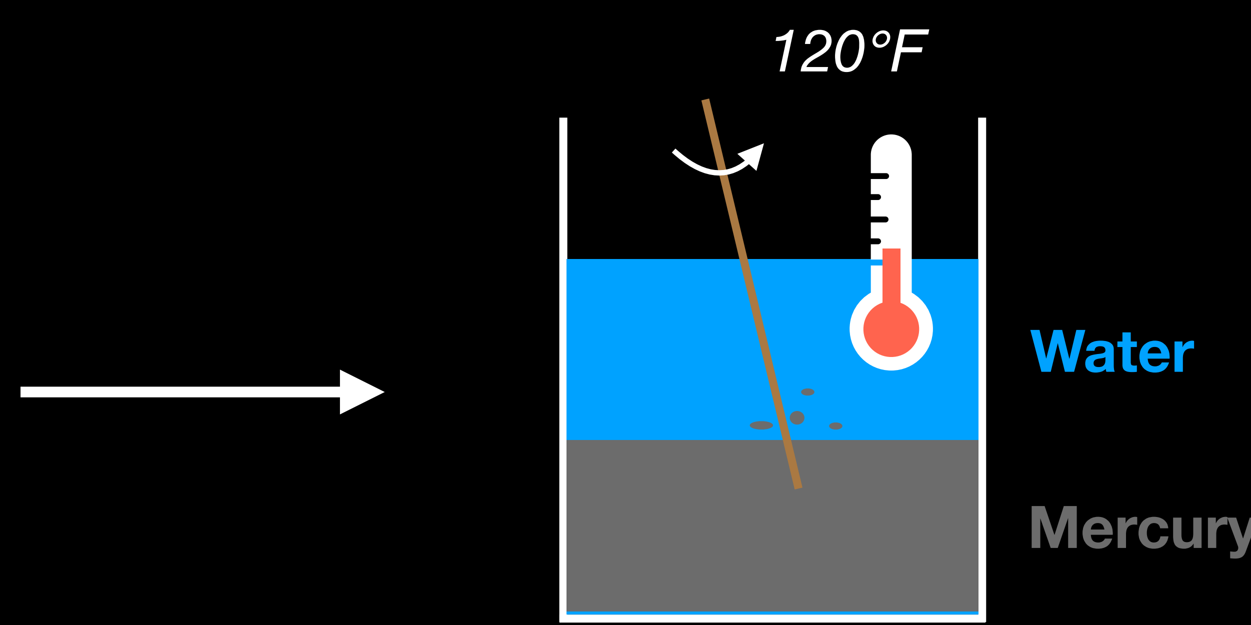




"The quicksilver, therefore, has cooled through 30 degrees, while the water has become warmer by 20 degrees only …"

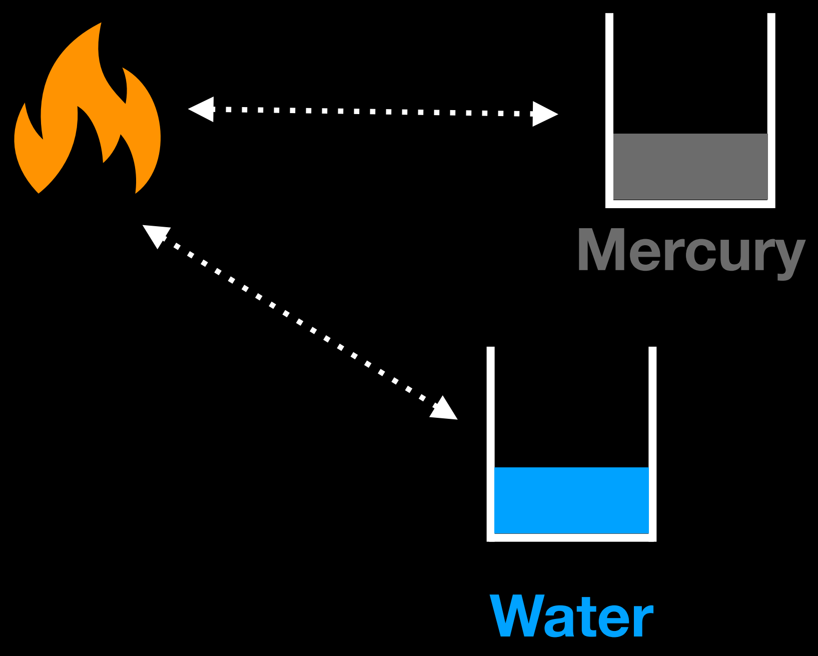
"… and yet the quantity of heat which the water has gained is the very same as that which the quicksilver has lost."

Interpreting second-hand experiments

Interpreting second-hand experiments

Experiment performed by Dr. Martine, analyzed by Black

"Dr. Martine found that the quicksilver was warmed by the fire almost twice as fast as the water."



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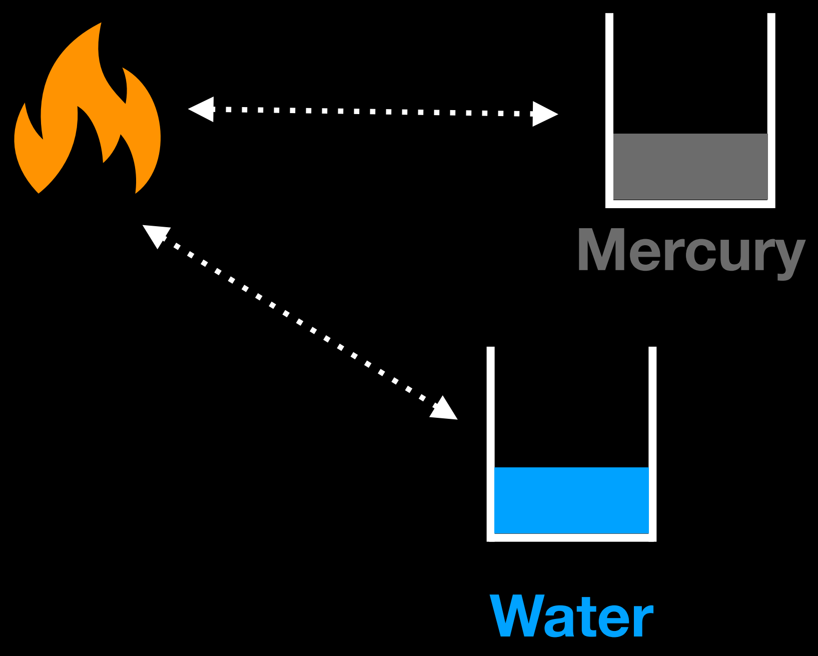

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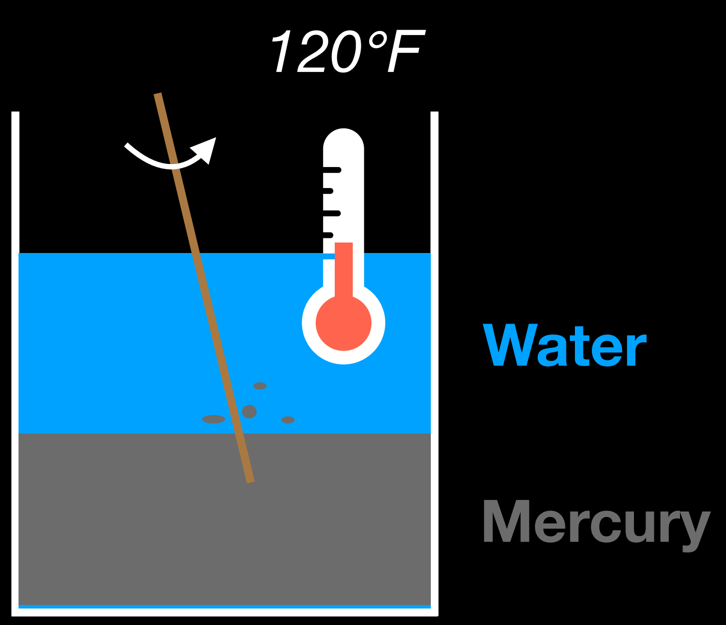

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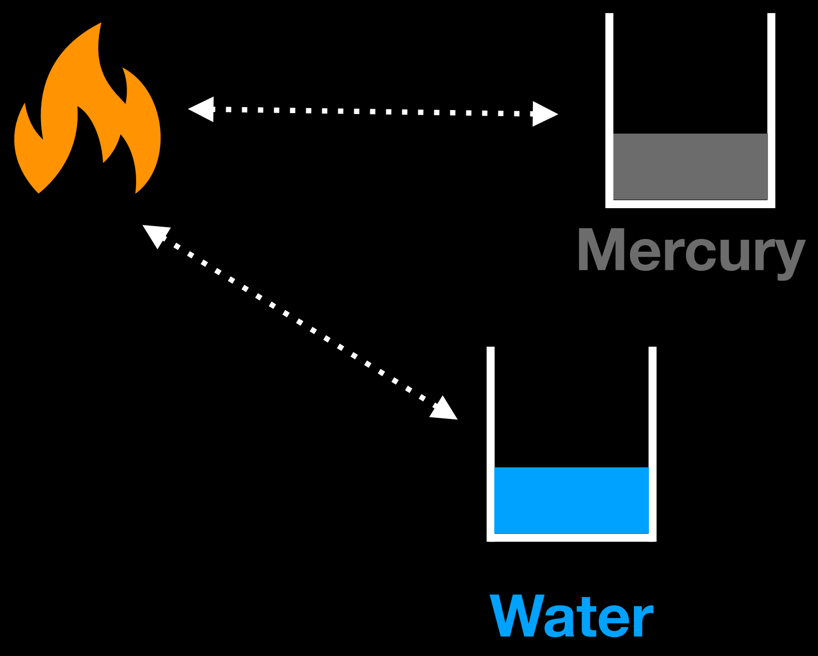

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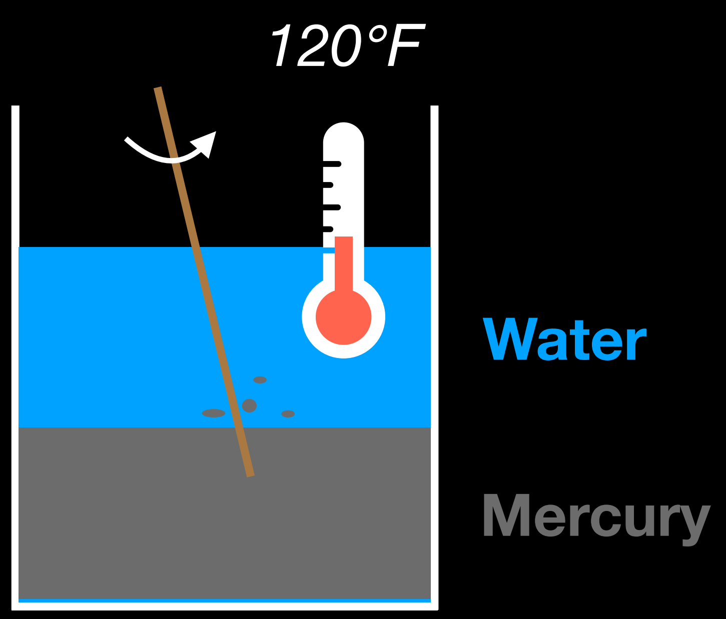

"The quicksilver, therefore, has cooled through 30 degrees, while the water has become warmer by 20 degrees only …"

Mercury reacts "faster" to heat!

Interpreting second-hand experiments

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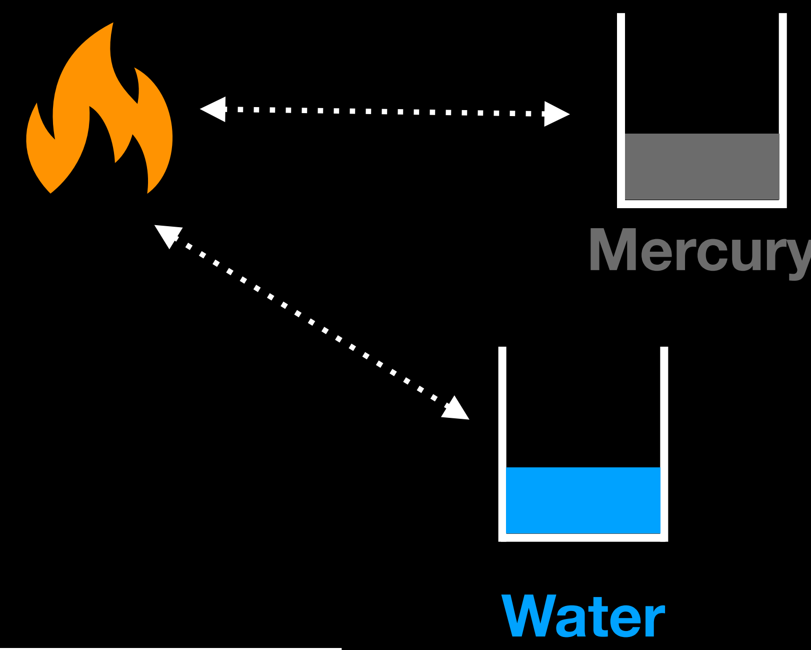

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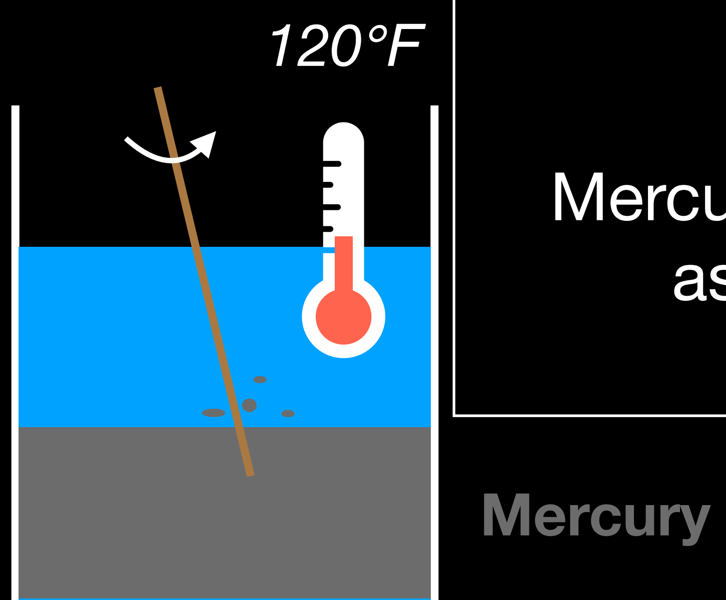


This is not obvious!

Mercury weighs 13-14 times as much as the same volume of water!

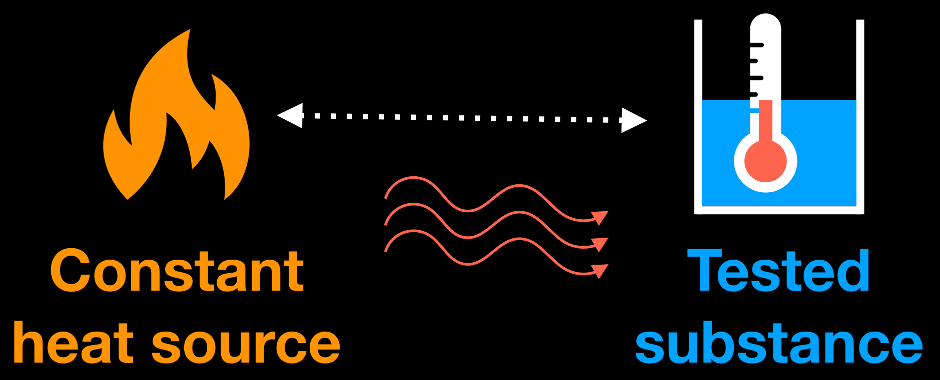
s cooled through
as become warmer
by 20 degrees only …”

Mercury reacts “faster” to heat!

Black's "capacity for heat"

1) Expose tested substance to constant heat source

2) Measure time needed to produce a certain temperature increase



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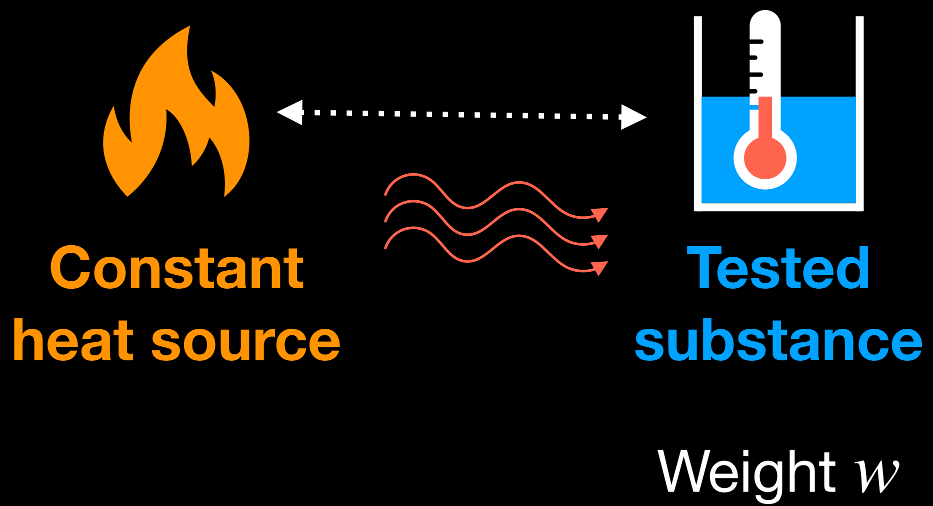

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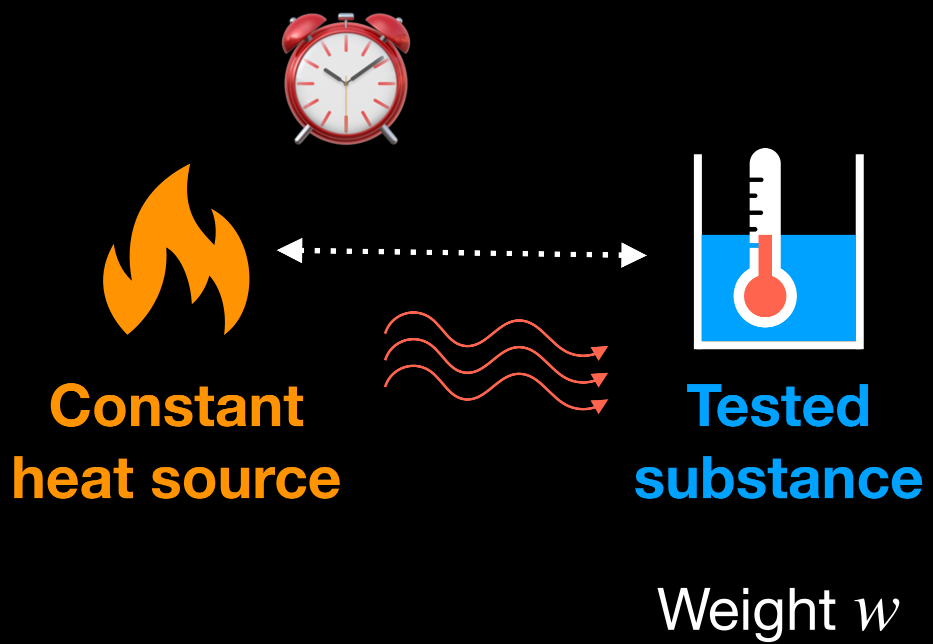

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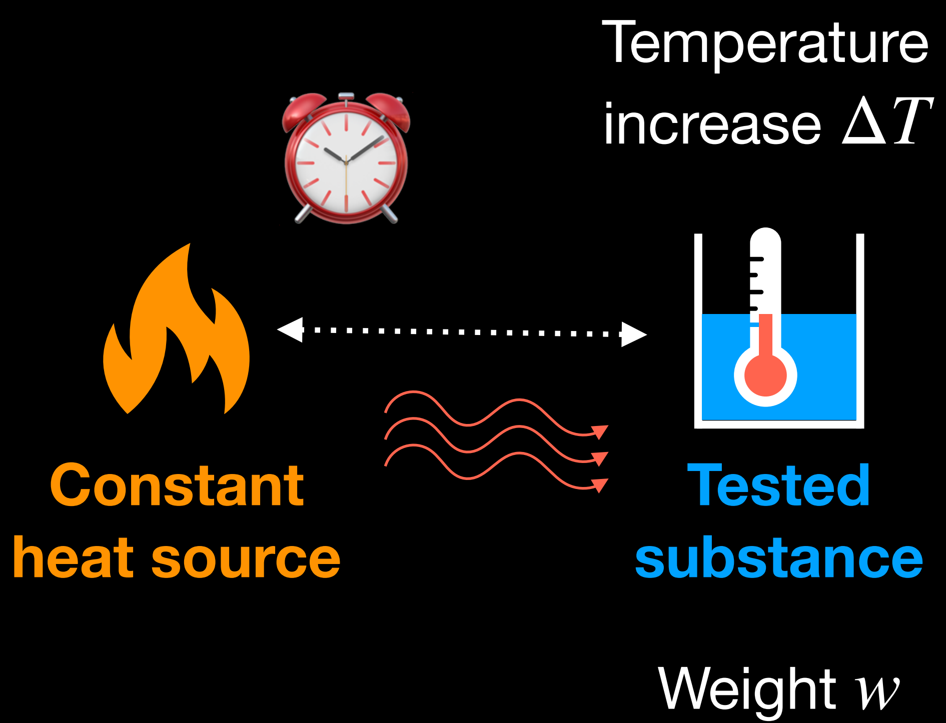

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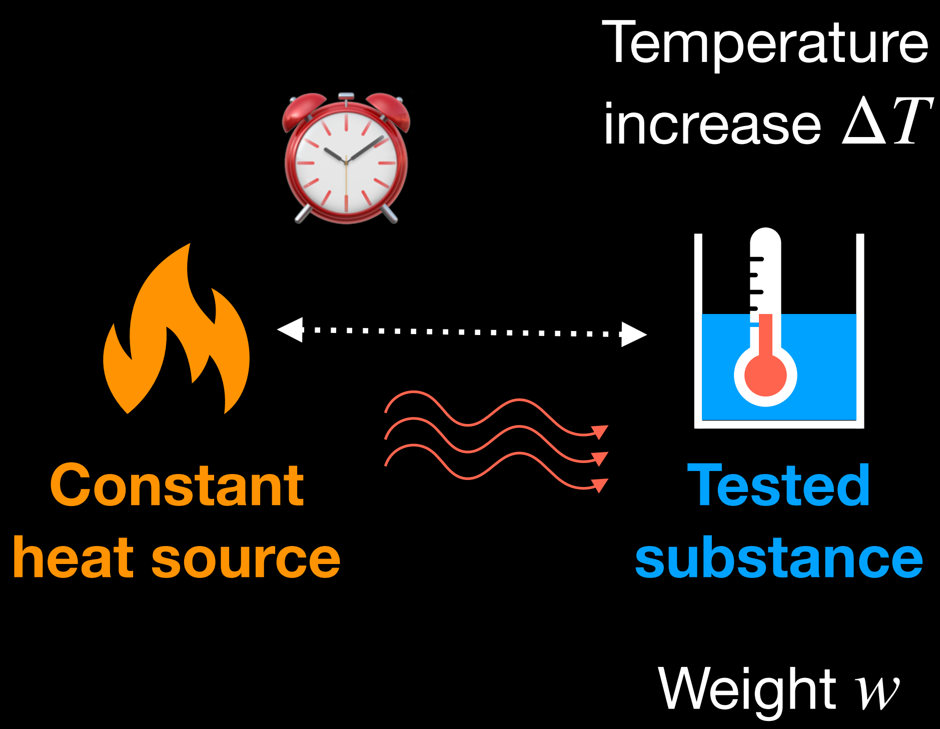

$$H \propto \quad w \cdot \Delta T$$

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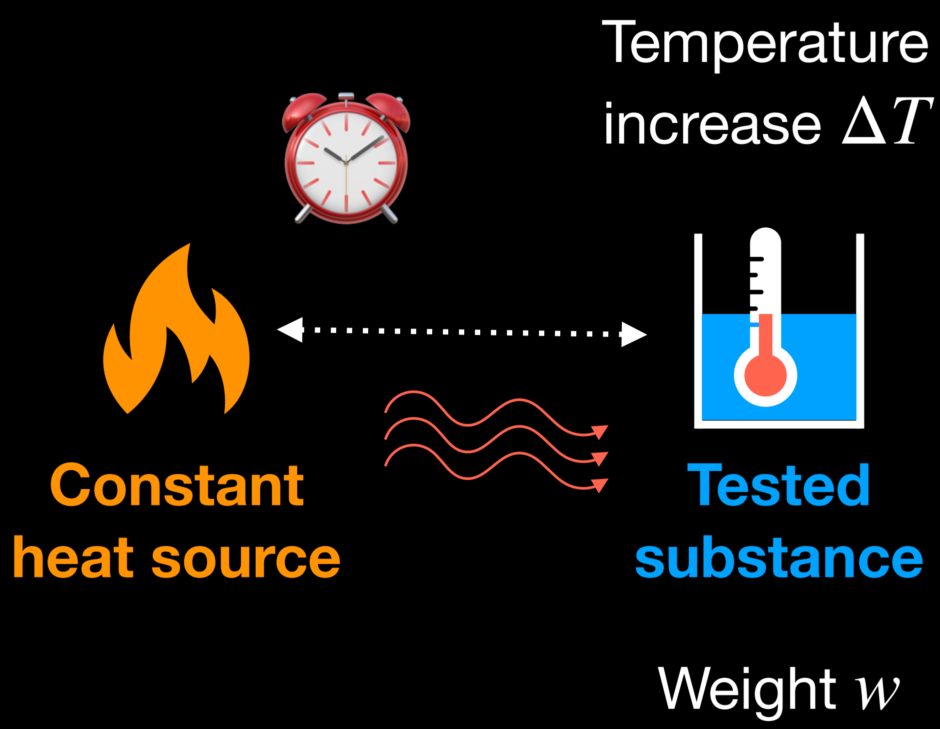

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"Sensible heat" provided

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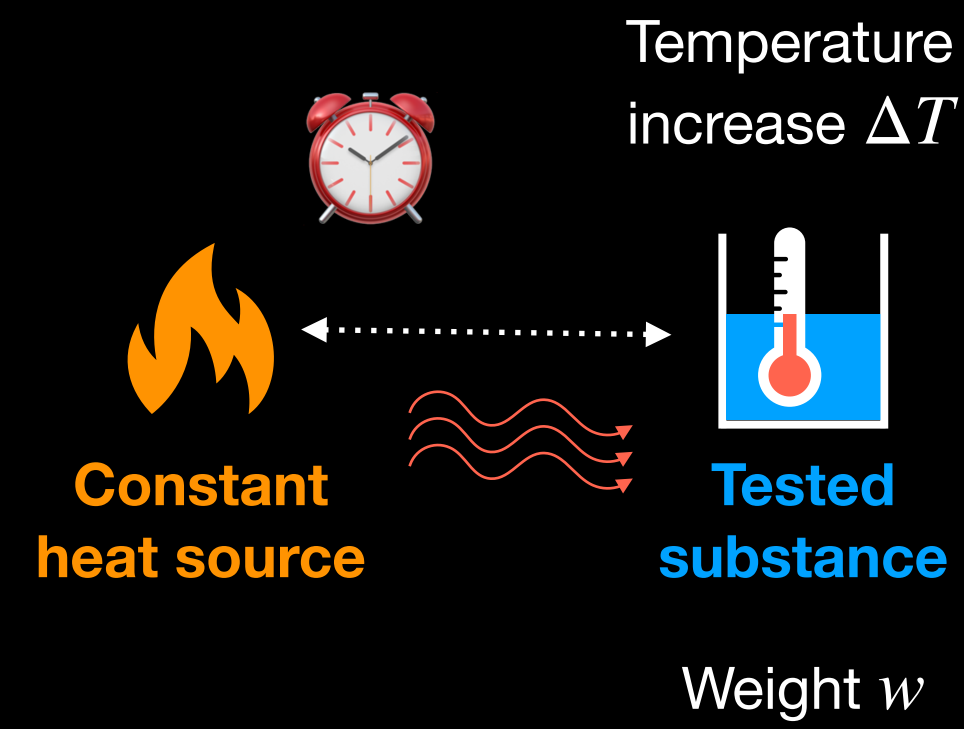

$$H \propto w \cdot \Delta T$$

"Sensible heat" provided

Weight of tested substance

Black's "capacity for heat"

1) Expose tested substance to constant heat source

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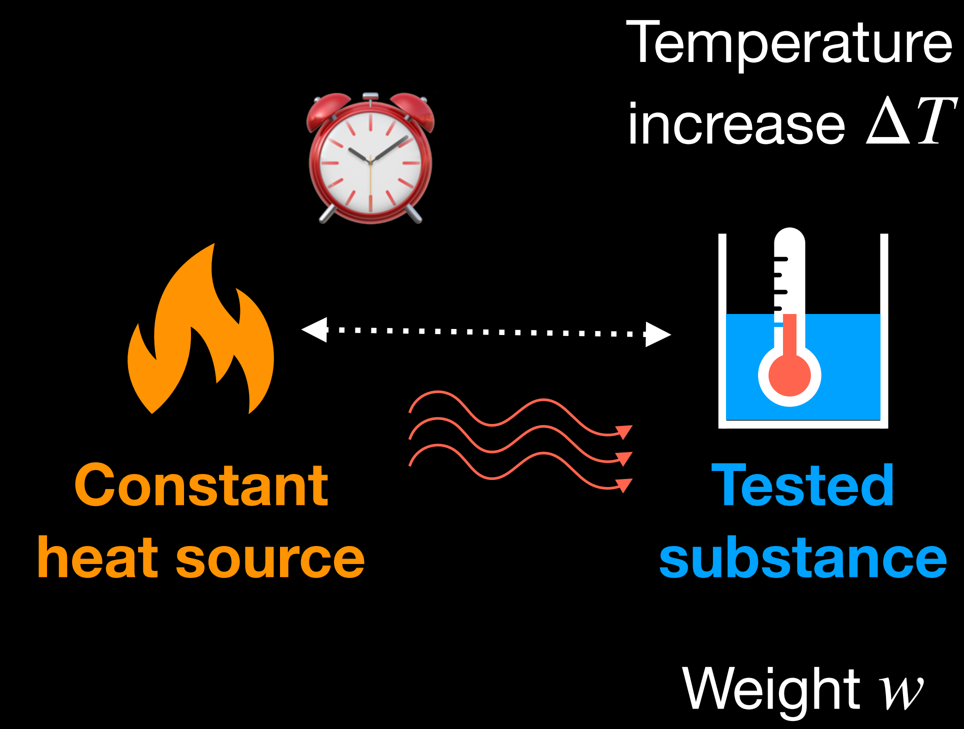

$$H \propto w \cdot \Delta T$$

"Sensible heat" provided → H

Weight of tested substance → w

Rise in temperature → ΔT

Black's "capacity for heat"

1) Expose tested substance to constant heat source

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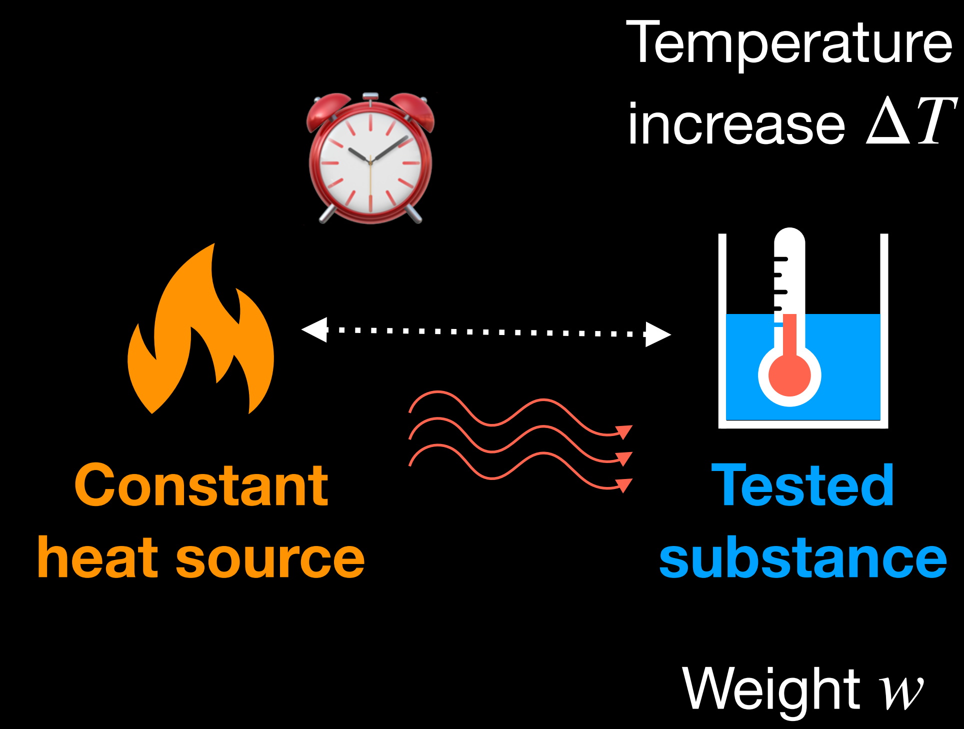


$$H \propto w \cdot \Delta T$$

"Sensible heat" provided

Weight of tested substance

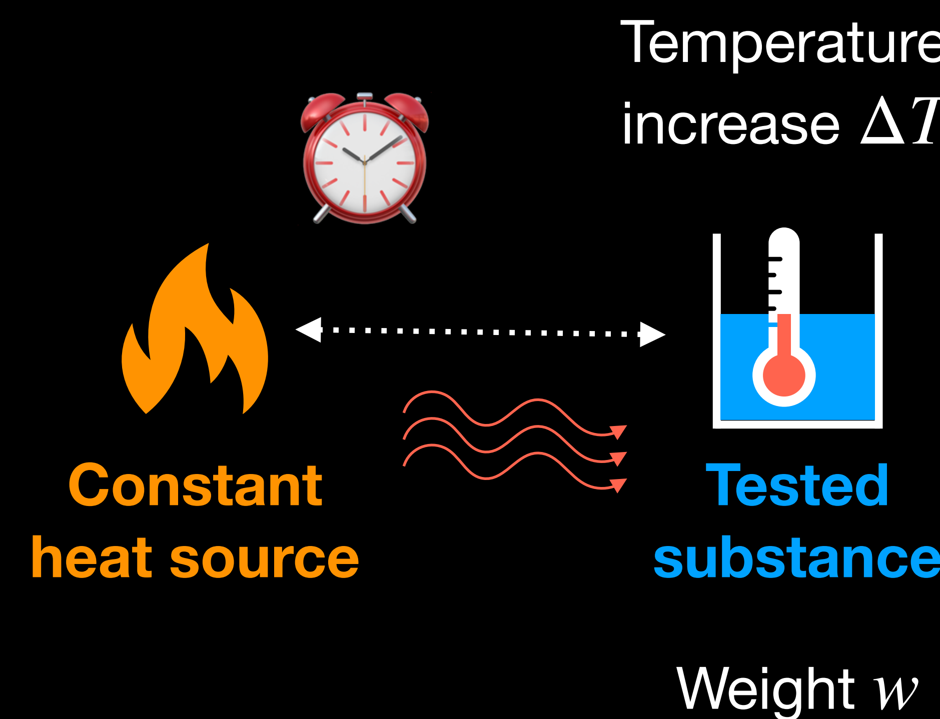
Rise in temperature

"Heating twice as much material takes twice the heat"

Black's "capacity for heat"

1) Expose tested substance to constant heat source

2) Measure time needed to produce a certain temperature increase



$$H \propto w \cdot \Delta T$$

"Sensible heat" provided

Weight of tested substance

Rise in temperature

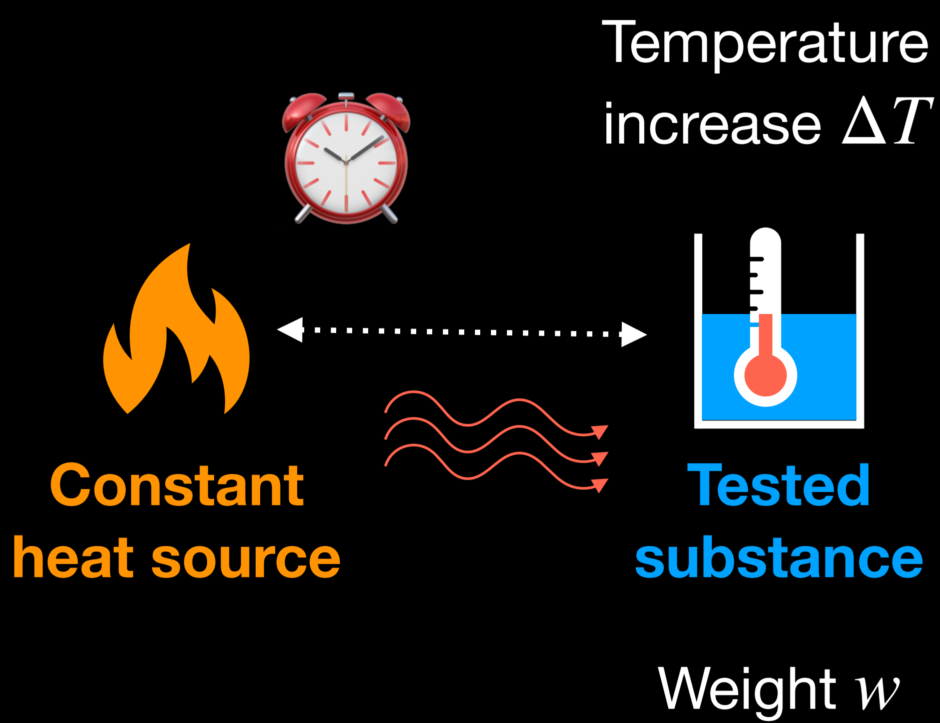
"Heating twice as much material takes twice the heat"

"Doubling the temperature increase takes twice the heat"

Black's "capacity for heat"

1) Expose tested substance to constant heat source

2) Measure time needed to produce a certain temperature increase



$$H = s \cdot w \cdot \Delta T$$

"Sensible heat" provided → H

Weight of tested substance → w

Rise in temperature → ΔT

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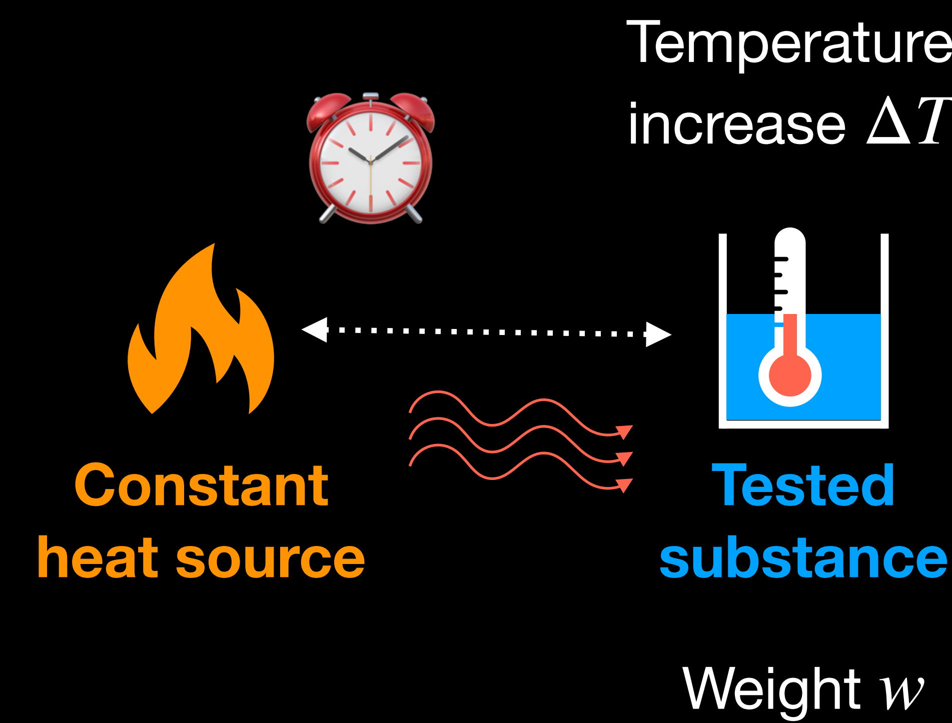


$$H = s \cdot w \cdot \Delta T$$

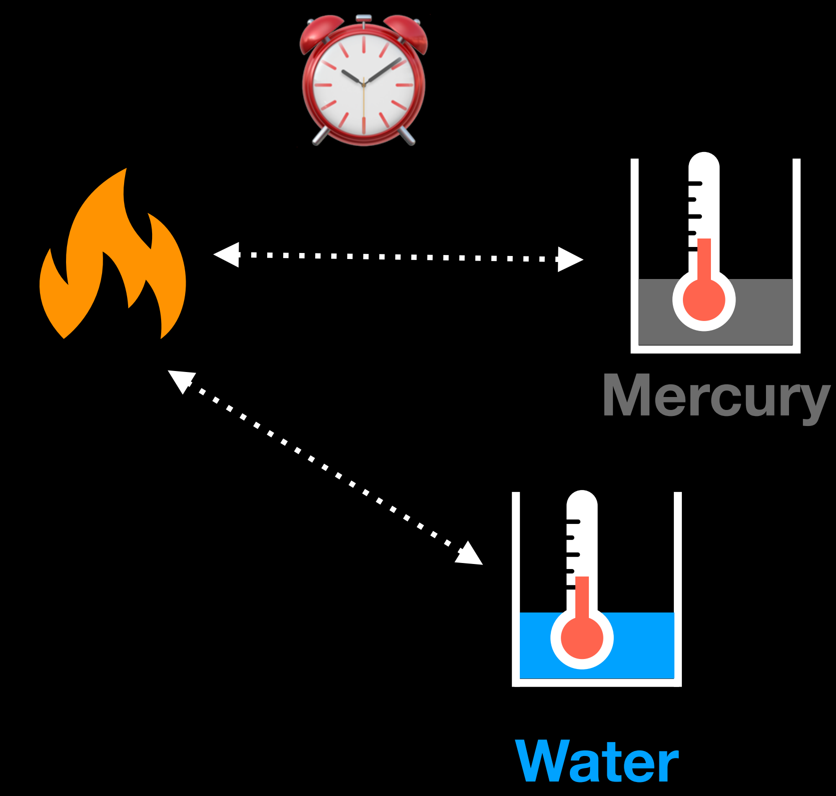
"Sensible heat" provided

"Capacity for the matter of heat"

Weight of tested substance

Rise in temperature

Black's "capacity for heat"



Martine's mercury experiment:

"Mercury is 13-14 times heavier than water, but heated up twice as fast."

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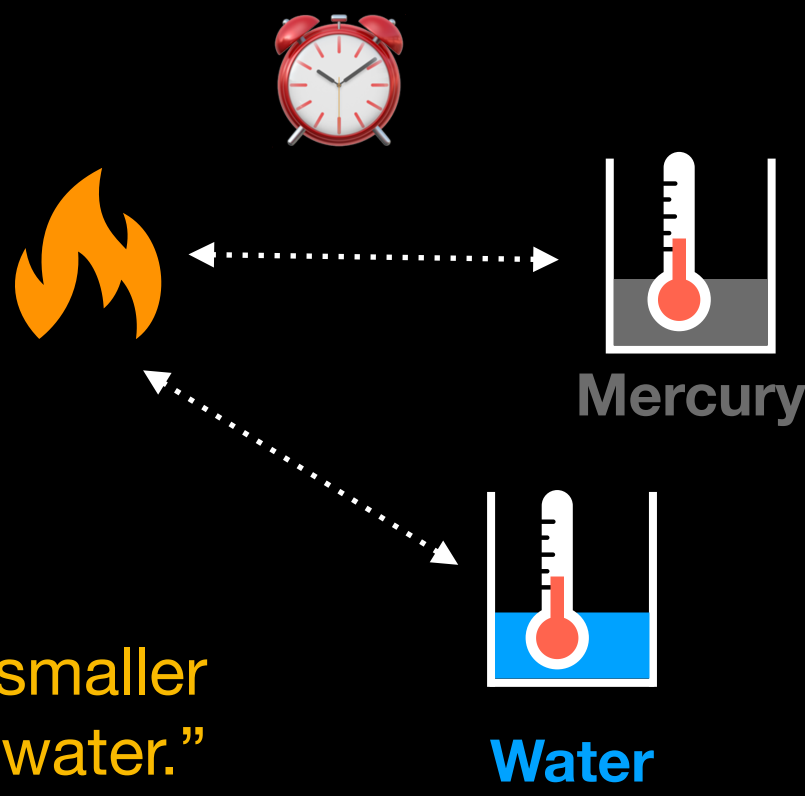


Martine's mercury experiment:

"Mercury is 13-14 times heavier than water, but heated up twice as fast."

→ "The heat capacity of mercury is 26-28 times smaller than that of water."

(The modern value is ~30 times smaller than water.)

$$H = s \cdot w \cdot \Delta T$$

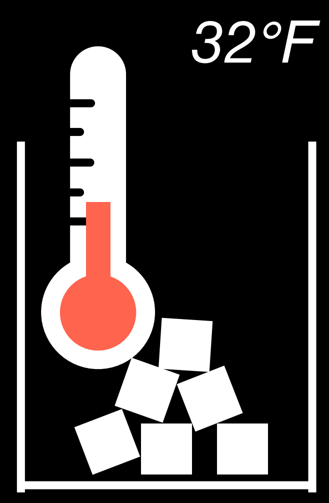
"Sensible heat" provided

"Capacity for the matter of heat"

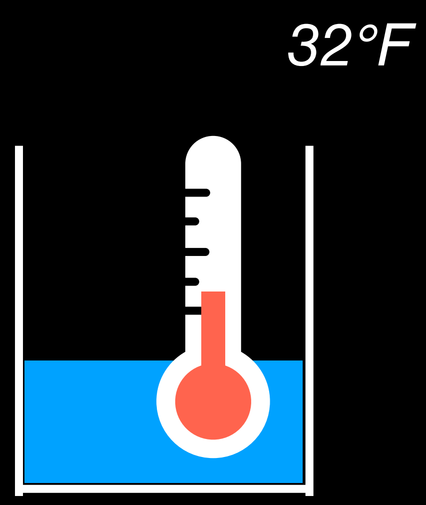
Weight of tested substance

Rise in temperature

A thought experiment

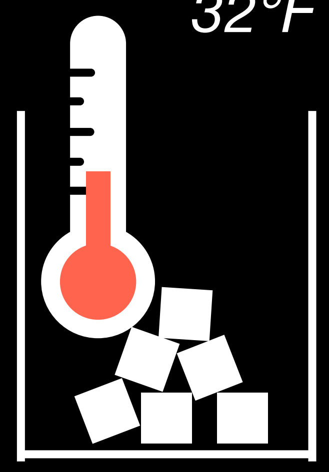


***Just* below freezing point**
Ice cubes



***Just* above freezing point**
Water

A thought experiment



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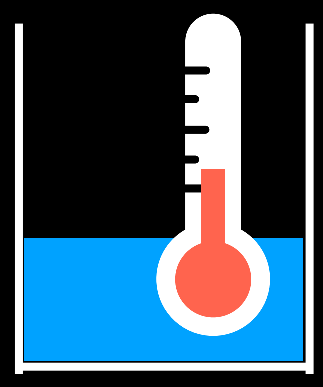

Just above freezing point
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"Capacity for the matter of heat"

Weight of tested substance

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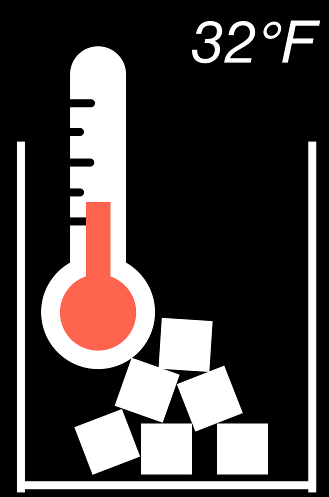

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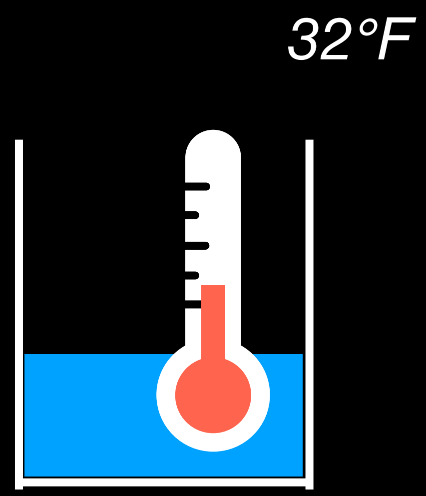

Just **above freezing point**

Water

"Sensible heat" provided

Rise in temperature

$$H = s \cdot w \cdot \Delta T$$

"Capacity for the matter of heat"

Weight of tested substance

If this were true, ice would melt almost instantaneously!

A thought experiment

A thought experiment

“Were this really the case, the consequences of it would be dreadful in many cases.

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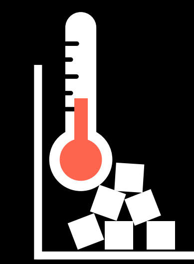
A thought experiment

"Were this really the case, the consequences of it would be dreadful in many cases.

Were the ice and snow to melt suddenly, the torrents and inundations would be irresistible and dreadful.

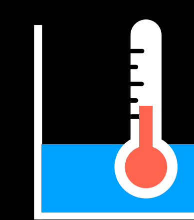
They would tear up and sweep away everything, and this so suddenly that mankind would have great difficulty in escaping from their ravages."

A new “type” of heat



Just **below freezing point**

Ice cubes



Just **above freezing point**

Water

“Sensible heat” provided

Rise in temperature

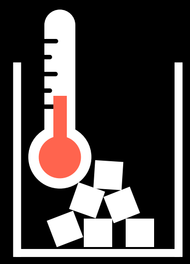
$$H = s \cdot w \cdot \Delta T$$

“Capacity for the matter of heat”

Weight of tested substance

A new “type” of heat

“When ice or any other solid substance is melted, it receives a much larger quantity of heat than what is perceptible by a thermometer.



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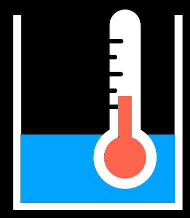

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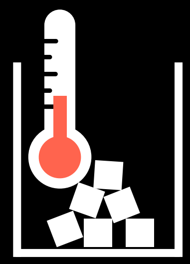

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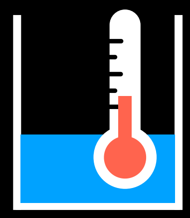


Just **above freezing point**

Water

$$H = s \cdot w \cdot \Delta T$$

“Sensible heat” provided

Rise in temperature

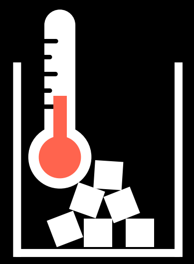
“Capacity for the matter of heat”

Weight of tested substance

A new “type” of heat

“When ice or any other solid substance is melted, it receives a much larger quantity of heat than what is perceptible by a thermometer.

This heat must be added to give it the form of a liquid.”



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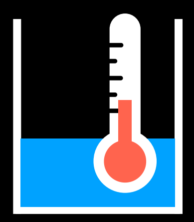

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Water

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$$H = s \cdot w \cdot \Delta T$$

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A new "type" of heat

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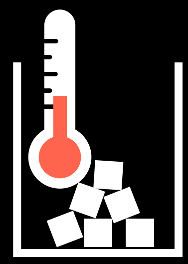

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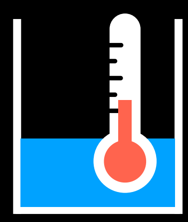


Just above freezing point
Water

This "new" type of heat is not "sensible heat"

Black called it *"latent heat"*

"Sensible heat" provided

Rise in temperature

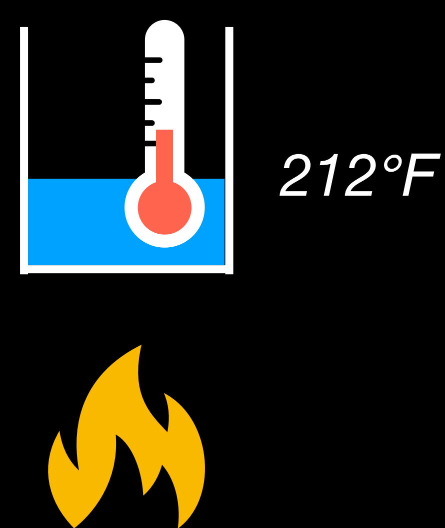
$$H = s \cdot w \cdot \Delta T$$

"Capacity for the matter of heat"

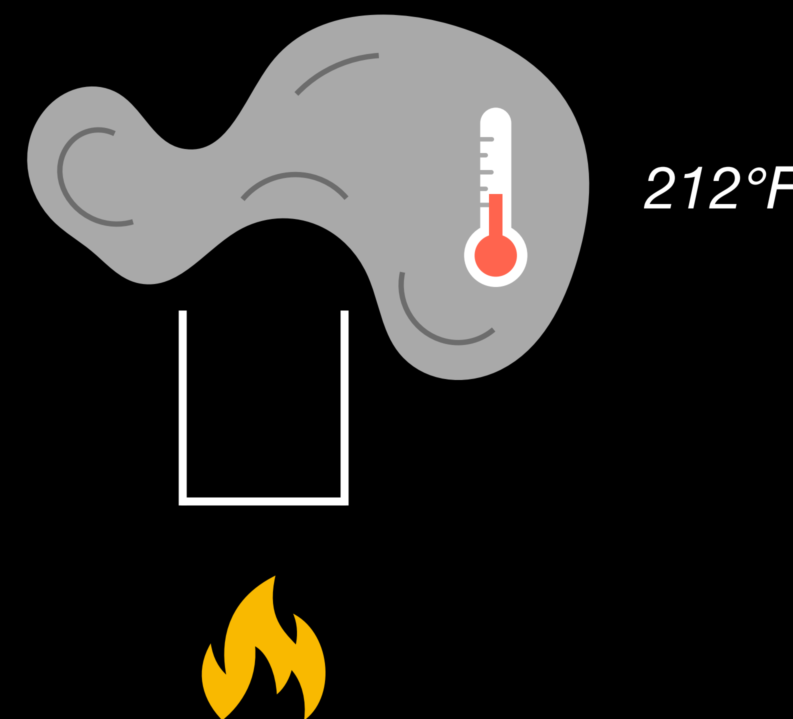
Weight of tested substance

On boiling water

"Another peculiarity attends the boiling of liquids."



Just **below boiling point**
Water

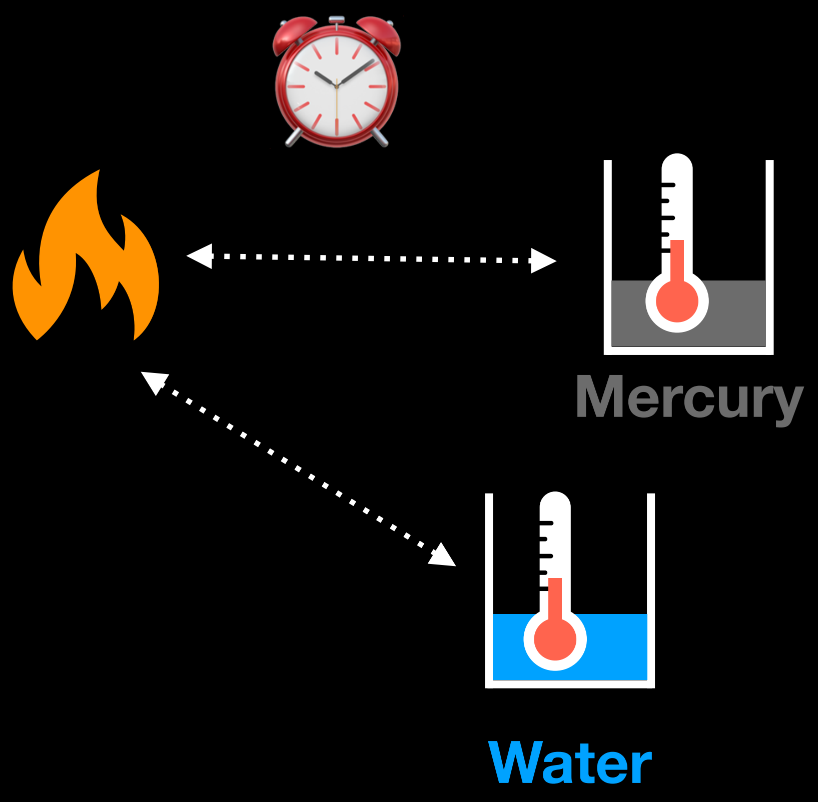


Just **above boiling point**
Steam

"The undeniable consequence of this, if the old view were correct, should be an explosion of the whole water with a violence equal to that of gun-powder."

Blacks' great synthesis

Blacks' great synthesis

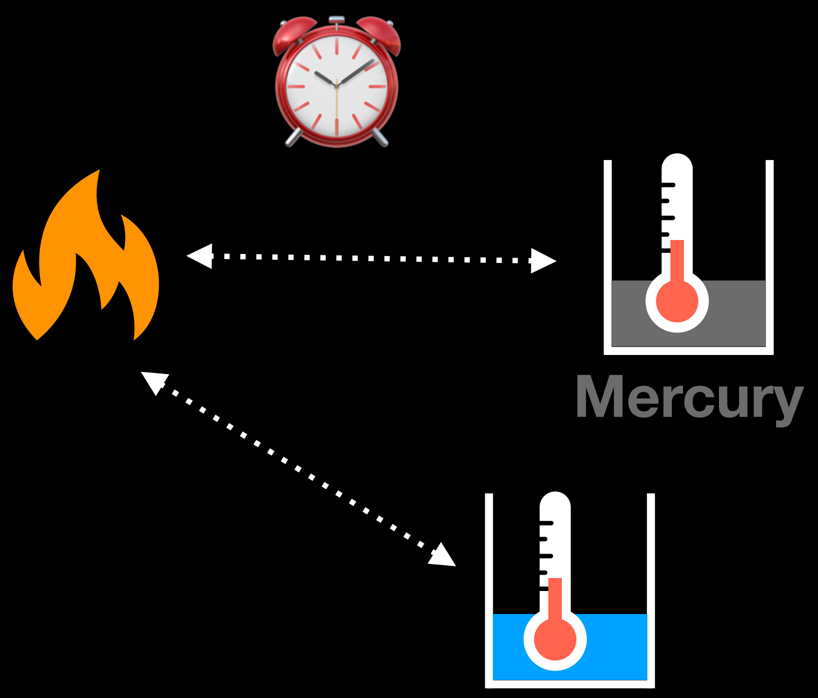


Bodies react differently to the same amount of "sensible" heat

$$H = s \cdot w \cdot \Delta T$$

"Capacity for the matter of heat"

Blacks' great synthesis



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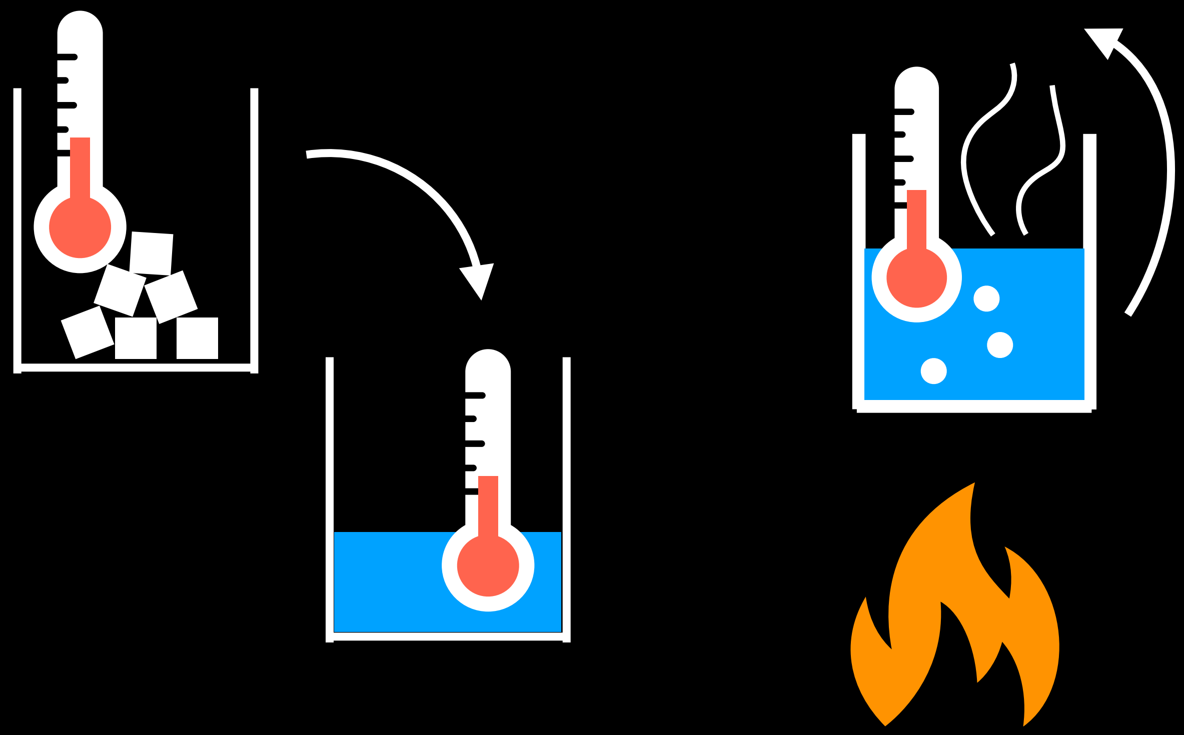

Sometimes, heat is not sensible, but "latent"

"Its effect consists, not in warming the bodies, but in converting the ice into water, or the water into steam."

We have already come a long way!

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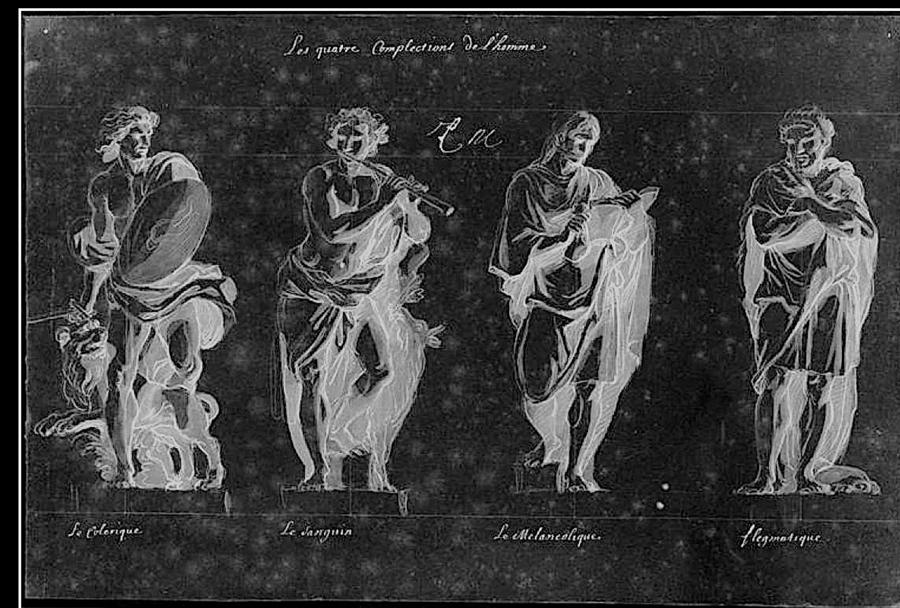

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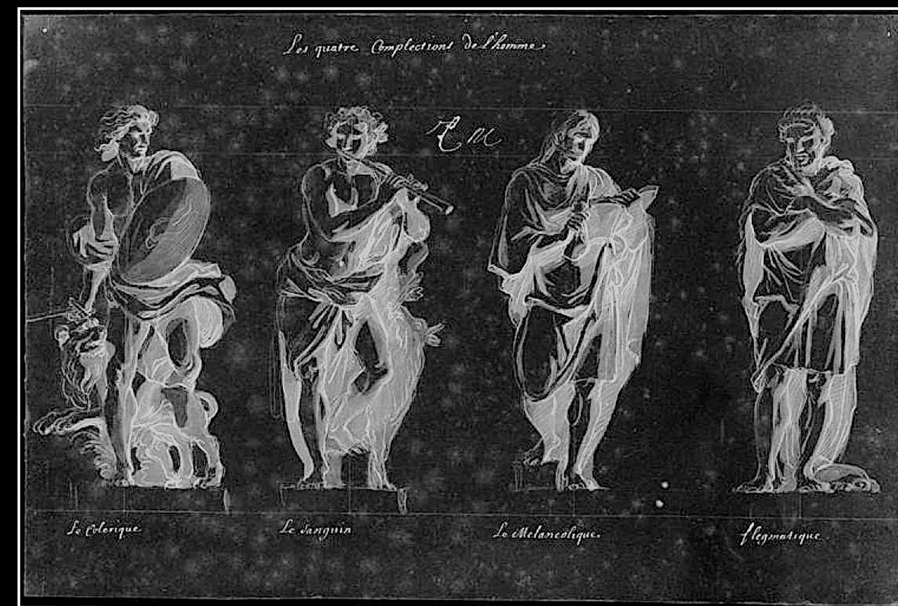

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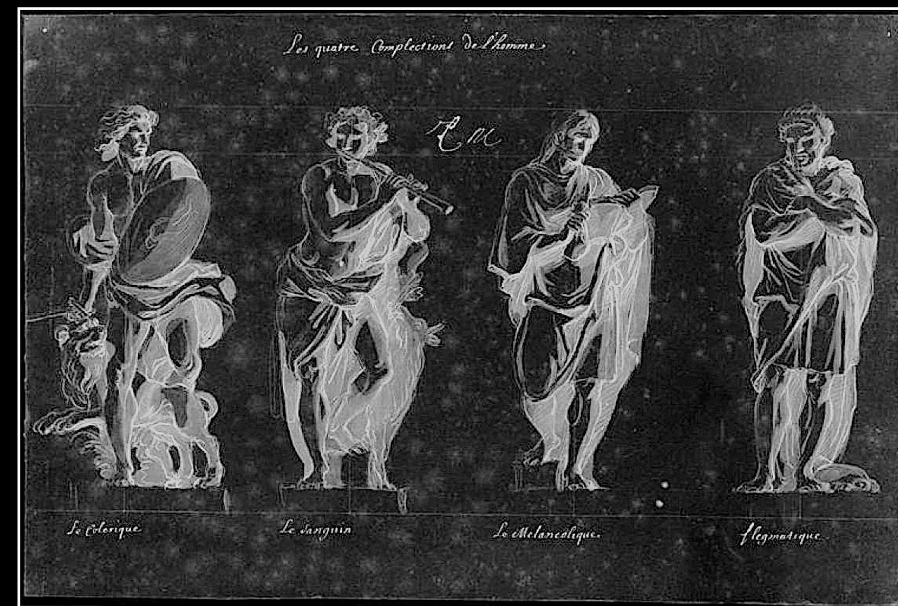

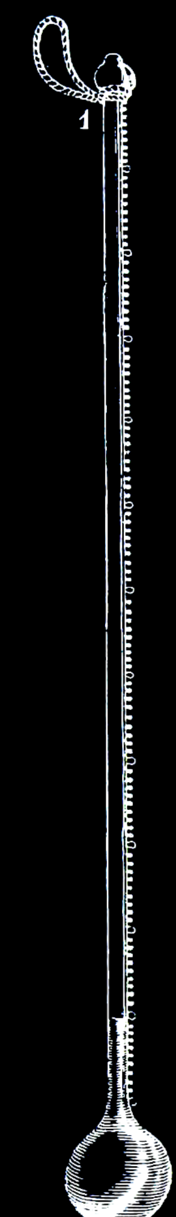

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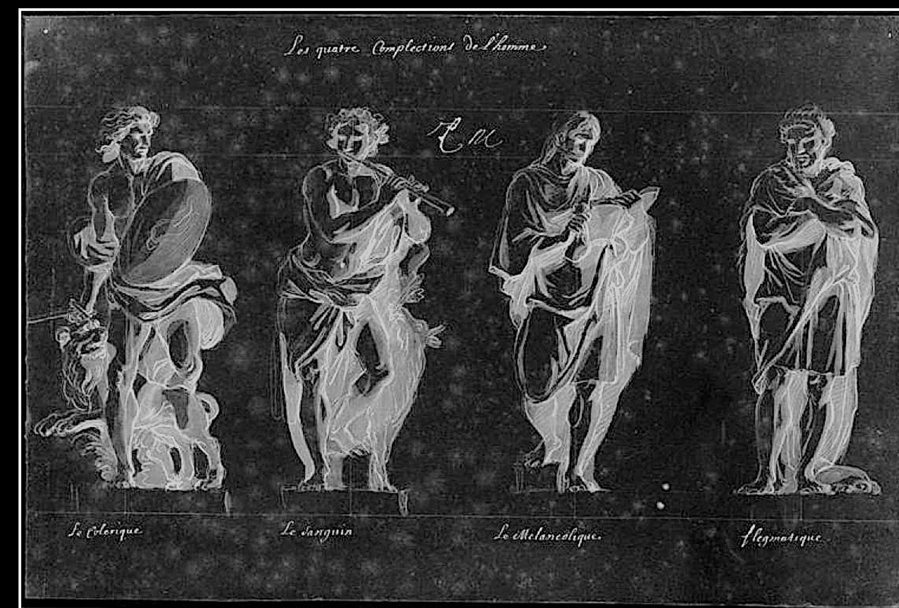

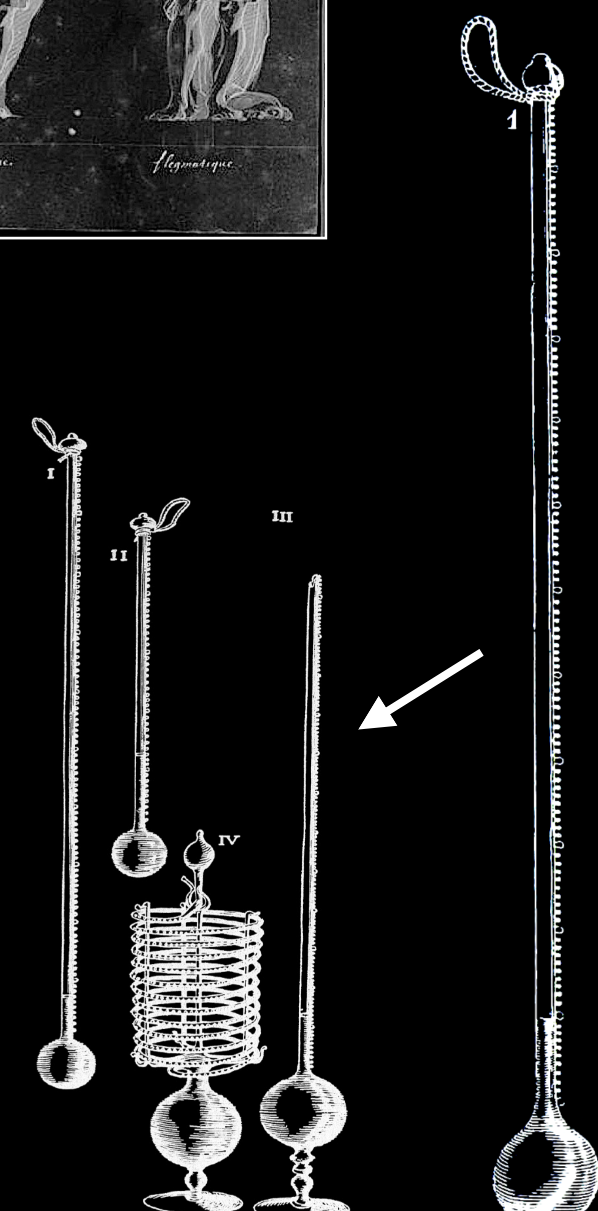

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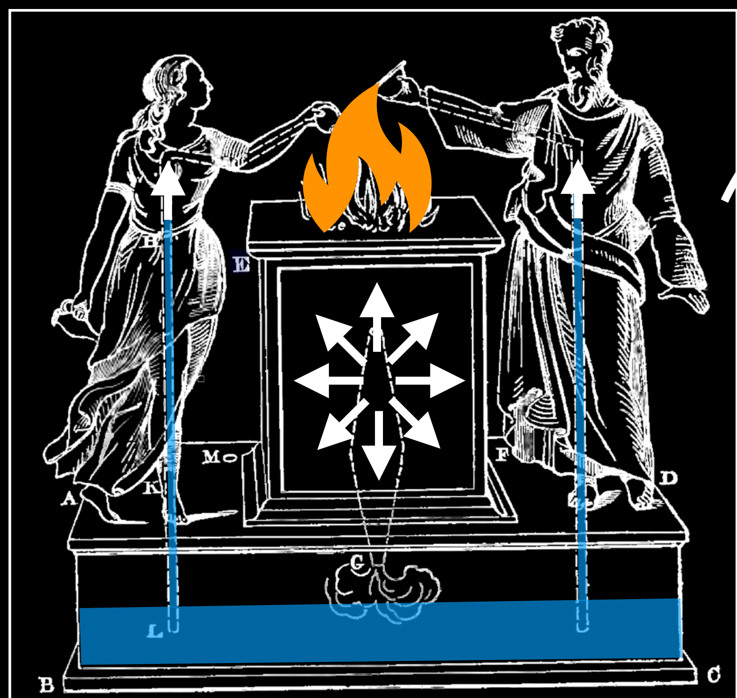

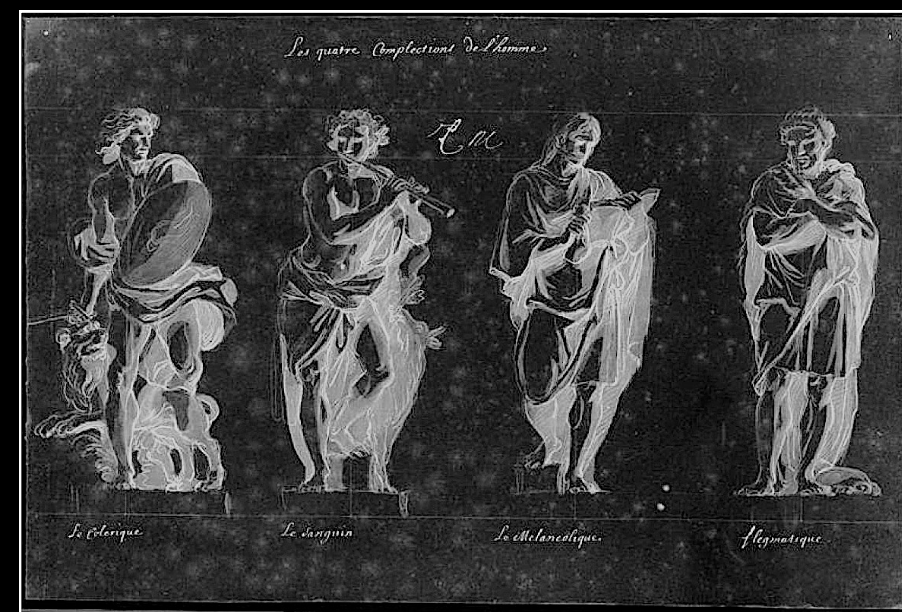

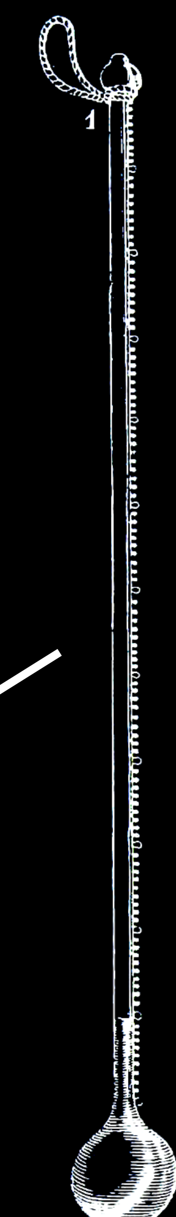

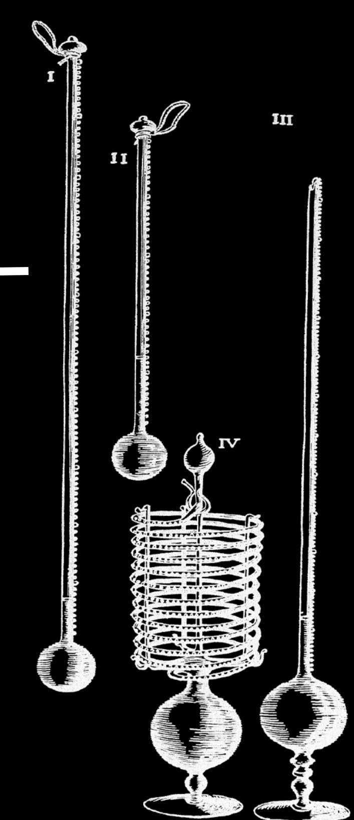

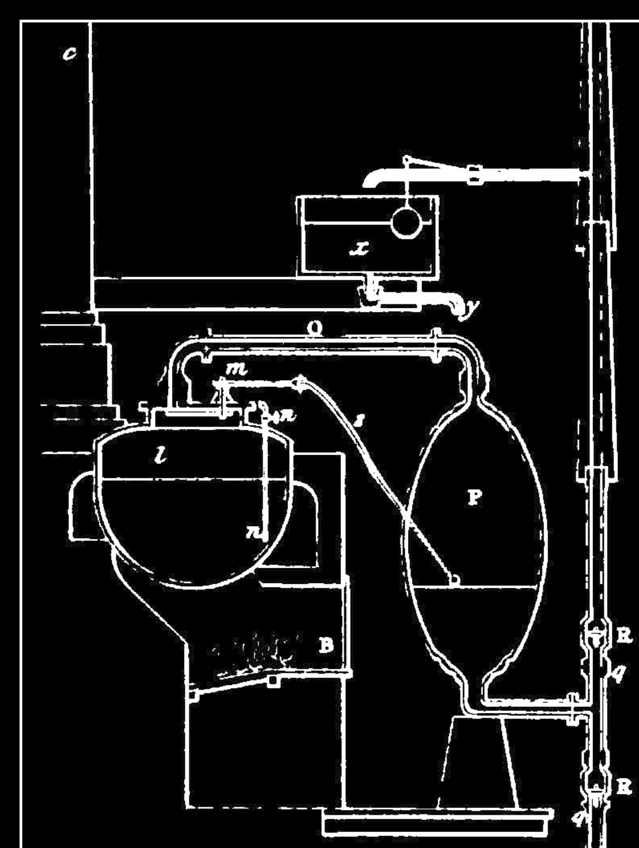

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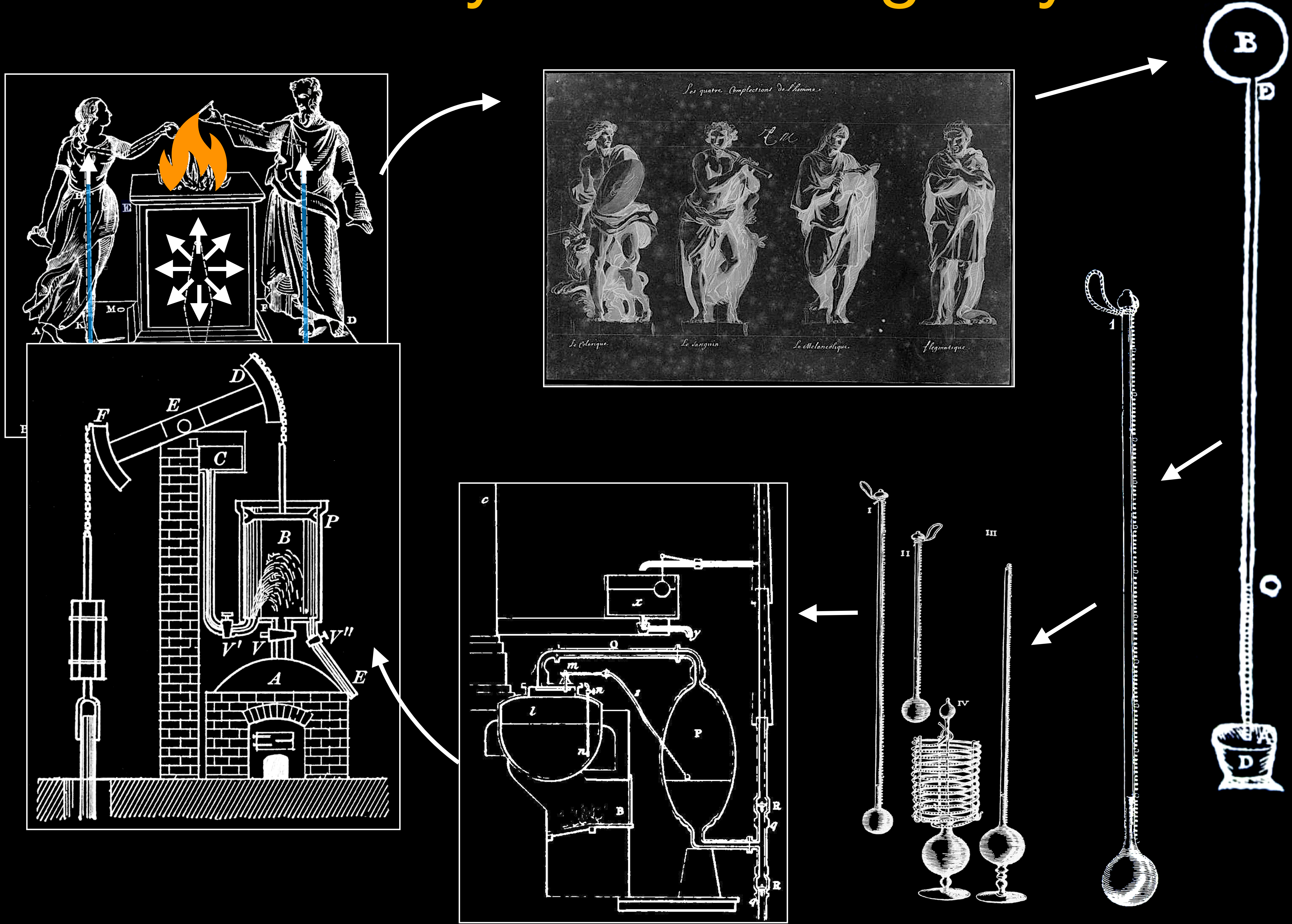

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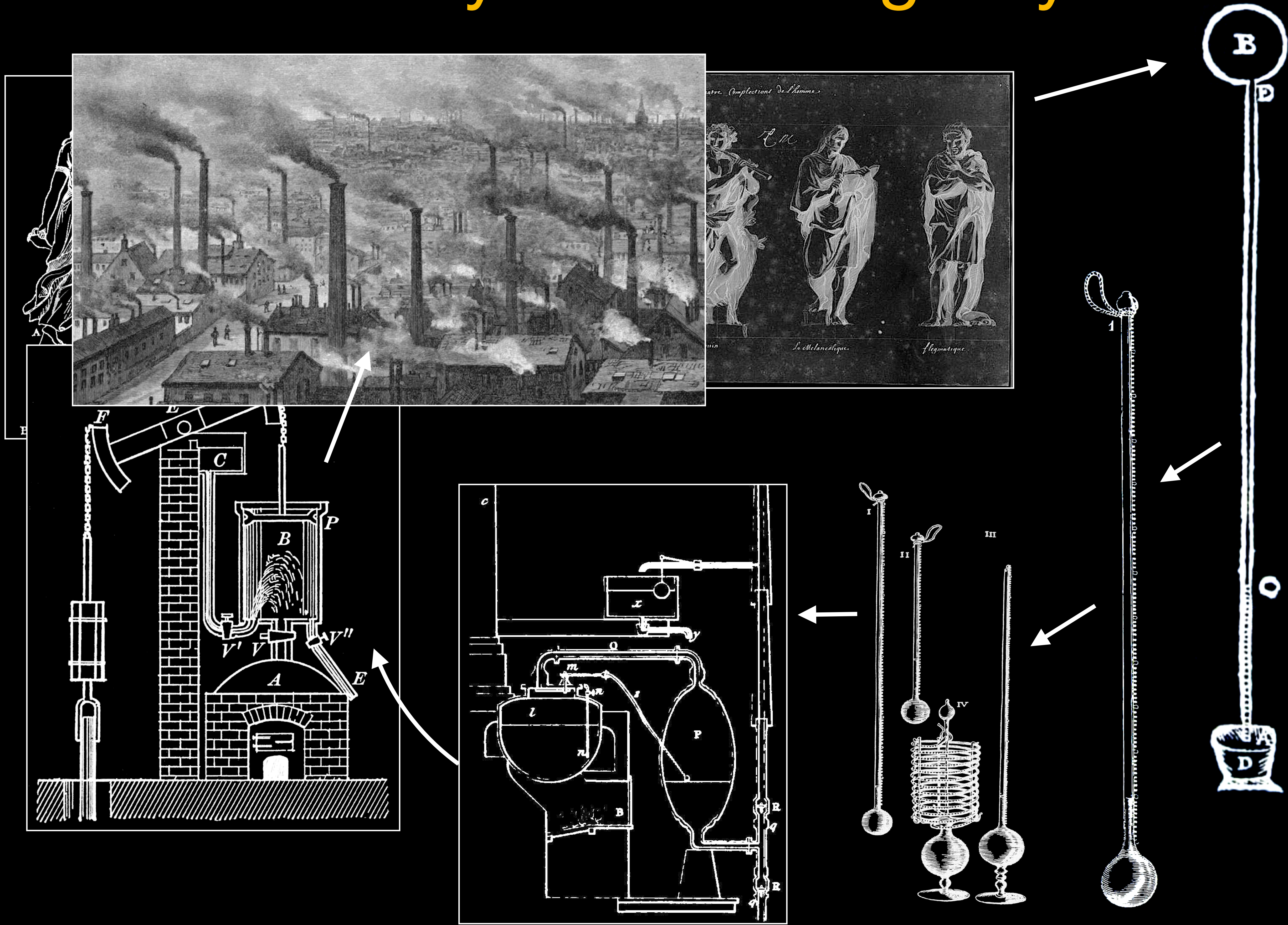

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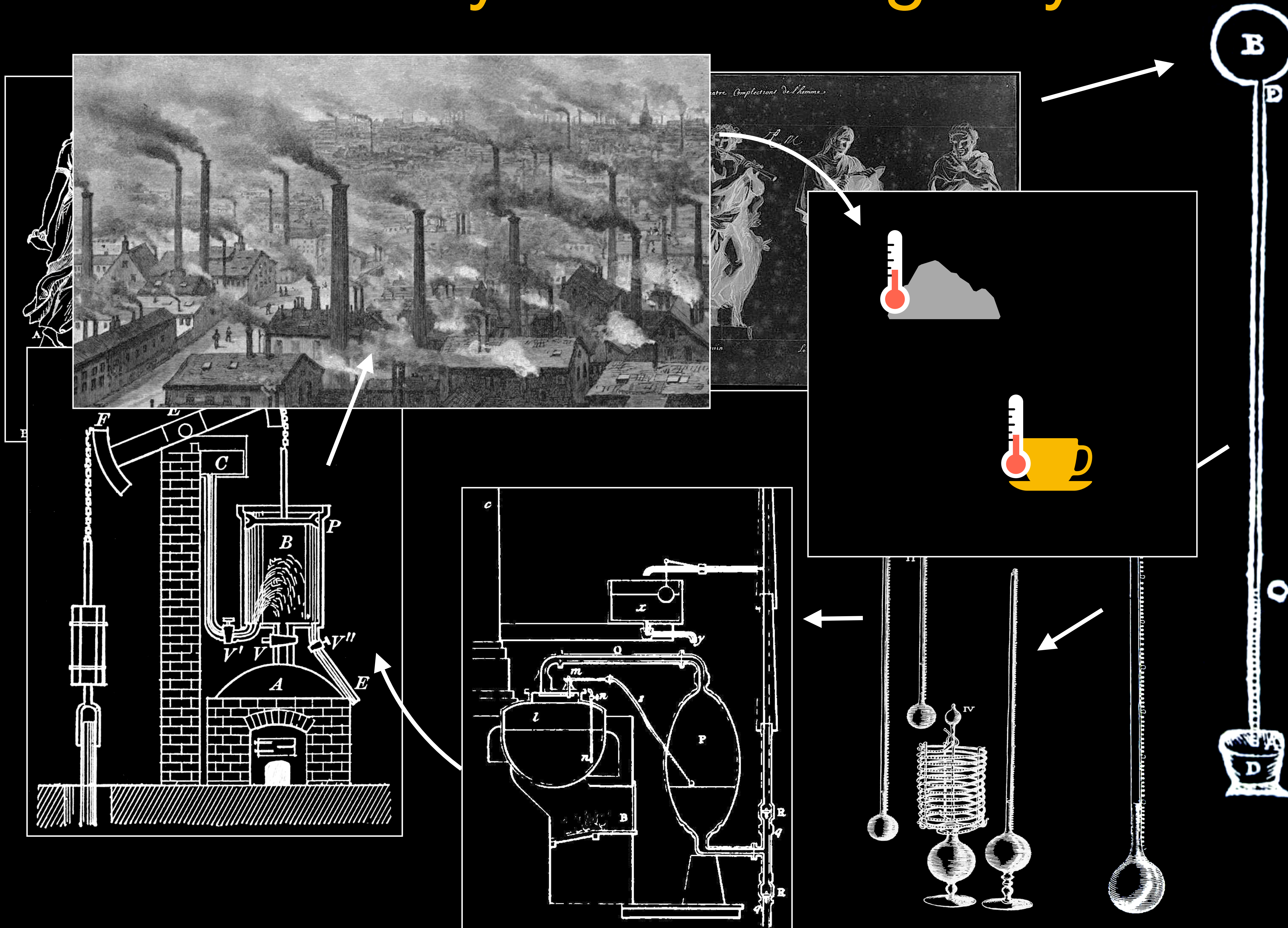

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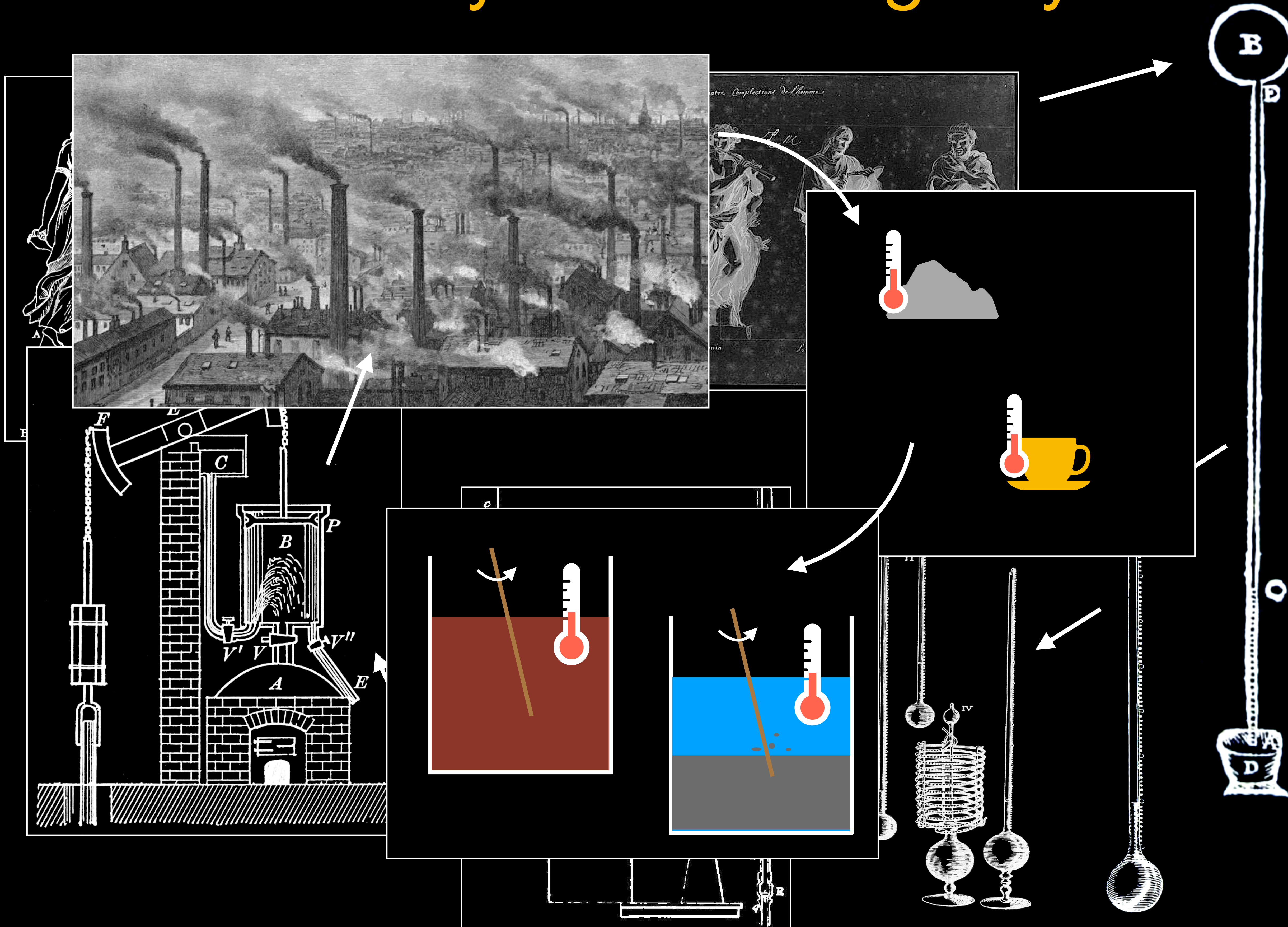

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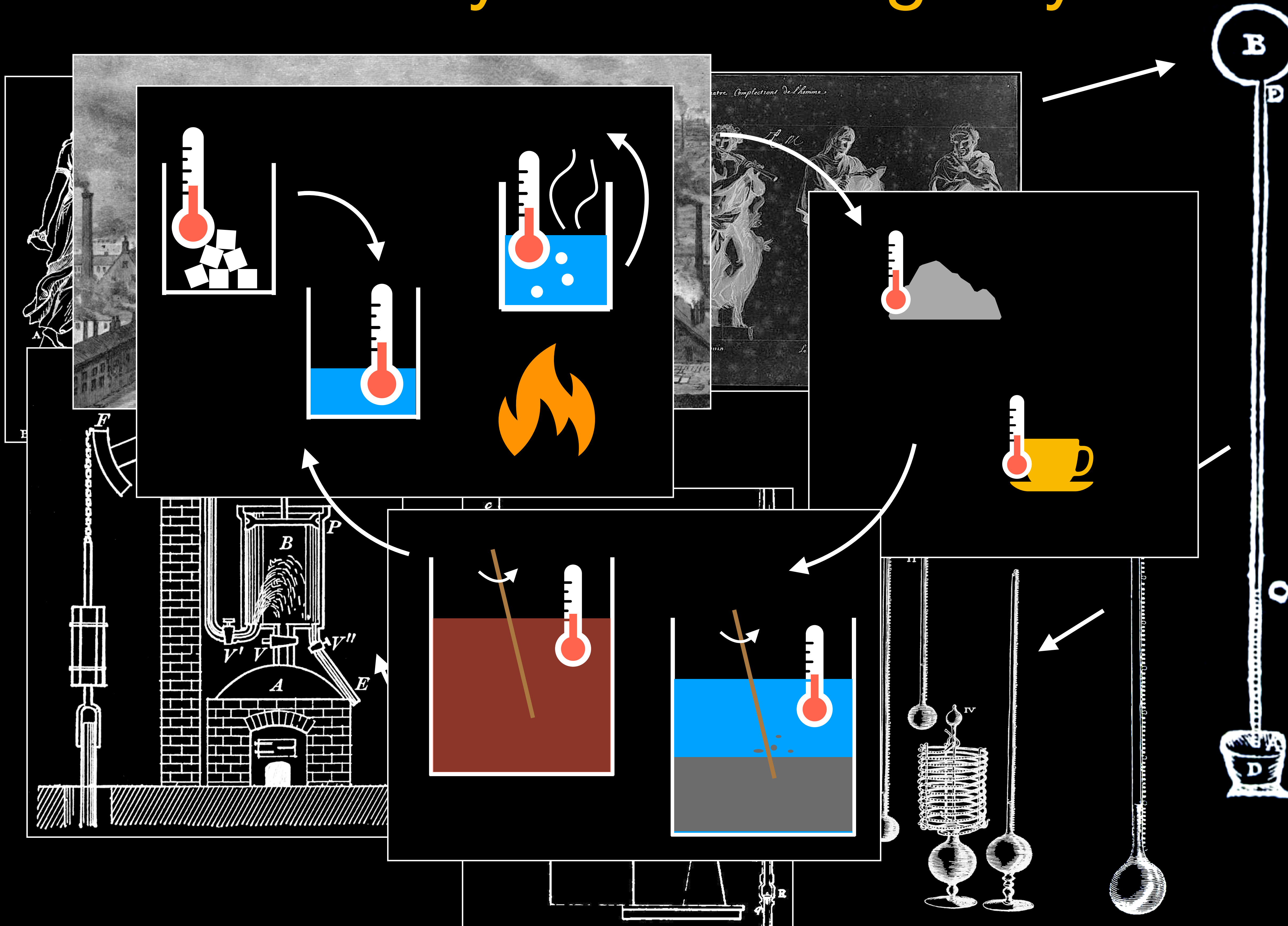
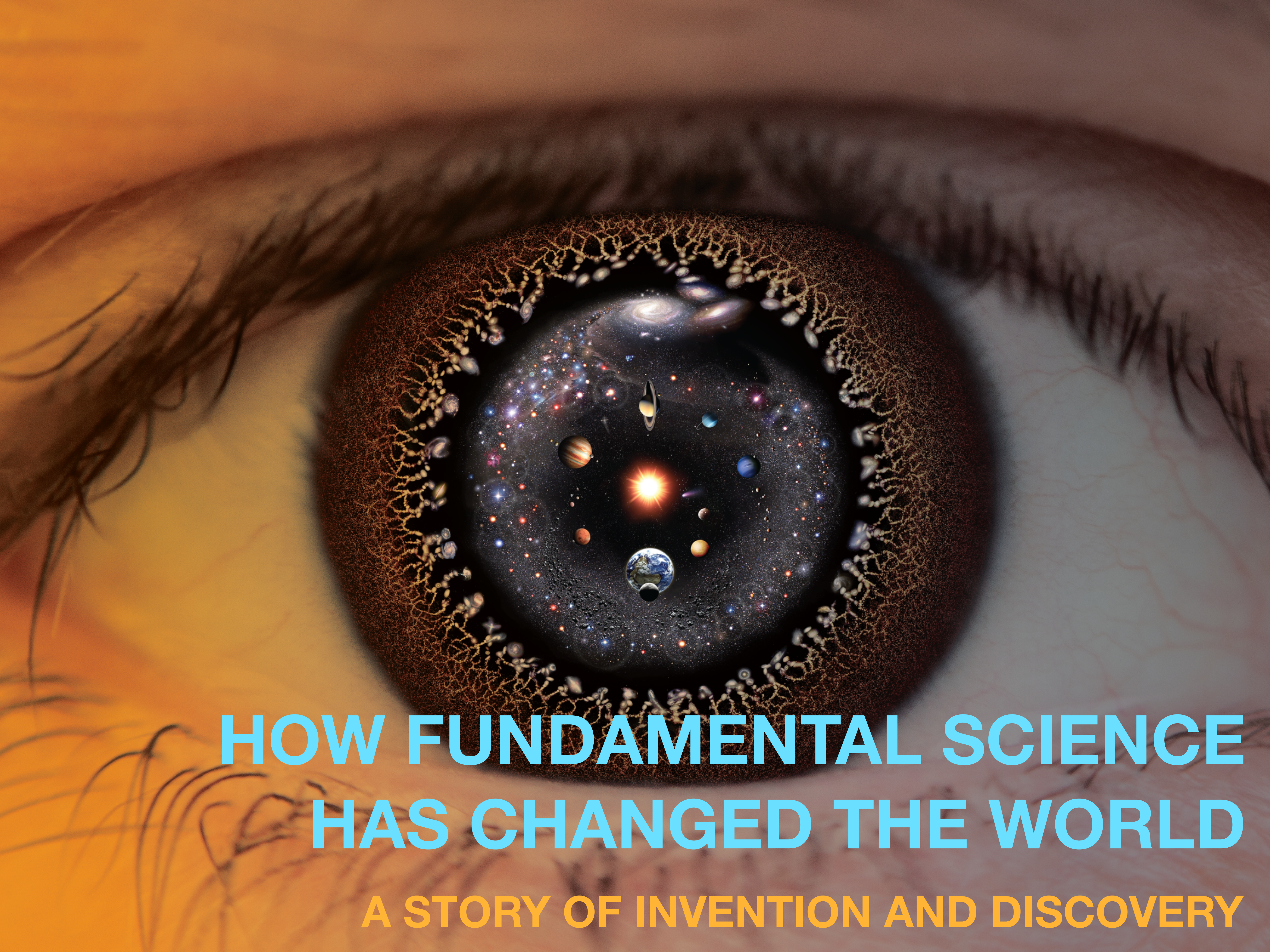


What is heat?



HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD

A STORY OF INVENTION AND DISCOVERY

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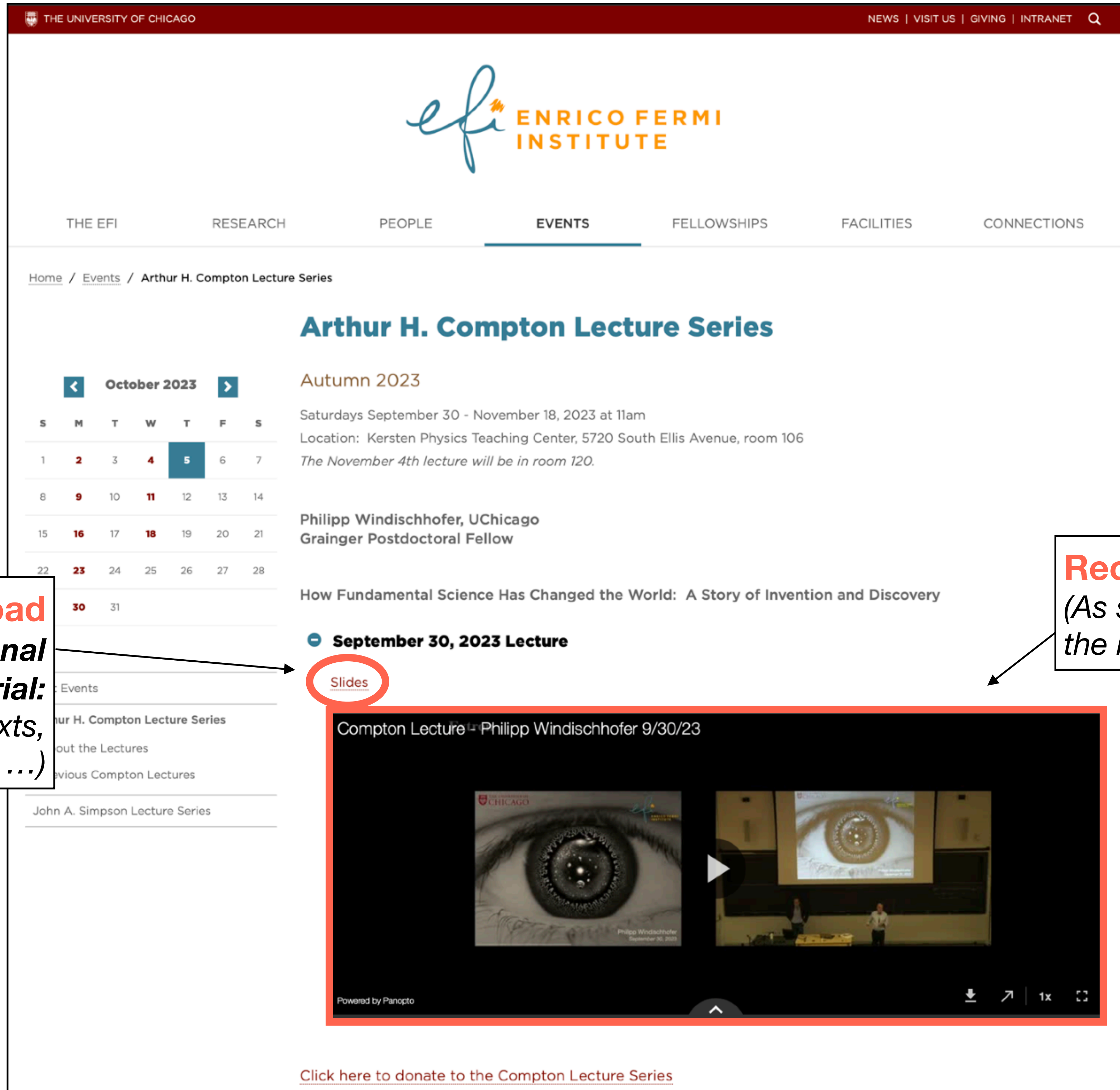

Slides for download
(Including ***additional bonus material:*** *original texts, references, links, …)*

Recording and slides
(As shown during the lecture)