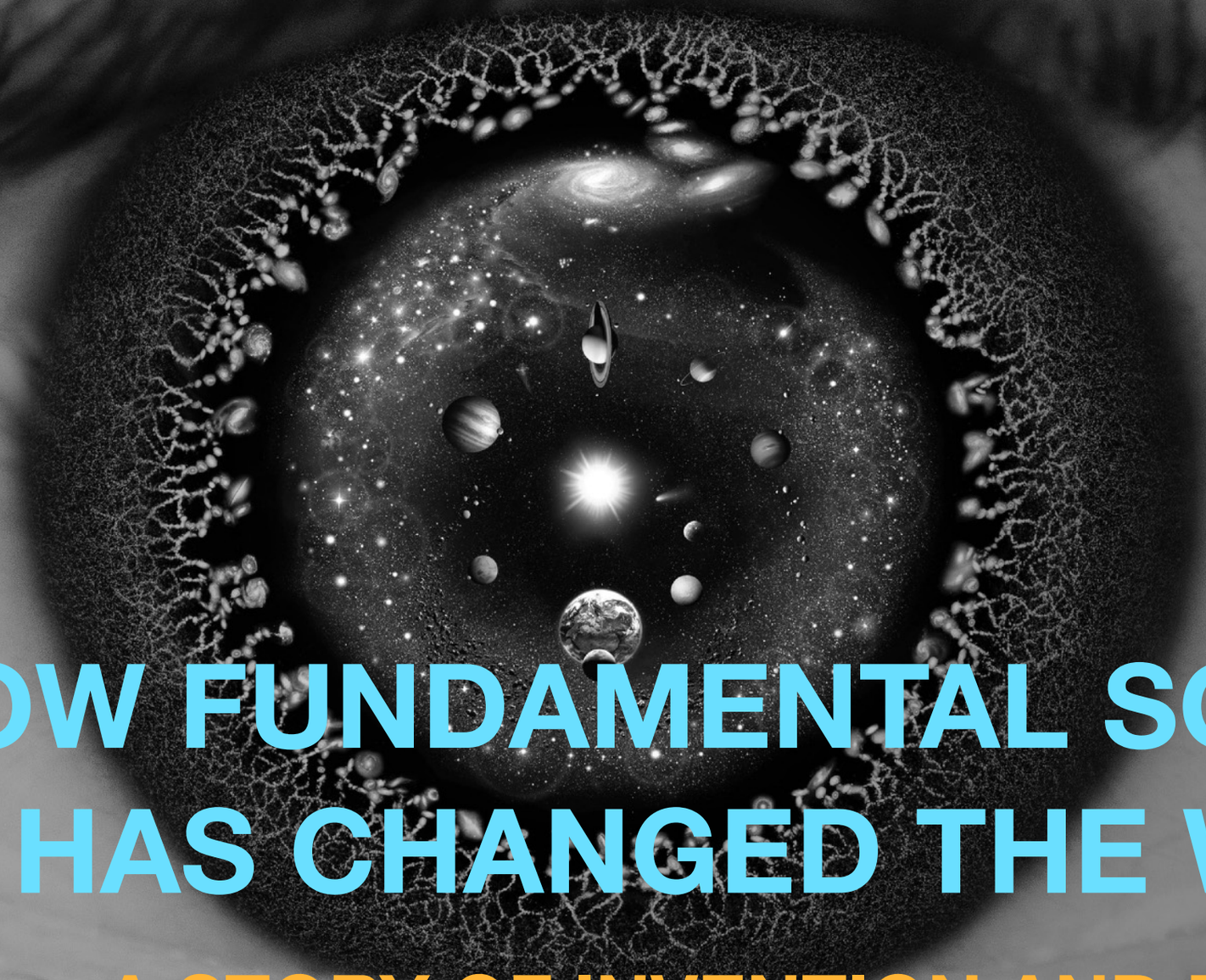
THE UNIVERSITY OF CHICAGO

ENRICO FERMI INSTITUTE



HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD

A STORY OF INVENTION AND DISCOVERY

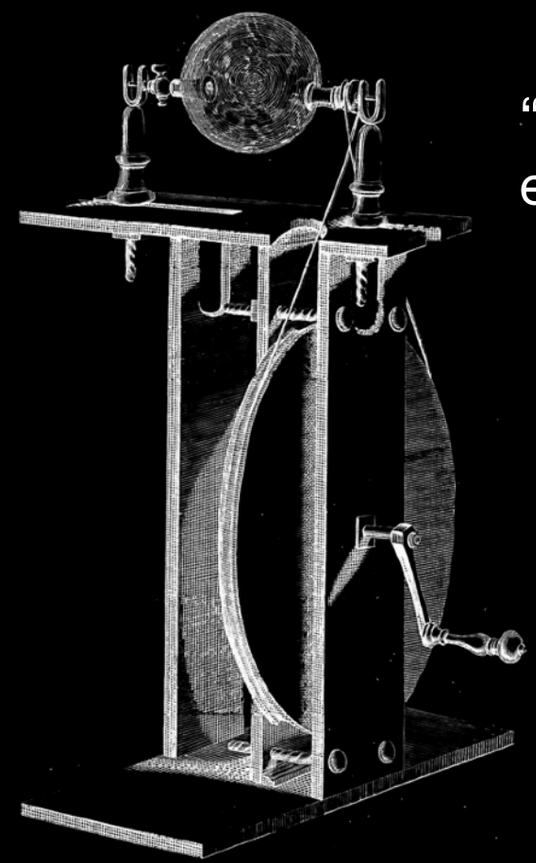
Philipp Windischhofer

October 28, 2023

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

ἤλεκτρον (elektron)

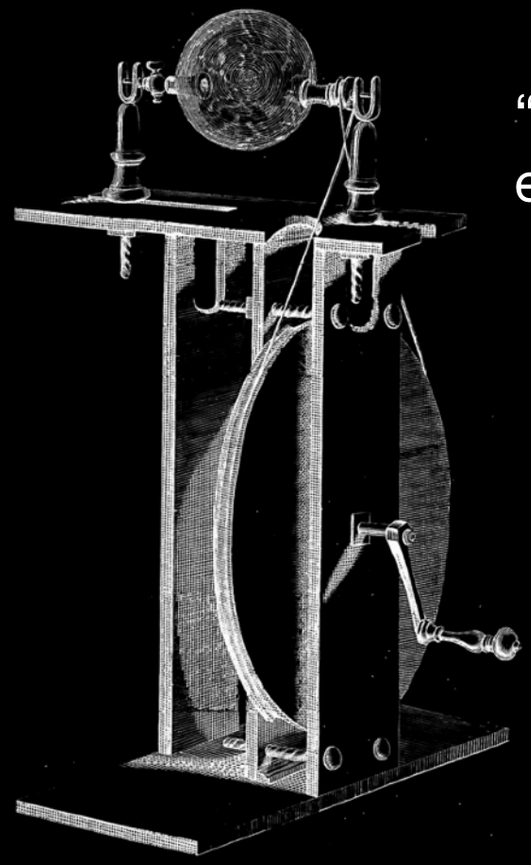
ἤλεκτρον (elektron)



"Ordinary" electricity

~1700

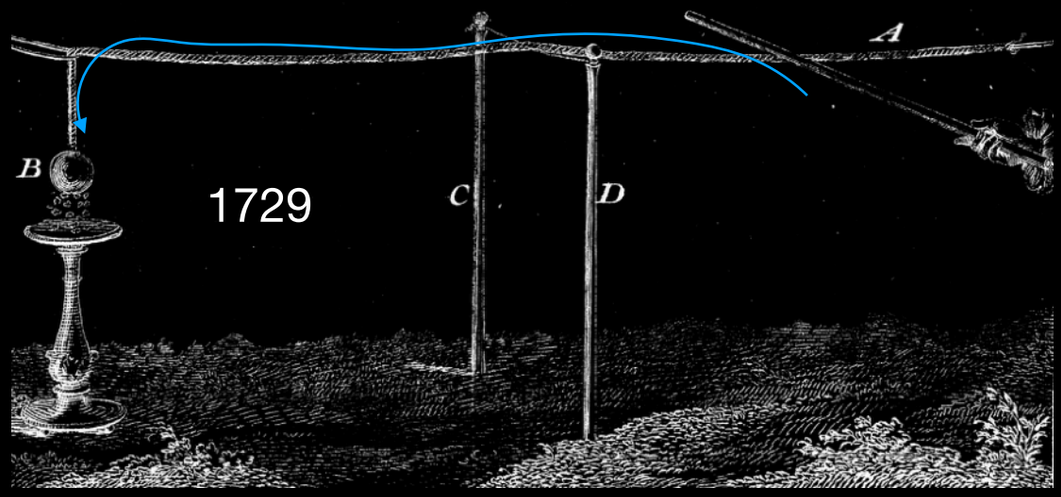
ἤλεκτρον (elektron)



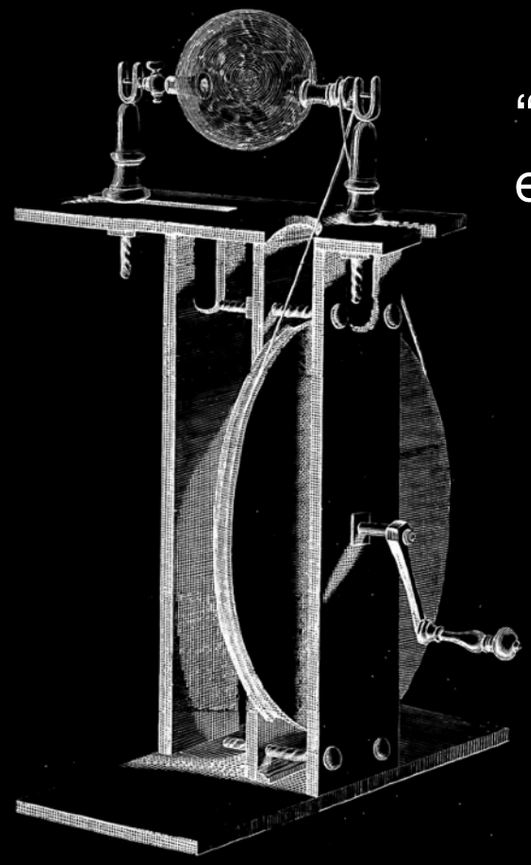
"Ordinary" electricity

~1700

Transportation of the "electrick vertue"



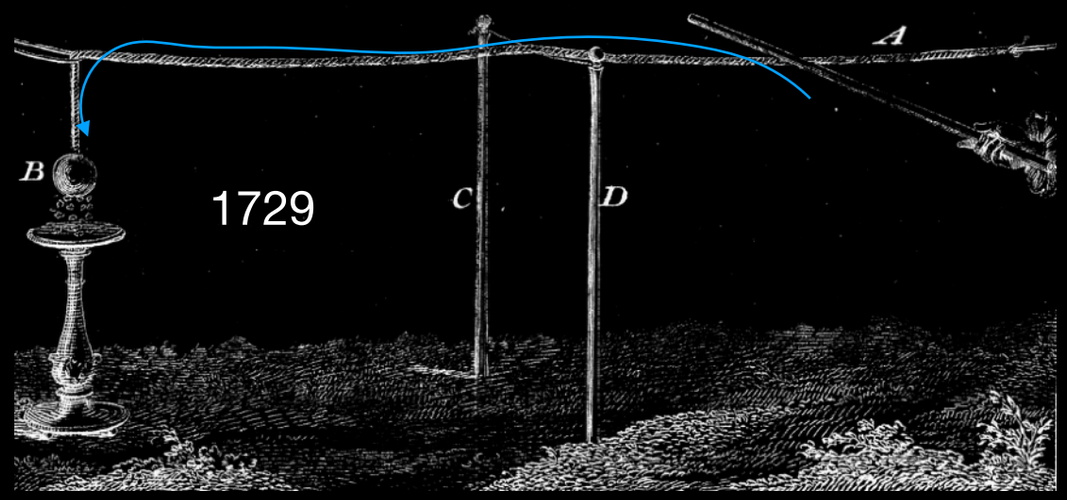
ἤλεκτρον (elektron)



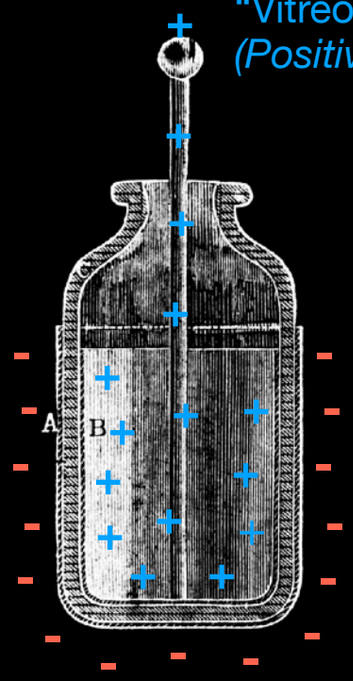
"Ordinary" electricity

~1700

Transportation of the "electrick vertue"



Leyden Jar: storage ("amplification")

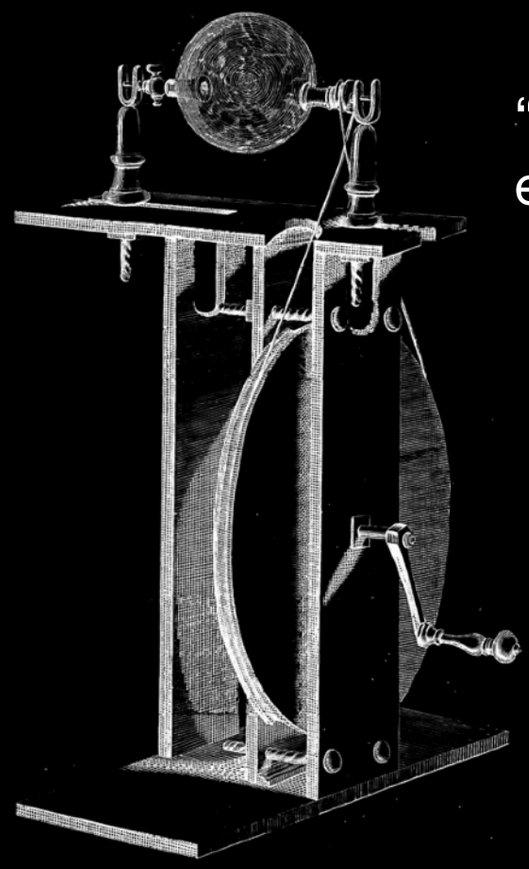


"Vitreous electricity" *(Positive)*

1745

"Resinous electricity" *(Negative)*

ἤλεκτρον (elektron)

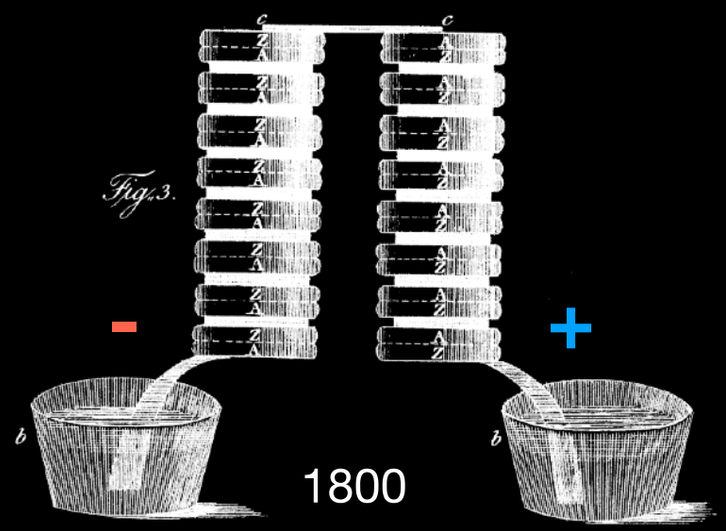


"Ordinary" electricity

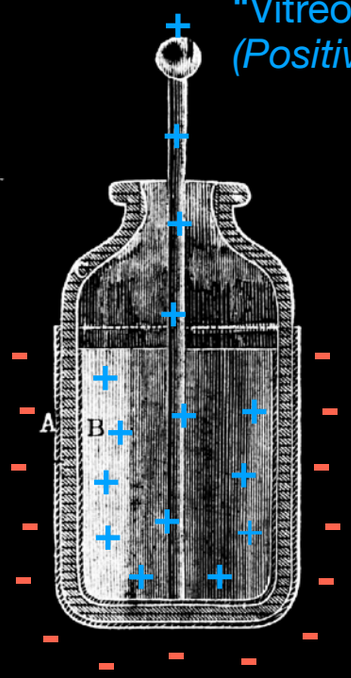
~1700

Transportation of the "electrick vertue"

"Voltaic electricity"



1800

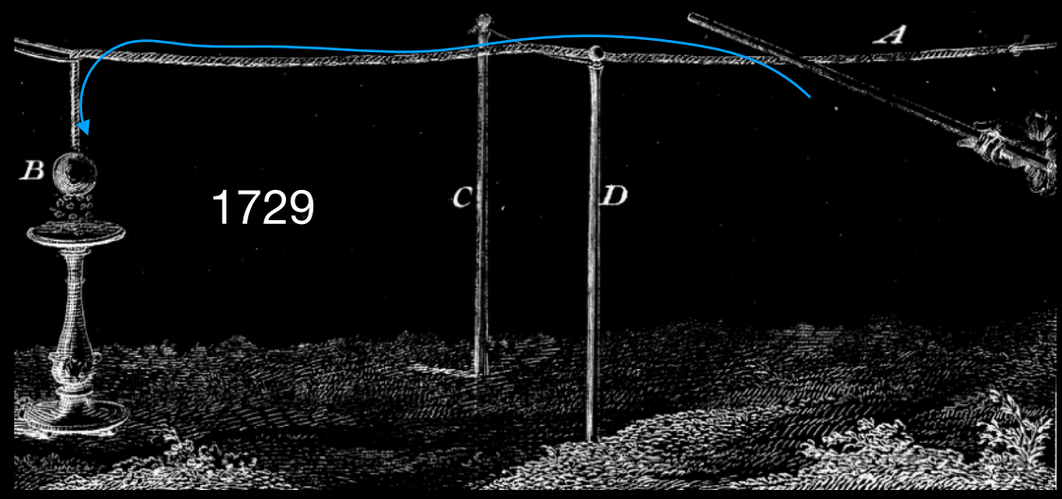


"Vitreous electricity" *(Positive)*

1745

"Resinous electricity" *(Negative)*

Leyden Jar: storage ("amplification")



1729

Stephen Gray:

Stephen Gray:

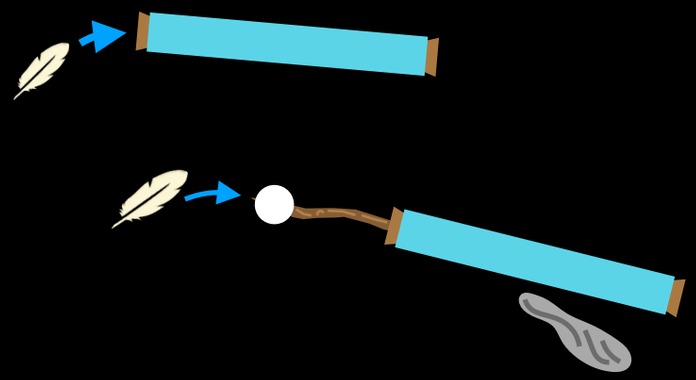
Electrical conductivity: a chance discovery

Stephen Gray:

Electrical conductivity: a chance discovery

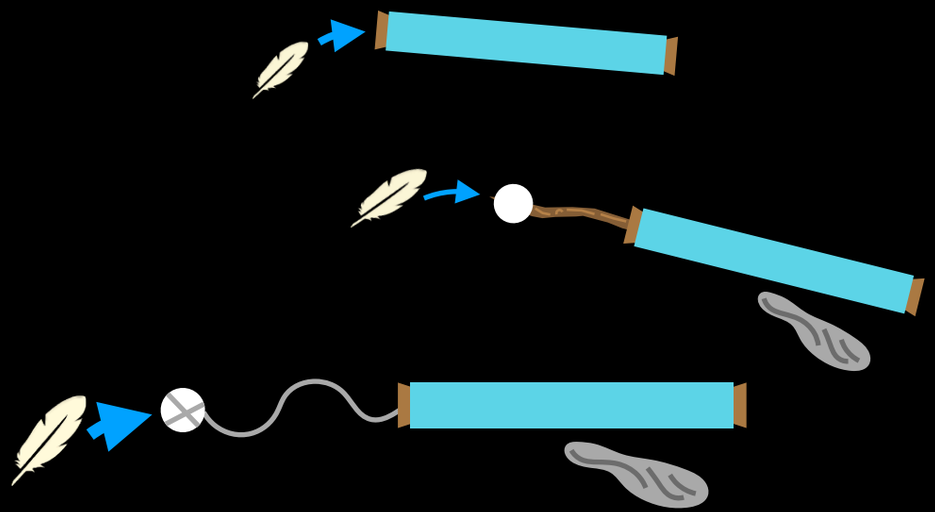
Stephen Gray:

Electrical conductivity: a chance discovery



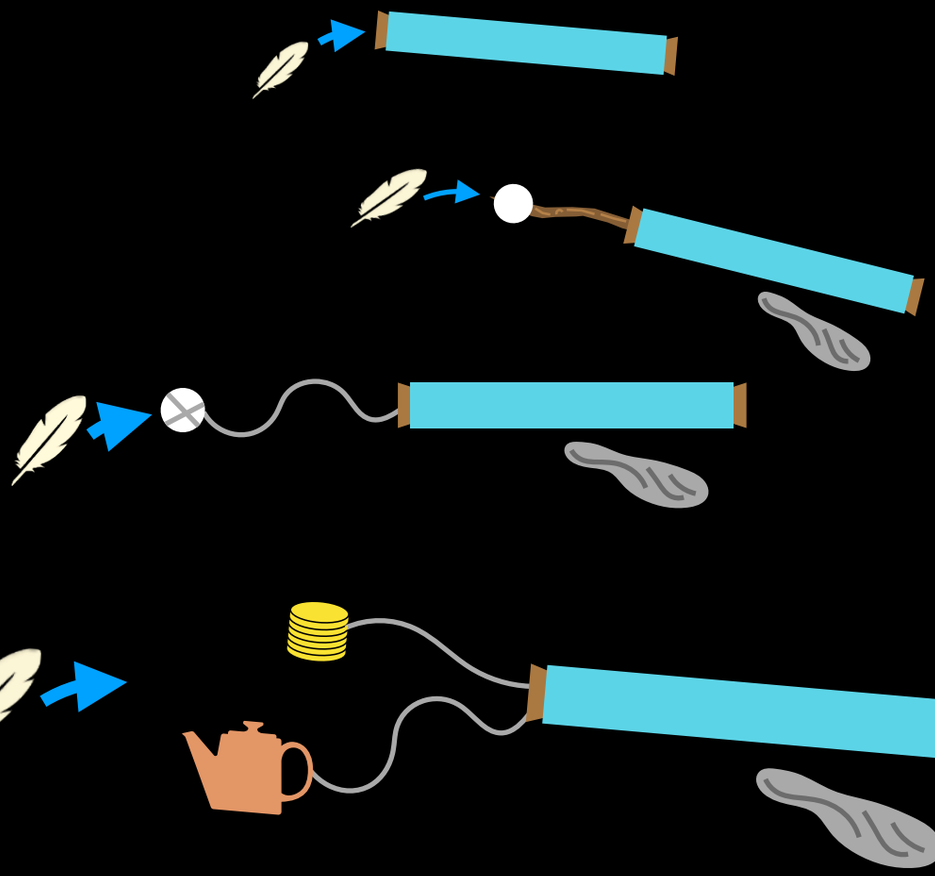
Stephen Gray:

Electrical conductivity: a chance discovery



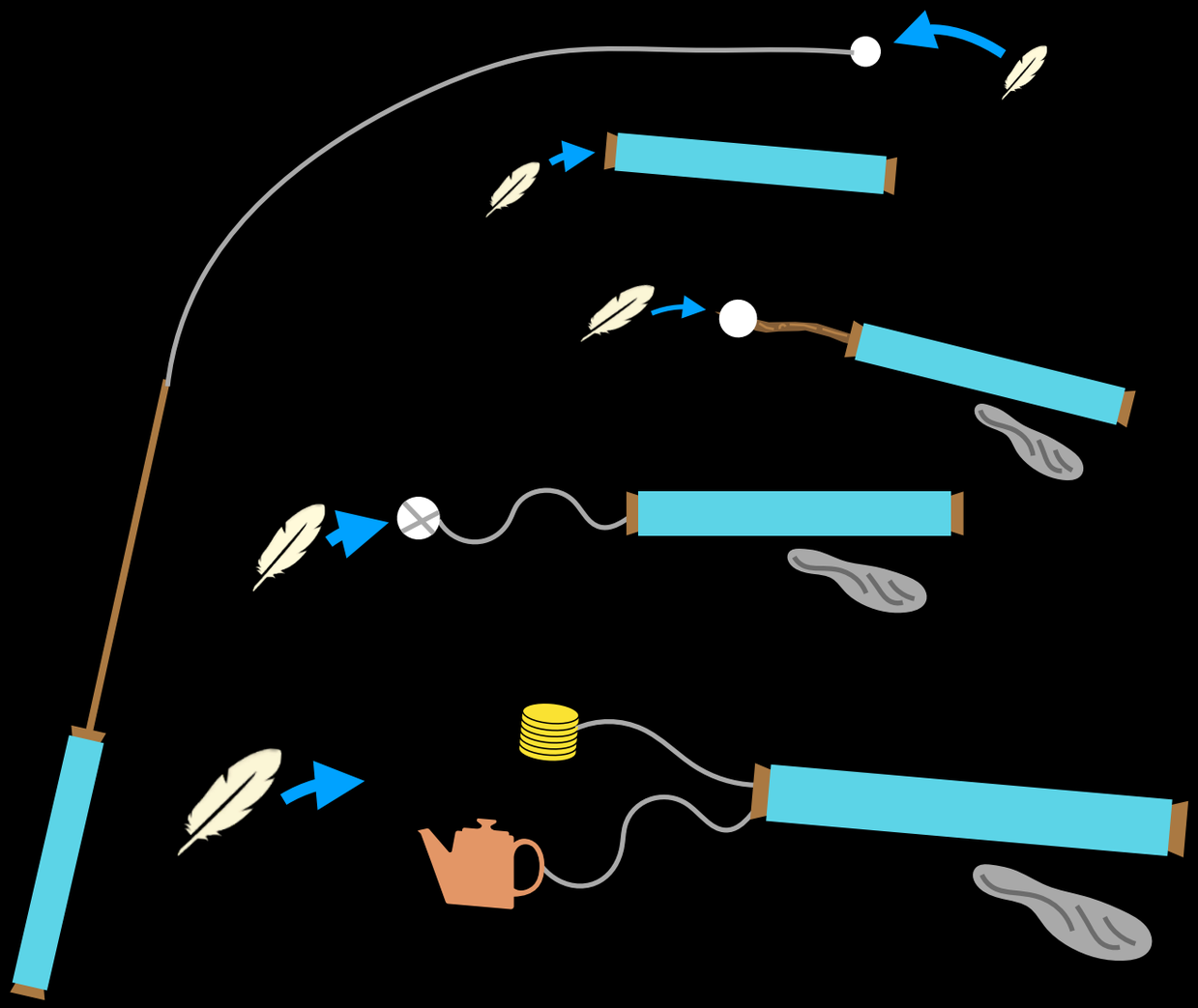
Stephen Gray:

Electrical conductivity: a chance discovery



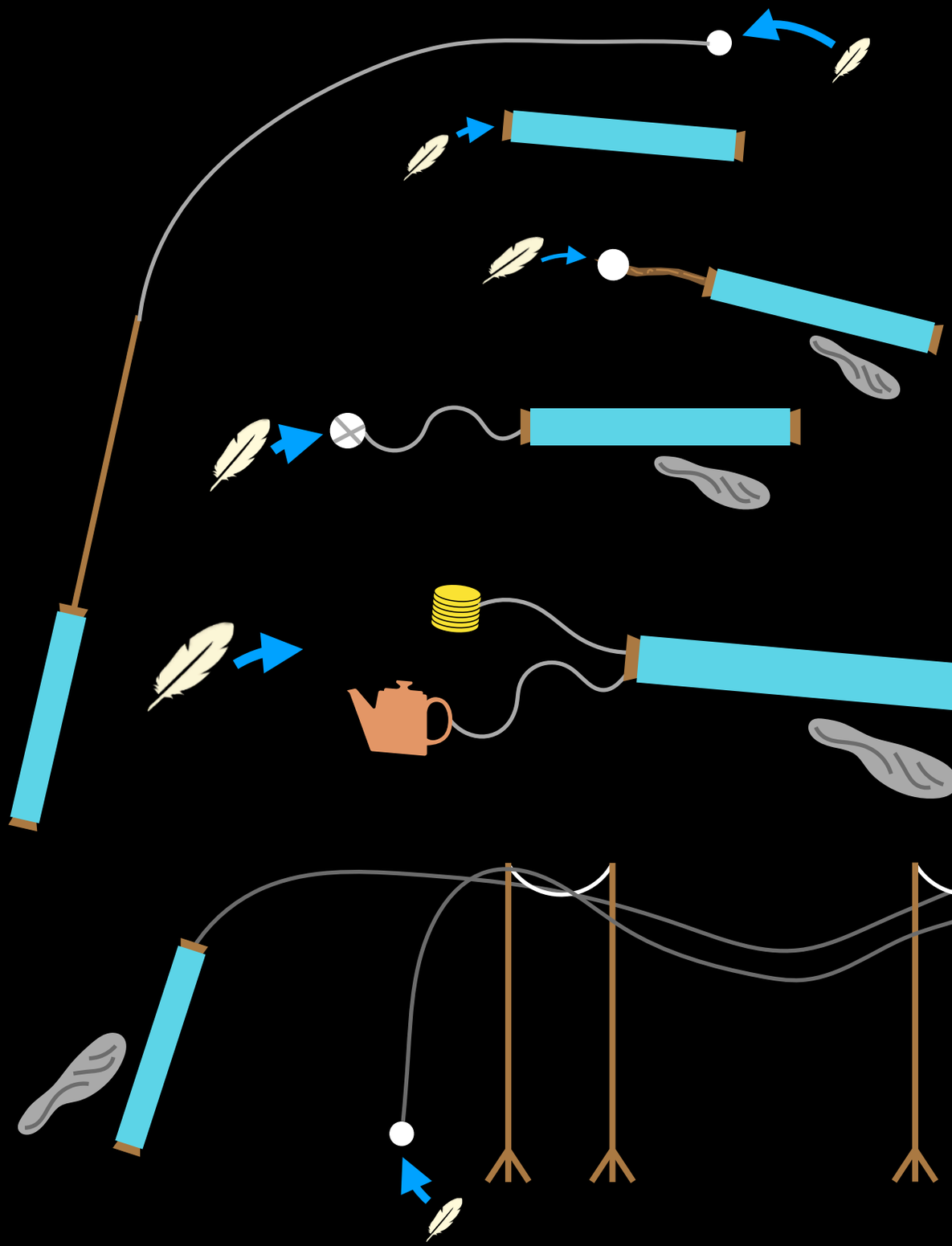
Stephen Gray:

Electrical conductivity: a chance discovery



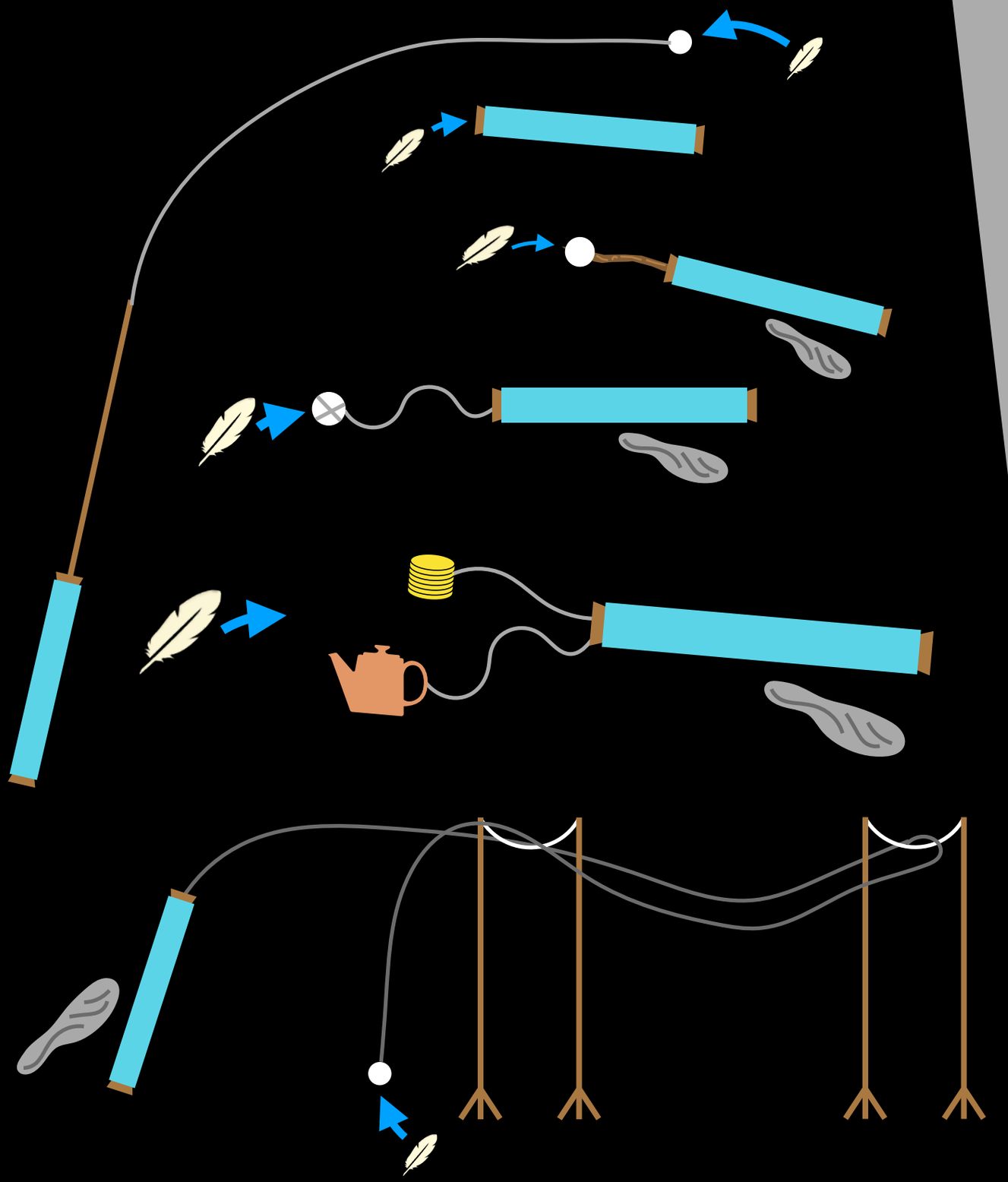
Stephen Gray:

Electrical conductivity: a chance discovery



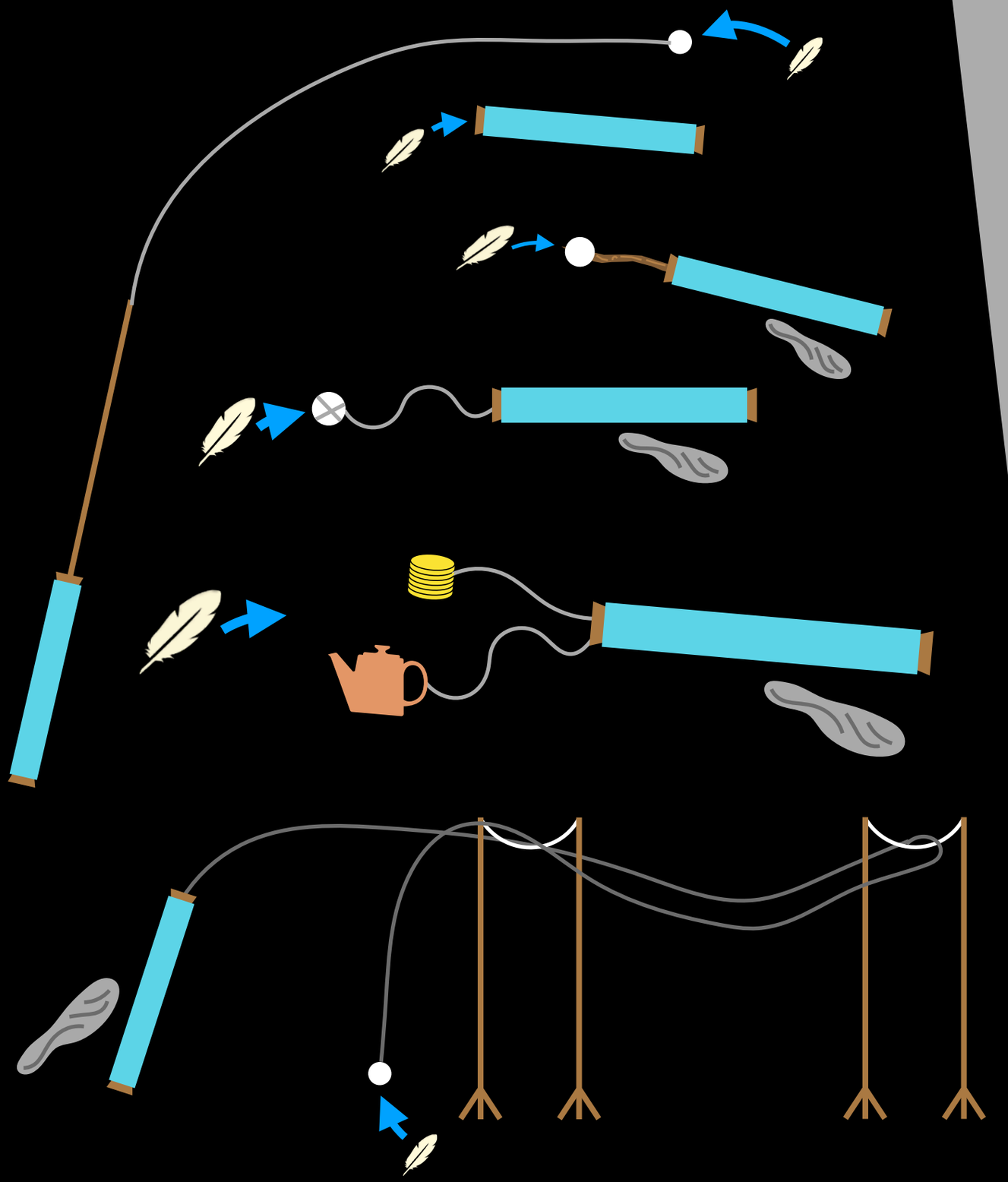
Stephen Gray:

Electrical conductivity: a chance discovery



Stephen Gray:

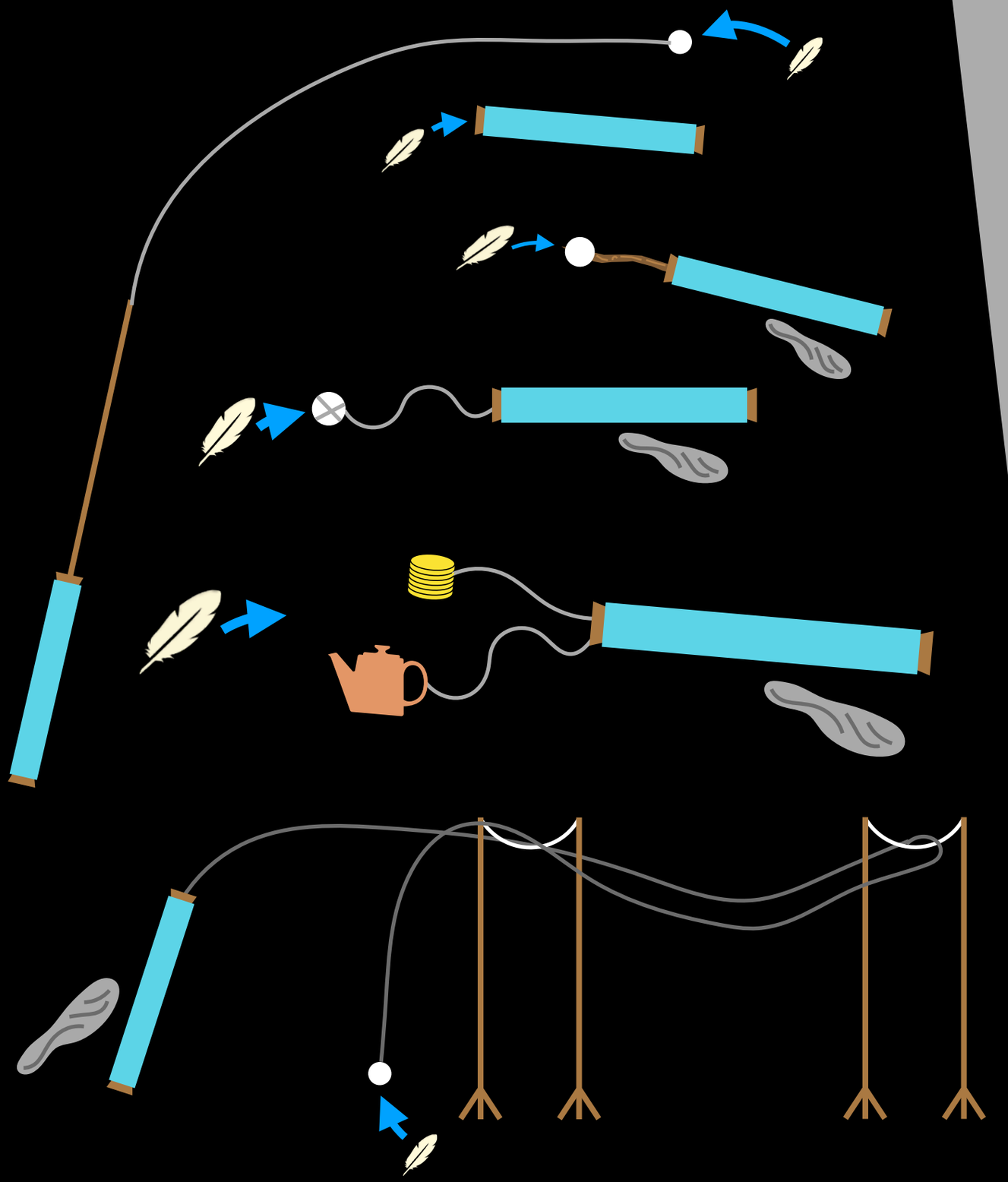
Electrical conductivity: a chance discovery



Charles du Fay:

Stephen Gray:

Electrical conductivity: a chance discovery

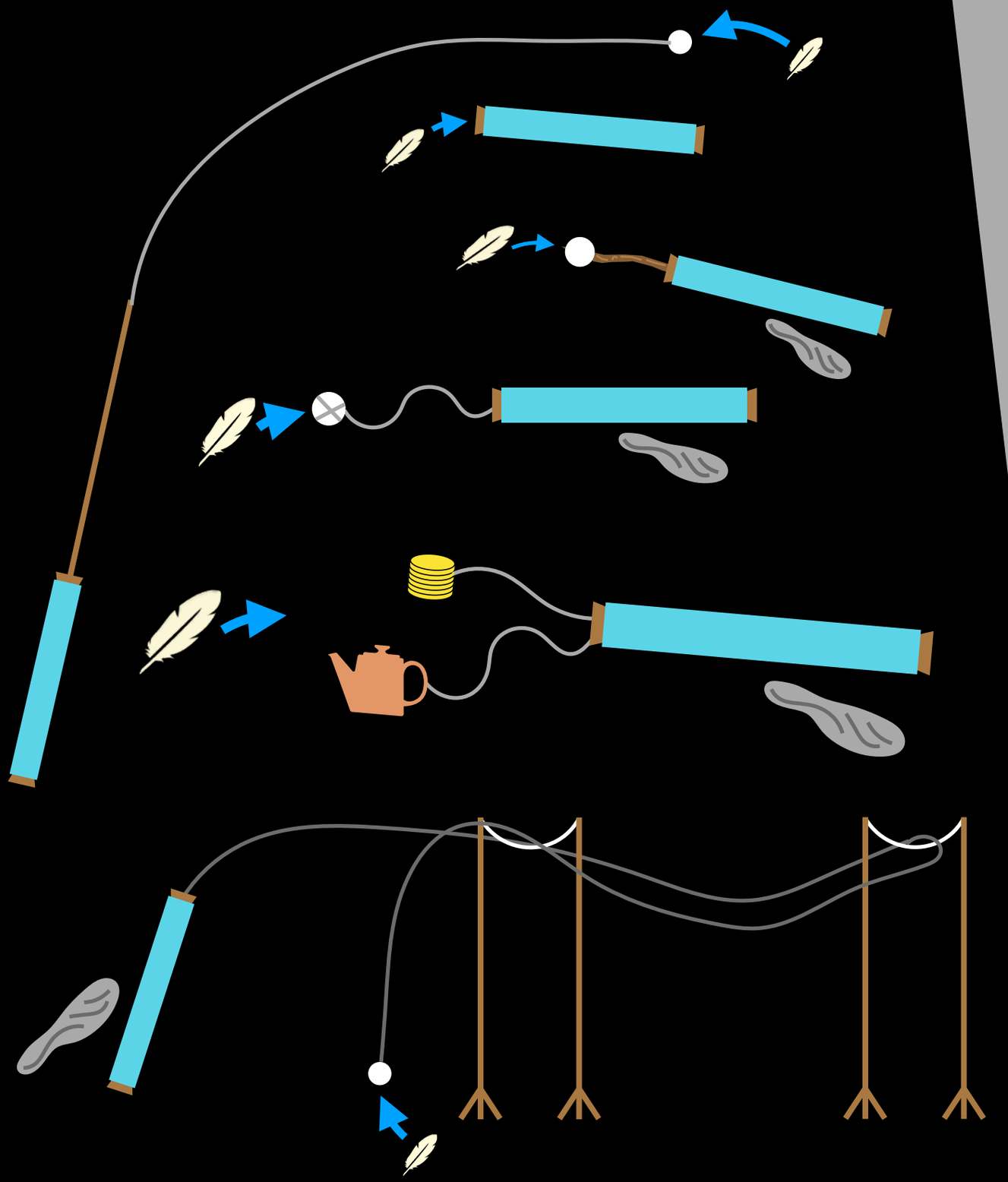


Charles du Fay:

Two kinds of electric charge:
a product of methodical investigation

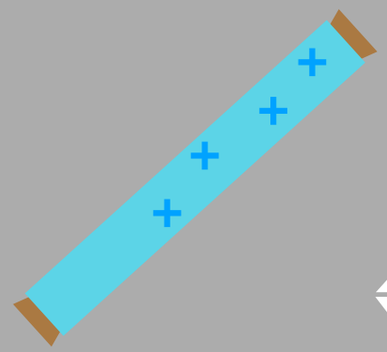
Stephen Gray:

Electrical conductivity: a chance discovery



Charles du Fay:

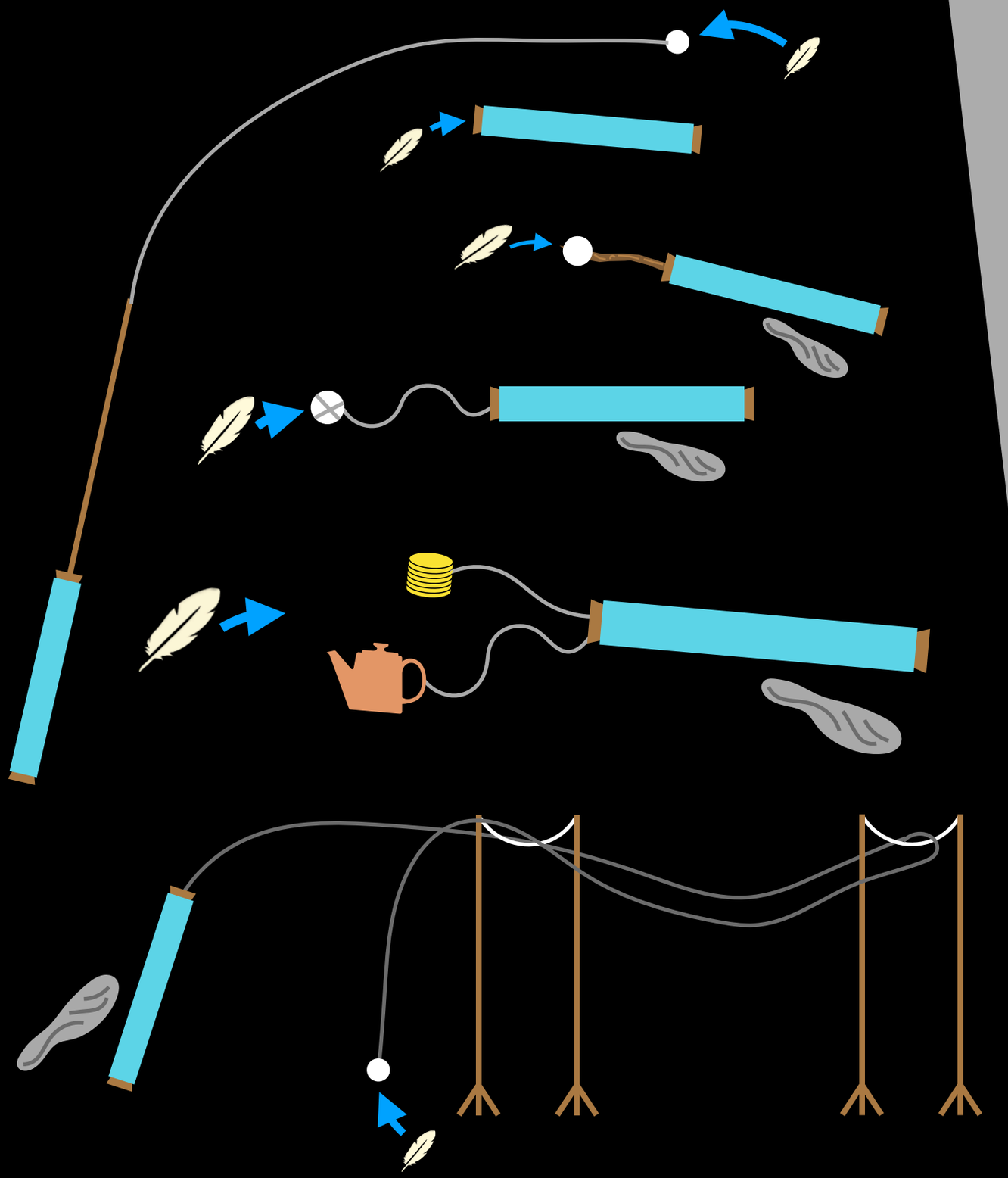
Two kinds of electric charge:
a product of methodical investigation



“Vitreous”

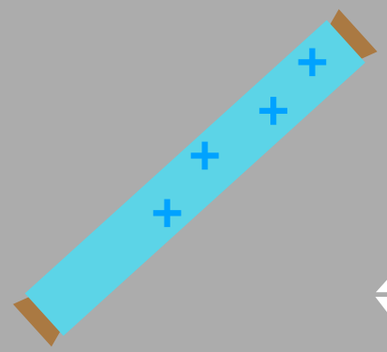
Stephen Gray:

Electrical conductivity: a chance discovery

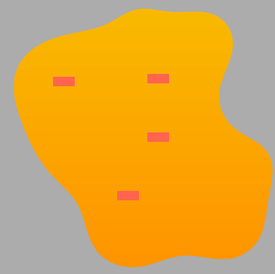


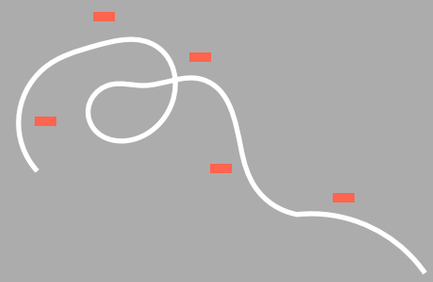
Charles du Fay:

Two kinds of electric charge:
a product of methodical investigation

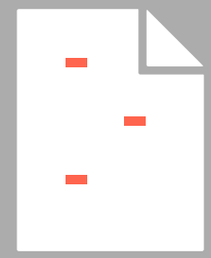


“Vitreous”

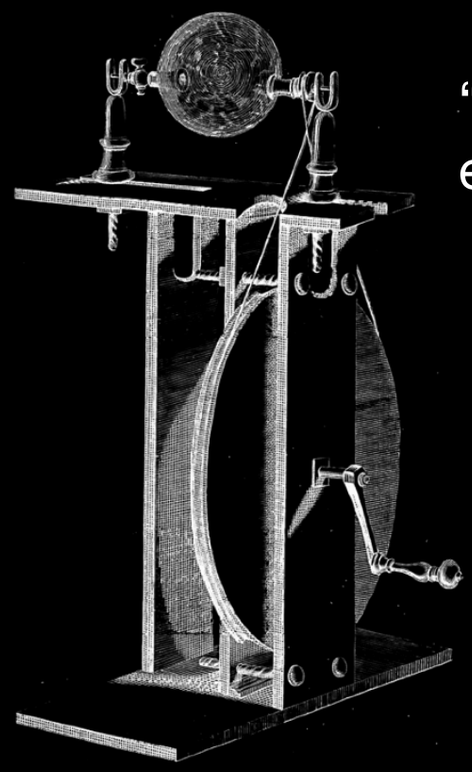




“Resinous”



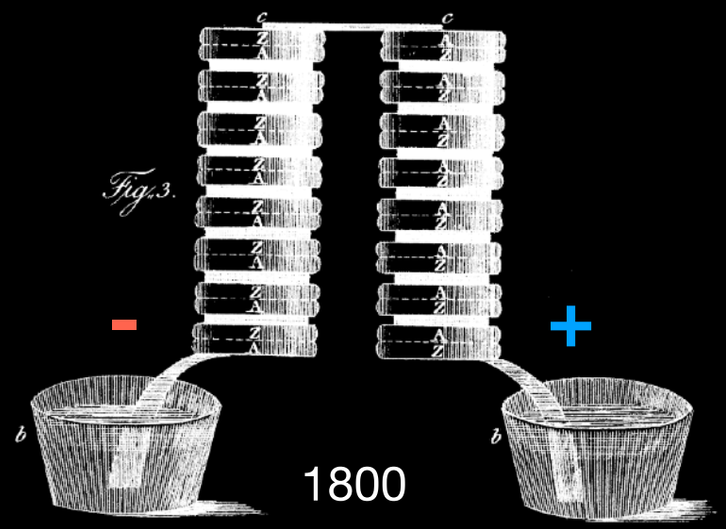
ἤλεκτρον (elektron)



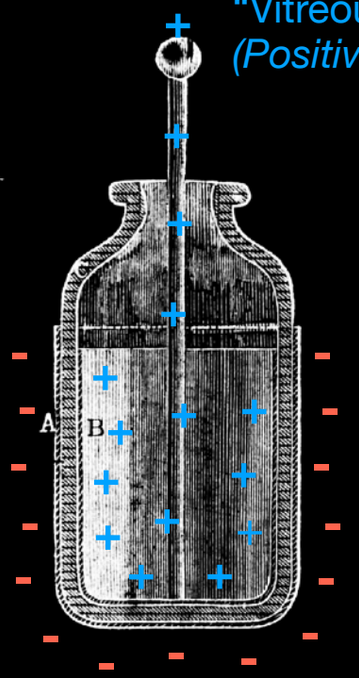
"Ordinary" electricity

~1700

"Voltaic electricity"



1800



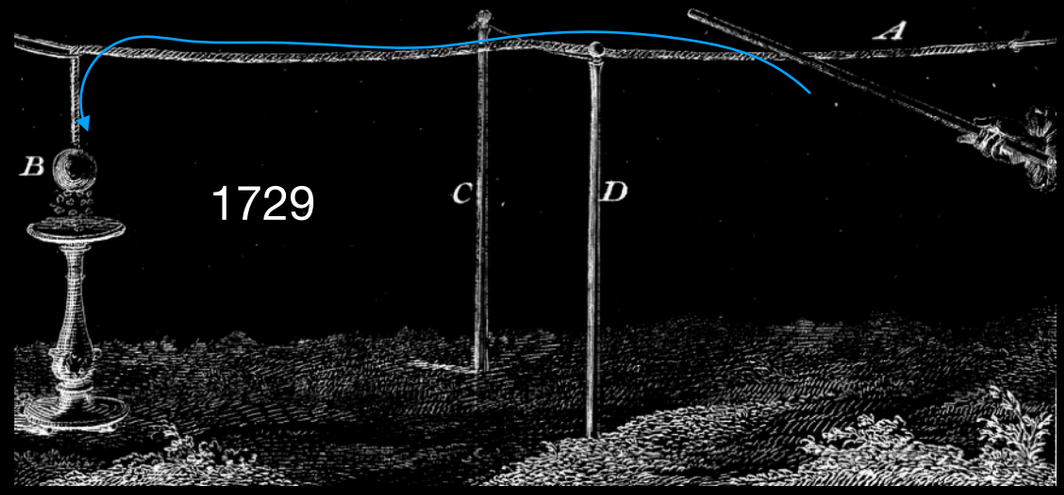
"Vitreous electricity"
(Positive)

1745

"Resinous electricity"
(Negative)

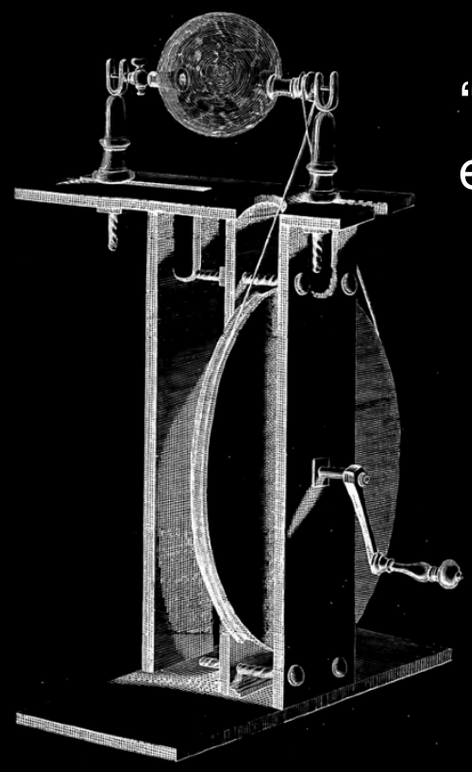
Leyden Jar: storage ("amplification")

Transportation of the "electrick vertue"



1729

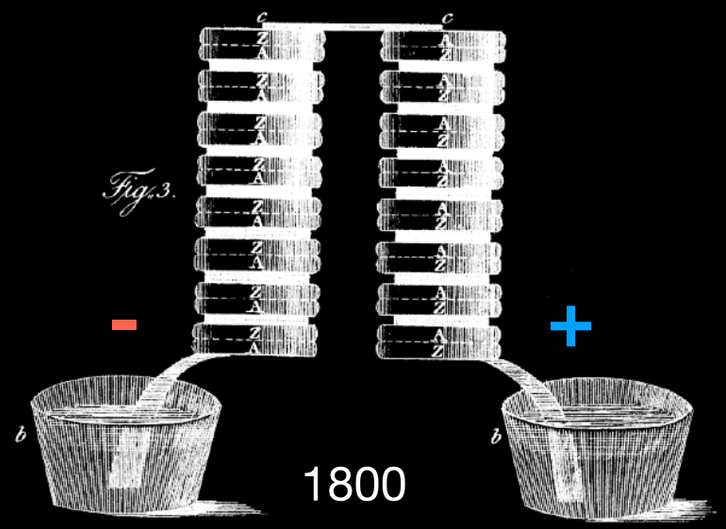
ἤλεκτρον (elektron)



"Ordinary" electricity

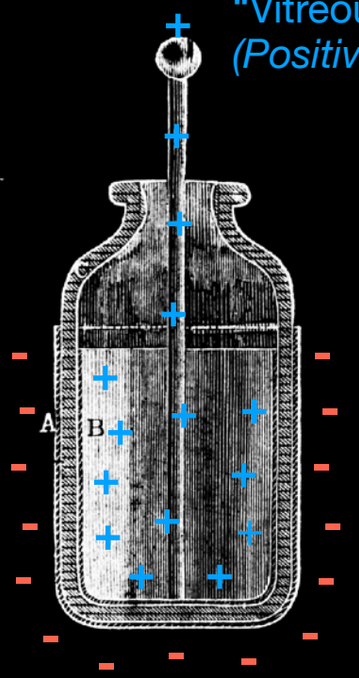
~1700

"Voltaic electricity"



1800

No precision instruments!



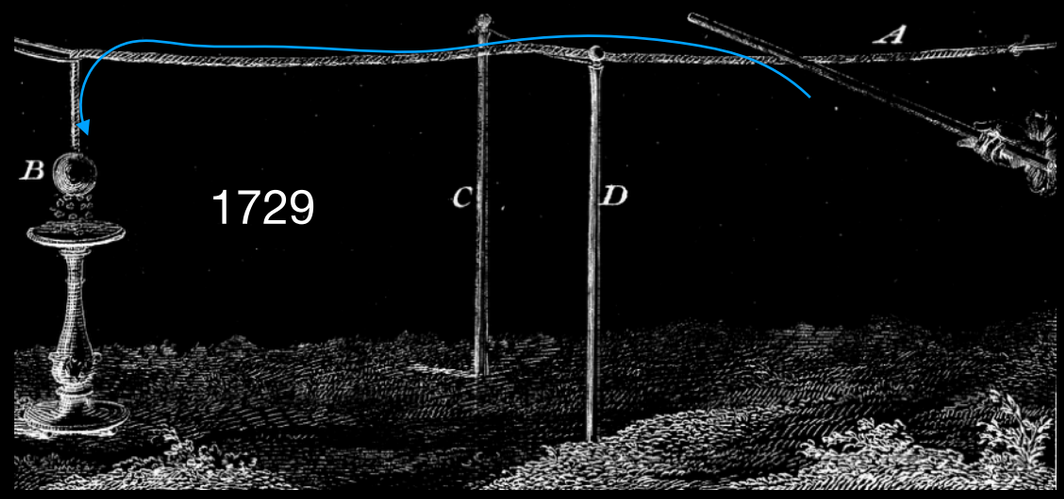
"Vitreous electricity" *(Positive)*

1745

"Resinous electricity" *(Negative)*

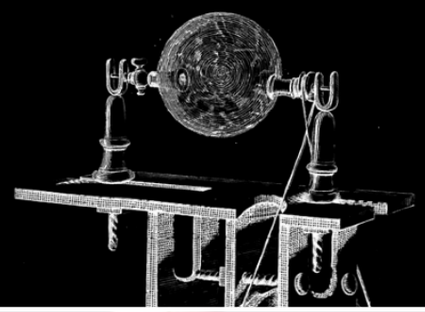
Leyden Jar: storage ("amplification")

Transportation of the "electrick vertue"



1729

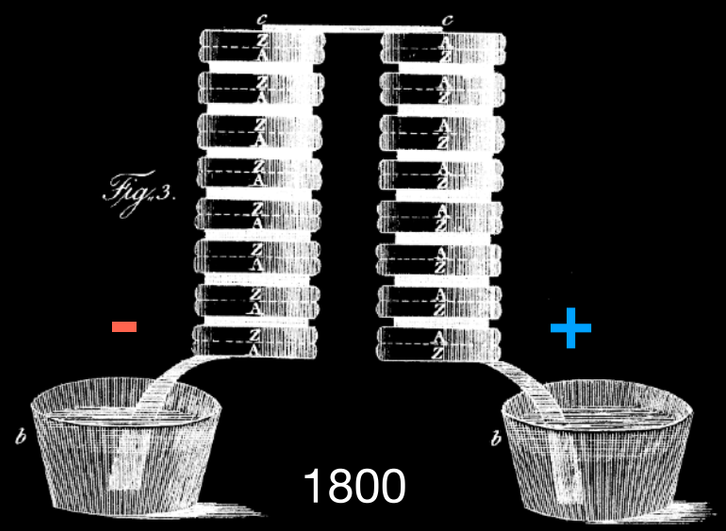
ἤλεκτρον (elektron)



"Ordinary" electricity

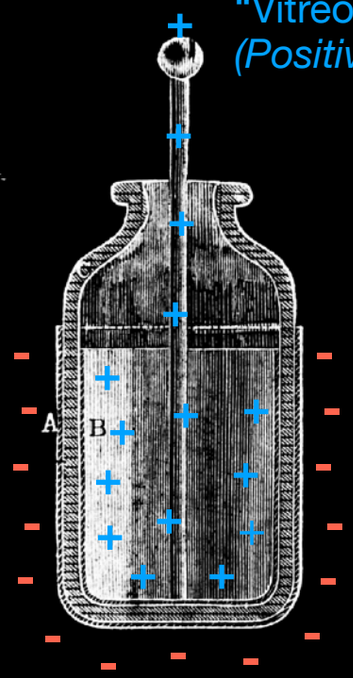
~1700

"Voltaic electricity"



1800

No precision instruments!



"Vitreous electricity" *(Positive)*

1745

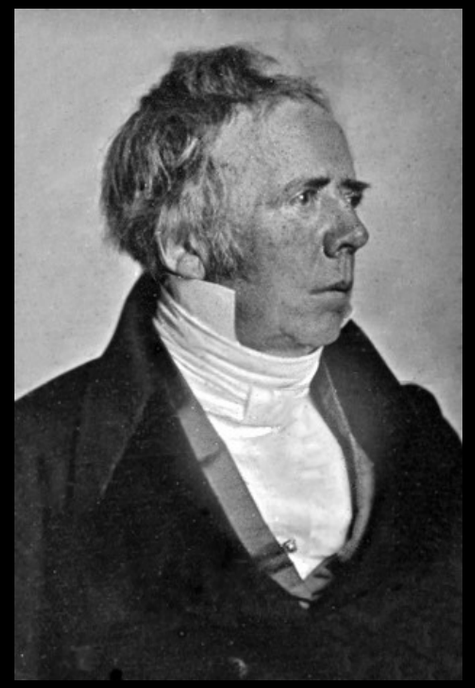
"Resinous elec *(Negative)*

Leyden Jar: storage ("amplification")

Theophrastus (300 BC):
"This stone, too, has the power of attraction."

Hans Christian Ørsted

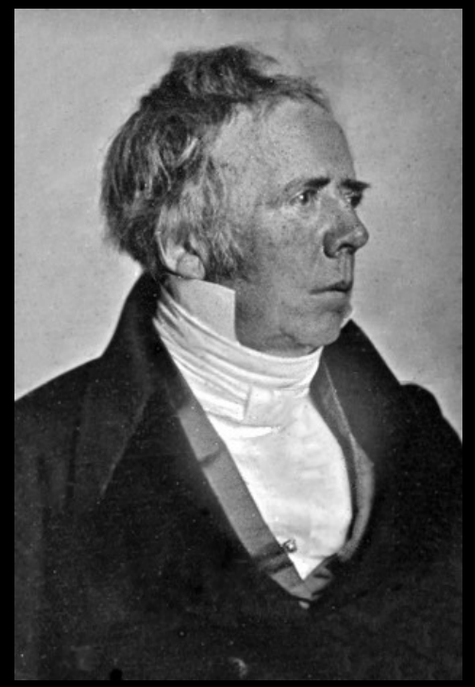
Physicist, chemist



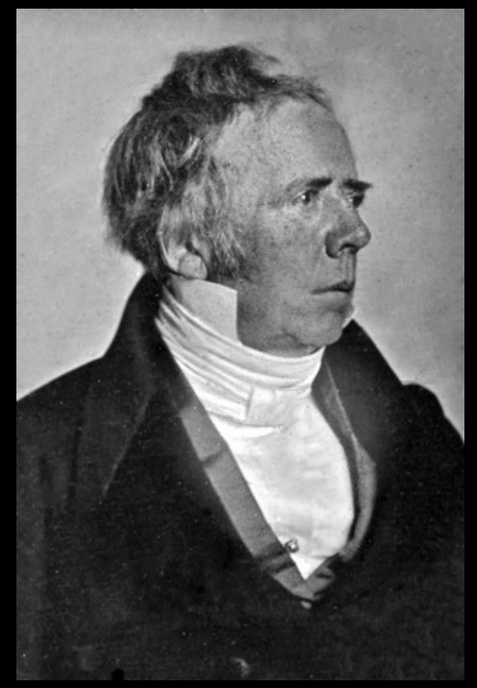
Hans Christian Ørsted

Physicist, chemist

Thesis at Copenhagen: “The Architectonics of Natural Metaphysics”



Hans Christian Ørsted

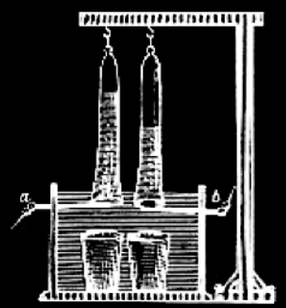


Physicist, chemist

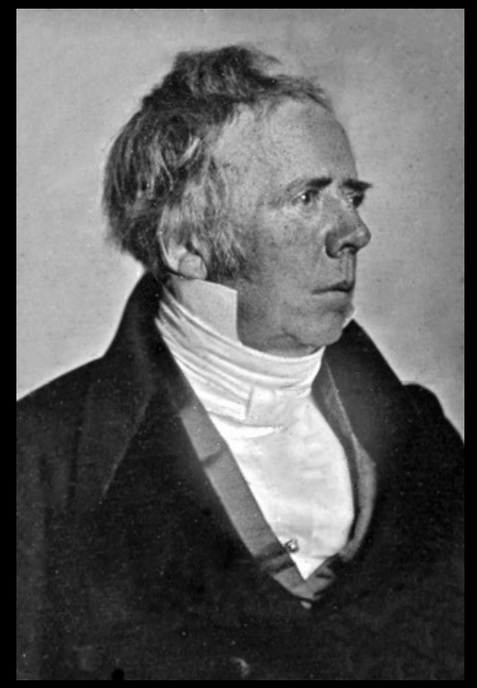
Thesis at Copenhagen: “The Architectonics of Natural Metaphysics”

3-year travel scholarship:
Scientific tour around Europe

J. Ritter



Hans Christian Ørsted

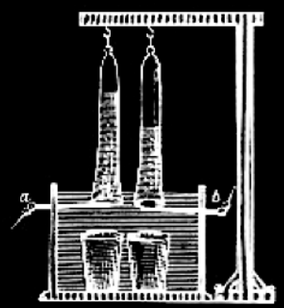


Physicist, chemist

Thesis at Copenhagen: “The Architectonics of Natural Metaphysics”

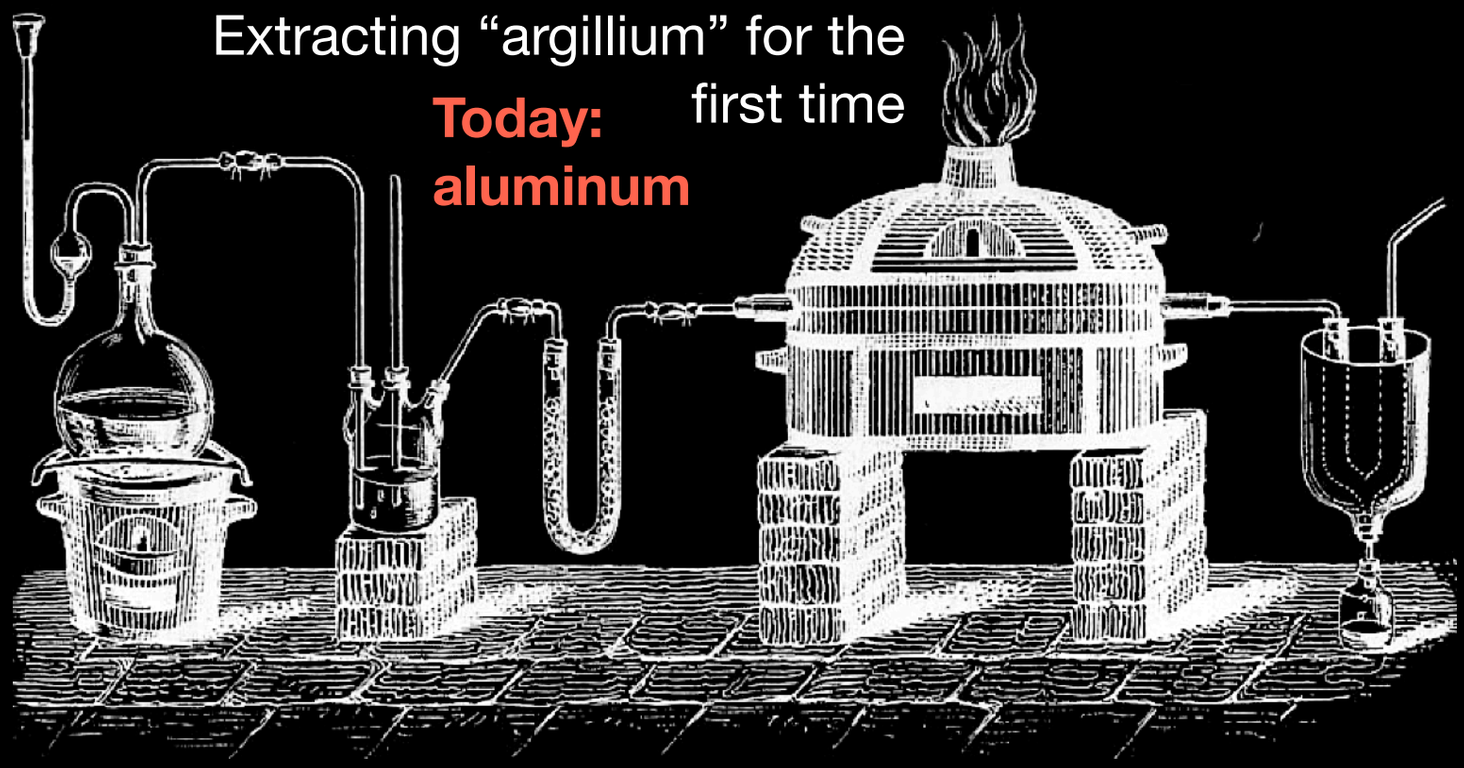
3-year travel scholarship:
Scientific tour around Europe

J. Ritter



Extracting “argillium” for the first time

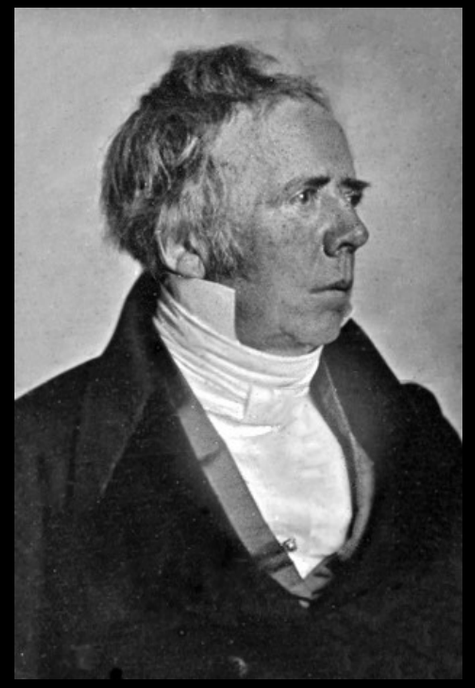
Today: aluminum



Hans Christian Ørsted

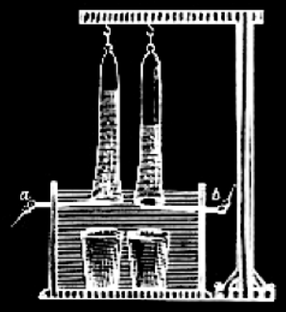
Physicist, chemist

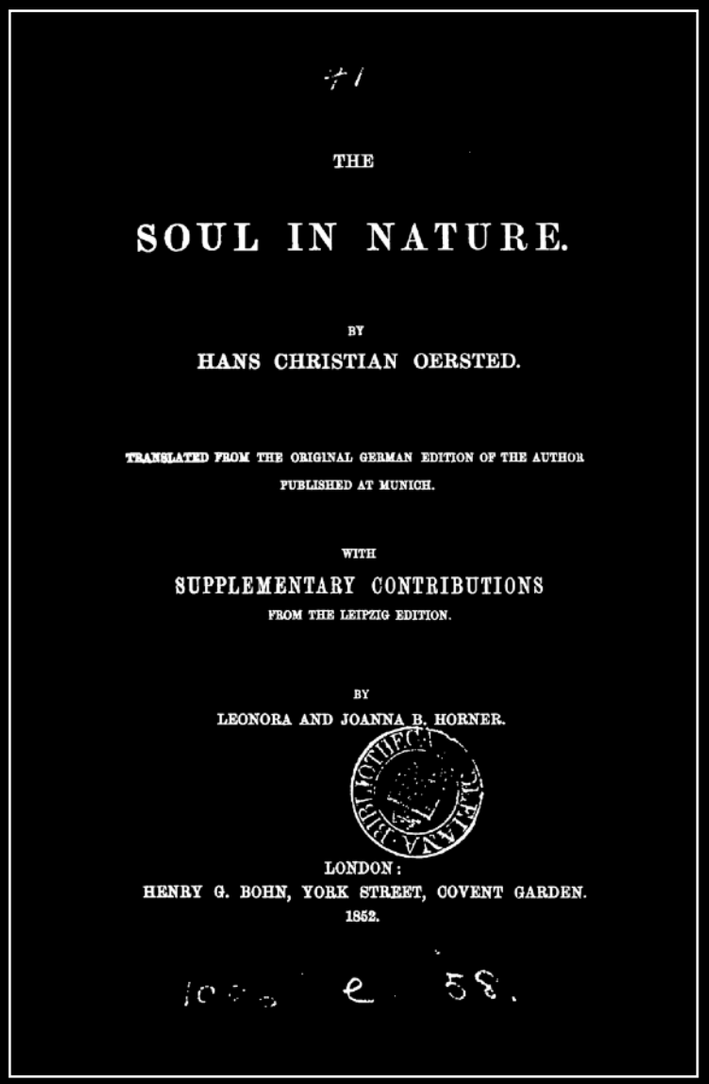
Thesis at Copenhagen: “The Architectonics of Natural Metaphysics”



3-year travel scholarship:
Scientific tour around Europe

J. Ritter





THE

SOUL IN NATURE.

BY

HANS CHRISTIAN OERSTED.

TRANSLATED FROM THE ORIGINAL GERMAN EDITION OF THE AUTHOR PUBLISHED AT MUNICH.

WITH

SUPPLEMENTARY CONTRIBUTIONS

FROM THE LEIPZIG EDITION.

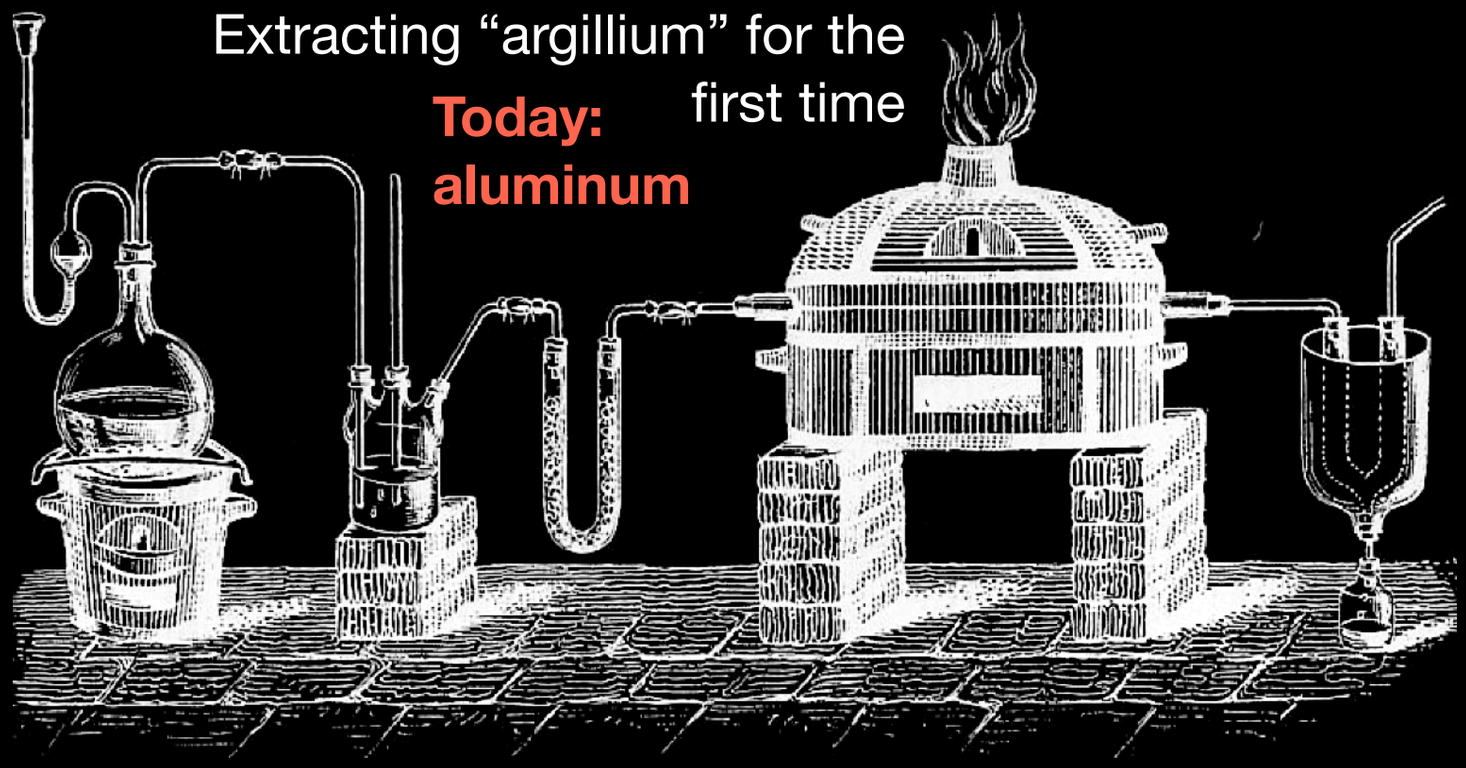
BY

LEONORA AND JOANNA B. HORNER.

LONDON:
HENRY G. BOHN, YORK STREET, COVENT GARDEN.
1852.

Extracting “argillium” for the first time

Today: aluminum



Electricity and magnetism around 1820

Electricity and magnetism around 1820

“The reasons for and against an essential resemblance between magnetism and electricity might seem to be nearly balanced.”

Electricity and magnetism around 1820

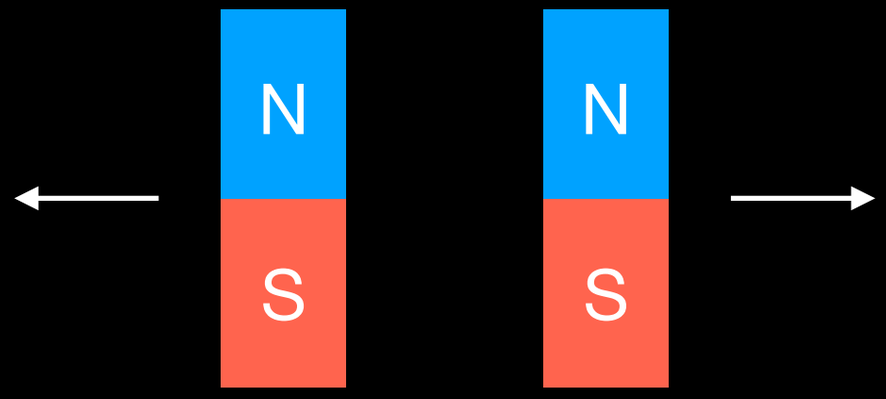
“The reasons for and against an essential resemblance between magnetism and electricity might seem to be nearly balanced.”

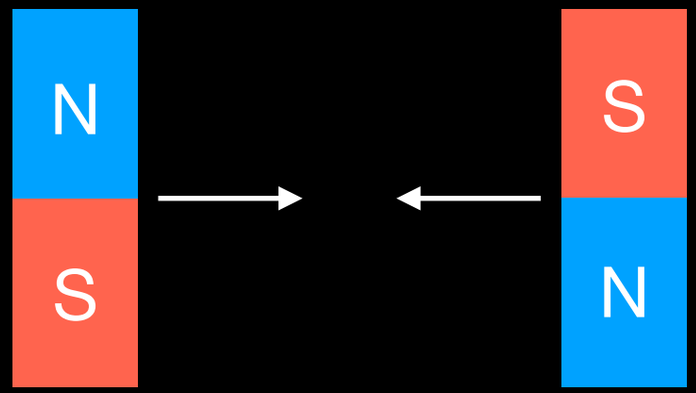
“Each of them consists of two powers, or directions of powers, of an opposite nature, submitted to the same laws of attraction and repulsion.”

Electricity and magnetism around 1820

“The reasons for and against an essential resemblance between magnetism and electricity might seem to be nearly balanced.”

“Each of them consists of two powers, or directions of powers, of an opposite nature, submitted to the same laws of attraction and repulsion.”

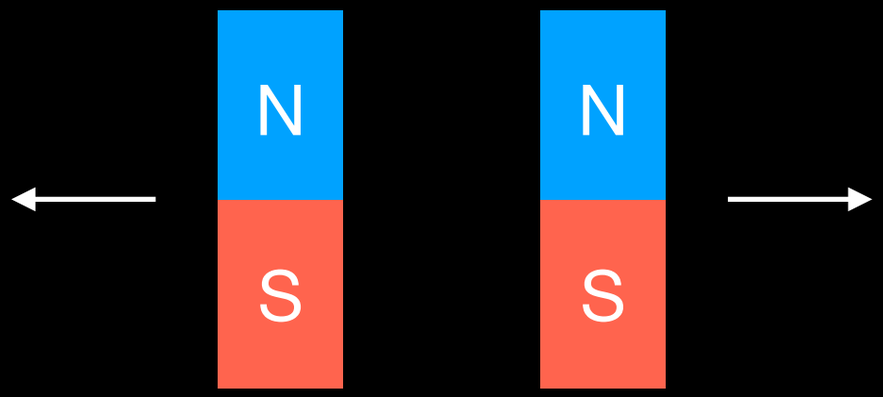


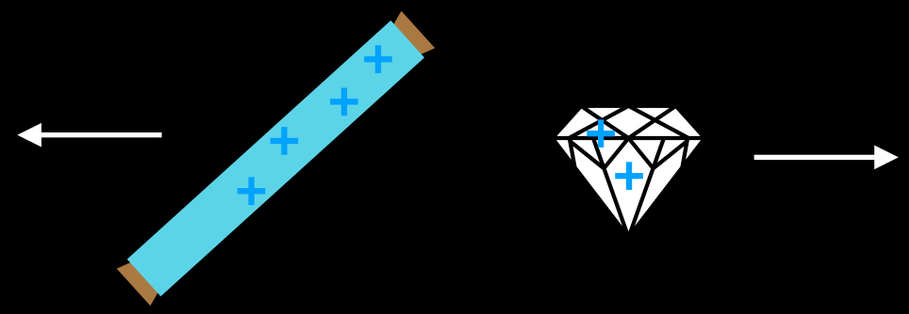


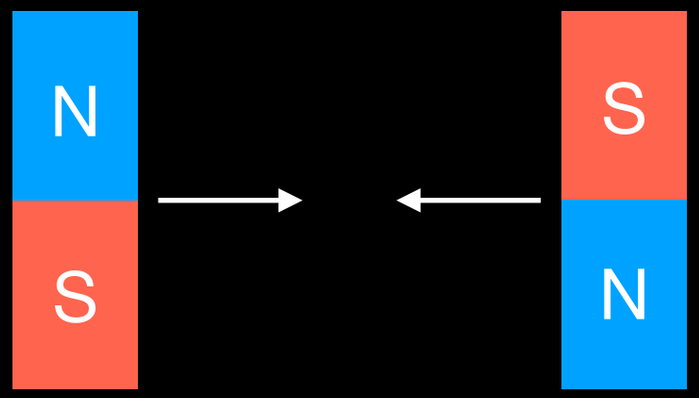
Electricity and magnetism around 1820

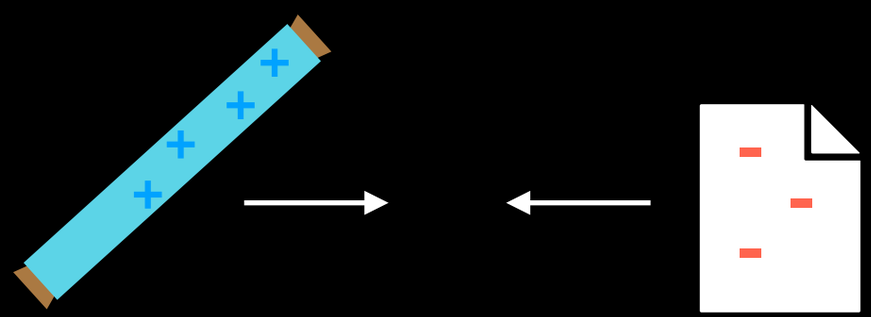
“The reasons for and against an essential resemblance between magnetism and electricity might seem to be nearly balanced.”

“Each of them consists of two powers, or directions of powers, of an opposite nature, submitted to the same laws of attraction and repulsion.”





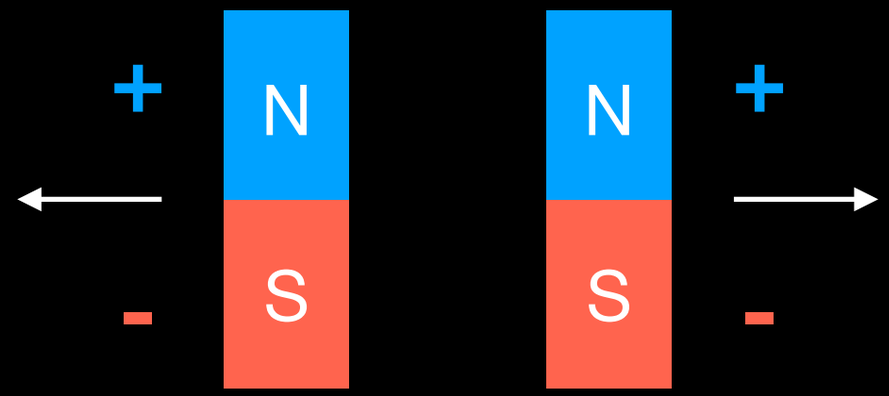


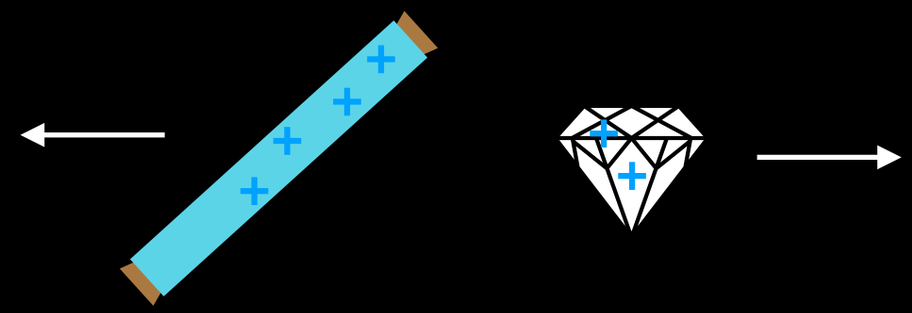


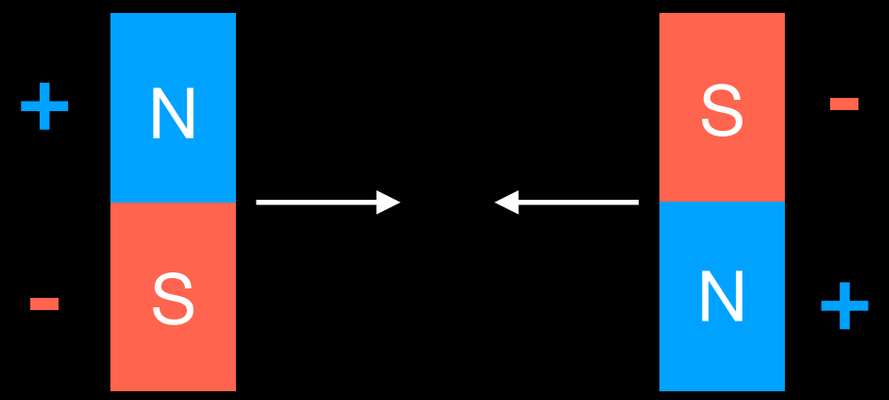
Electricity and magnetism around 1820

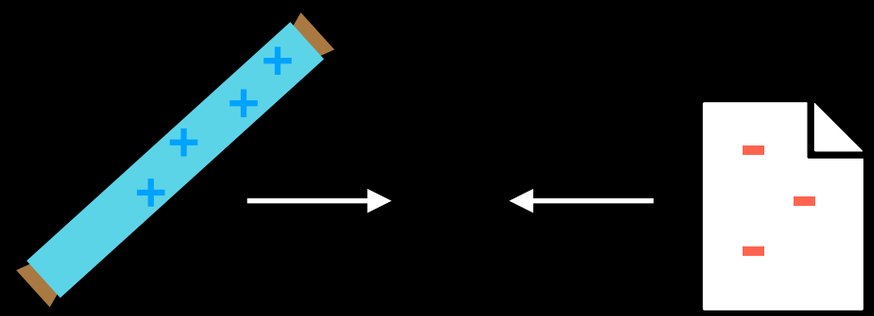
“The reasons for and against an essential resemblance between magnetism and electricity might seem to be nearly balanced.”

“Each of them consists of two powers, or directions of powers, of an opposite nature, submitted to the same laws of attraction and repulsion.”









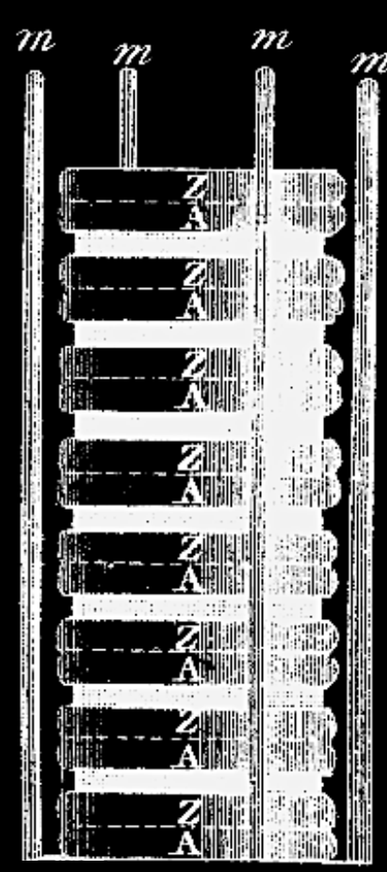
Electricity and magnetism around 1820

“If we imagine a Voltaic pile, it would have the most perfect analogy with a magnet.”

N

S

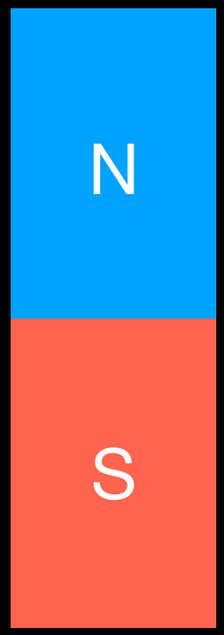
+

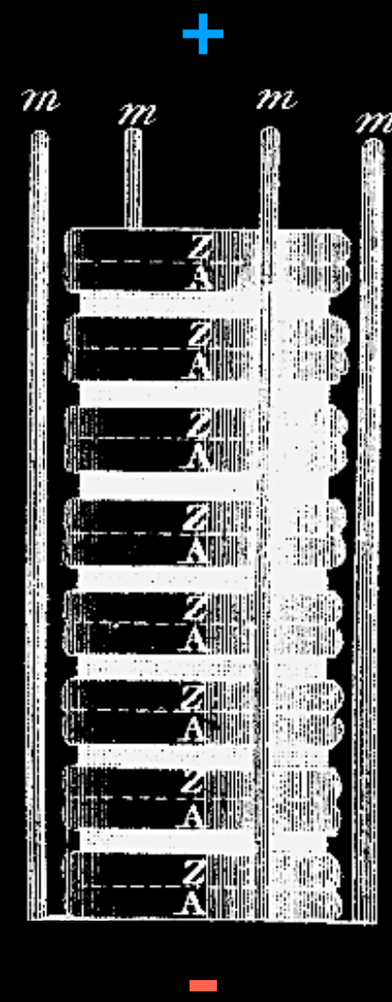


−

Electricity and magnetism around 1820

“If we imagine a Voltaic pile, it would have the most perfect analogy with a magnet.”

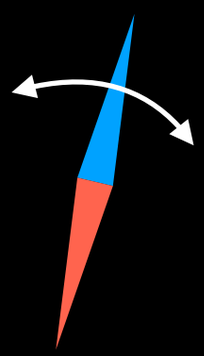


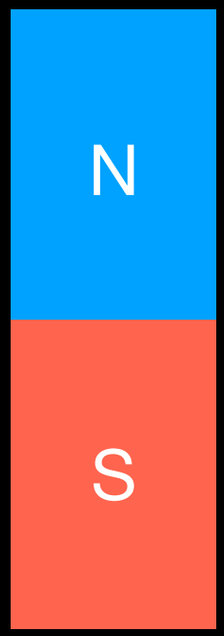


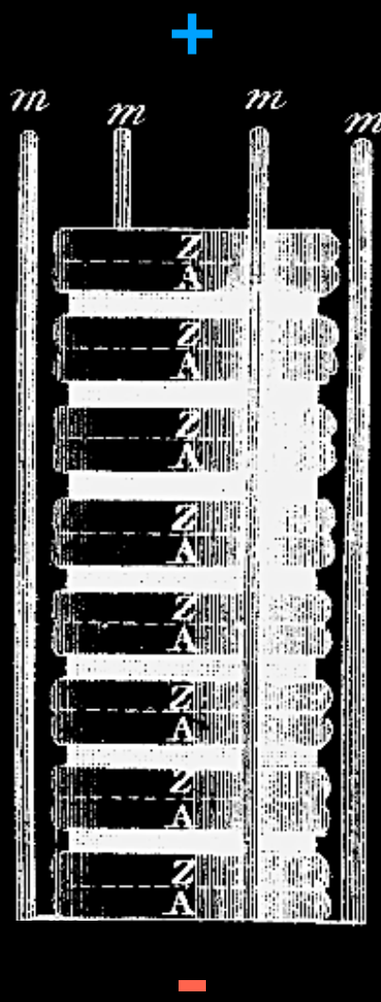
“It must be tested whether electricity in its most latent state has any action on the magnet as such.”

Electricity and magnetism around 1820

“If we imagine a Voltaic pile, it would have the most perfect analogy with a magnet.”



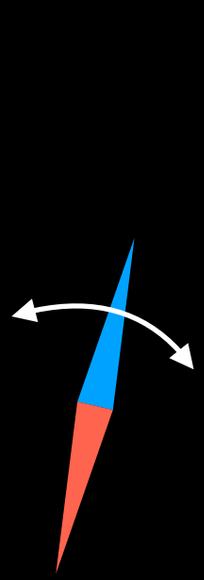


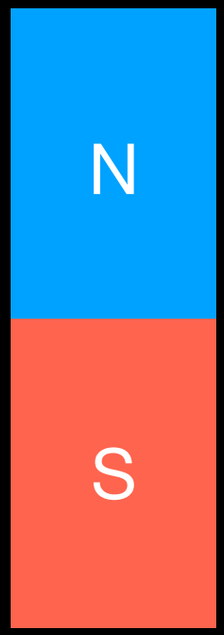


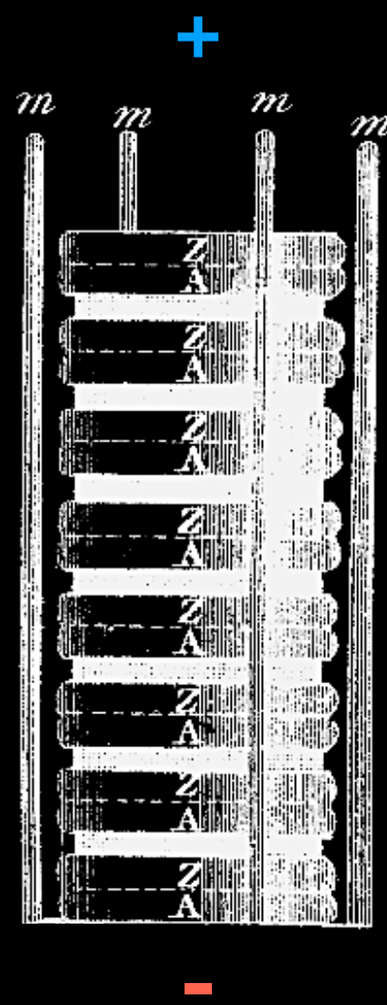
“It must be tested whether electricity in its most latent state has any action on the magnet as such.”

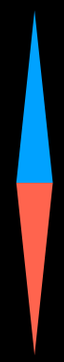
Electricity and magnetism around 1820

“If we imagine a Voltaic pile, it would have the most perfect analogy with a magnet.”





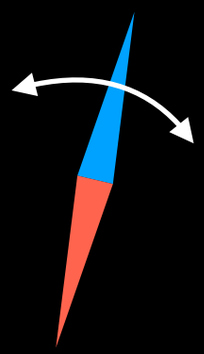


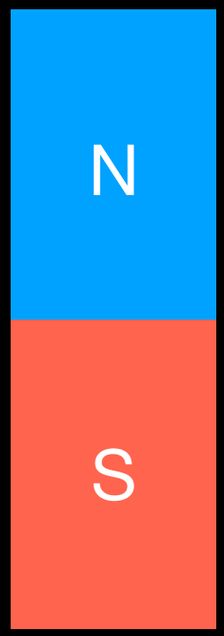


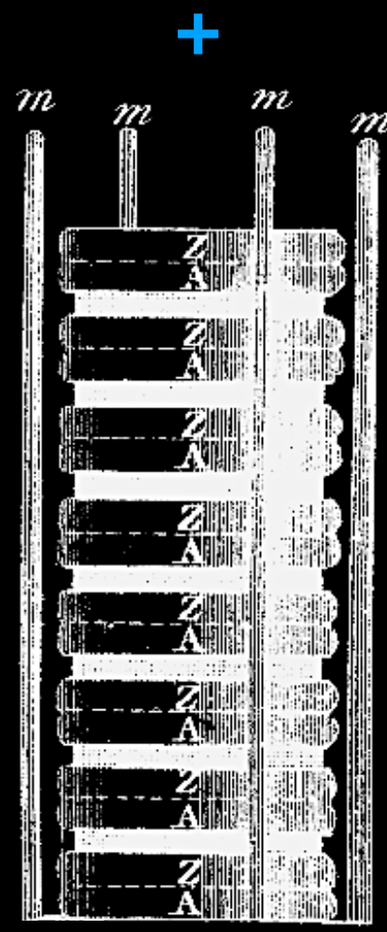
“It must be tested whether electricity in its most latent state has any action on the magnet as such.”

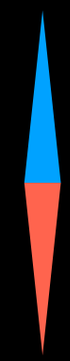
Electricity and magnetism around 1820

“If we imagine a Voltaic pile, it would have the most perfect analogy with a magnet.”









“It must be tested whether electricity in its most latent state has any action on the magnet as such.”

… but nothing!

Electricity meets magnetism

Electricity meets magnetism

“I called attention to the variations of the magnetic needle during a thunderstorm.”

Electricity meets magnetism

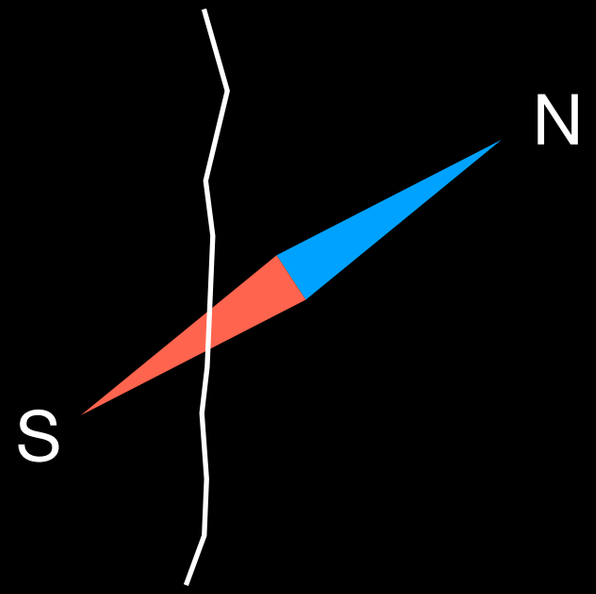
“I called attention to the variations of the magnetic needle during a thunderstorm.”

“Since I expected the greatest effect from a discharge associated with incandescence, I inserted in the circuit a very fine platinum wire above the place where the needle was located.”

Electricity meets magnetism

“I called attention to the variations of the magnetic needle during a thunderstorm.”

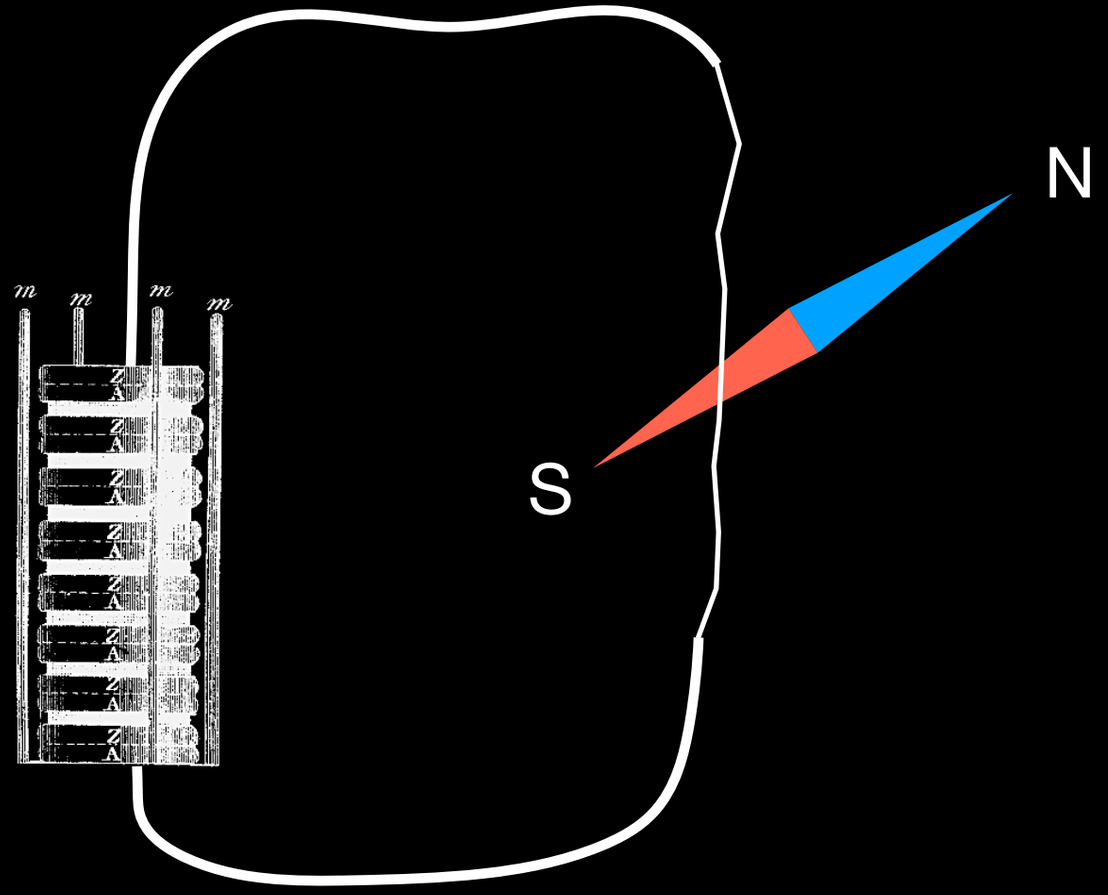
“Since I expected the greatest effect from a discharge associated with incandescence, I inserted in the circuit a very fine platinum wire above the place where the needle was located.”



Electricity meets magnetism

“I called attention to the variations of the magnetic needle during a thunderstorm.”

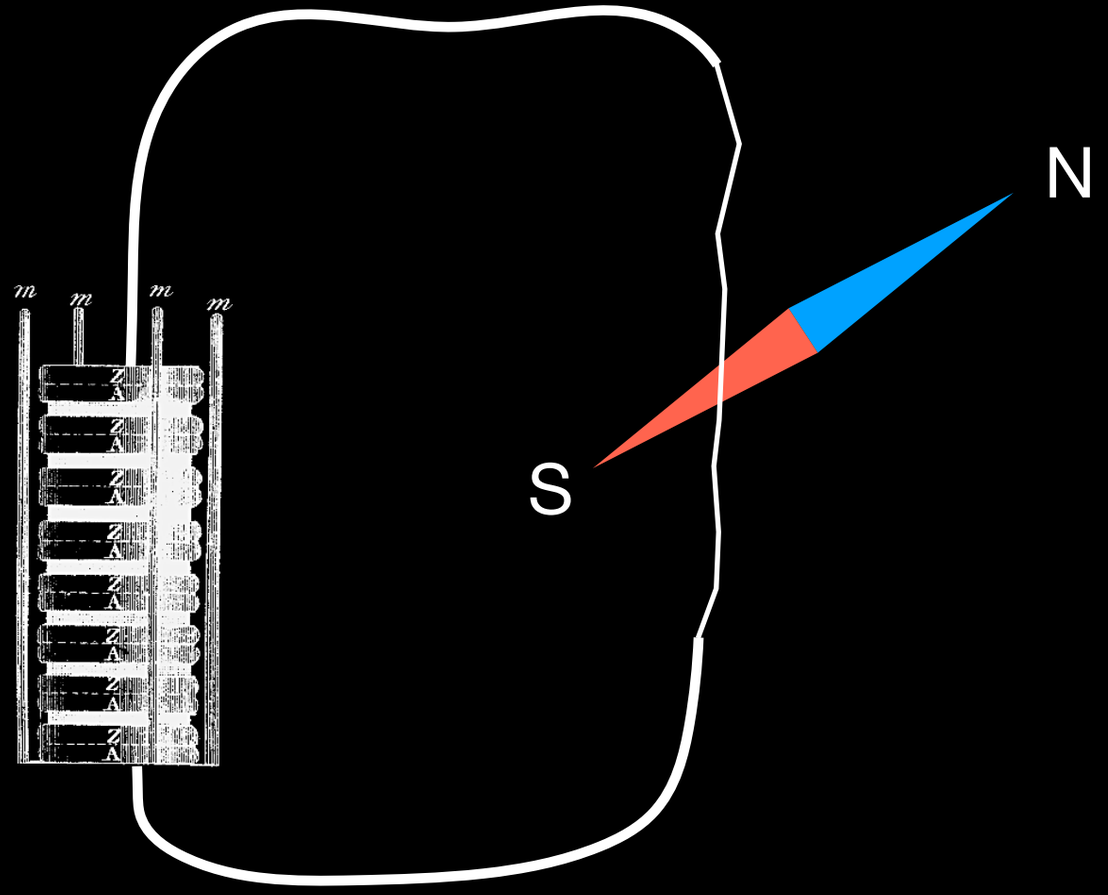
“Since I expected the greatest effect from a discharge associated with incandescence, I inserted in the circuit a very fine platinum wire above the place where the needle was located.”

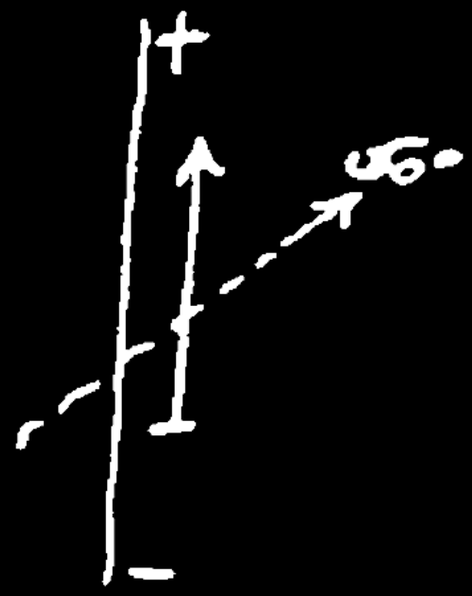


Electricity meets magnetism

"I called attention to the variations of the magnetic needle during a thunderstorm."

"Since I expected the greatest effect from a discharge associated with incandescence, I inserted in the circuit a very fine platinum wire above the place where the needle was located."



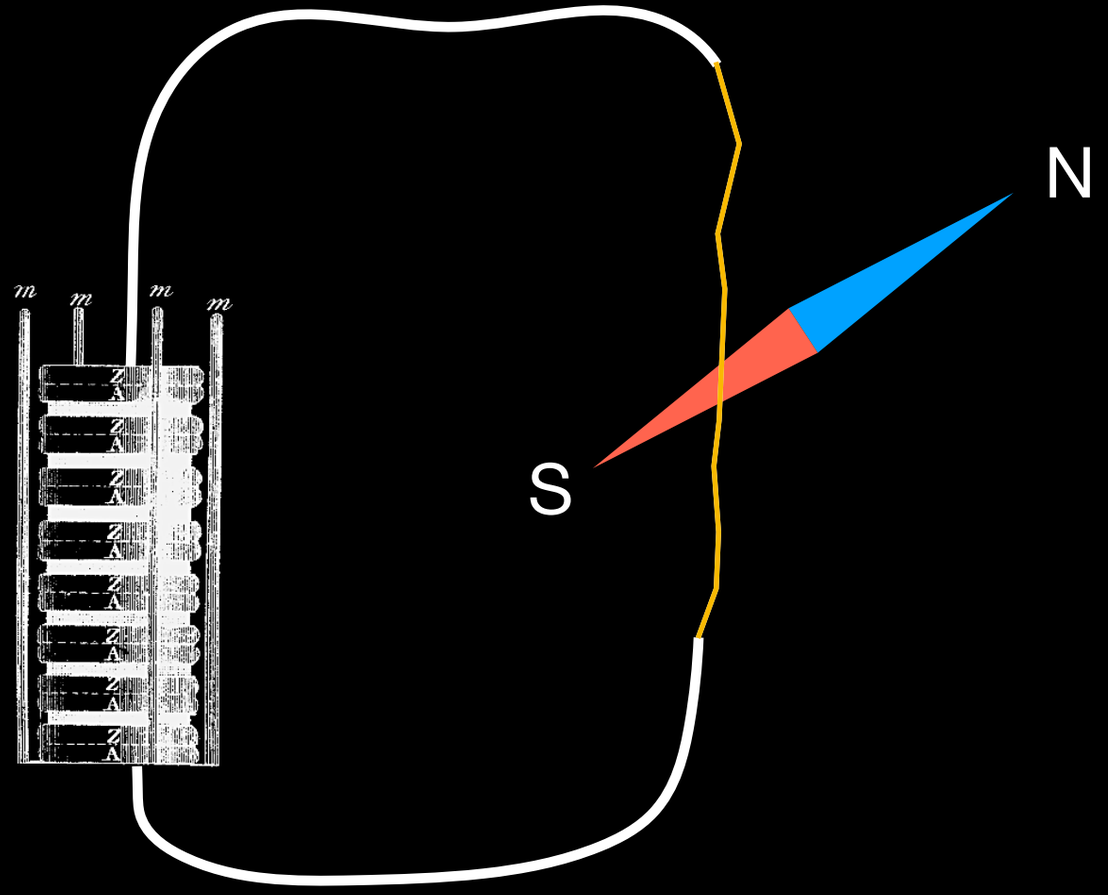


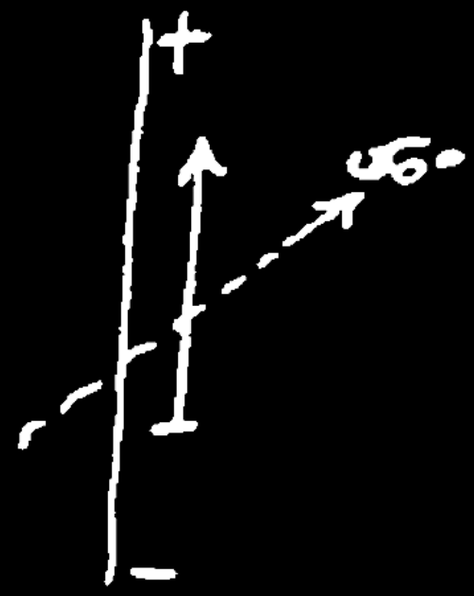
From Ørsted's notebook

Electricity meets magnetism

"I called attention to the variations of the magnetic needle during a thunderstorm."

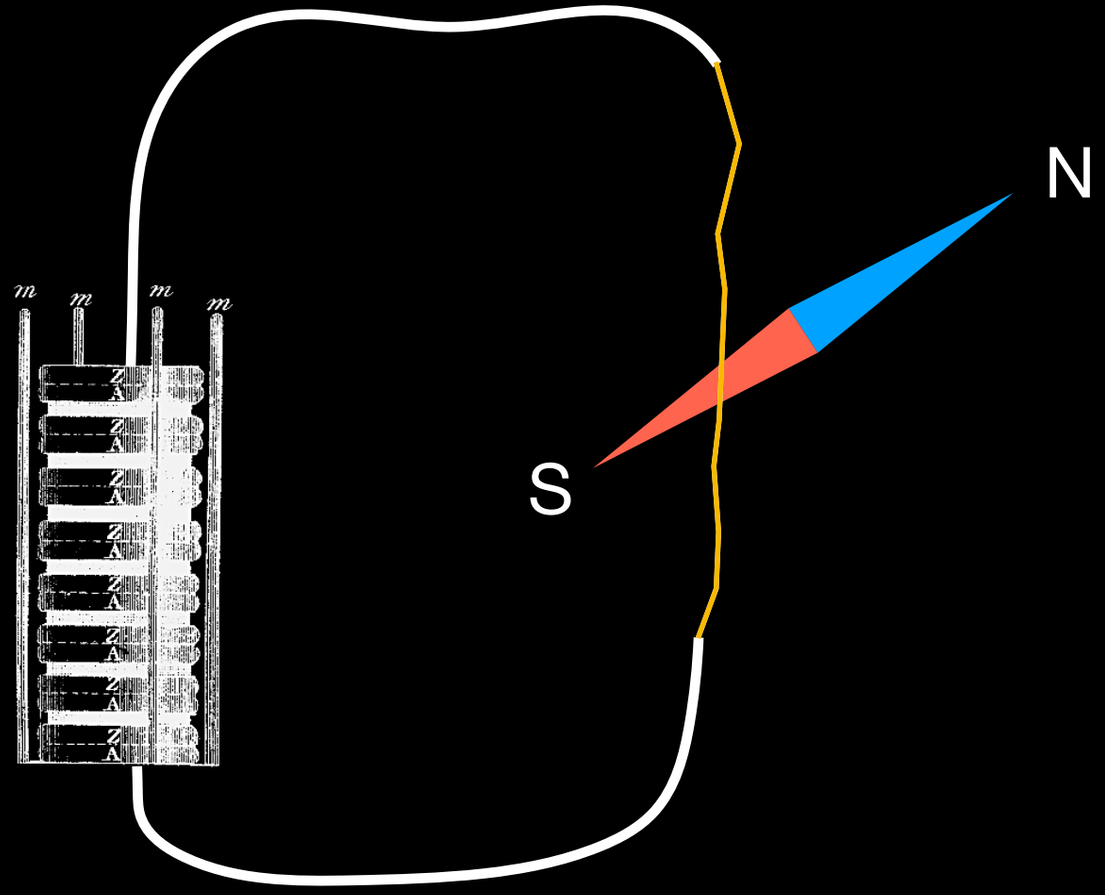
"Since I expected the greatest effect from a discharge associated with incandescence, I inserted in the circuit a very fine platinum wire above the place where the needle was located."

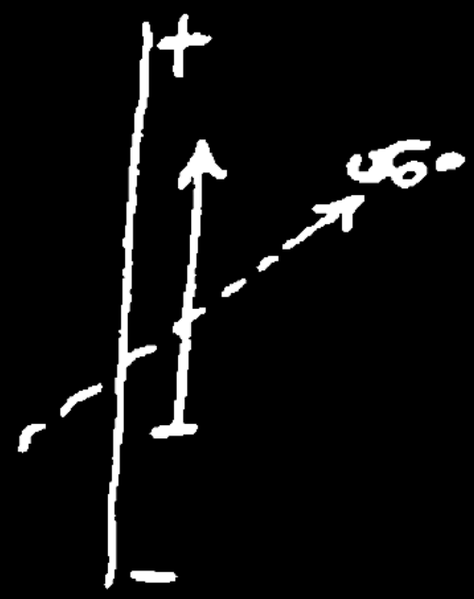




From Ørsted's notebook

Electricity meets magnetism

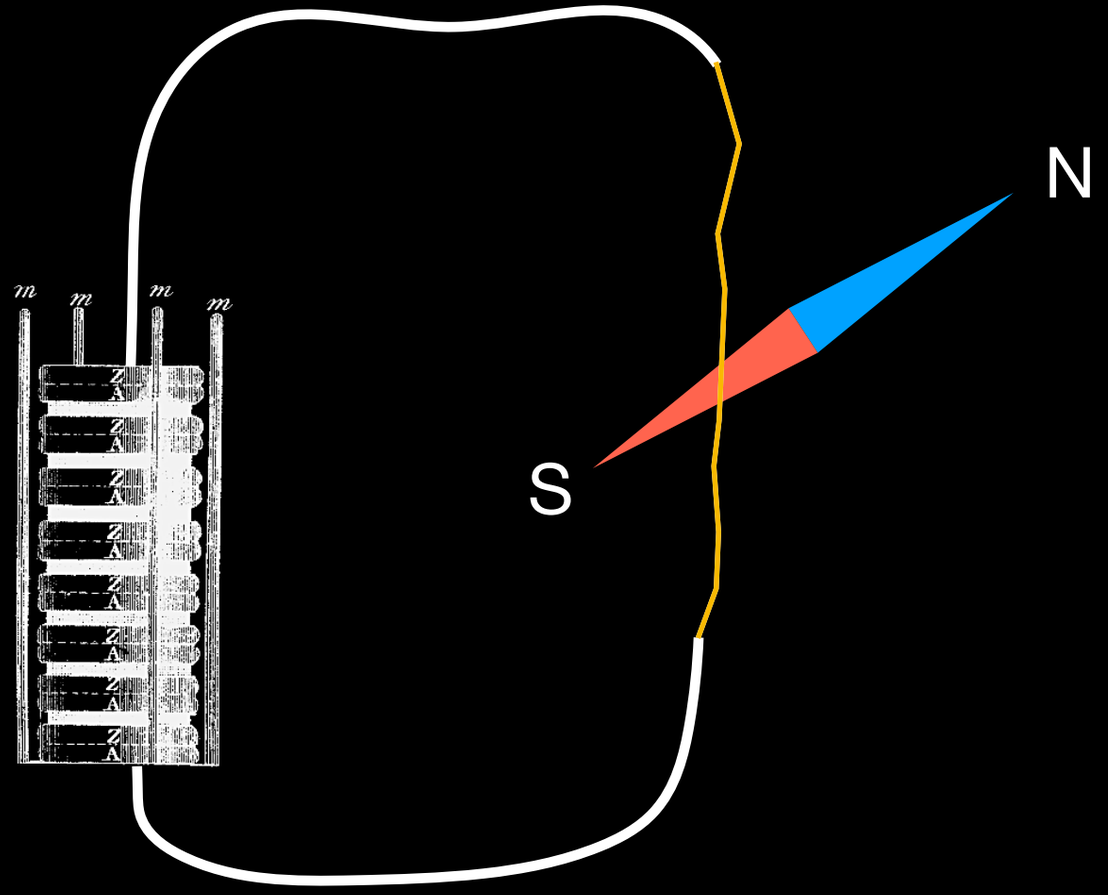


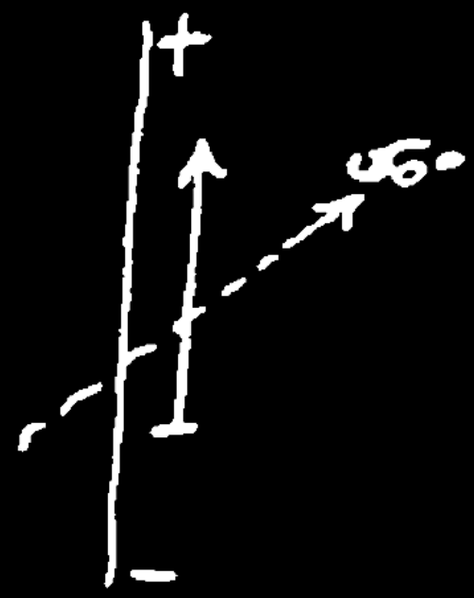


From Ørsted's notebook

Electricity meets magnetism

“The magnetic needle, though included in a box, was disturbed; but the effect was very feeble, and no particular law could immediately be observed from it.”

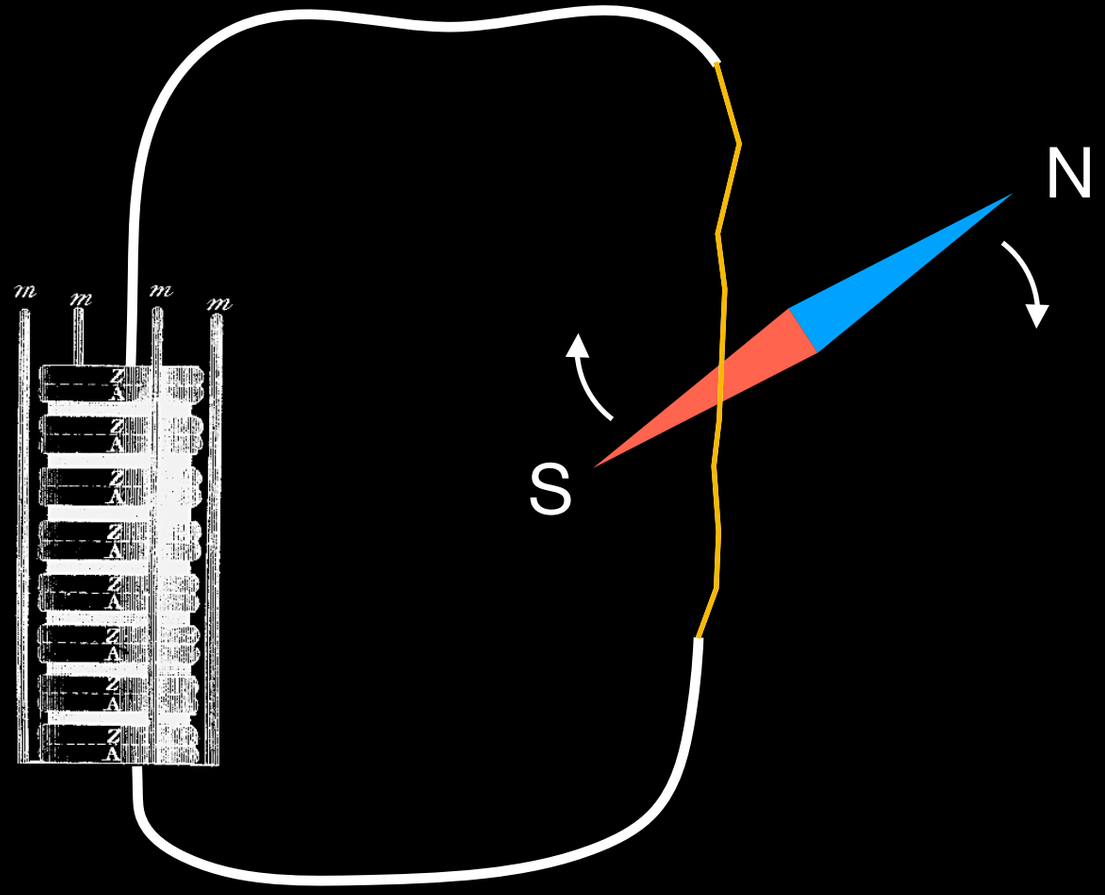


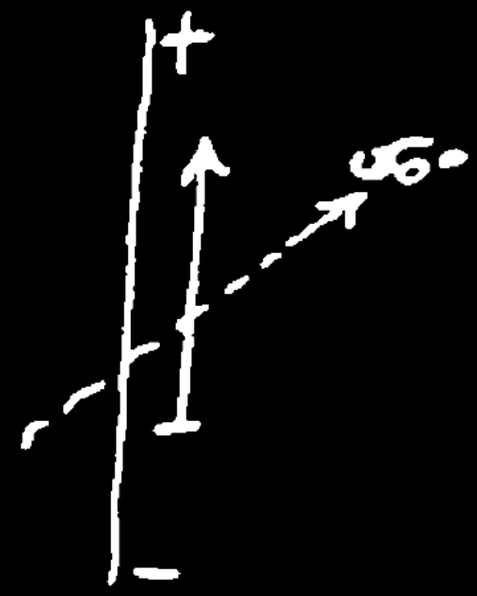


From Ørsted’s notebook

Electricity meets magnetism

“The magnetic needle, though included in a box, was disturbed; but the effect was very feeble, and no particular law could immediately be observed from it.”



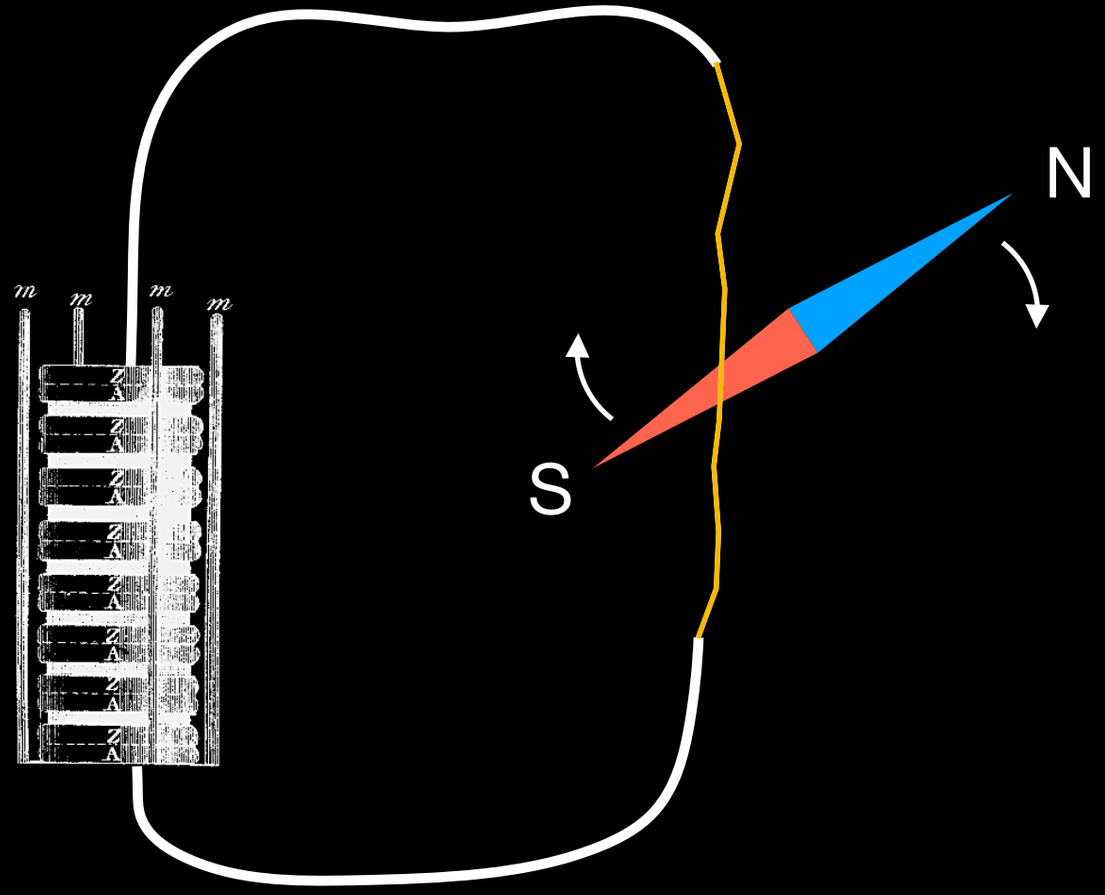


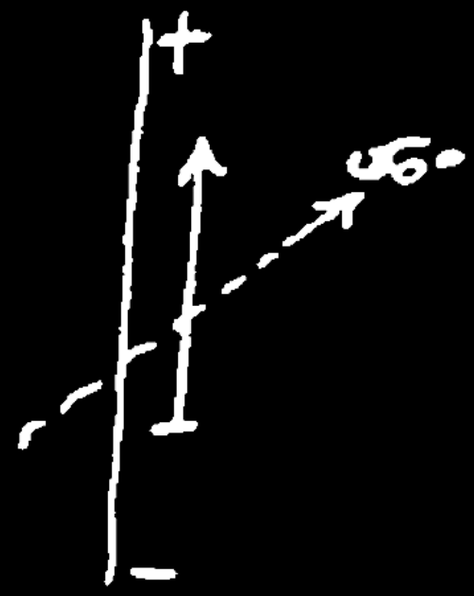
From Ørsted’s notebook

Electricity meets magnetism

“The magnetic needle, though included in a box, was disturbed; but the effect was very feeble, and no particular law could immediately be observed from it.”

“The experiment made no strong impression on the audience.”





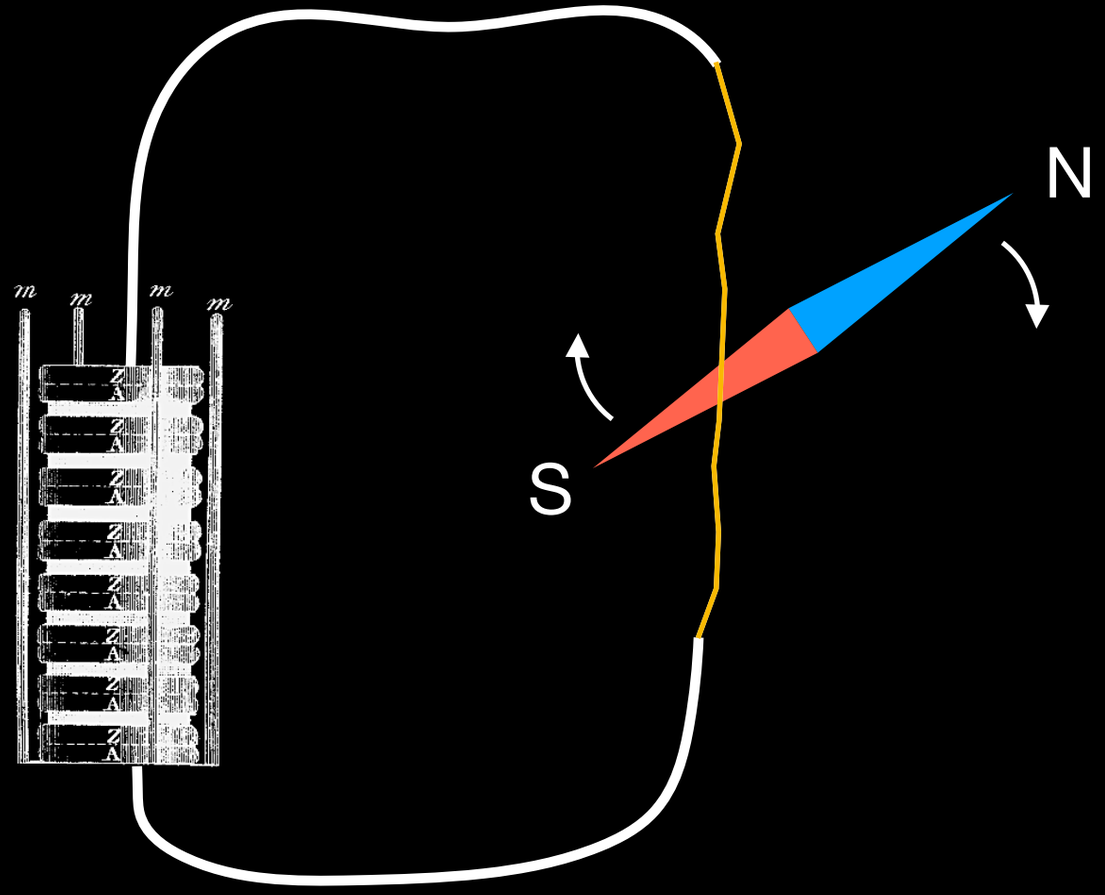
From Ørsted’s notebook

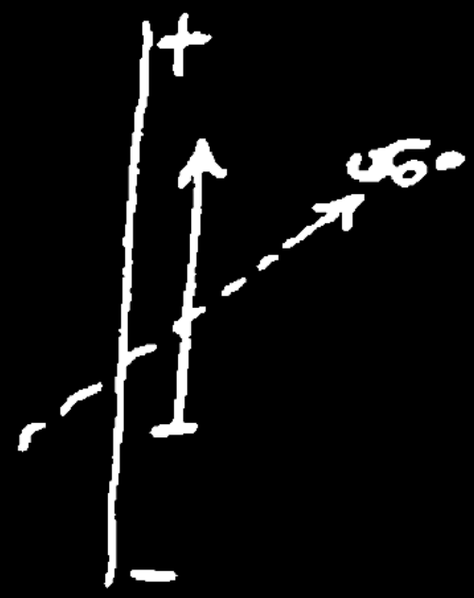
Electricity meets magnetism

“The magnetic needle, though included in a box, was disturbed; but the effect was very feeble, and no particular law could immediately be observed from it.”

“The experiment made no strong impression on the audience.”

(He tried this during a lecture in winter 1819/20!)





From Ørsted’s notebook

Finding the law

July 1820:

What is the magnetic effect of an electric current?

Finding the law

July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

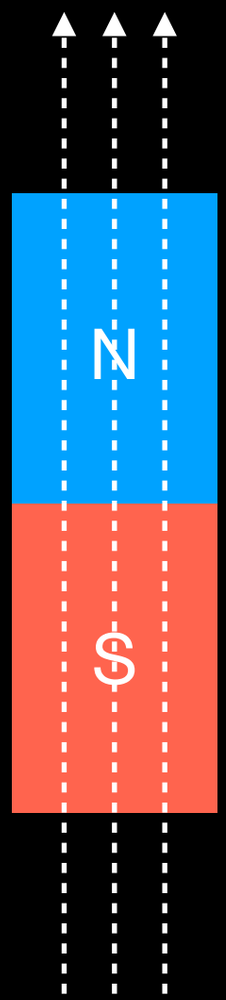
What is the magnetic effect of an electric current?

Finding the law

July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?



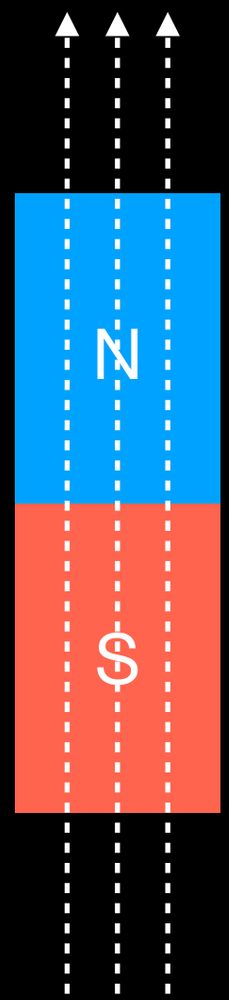
Finding the law

July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Along the direction of the current?



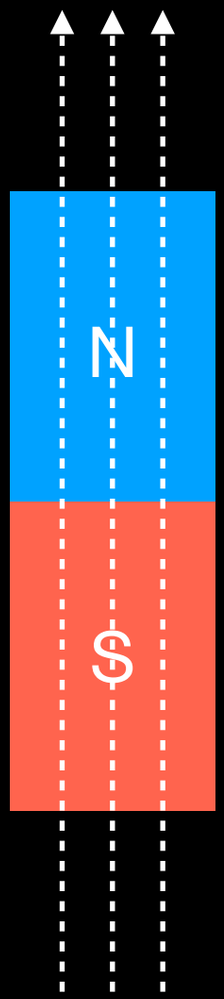
Finding the law

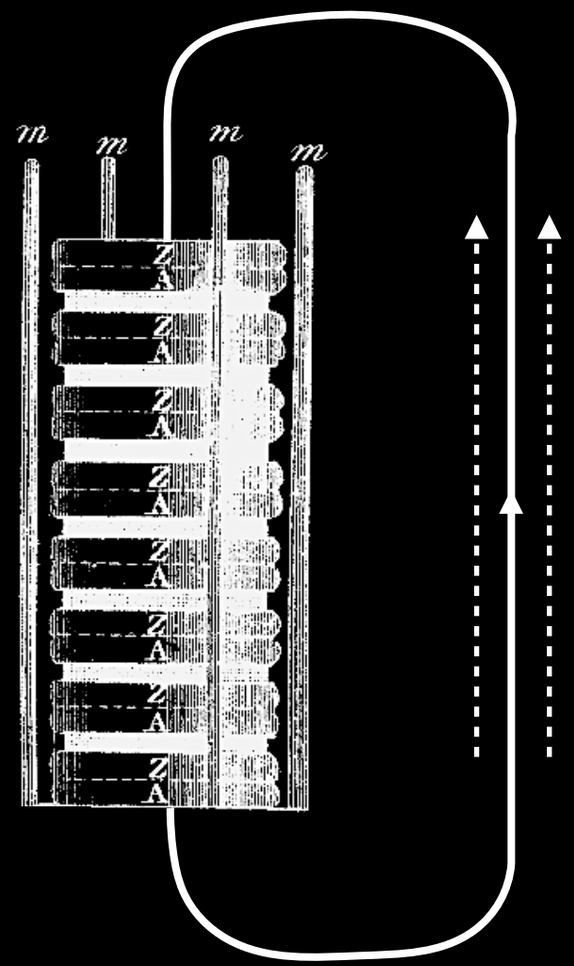
July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Along the direction of the current?





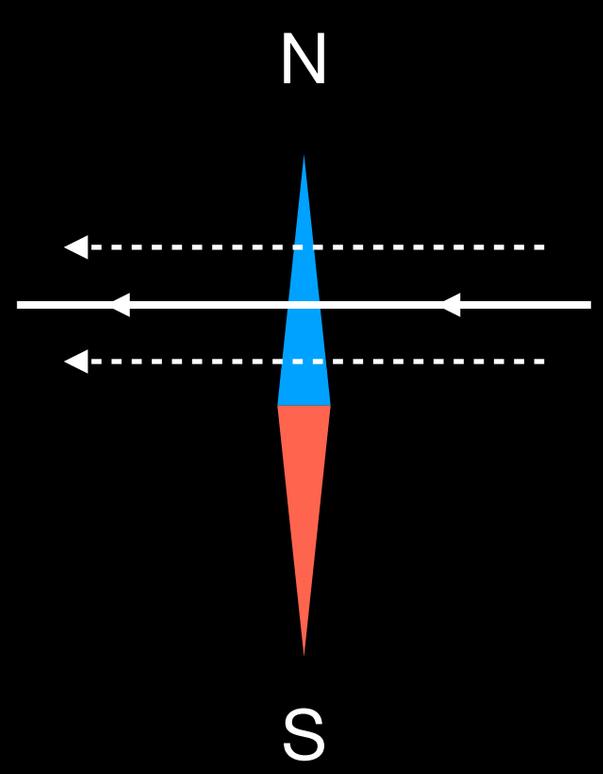
Finding the law

July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Along the direction of the current?



Finding the law

July 1820:

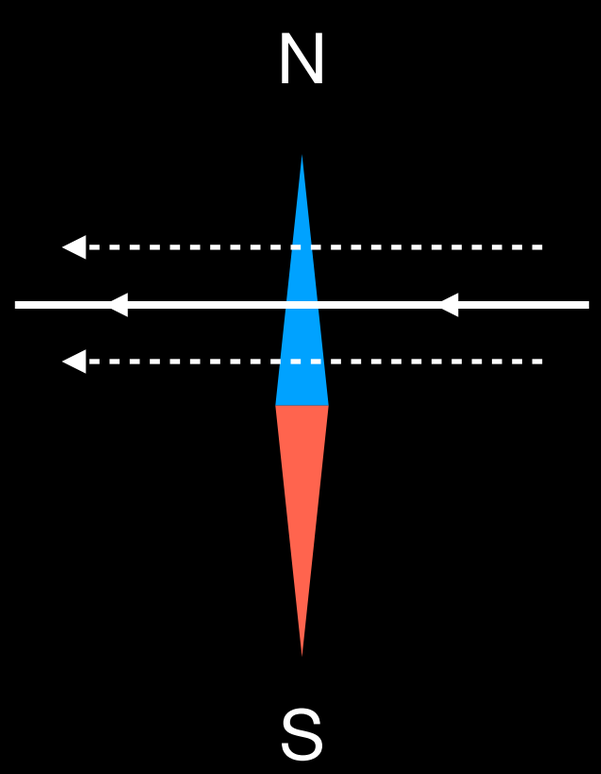
“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Along the direction of the current?

Wire in east-west orientation:

Nothing!



Finding the law

July 1820:

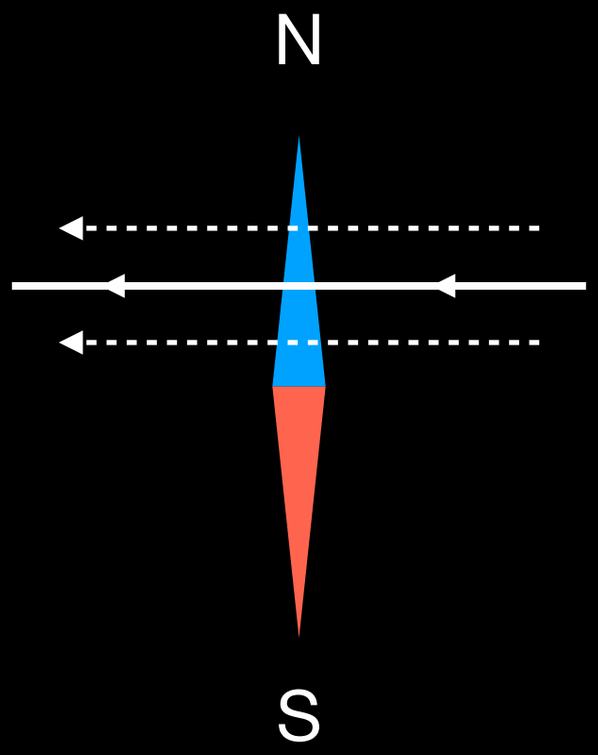
“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Along the direction of the current?

Wire in east-west orientation:

Nothing!



“This had so often been tried in vain; it must be produced by a lateral action.”

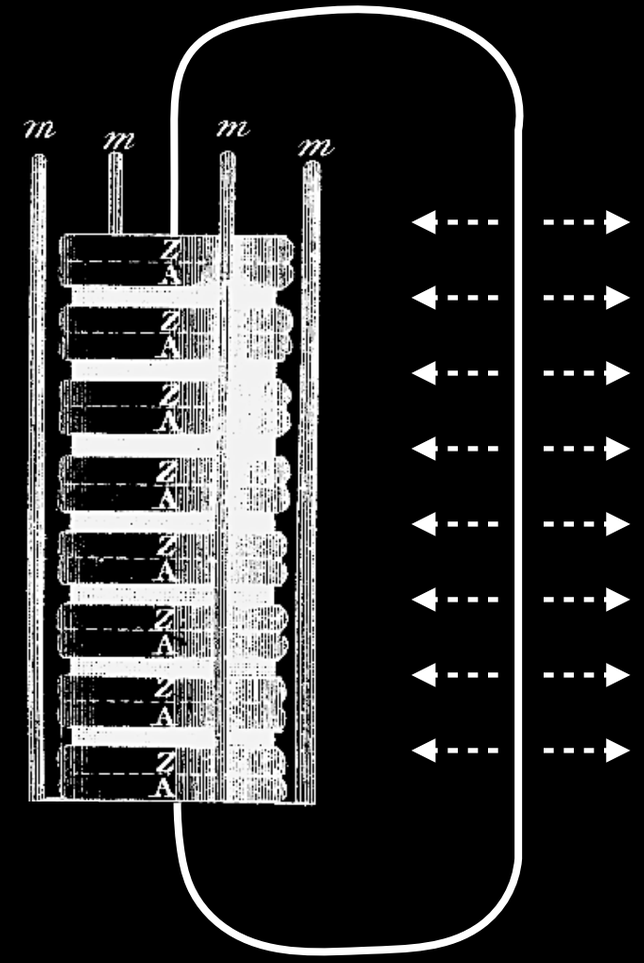
Finding the law

July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Outwards from the wire?



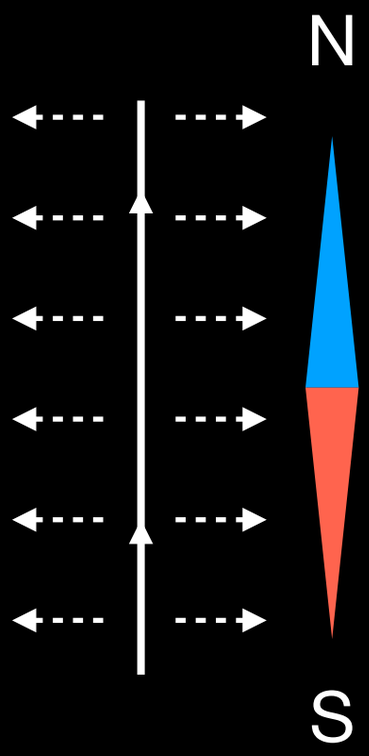
Finding the law

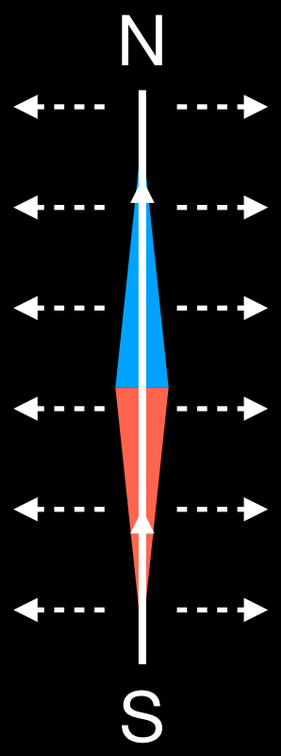
July 1820:

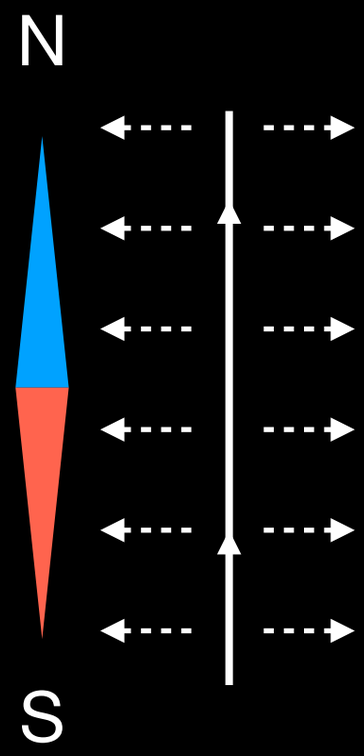
“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Outwards from the wire?







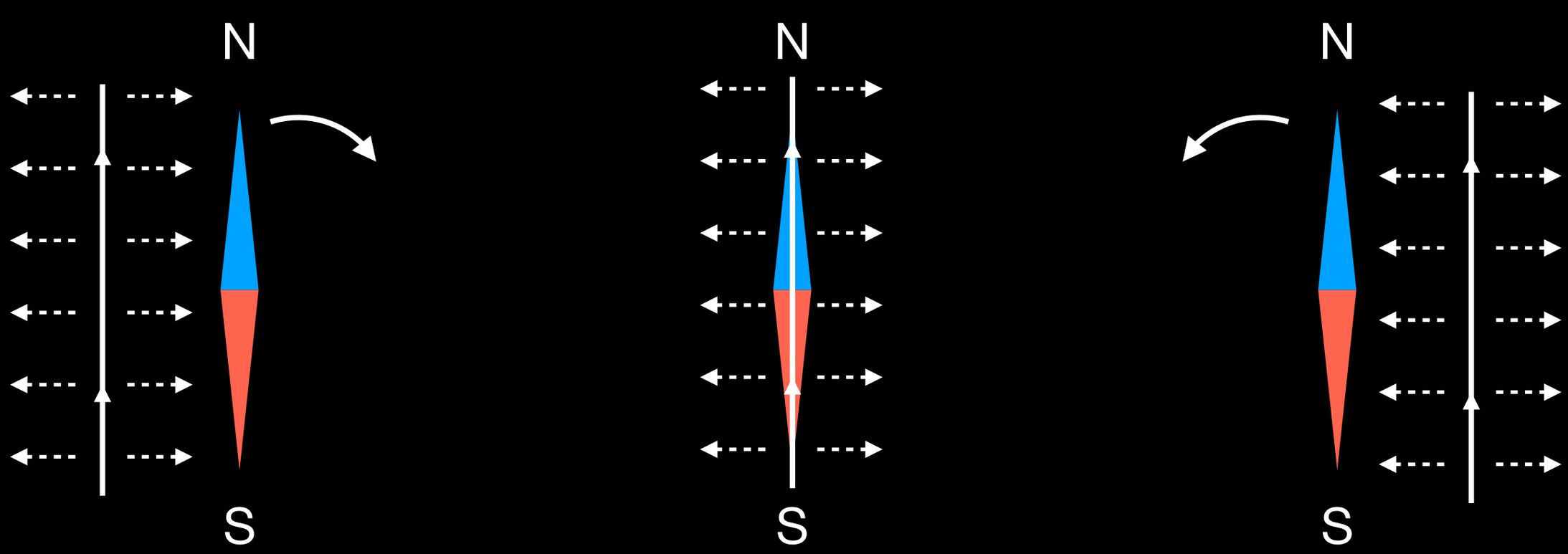
Finding the law

July 1820:

“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Outwards from the wire?



Finding the law

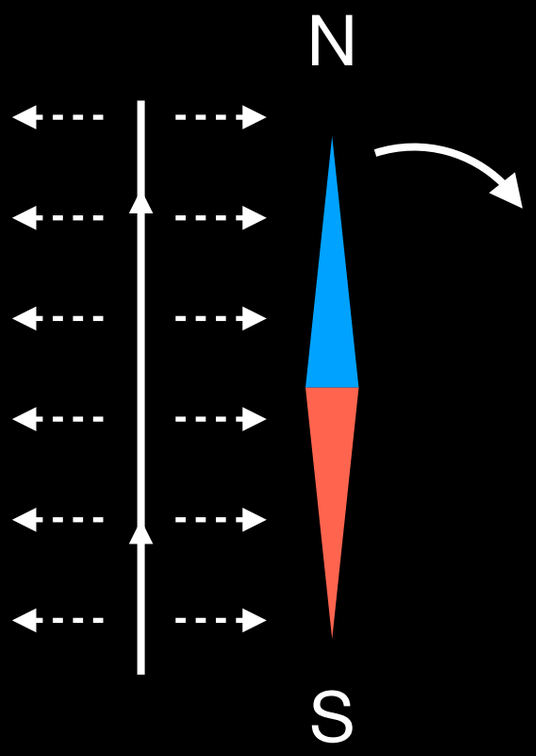
July 1820:

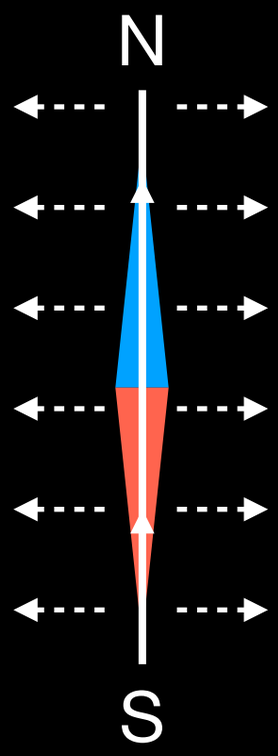
“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

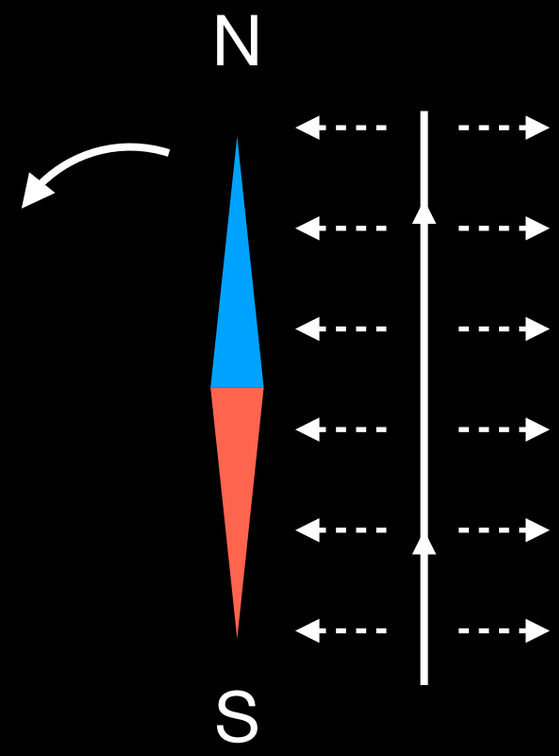
What is the magnetic effect of an electric current?

Outwards from the wire?

This is not what happened!







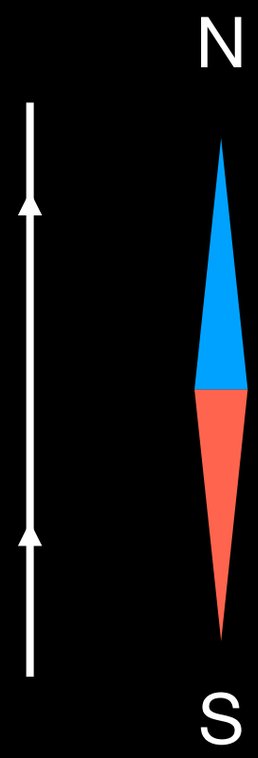
Finding the law

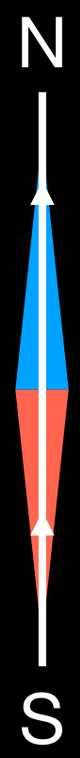
July 1820:

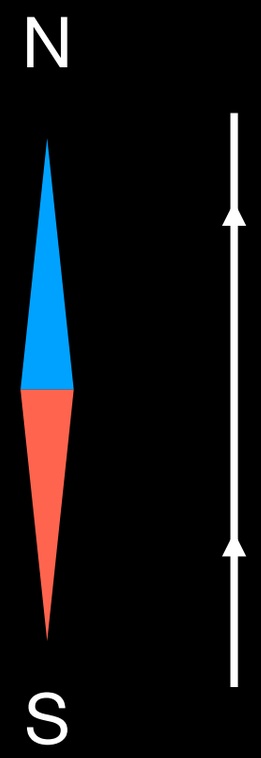
“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

What is the magnetic effect of an electric current?

Outwards from the wire?







Finding the law

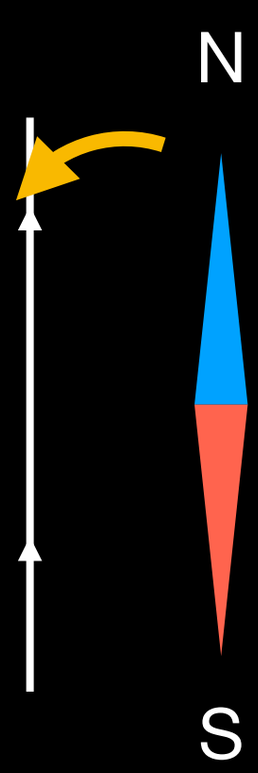
July 1820:

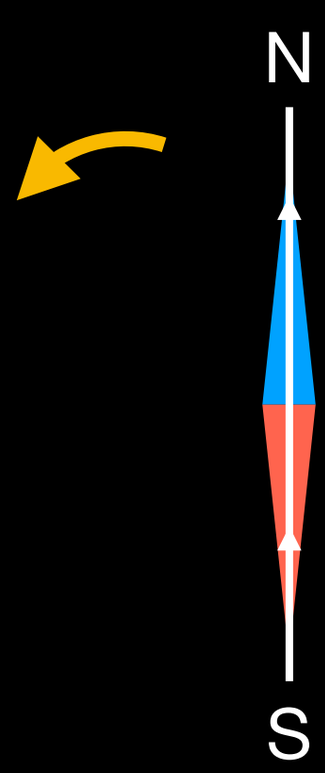
“Many days of experimenting were required before I could find the law governing the effect. As soon as I had discovered it, I rushed to publish the work."

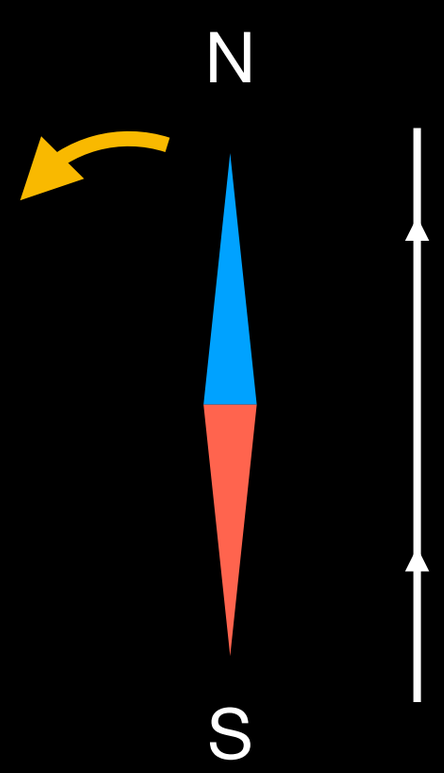
What is the magnetic effect of an electric current?

Outwards from the wire?

The needle always moved in the same direction!





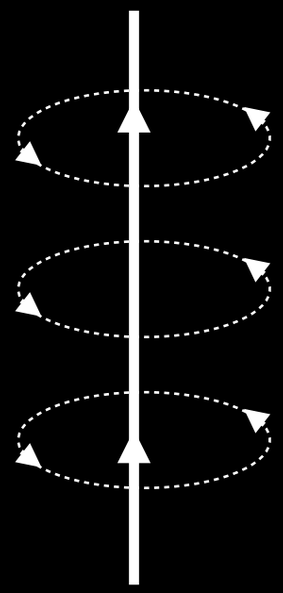


Finding the law

What is the magnetic effect of an electric current?

Finding the law

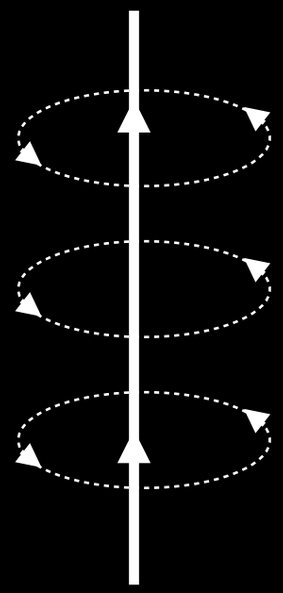
What is the magnetic effect of an electric current?



Finding the law

What is the magnetic effect of an electric current?

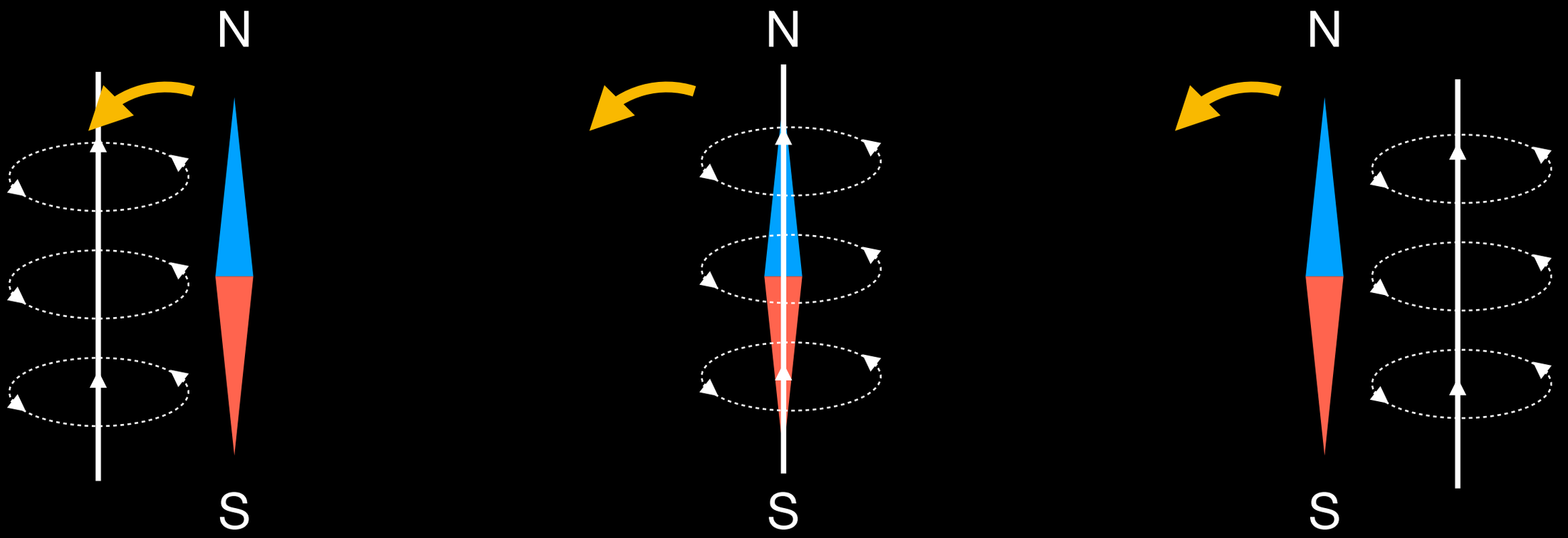
A circular force around the wire!



Finding the law

What is the magnetic effect of an electric current?

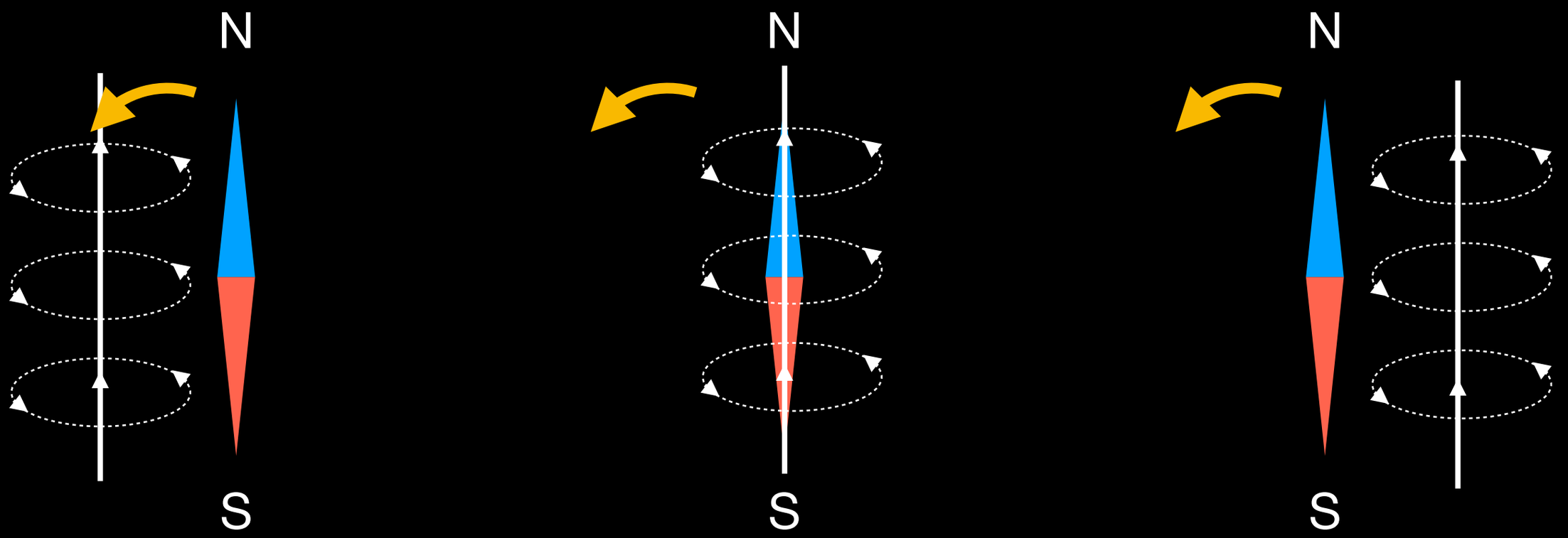
A circular force around the wire!



Finding the law

What is the magnetic effect of an electric current?

A circular force around the wire!

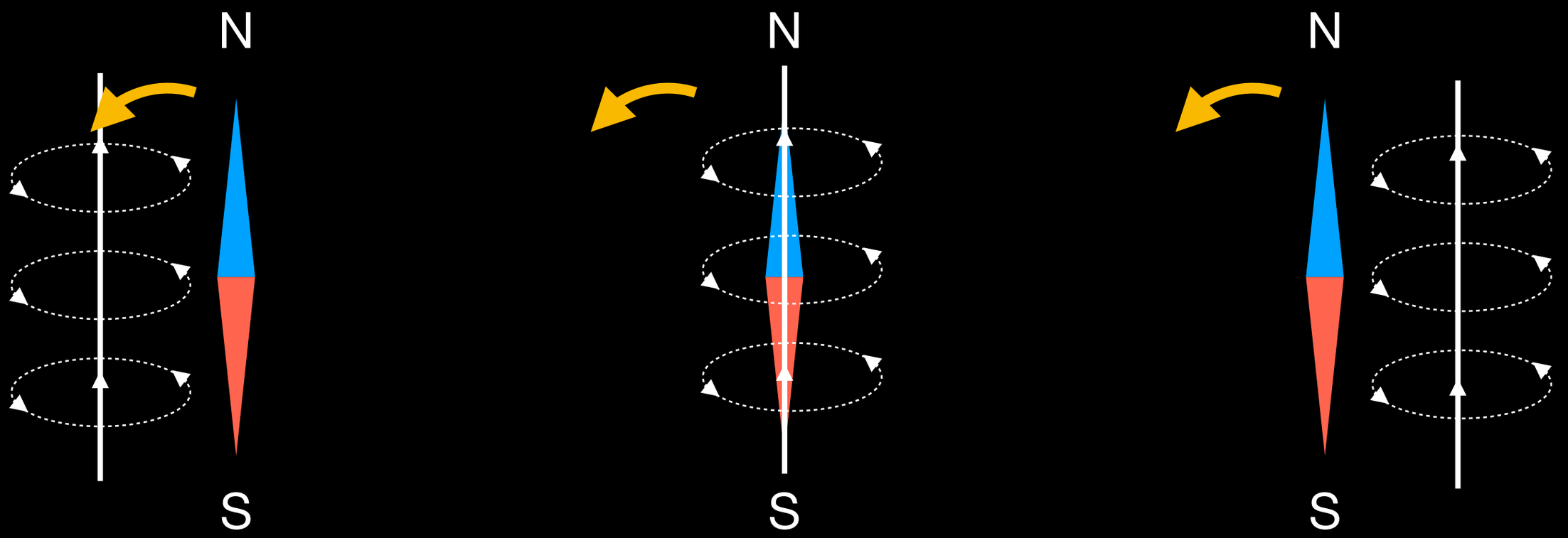


“A circular force was both unanticipated and inexplicable.”

Finding the law

What is the magnetic effect of an electric current?

A circular force around the wire!

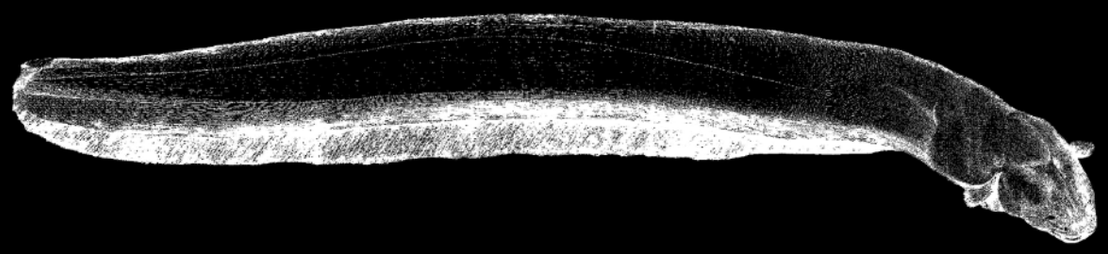


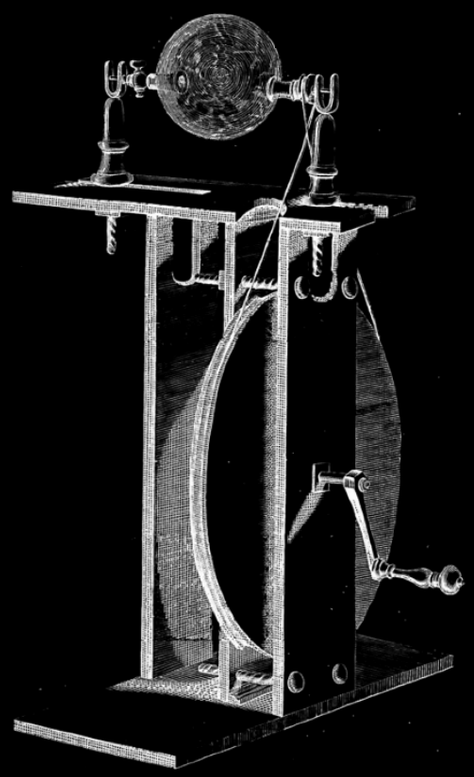
“A circular force was both unanticipated and inexplicable.”

Magnetism from electricity!

Electricity in 1800

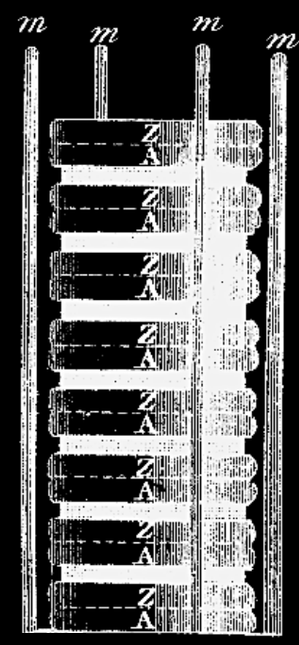
"Animal electricity"





"Ordinary electricity"

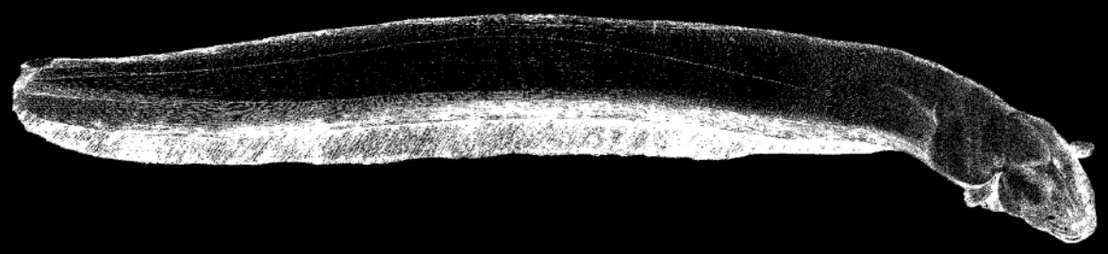
"Voltaic electricity"

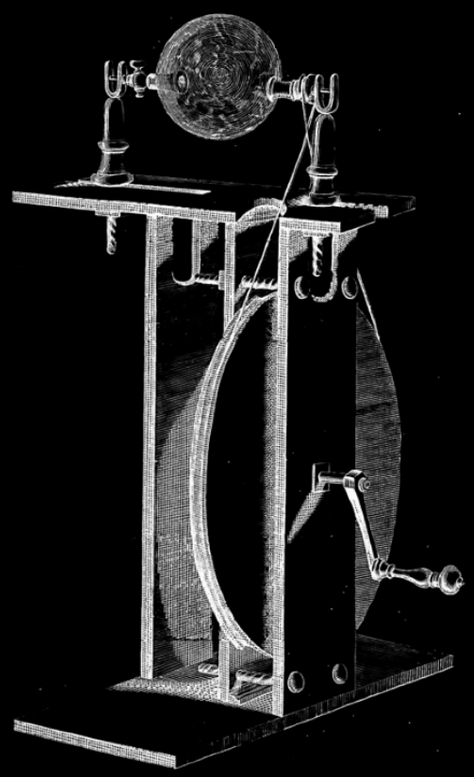


Utter confusion!

Electricity in ~~1800~~ 1820

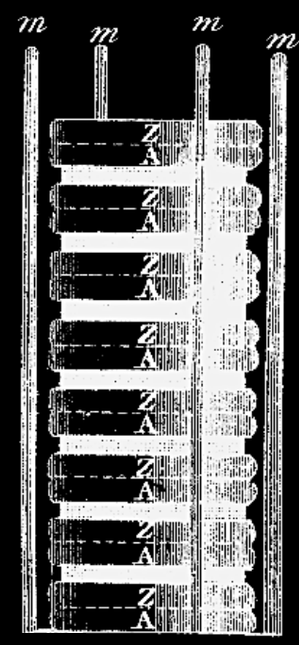
"Animal electricity"





"Ordinary electricity"

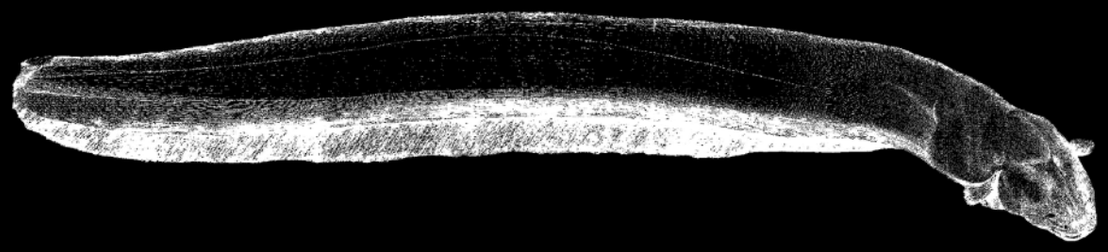
"Voltaic electricity"

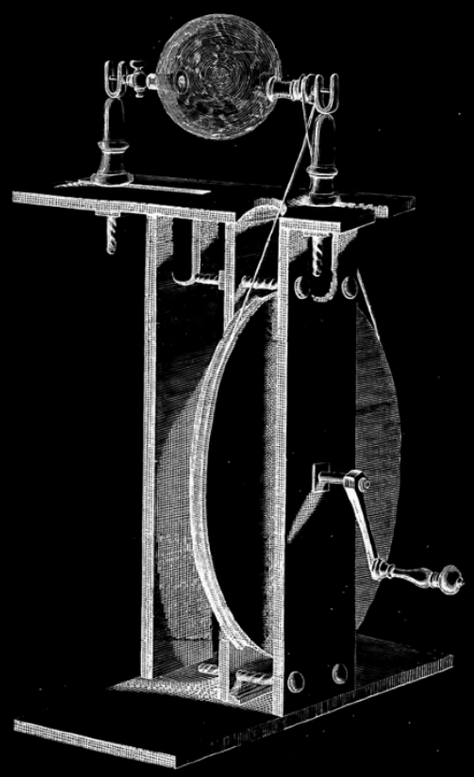


Utter confusion!

Electricity in ~~1800~~ 1820

"Animal electricity"

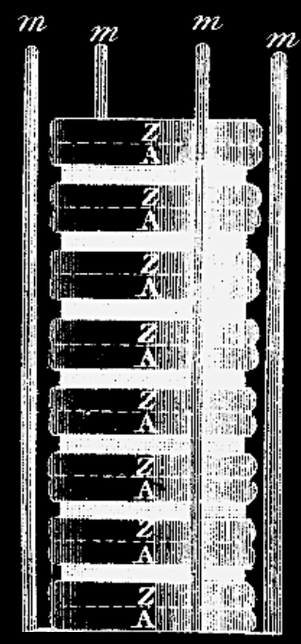


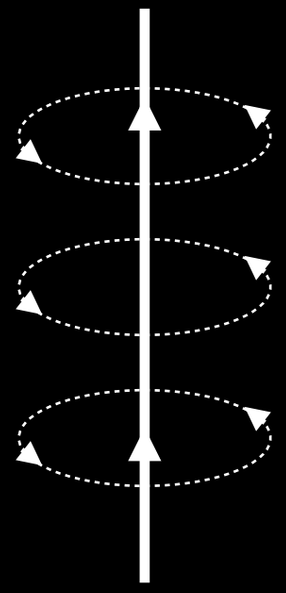


"Ordinary electricity"

Utter confusion!

"Voltaic electricity"

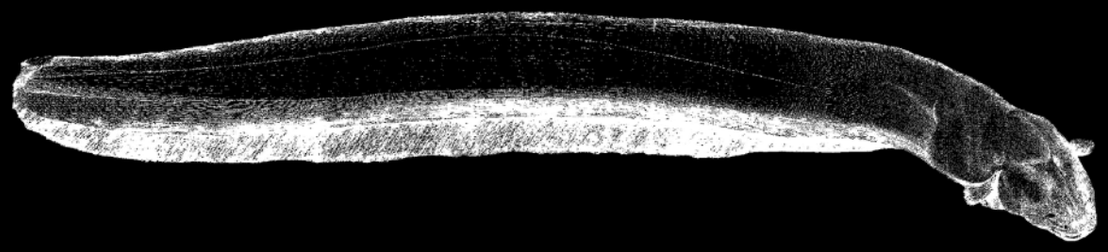


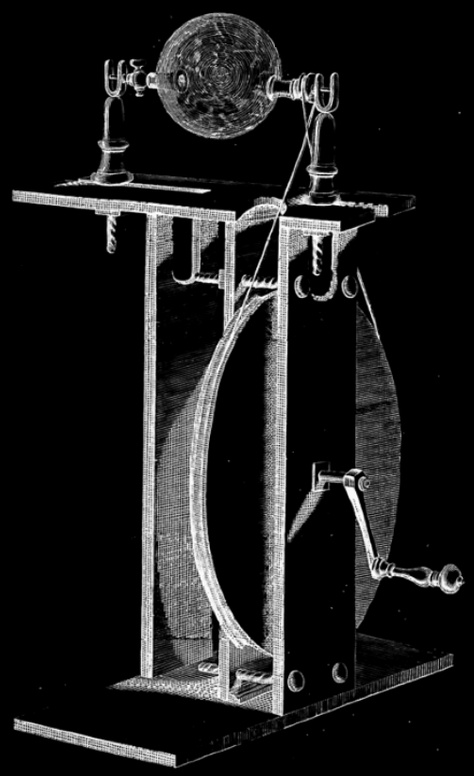


"Electro-magnetism"

Electricity in ~~1800~~ 1820

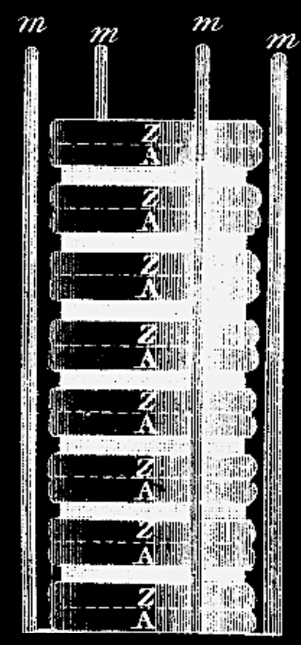
"Animal electricity"





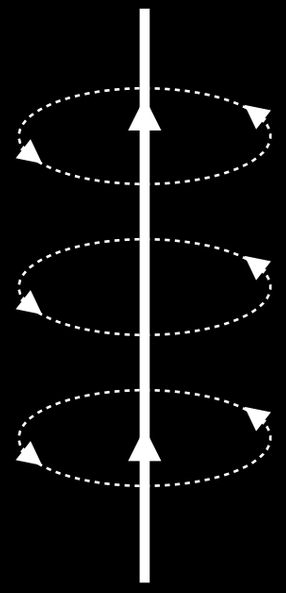
"Ordinary electricity"

"Voltaic electricity"



Utter confusion!

It will get worse before it gets better …



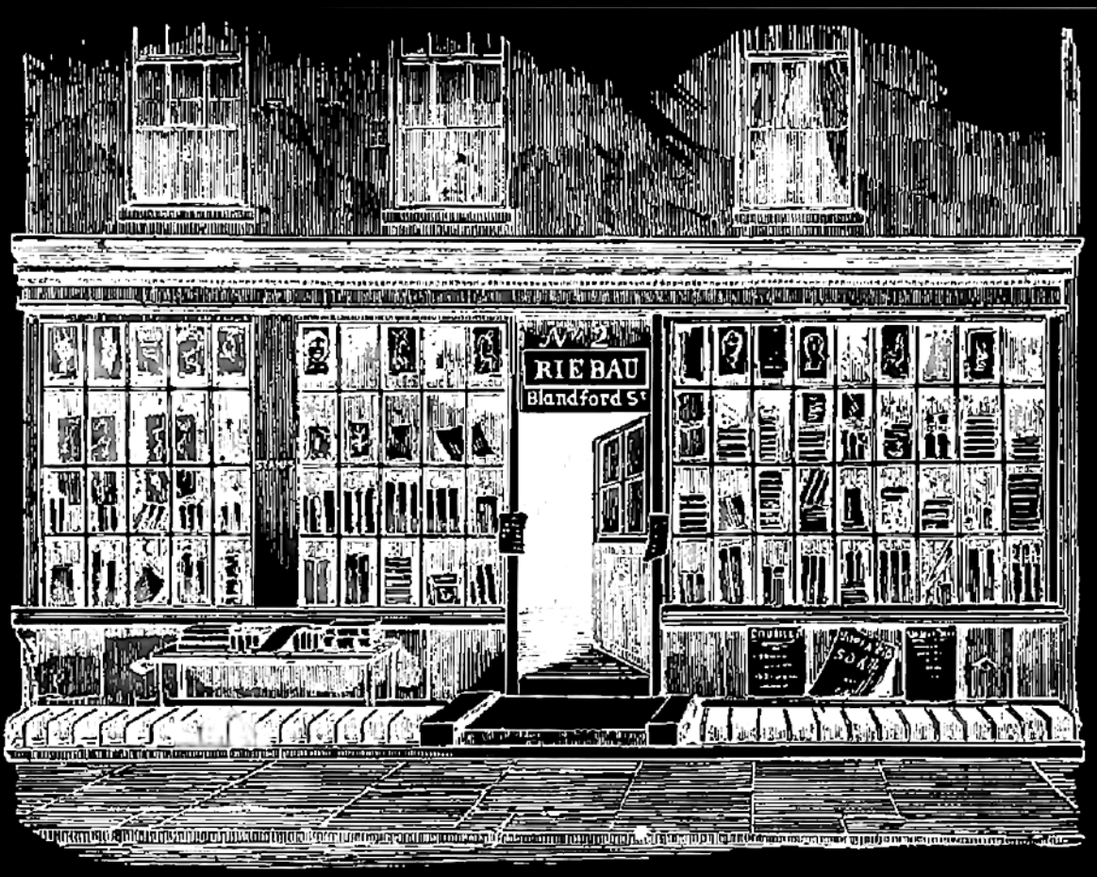
"Electro-magnetism"

Michael Faraday

Bookbinder, laboratory assistant, experimenter

Michael Faraday

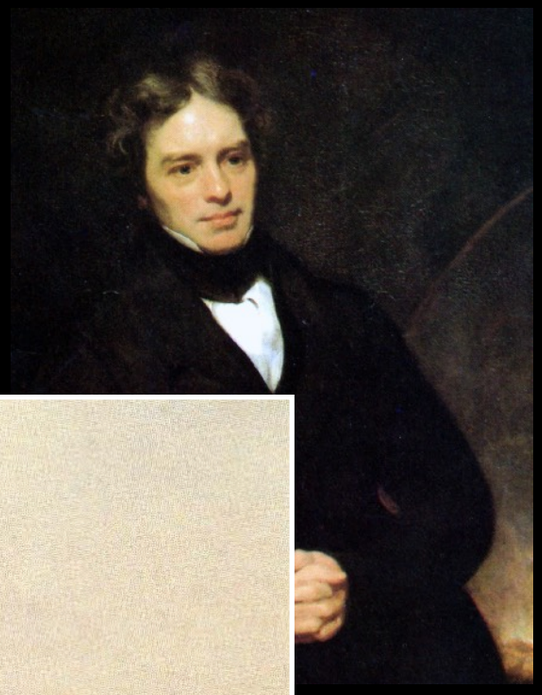
Bookbinder, laboratory assistant, experimenter



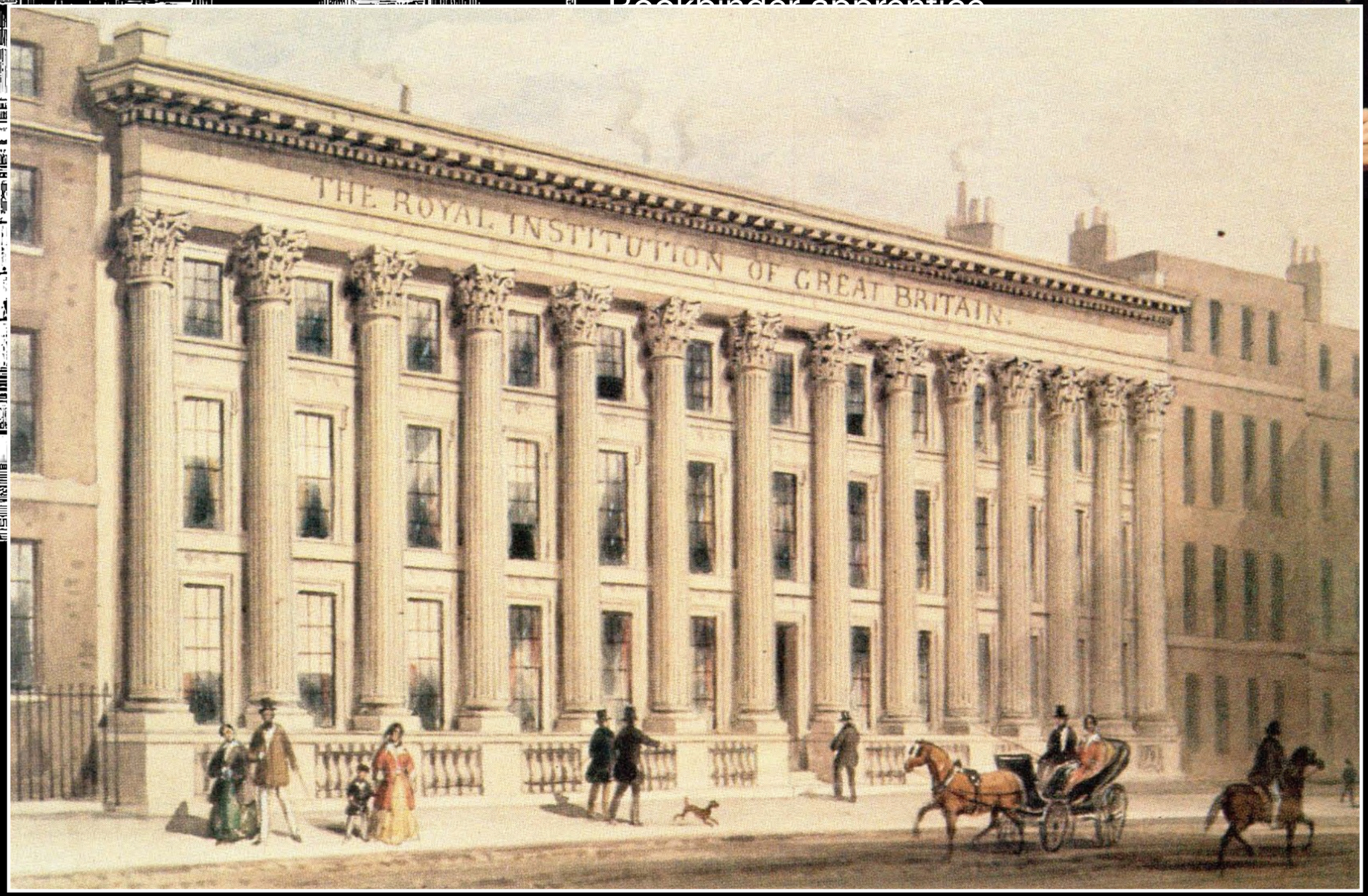
Bookbinder apprentice
at Riebau’s

Michael Faraday

Bookbinder, laboratory assistant, experimenter

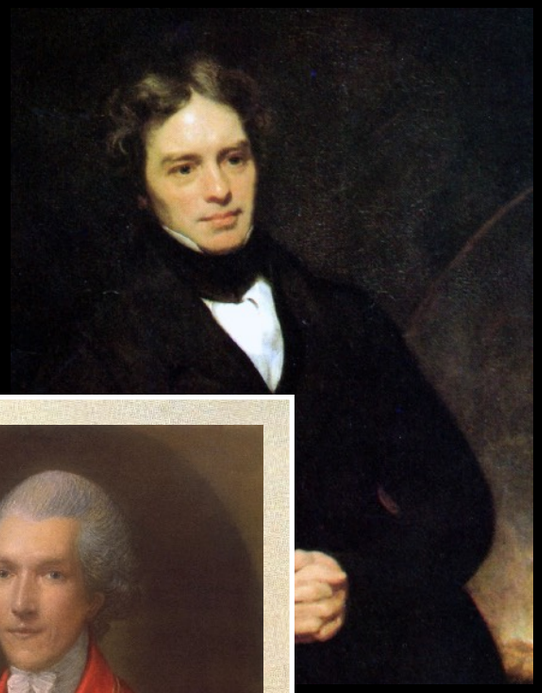


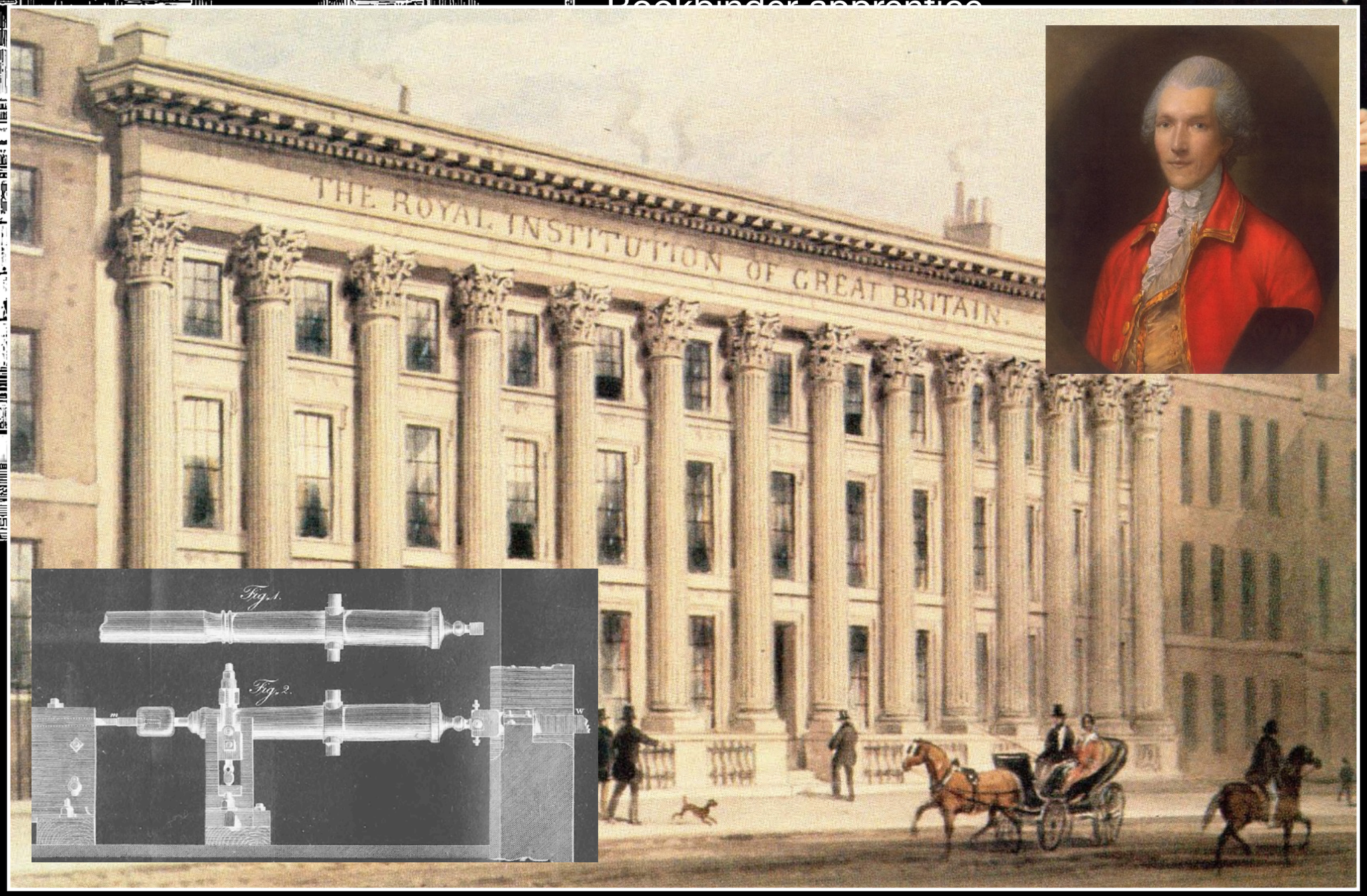
Bookbinder apprentice



Michael Faraday

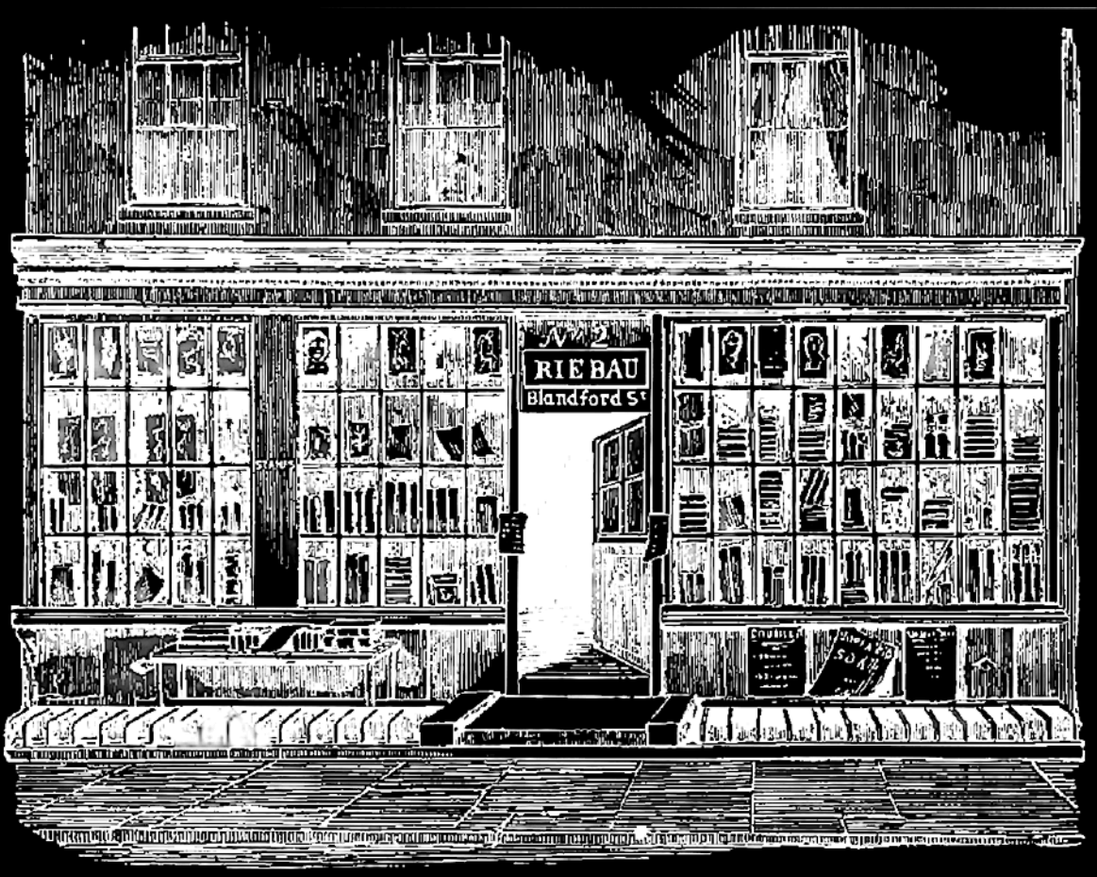
Bookbinder, laboratory assistant, experimenter





Michael Faraday

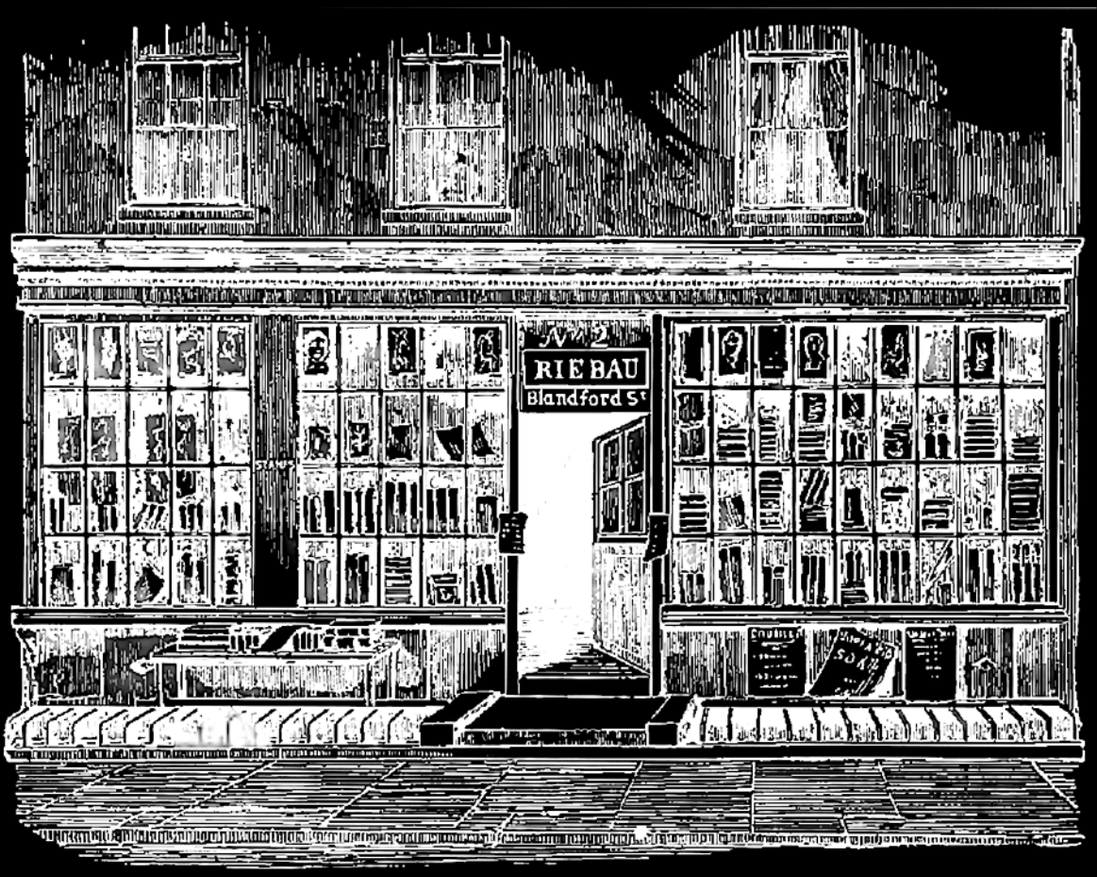
Bookbinder, laboratory assistant, experimenter



Bookbinder apprentice
at Riebau’s

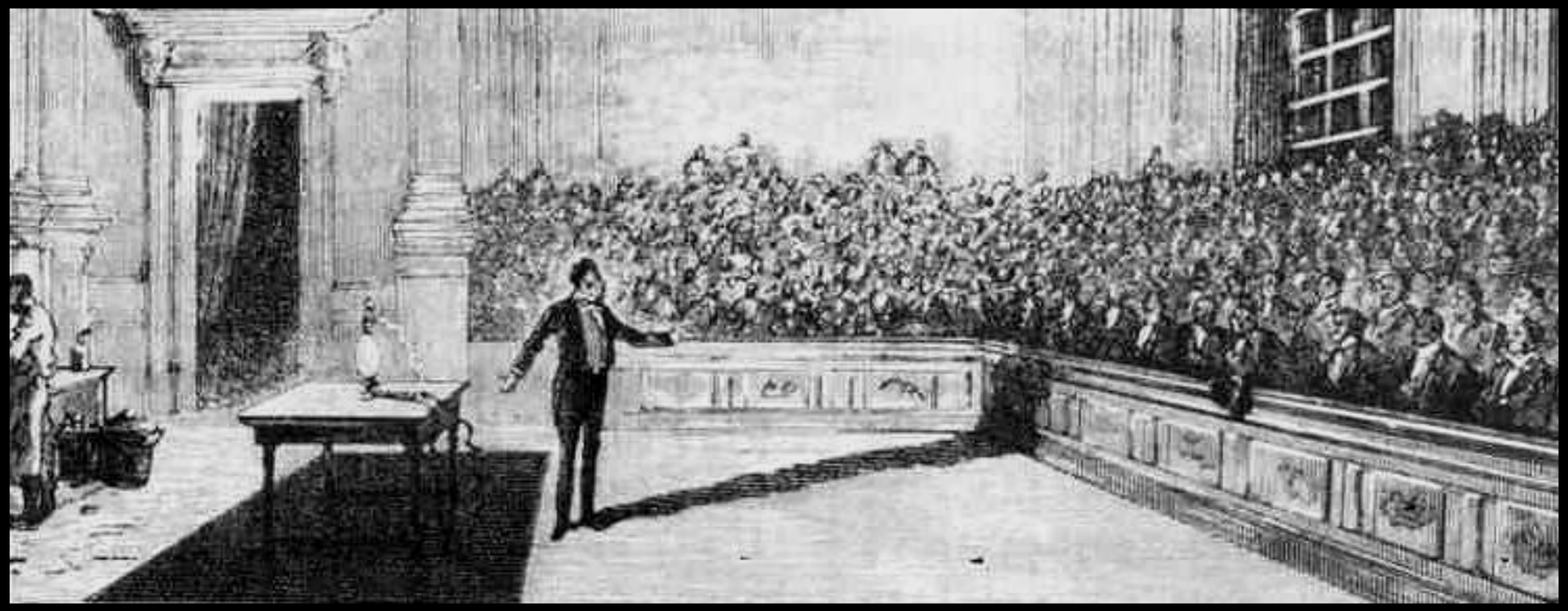
Michael Faraday

Bookbinder, laboratory assistant, experimenter



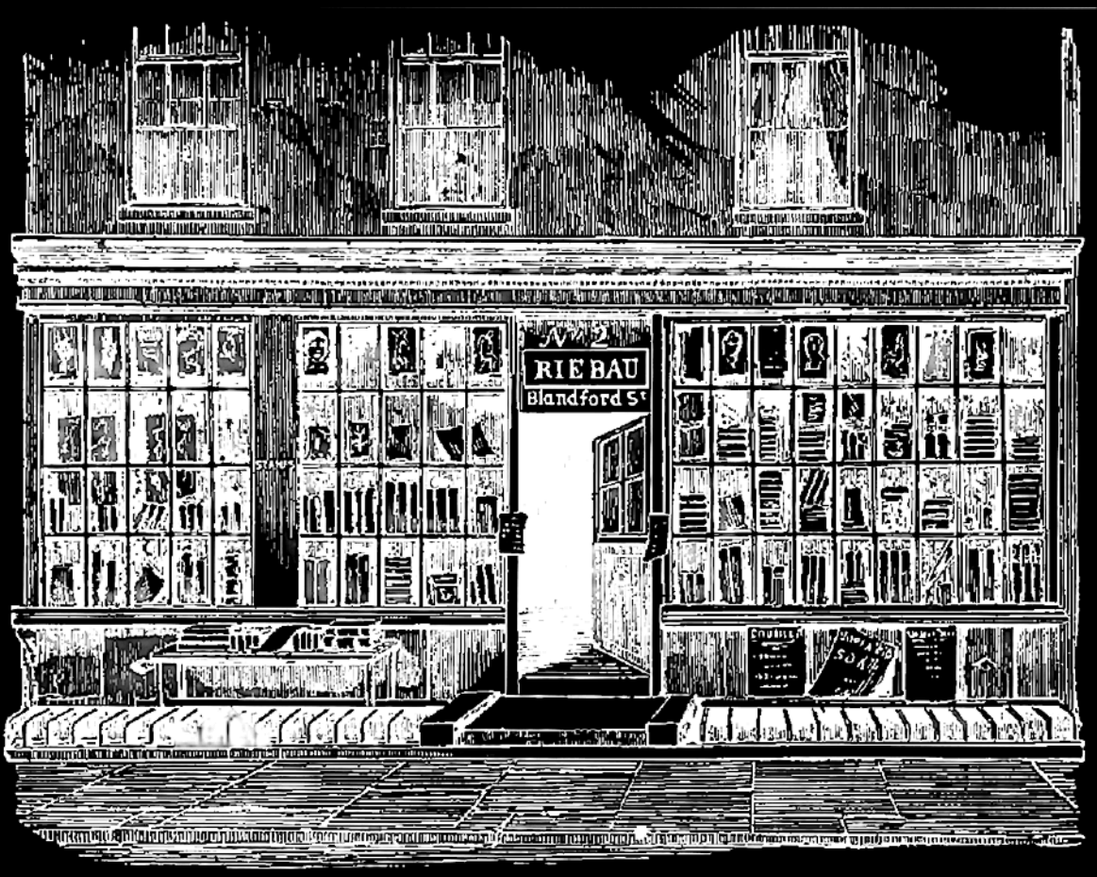
Bookbinder apprentice
at Riebau’s

Humphrey Davy’s lectures
at the Royal Institution

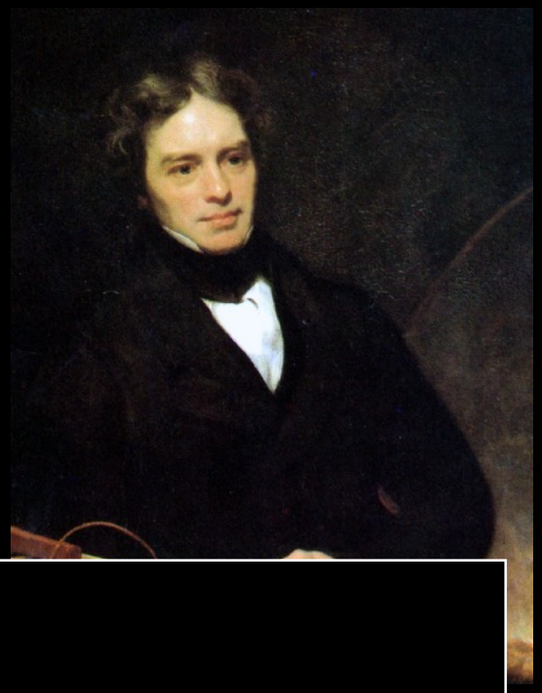


Michael Faraday

Bookbinder, laboratory assistant, experimenter



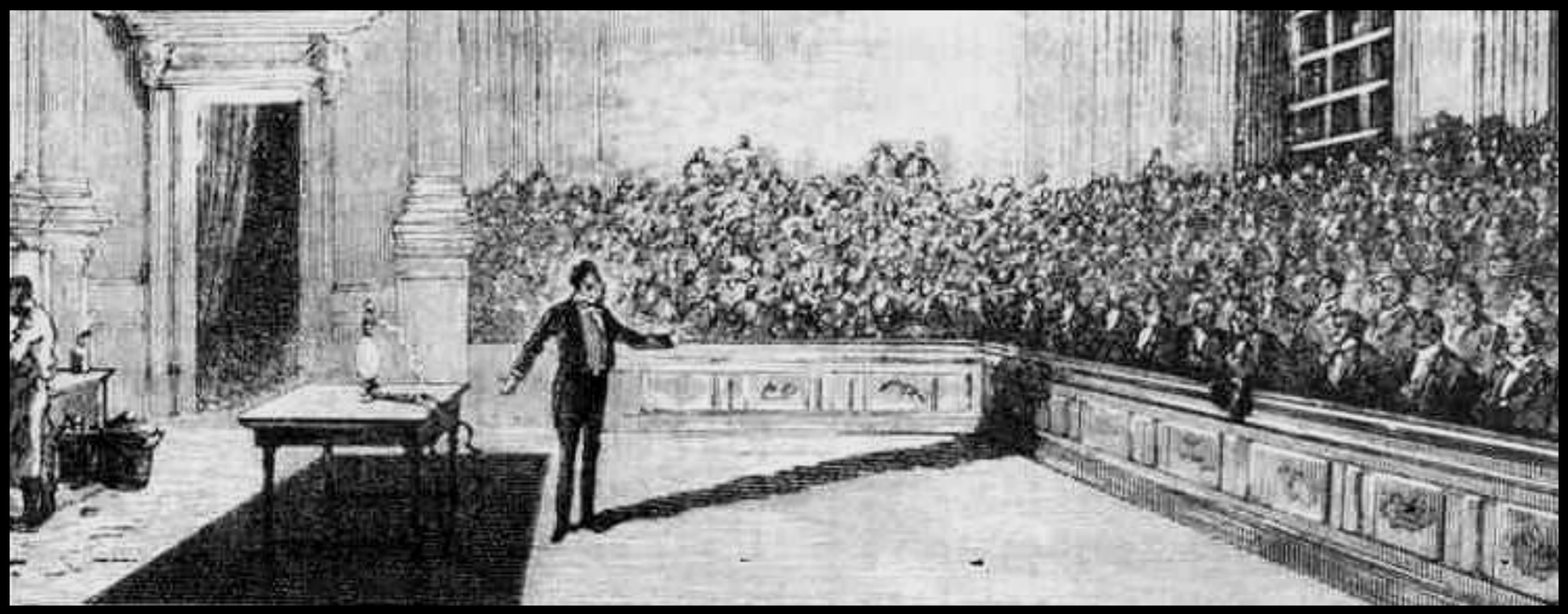
Bookbinder apprentice
at Riebau's



Dear Faraday,

I write you this just to jog your memory that we expect from you this month and as early as suits you the remainder of the history of Electro-magnetism.

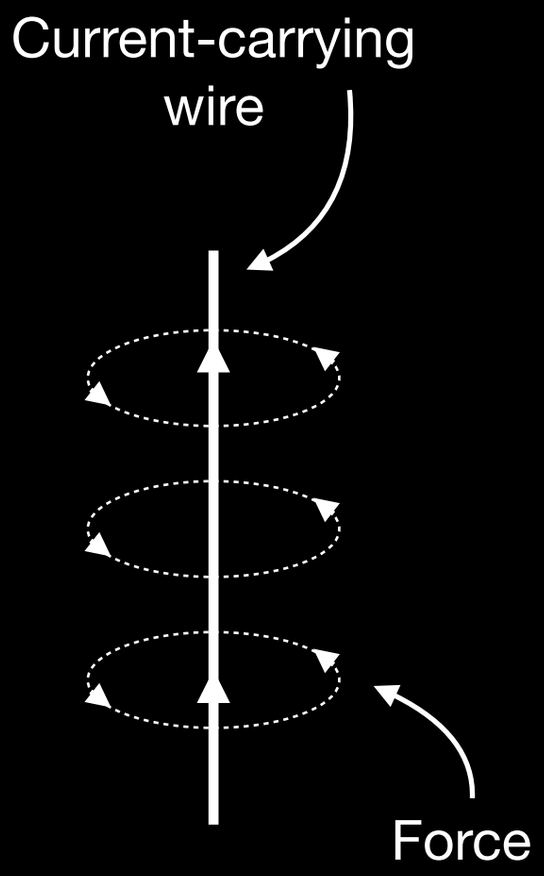
Yours very truly,
R. Phillips



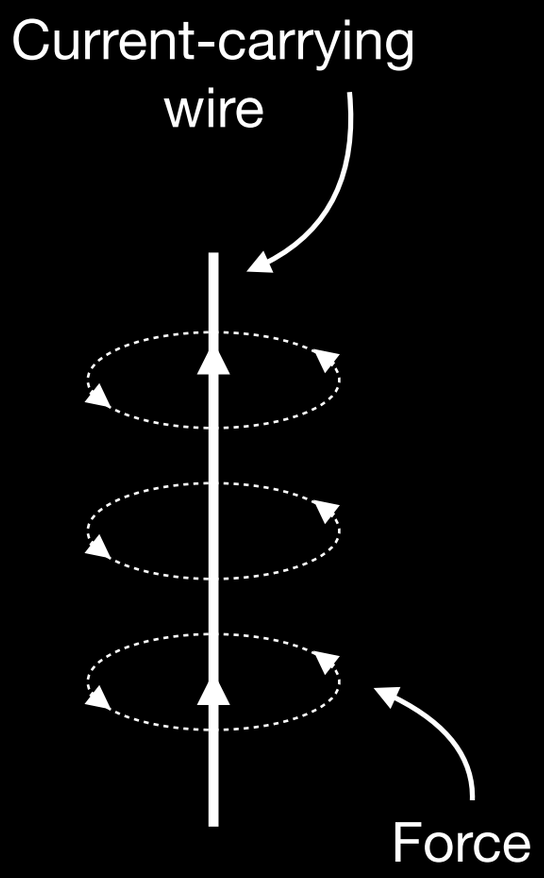
Humphrey Davy's lectures
at the Royal Institution

Ørsted’s discovery

Ørsted’s discovery

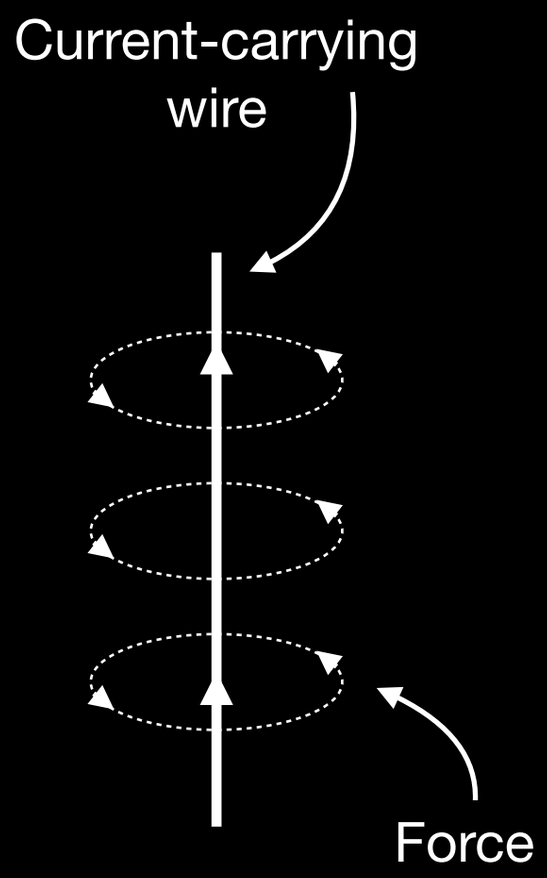


Ørsted’s discovery

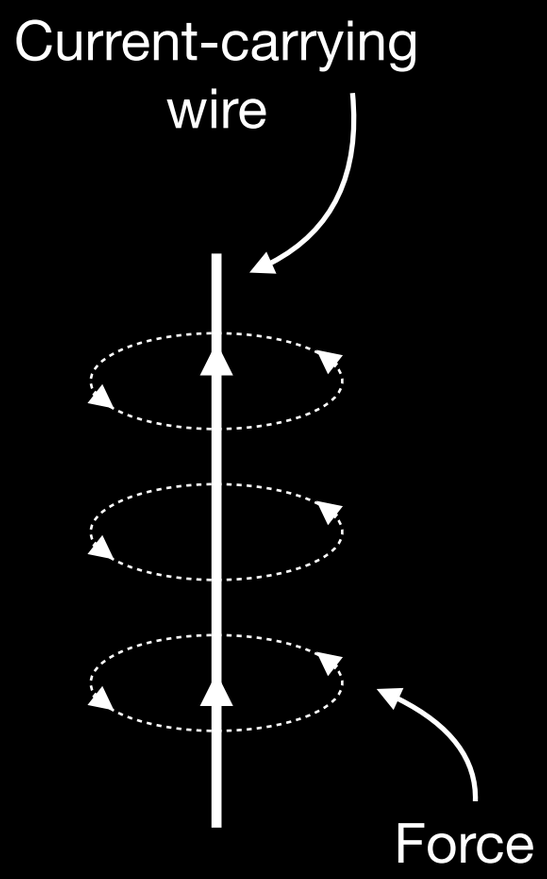


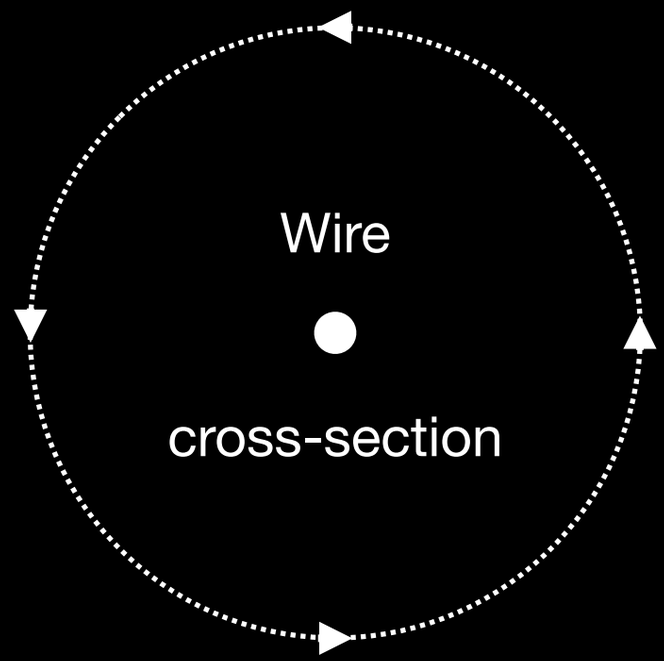
Ørsted: “A circular force was both unanticipated and inexplicable.”

Faraday takes over

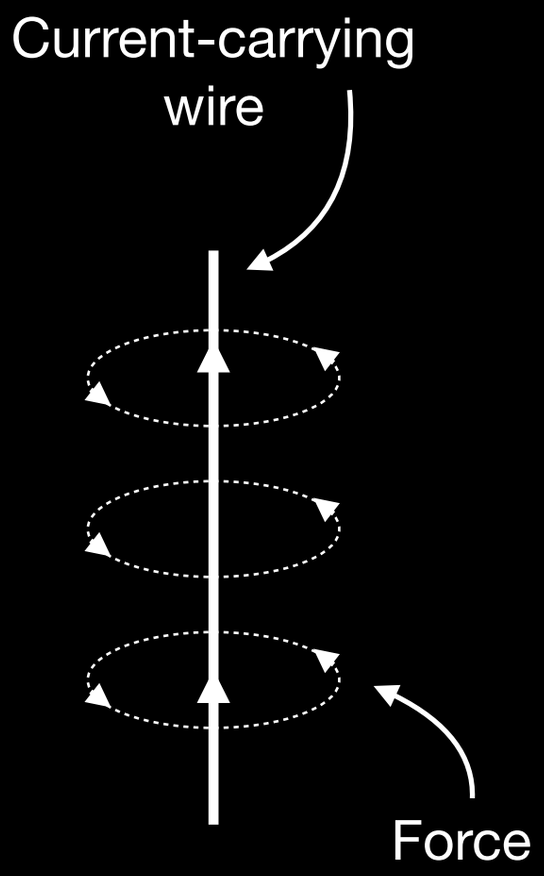


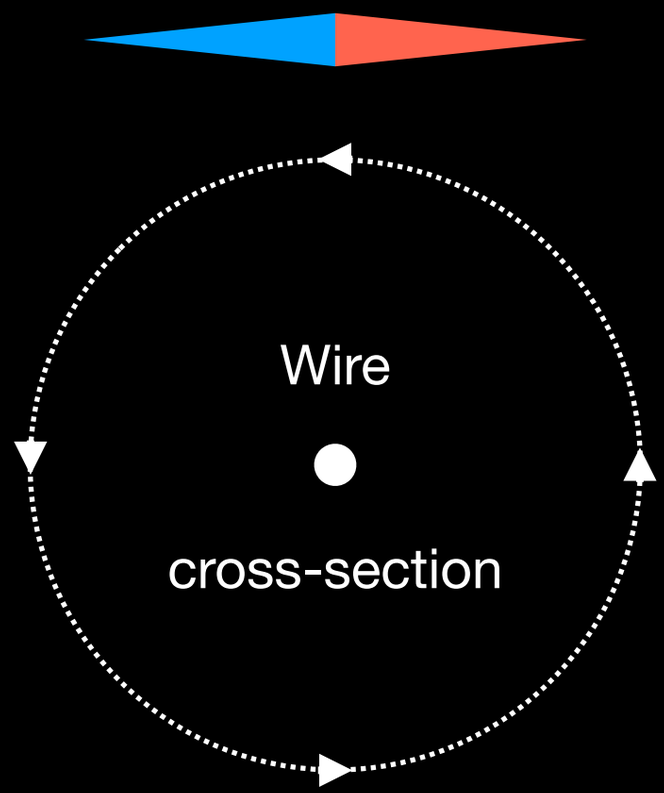
Faraday takes over



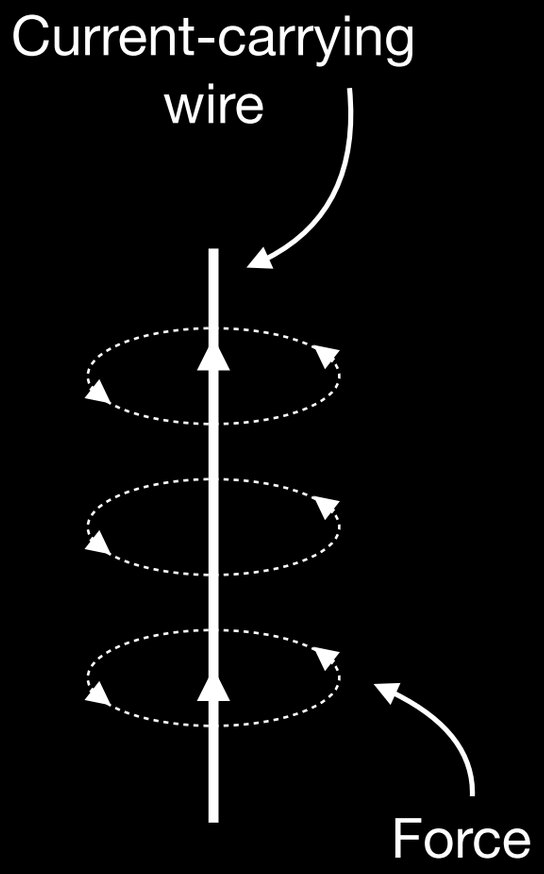


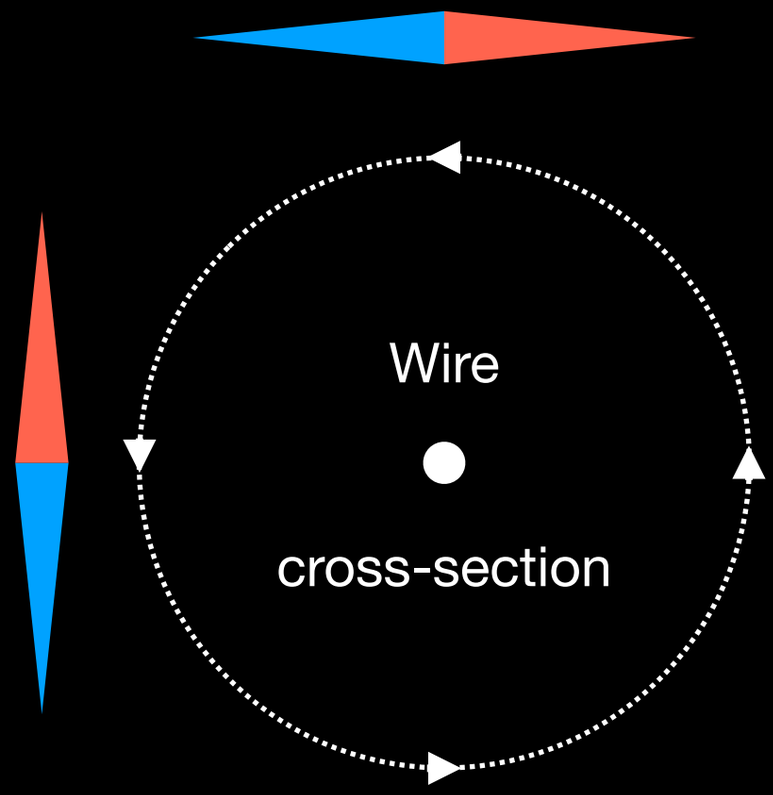
Faraday takes over



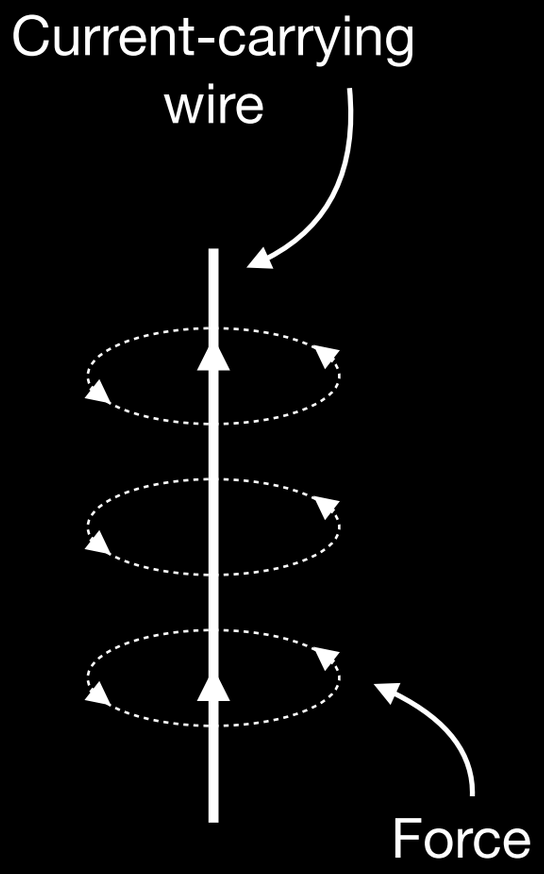


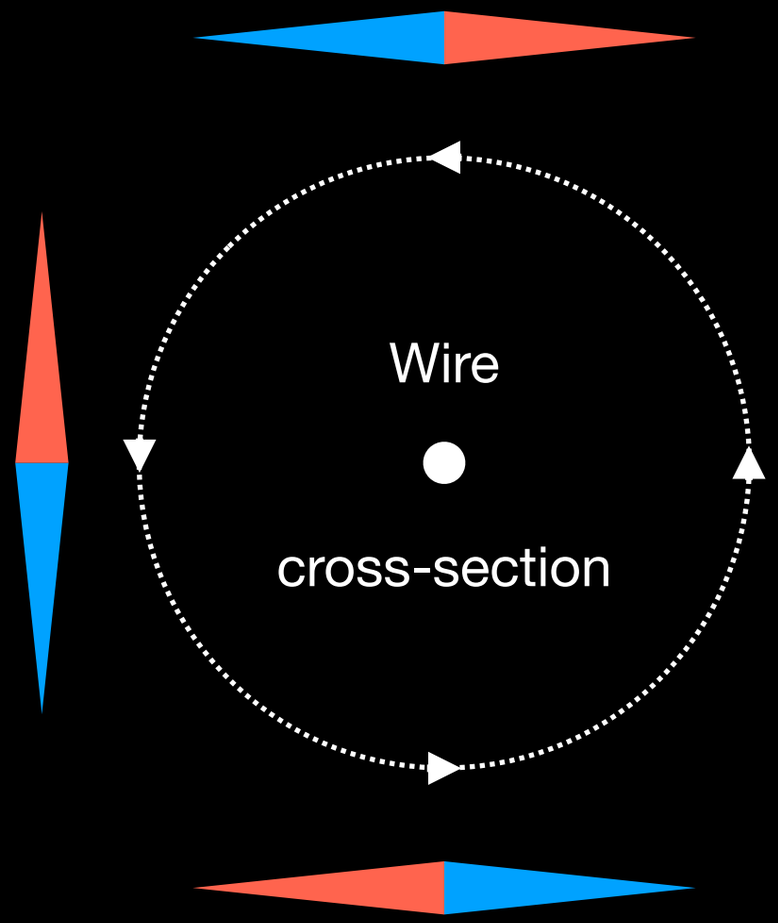
Faraday takes over



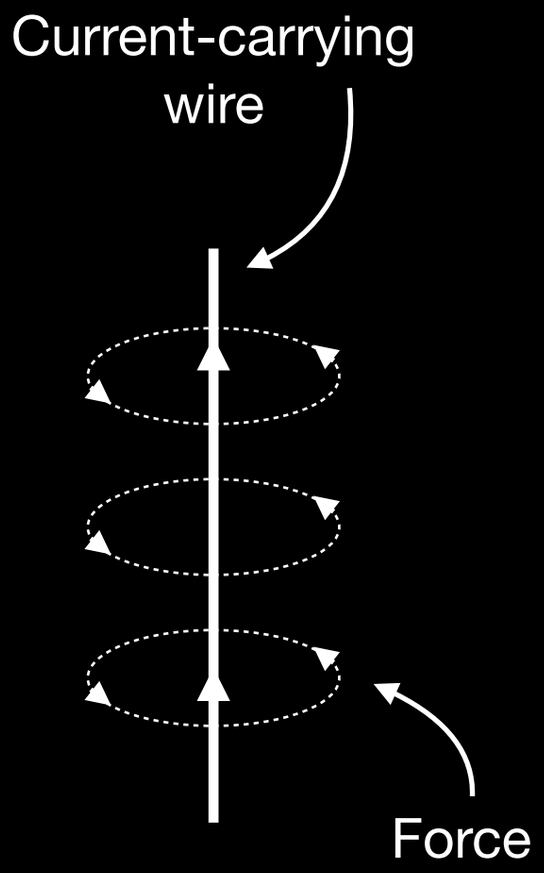


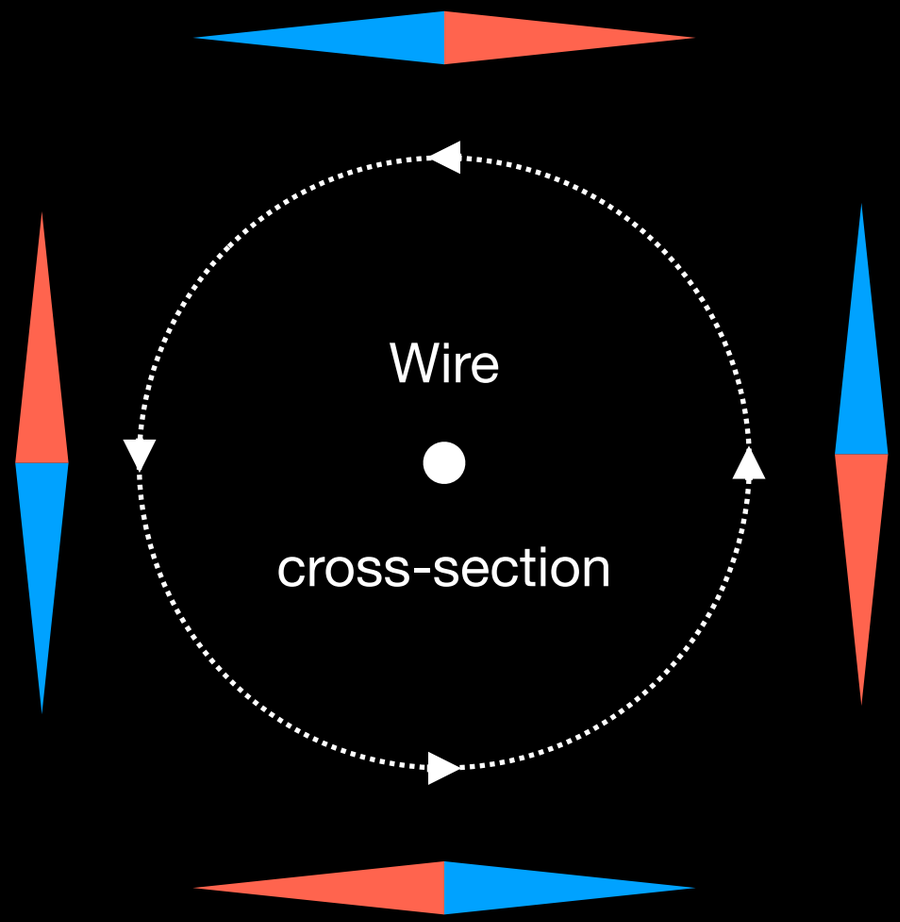
Faraday takes over



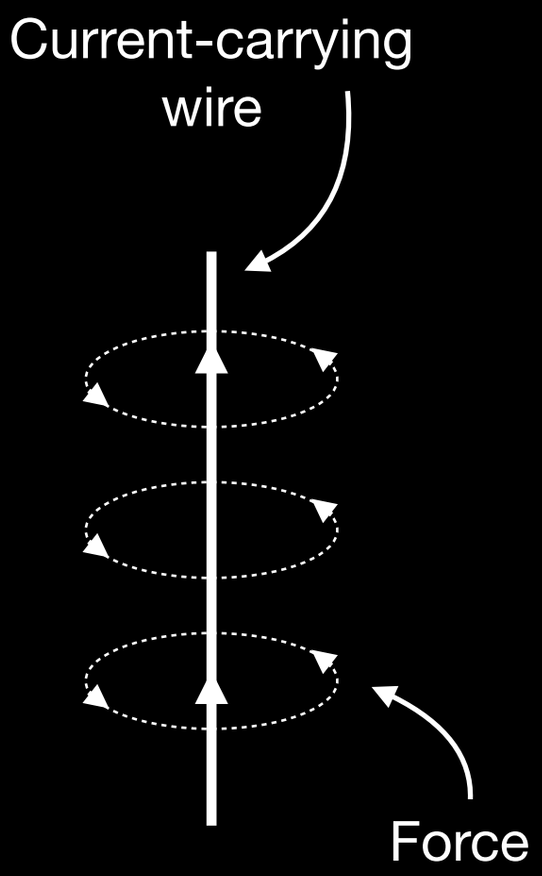


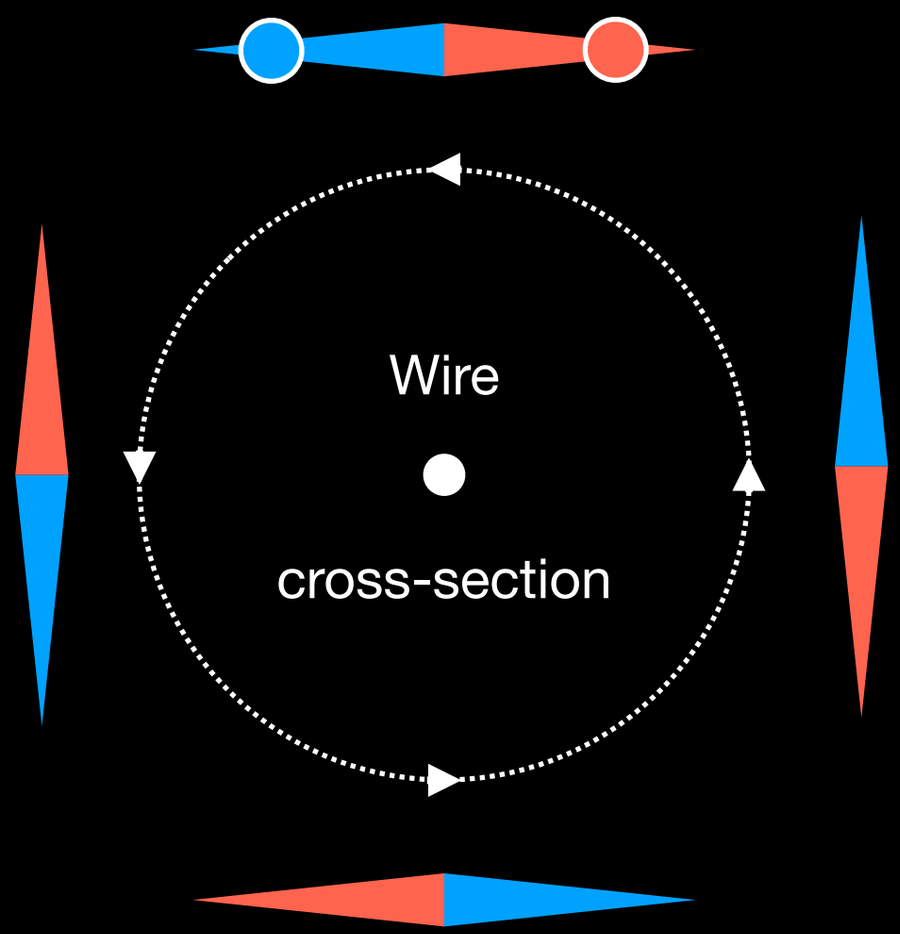
Faraday takes over



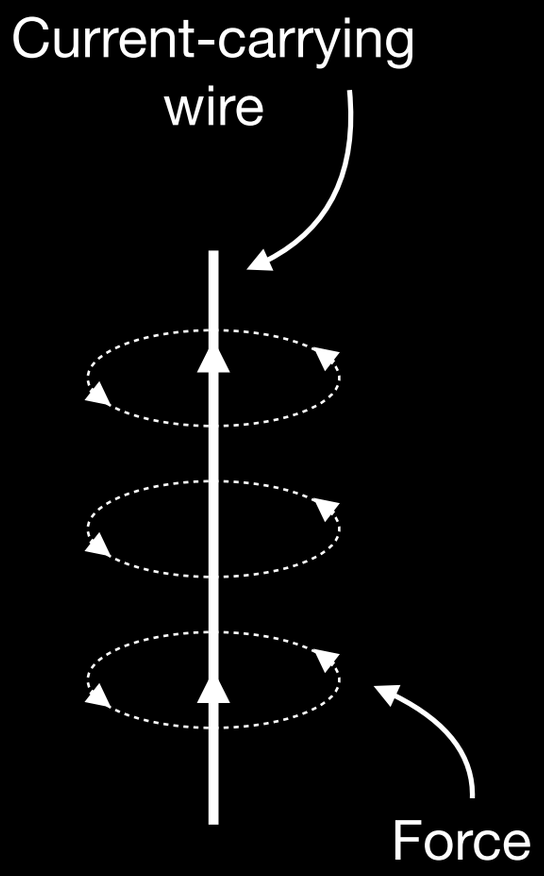


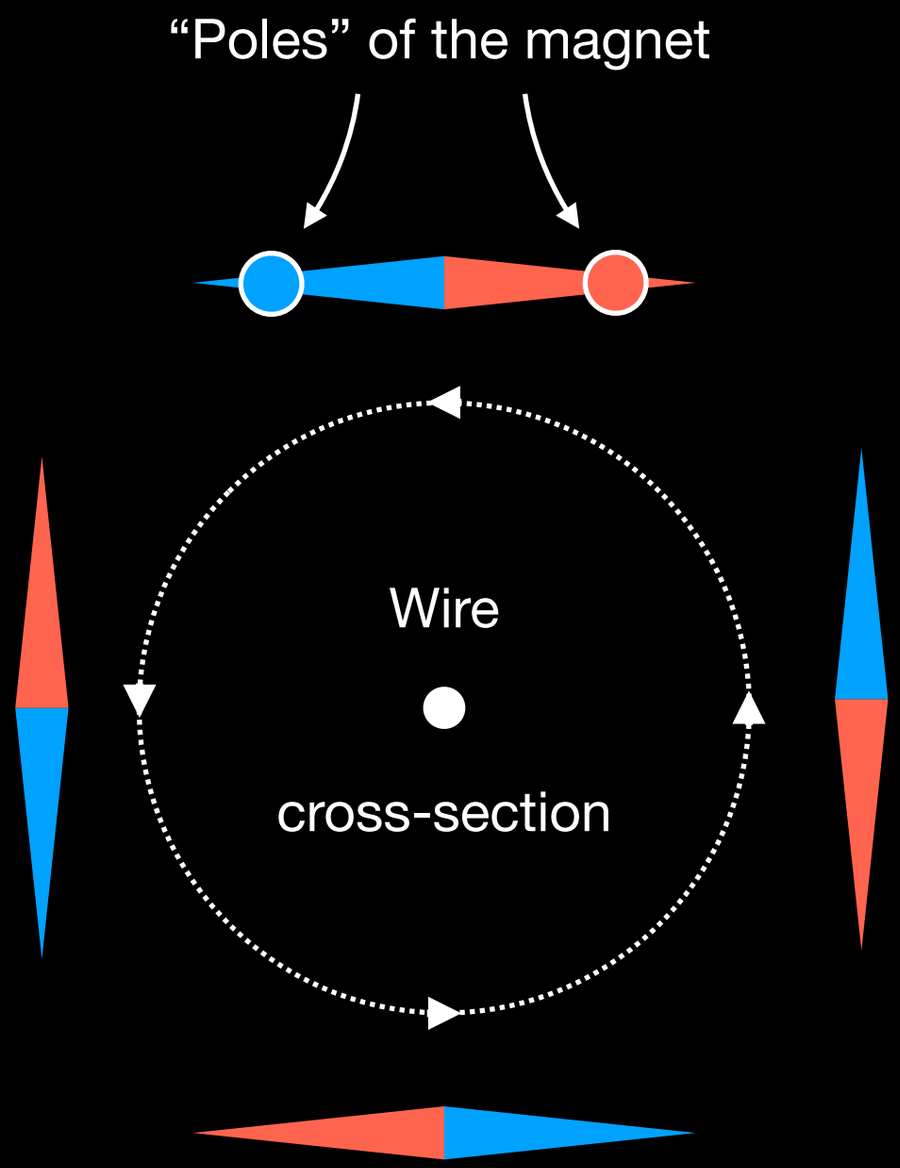
Faraday takes over



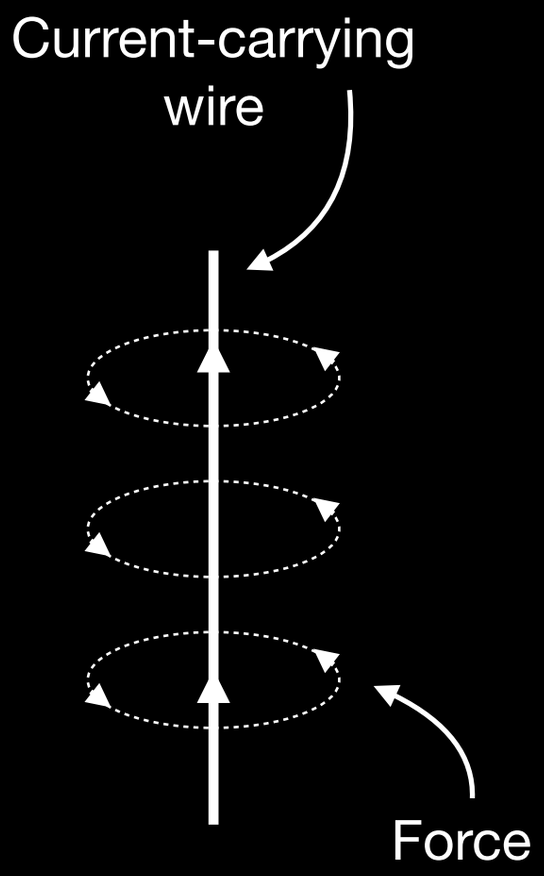


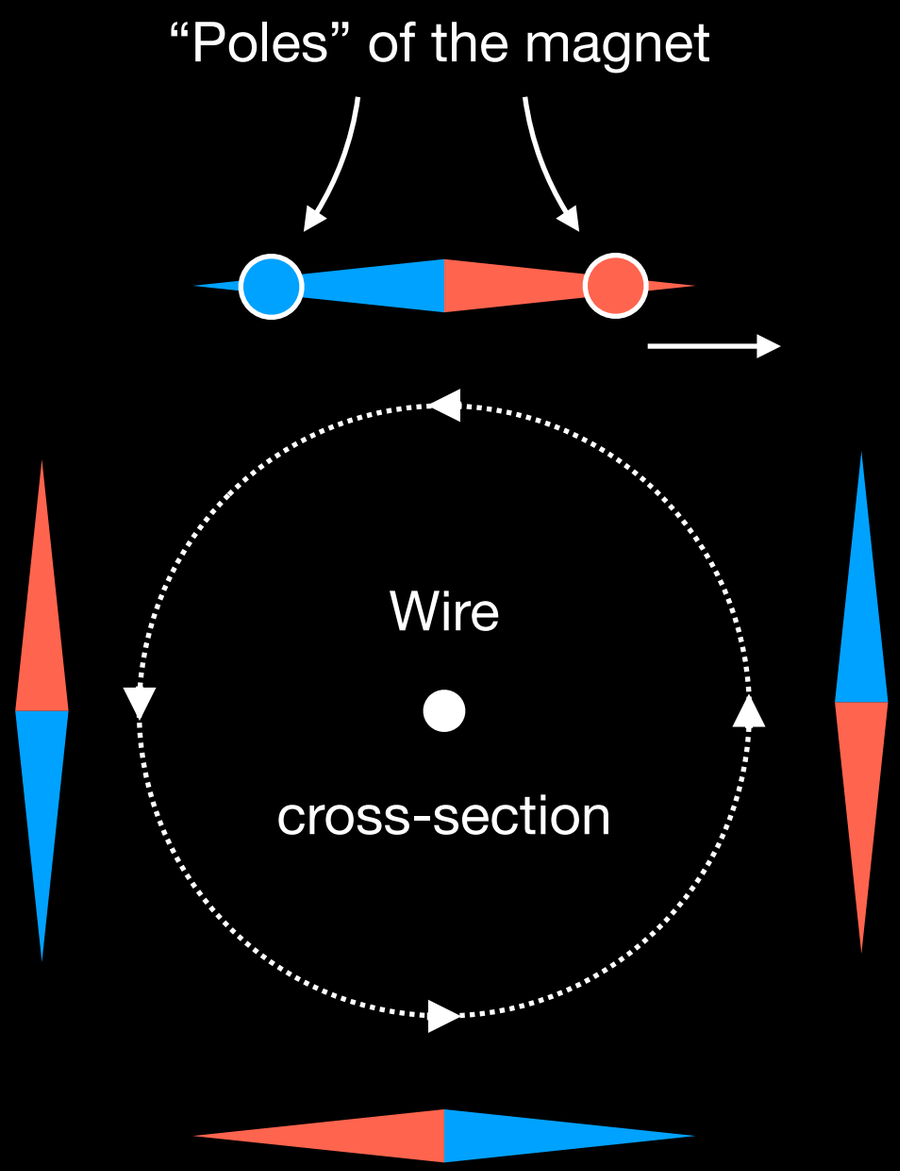
Faraday takes over



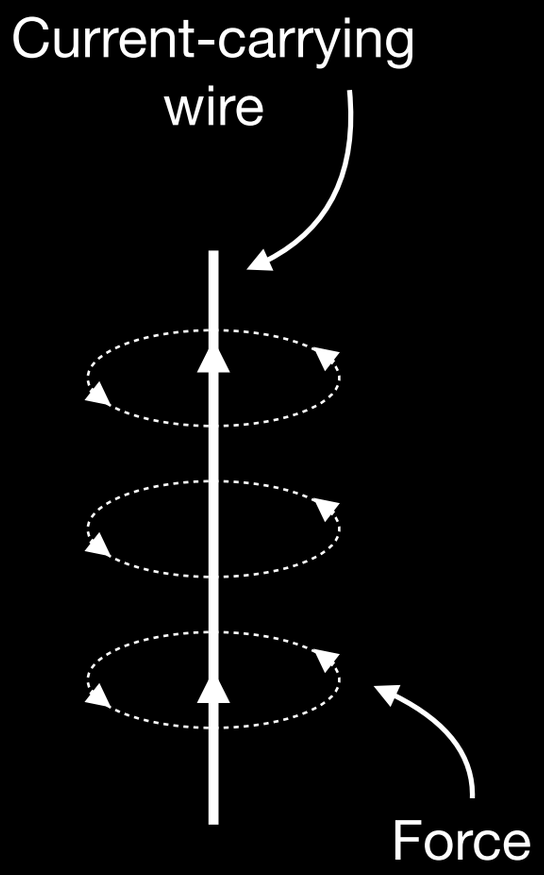


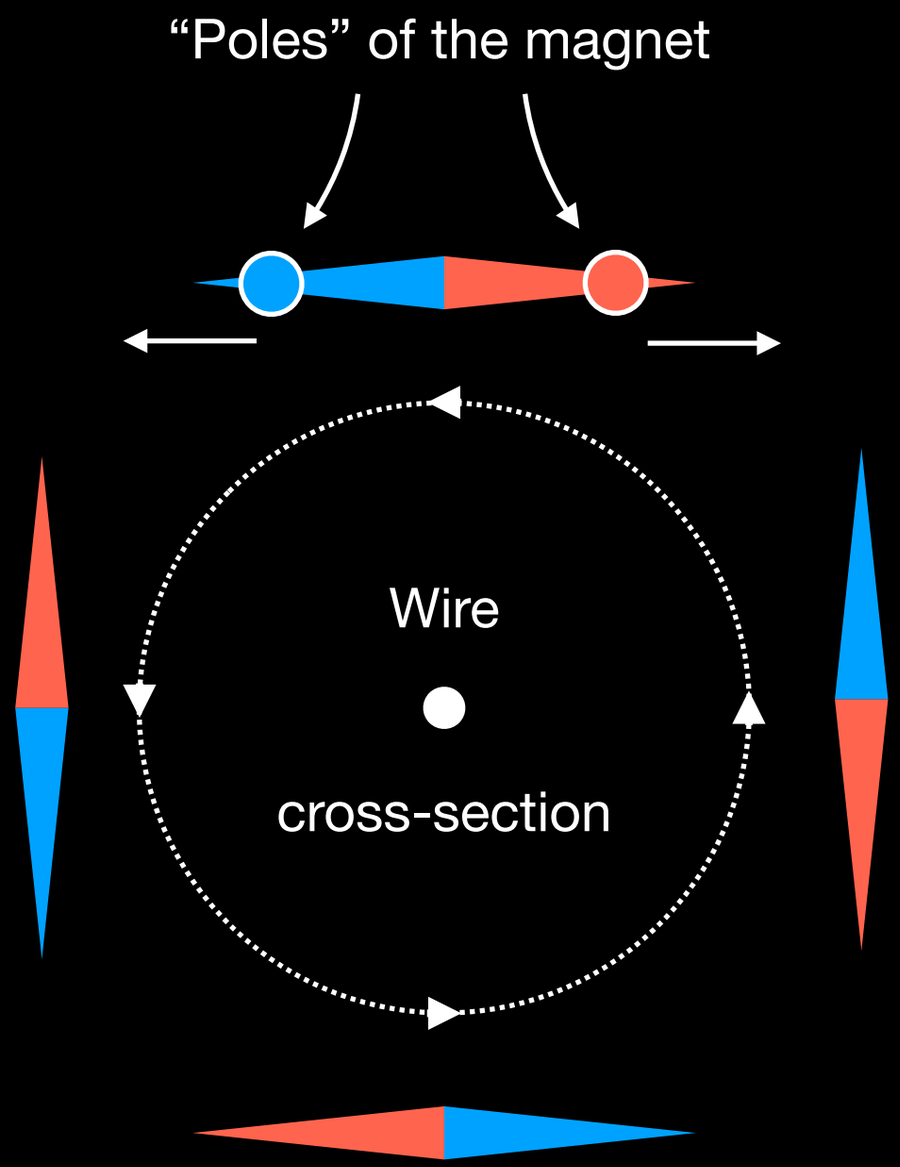
Faraday takes over



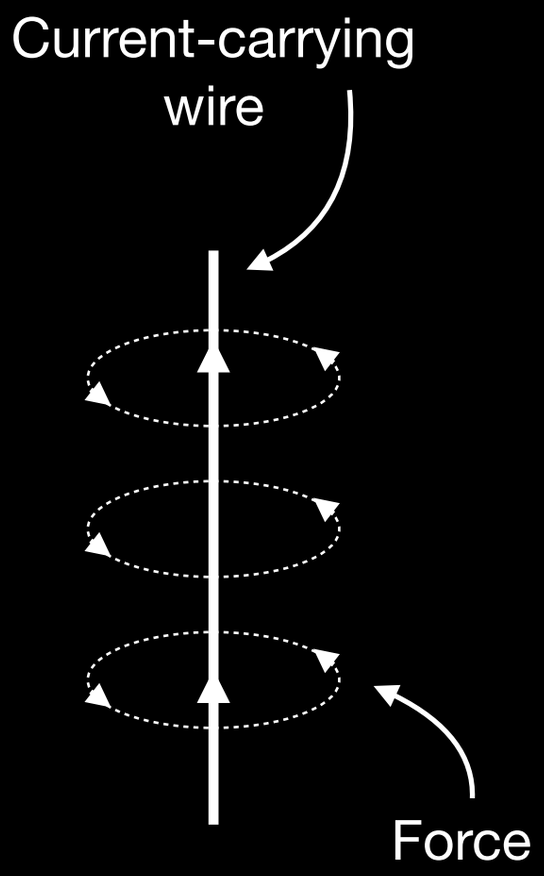


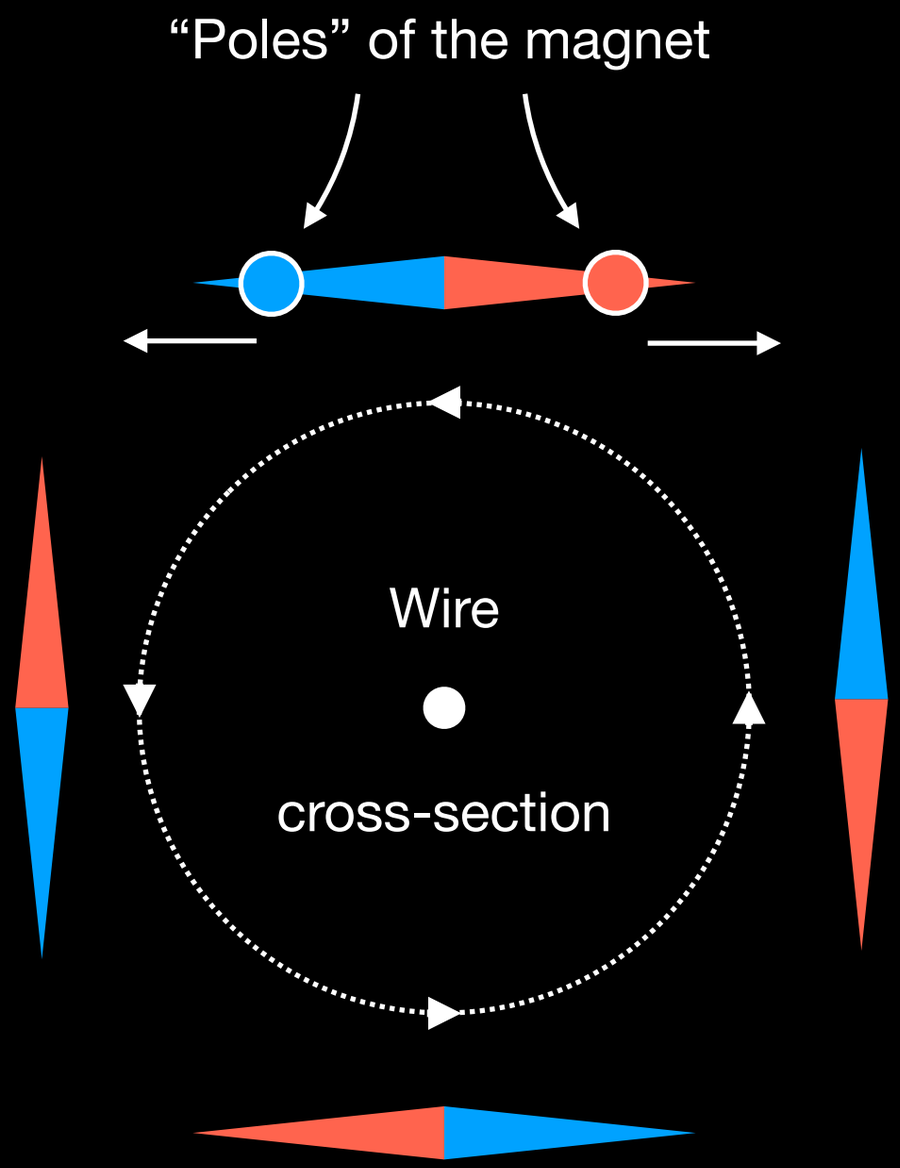
Faraday takes over





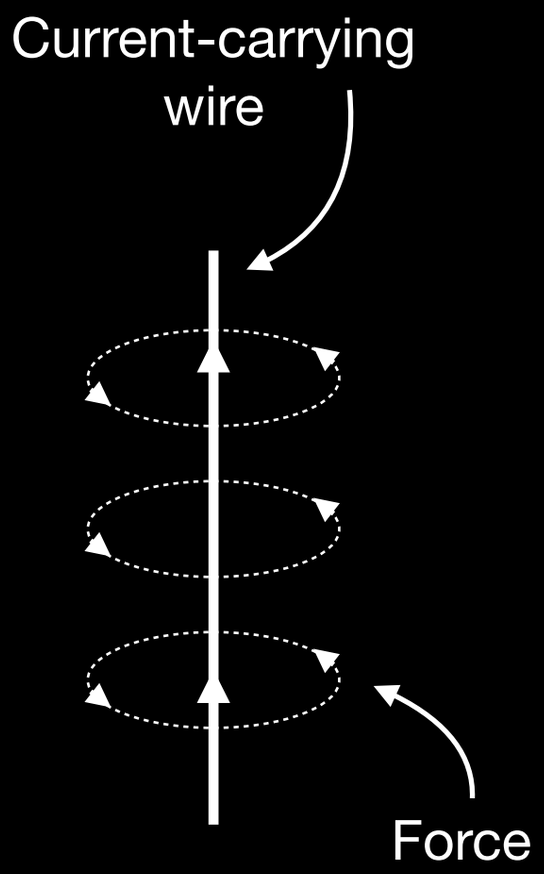
Faraday takes over

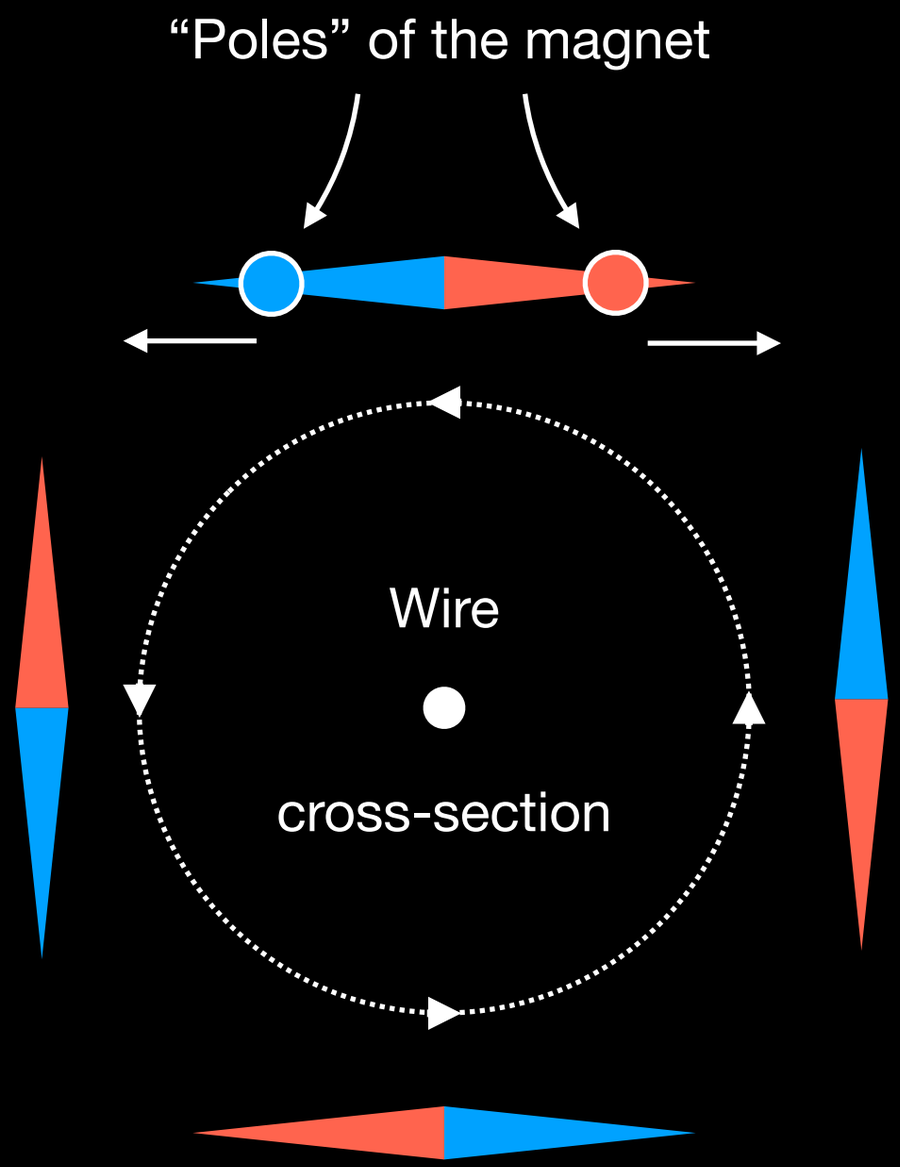




“It was evident, also, that the pole of the magnet had a tendency to revolve round the wire …”

Faraday takes over





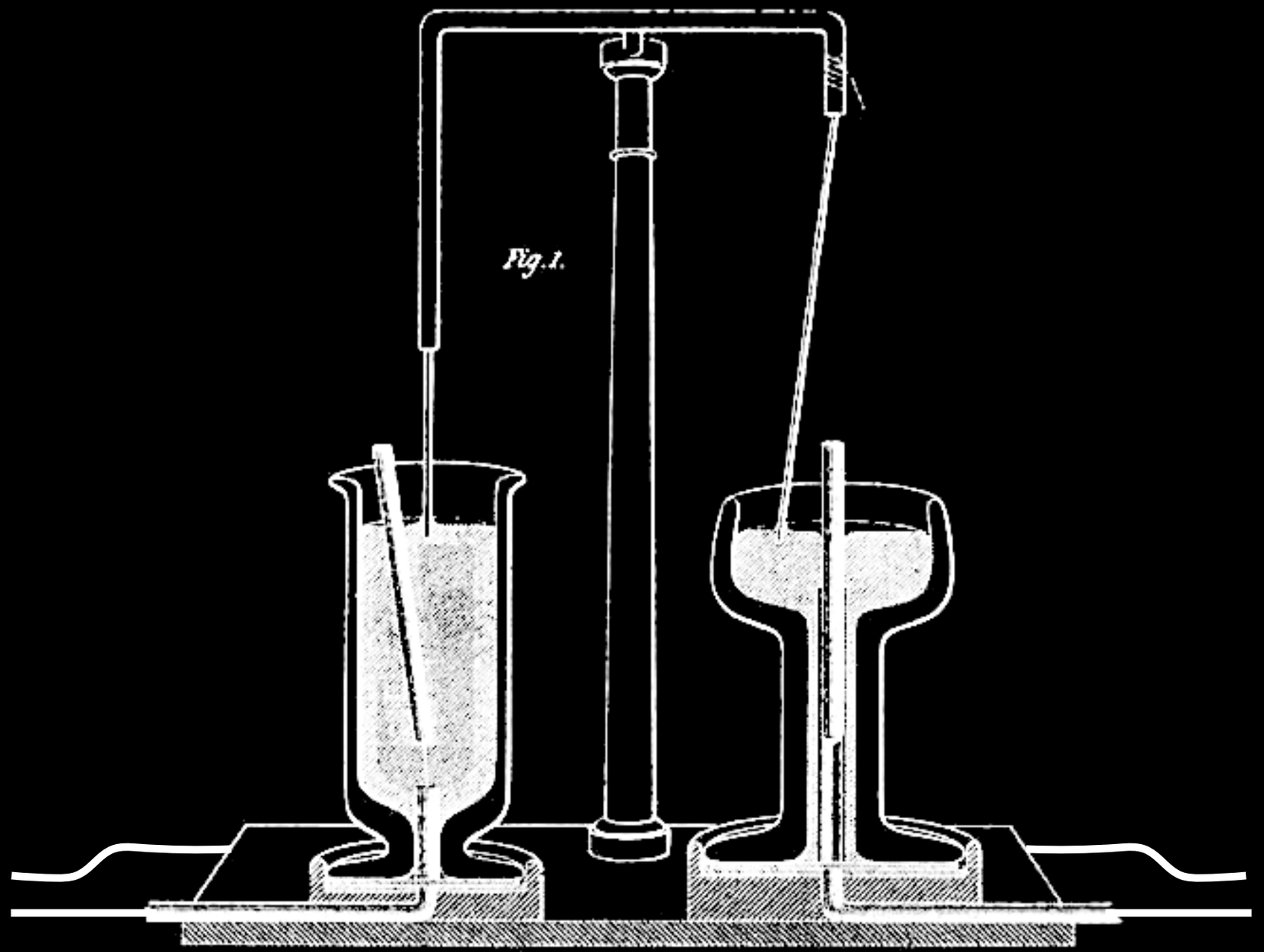
“It was evident, also, that the pole of the magnet had a tendency to revolve round the wire …”

“… and necessarily, therefore, the wire round the pole.”

The first electric “motor” (1821)

“Rotation of a pole around a wire”

“Rotation of a wire around a pole”



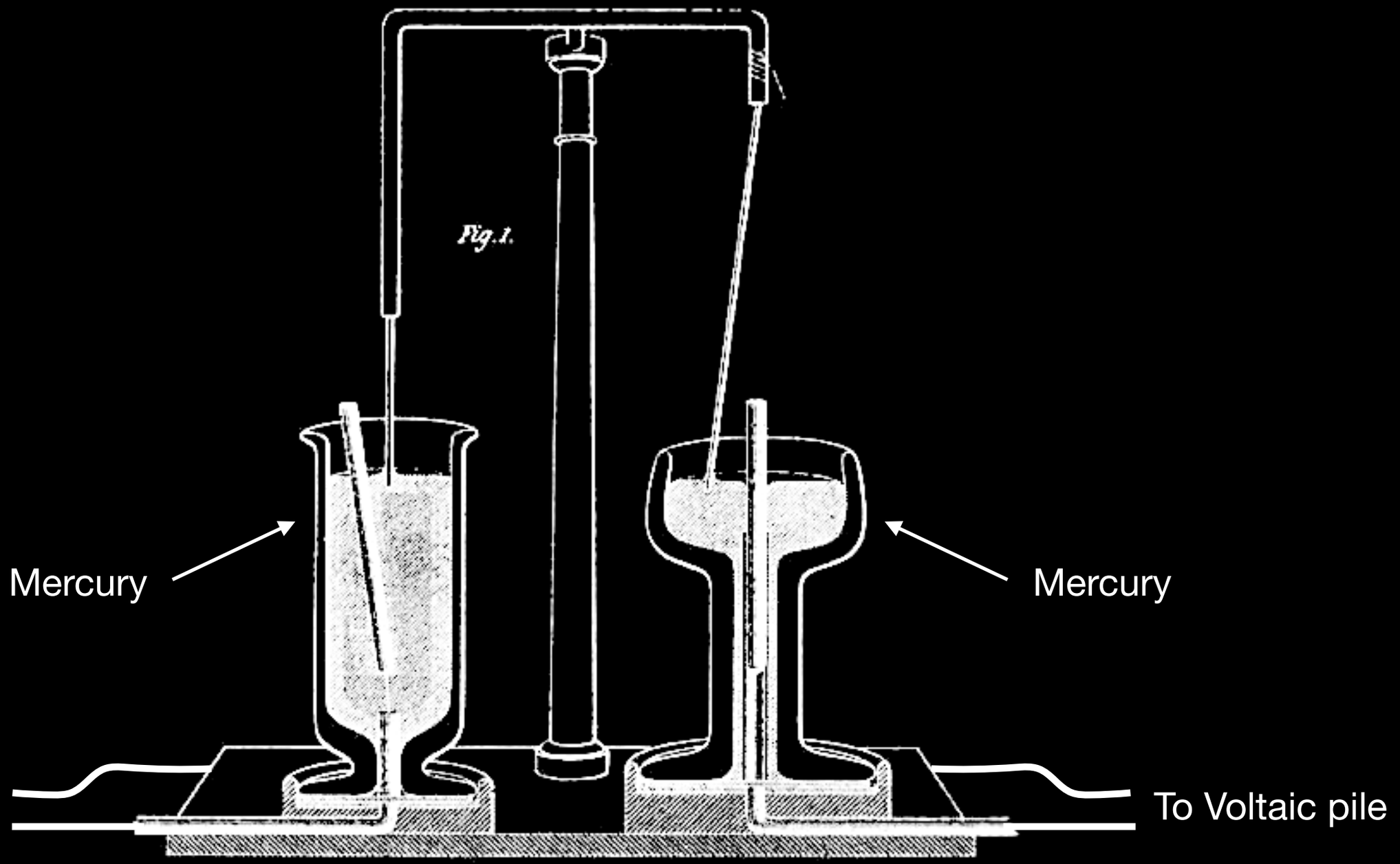
To Voltaic pile

To Voltaic pile

The first electric “motor” (1821)

“Rotation of a pole around a wire”

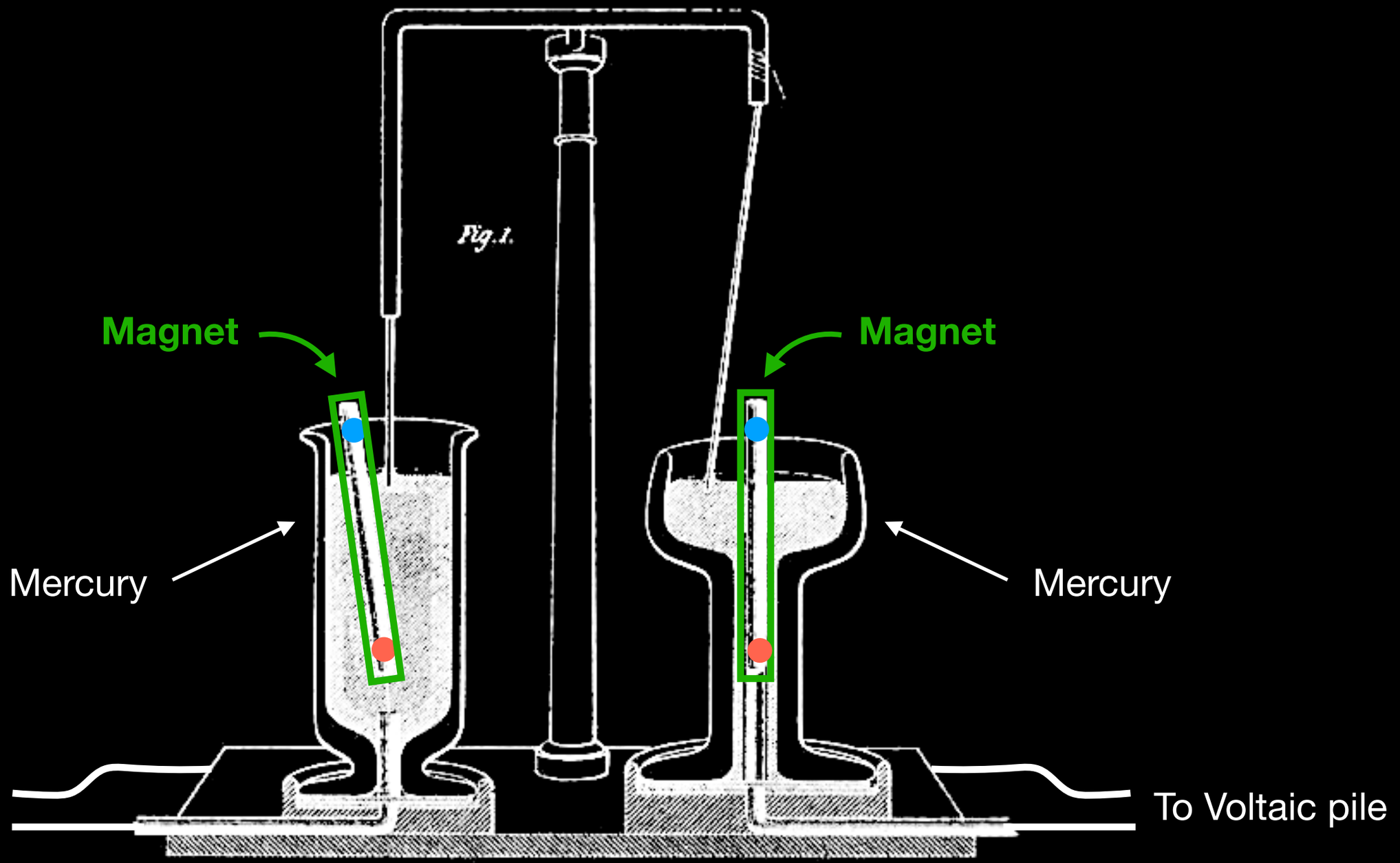
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

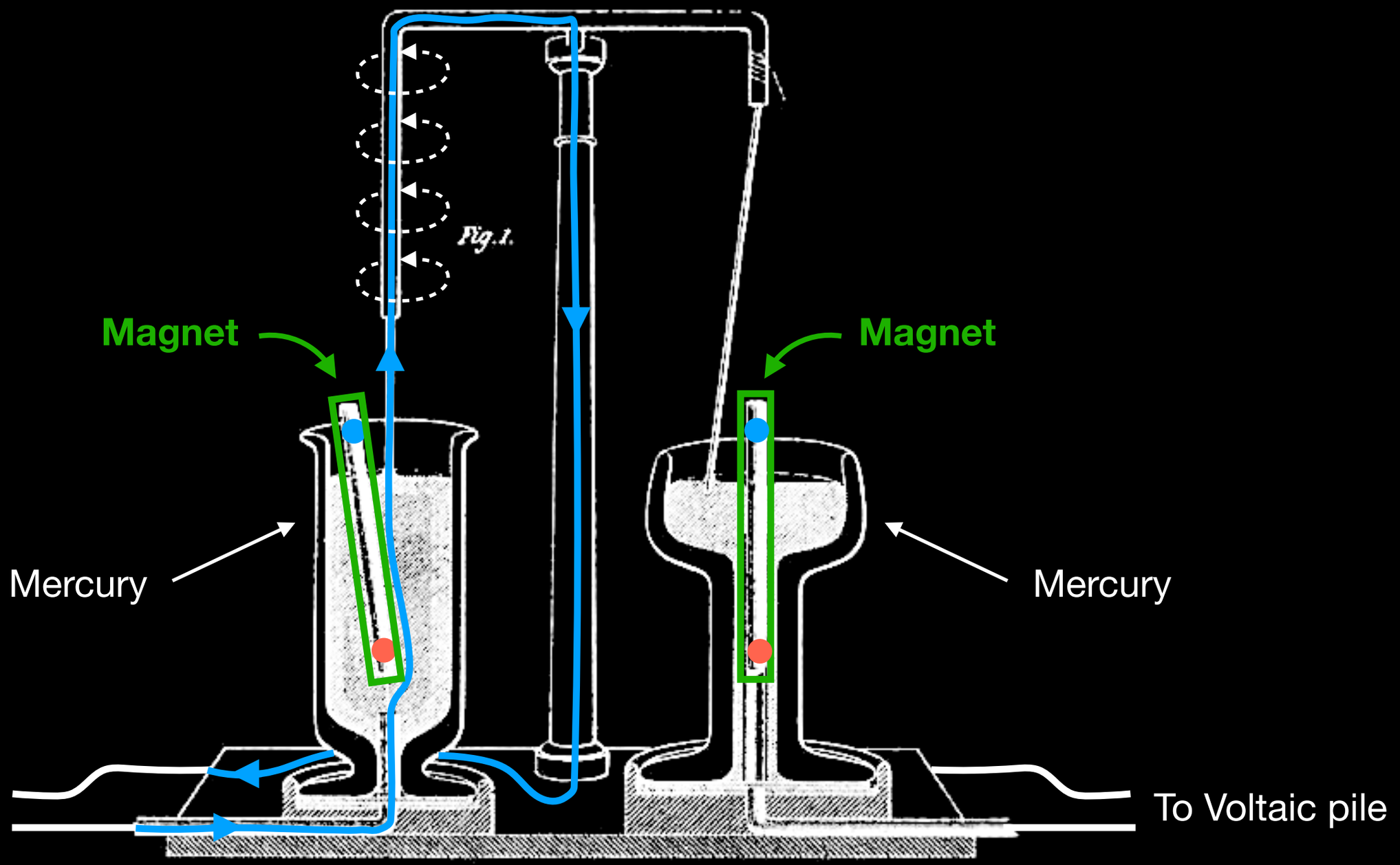
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

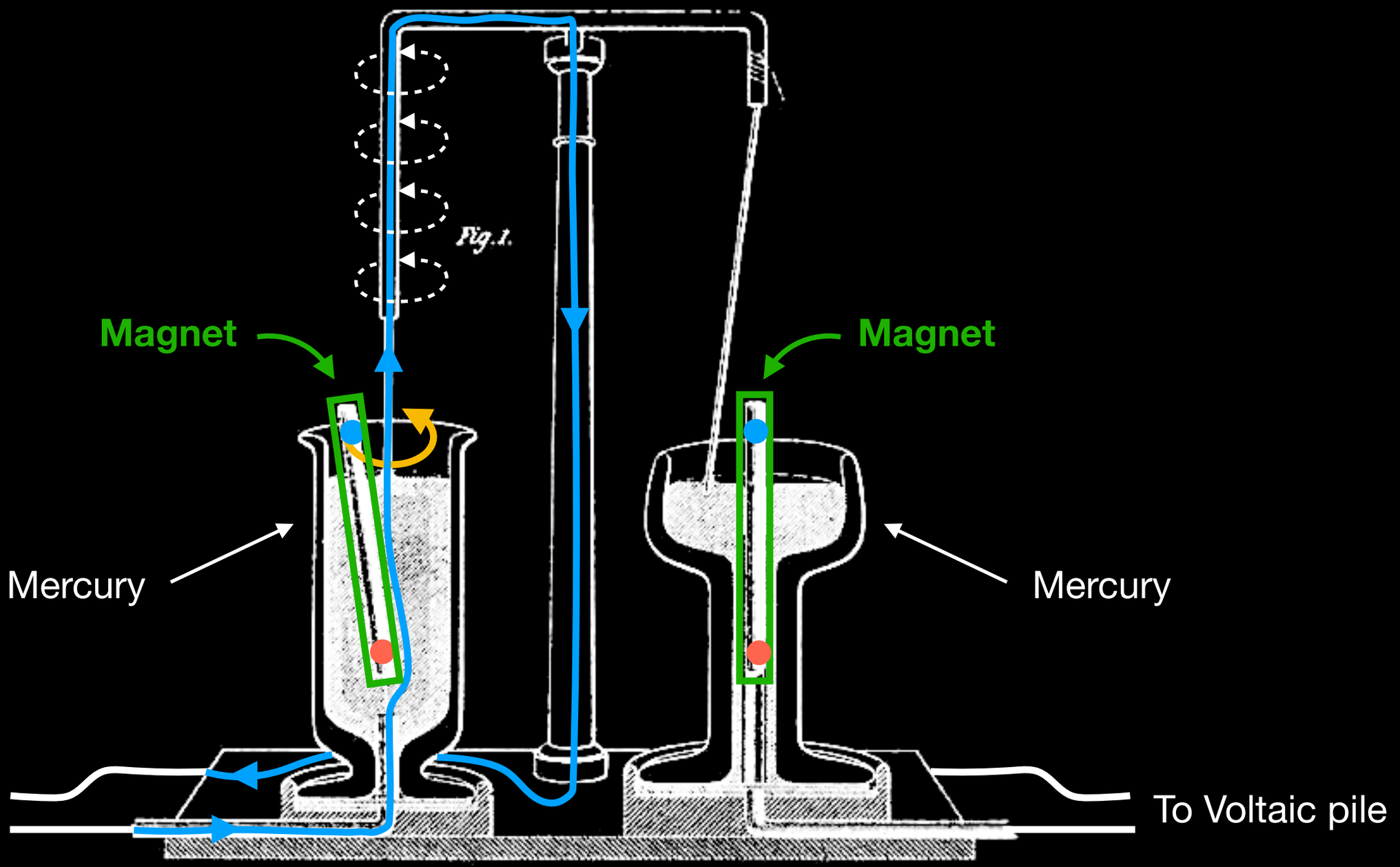
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

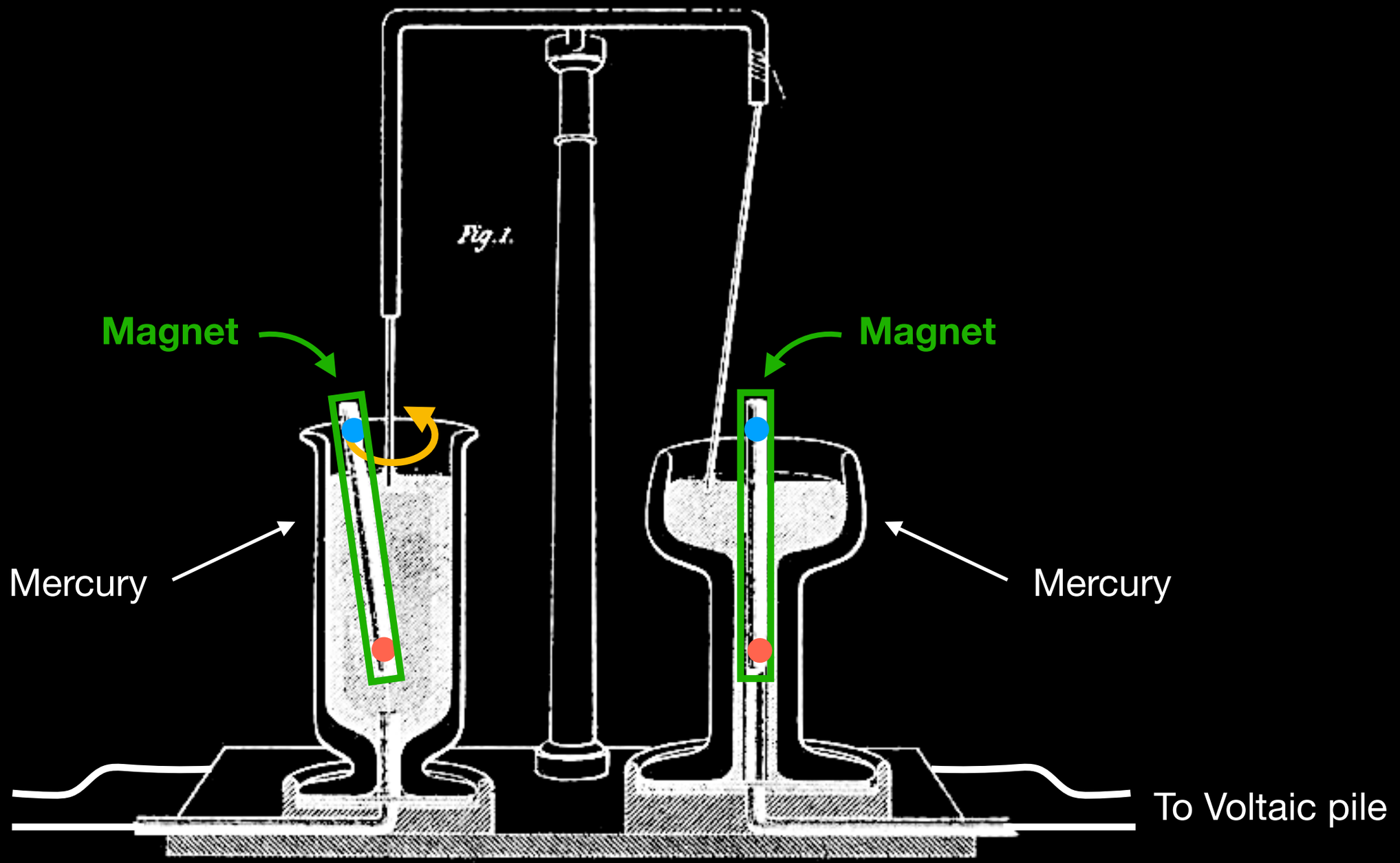
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

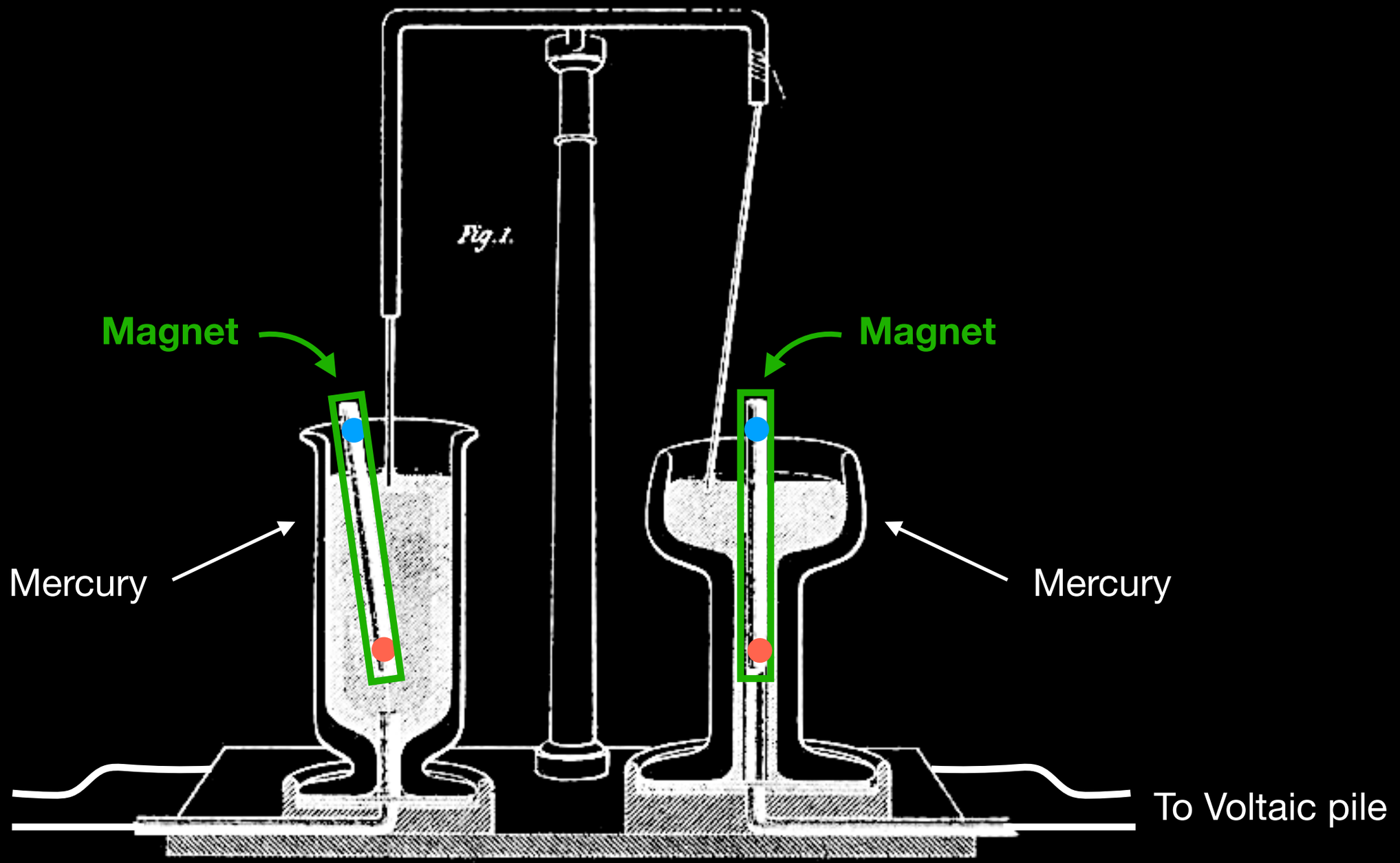
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

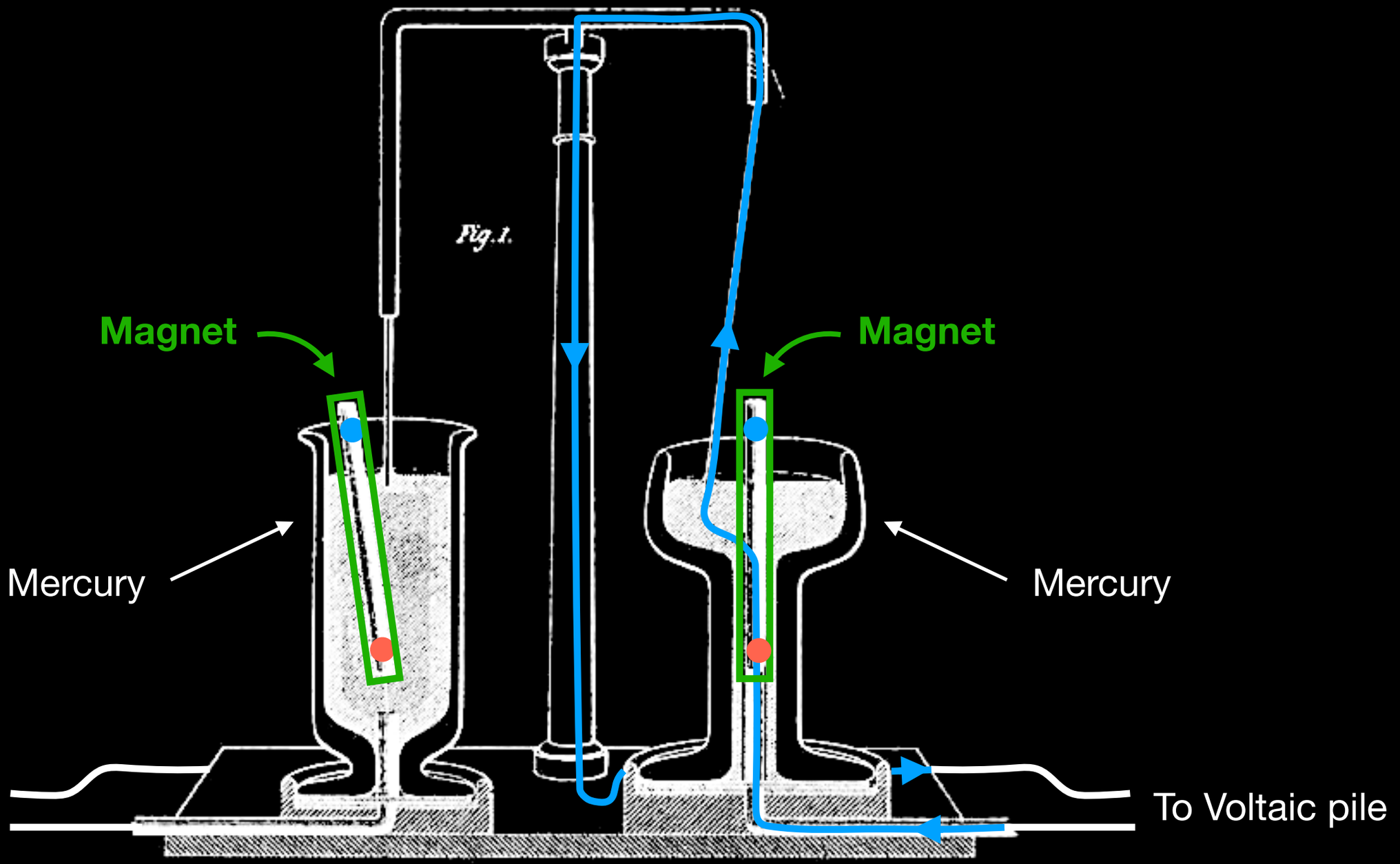
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

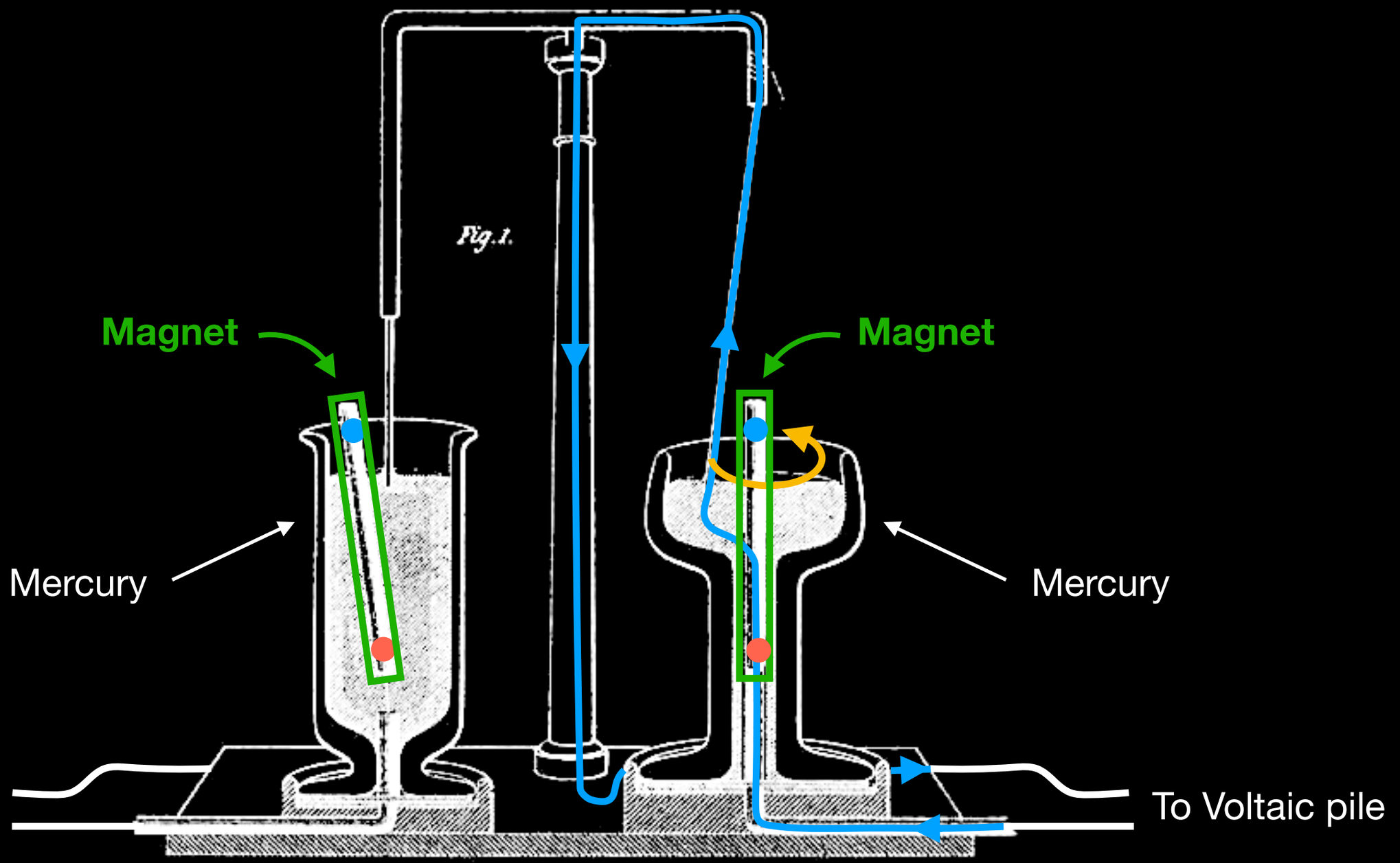
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

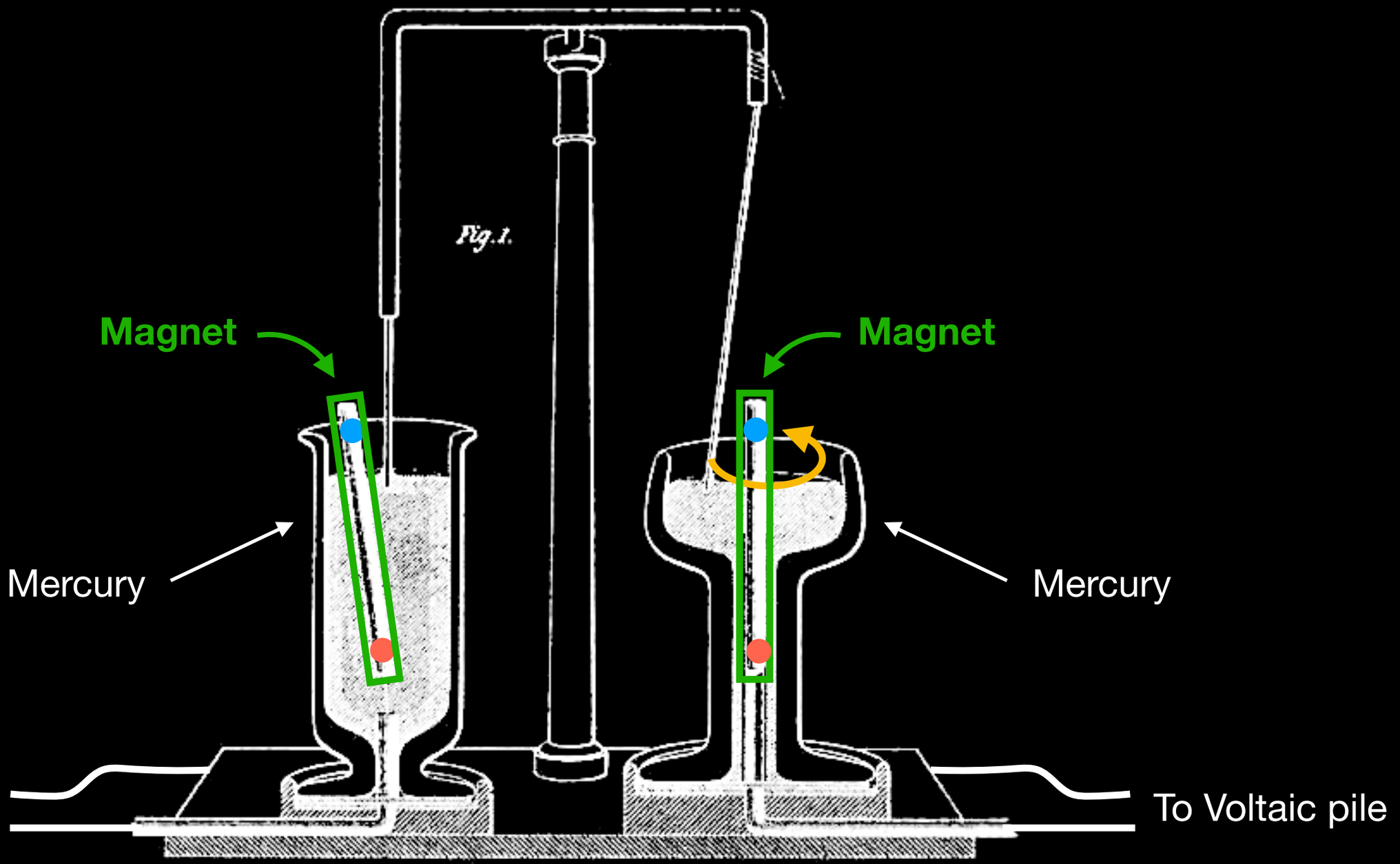
“Rotation of a wire around a pole”



The first electric “motor” (1821)

“Rotation of a pole around a wire”

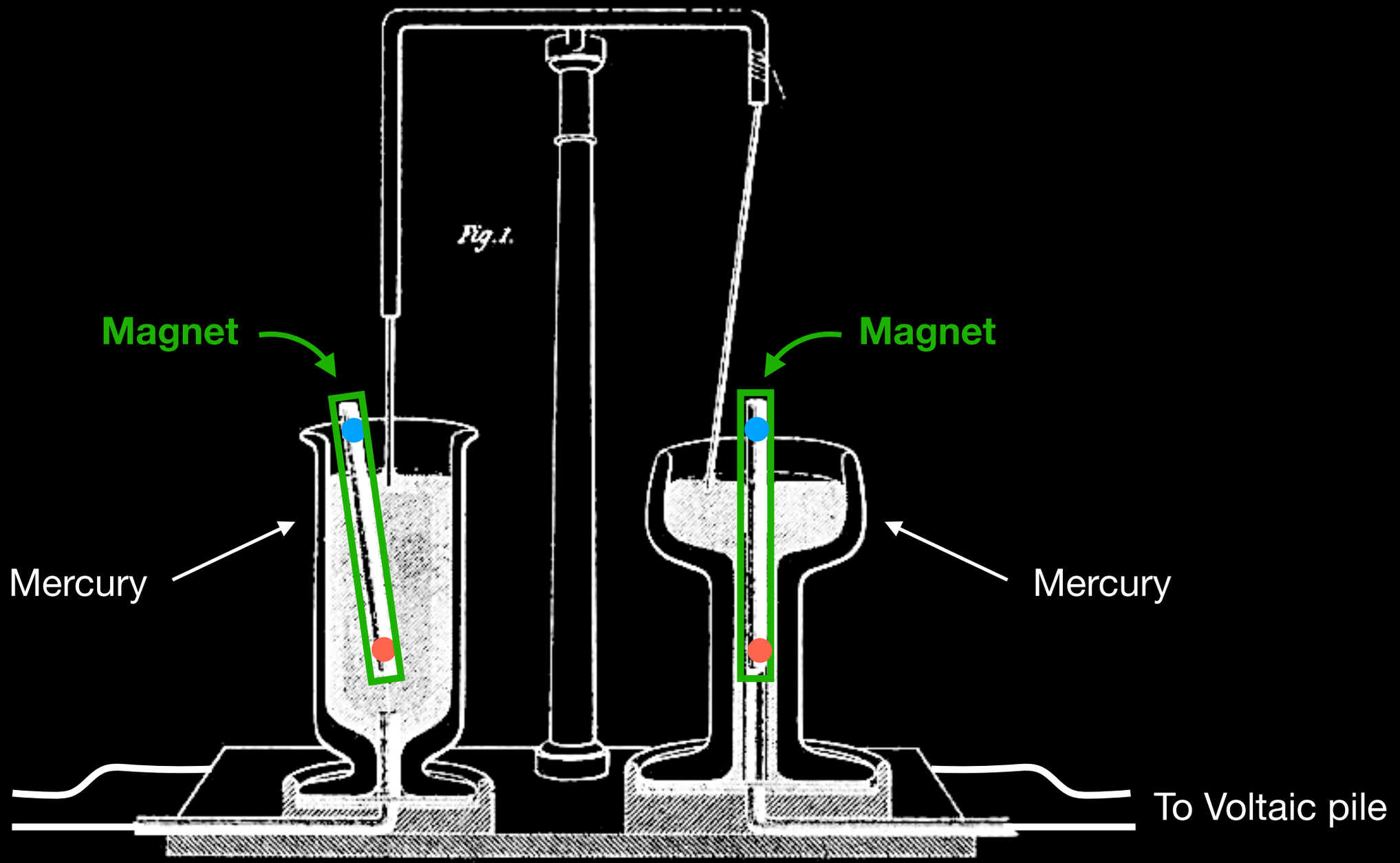
“Rotation of a wire around a pole”



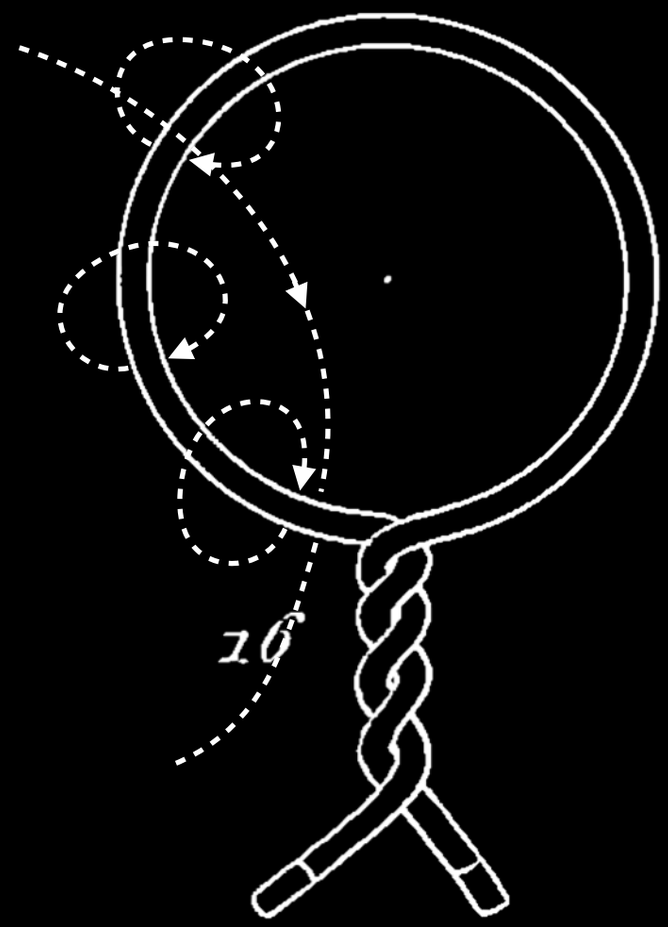
The first electric “motor” (1821)

“Rotation of a pole around a wire”

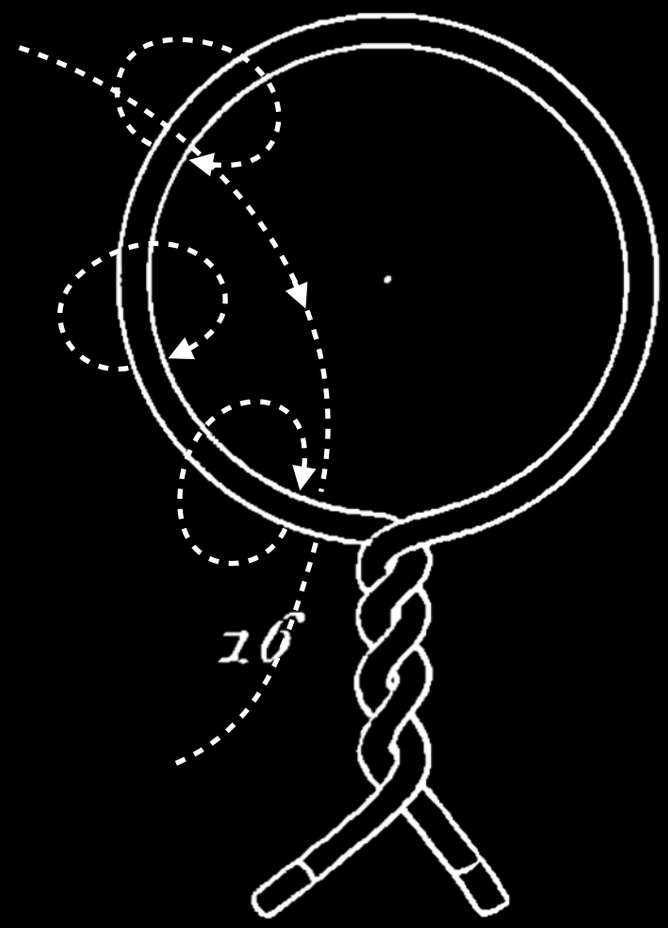
“Rotation of a wire around a pole”



Other wire arrangements



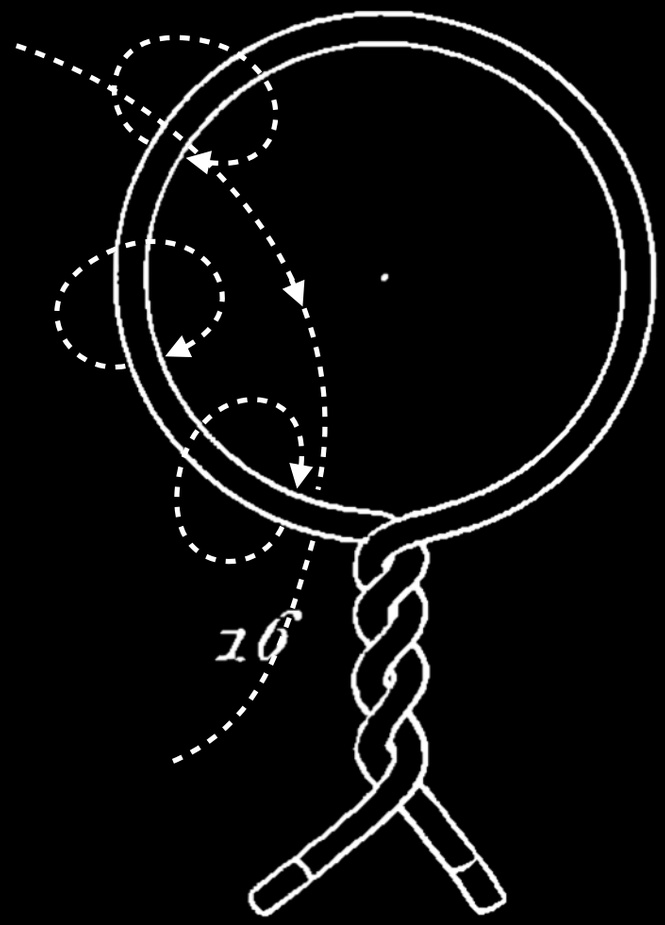
Other wire arrangements



“With iron filings, the appearance was extremely beautiful and instructive;

Other wire arrangements

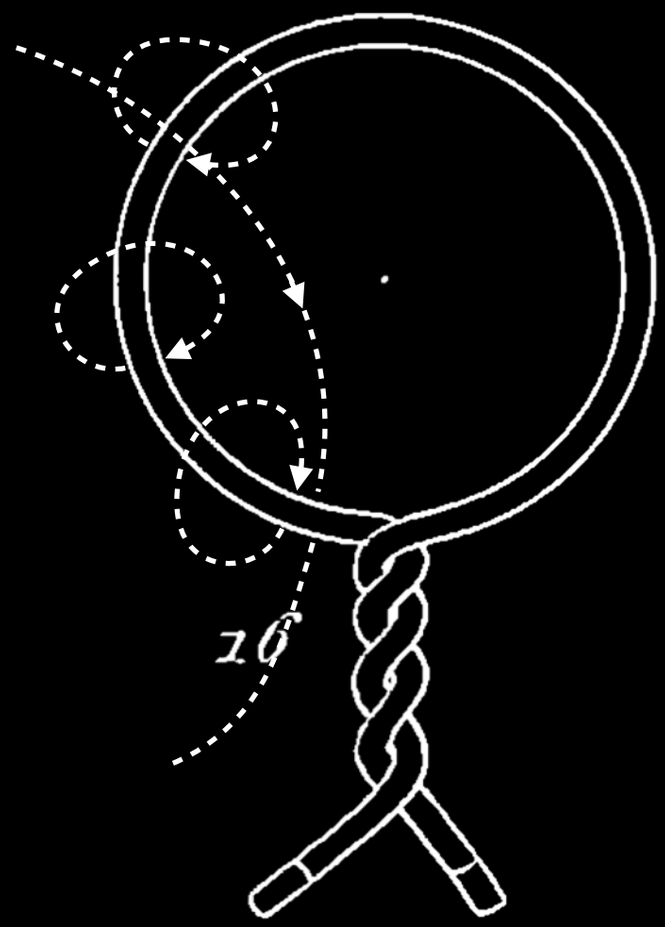
[source]



“With iron filings, the appearance was extremely beautiful and instructive;

Other wire arrangements

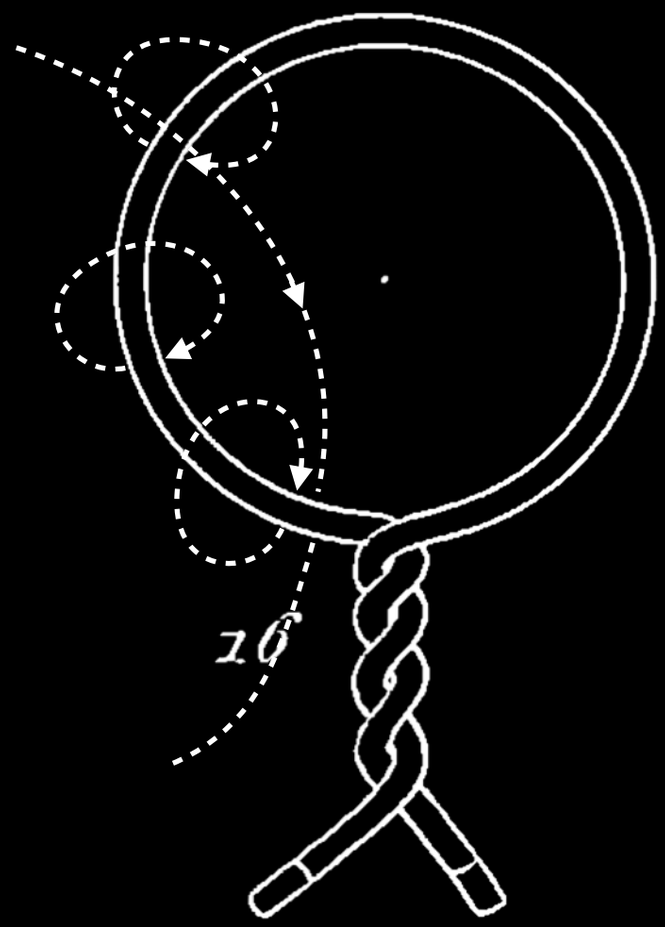
[source]



“With iron filings, the appearance was extremely beautiful and instructive; they arranged themselves in lines, passing through the ring parallel to its axis, and then folding up on either side as radii round to the edge;

Other wire arrangements

[source]



“With iron filings, the appearance was extremely beautiful and instructive;
they arranged themselves in lines, passing through the ring parallel to its axis, and
then folding up on either side as radii round to the edge;
so that they represented, exactly, the lines which a pole would have described.”

Electricity from magnetism?

Electricity from magnetism?

“The hope of obtaining electricity from ordinary magnetism has stimulated me at various times to investigate experimentally the inductive effect of electric currents.”

Electricity from magnetism?

“The hope of obtaining electricity from ordinary magnetism has stimulated me at various times to investigate experimentally the inductive effect of electric currents.”

“I lately arrived at positive results.”

Electricity from magnetism?

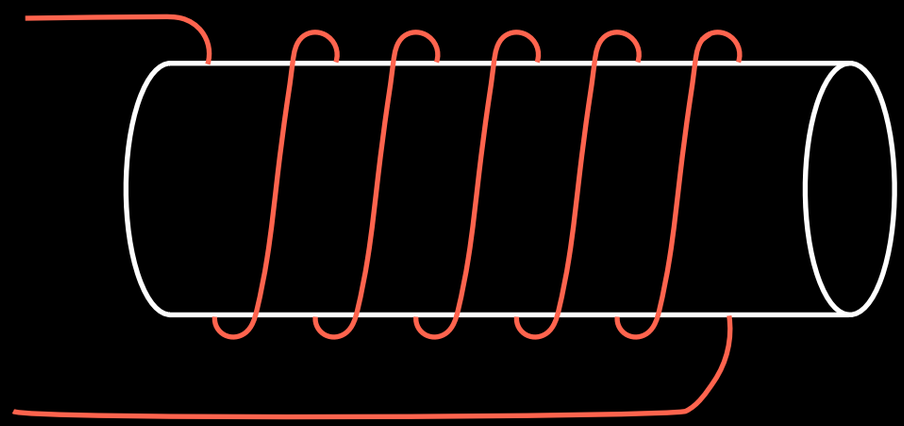
“The hope of obtaining electricity from ordinary magnetism has stimulated me at various times to investigate experimentally the inductive effect of electric currents.”

“I lately arrived at positive results.”

V. *Experimental Researches in Electricity.* *By* MICHAEL FARADAY, *F.R.S.*, *M.R.I., Corr. Mem. Royal Acad. of Sciences of Paris, Petersburgh, &c. &c.*

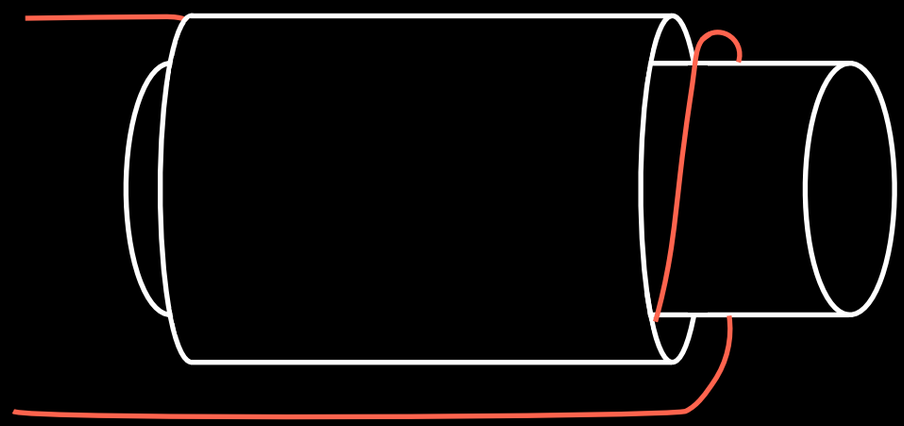
Read November 24, 1831.

The first experiment



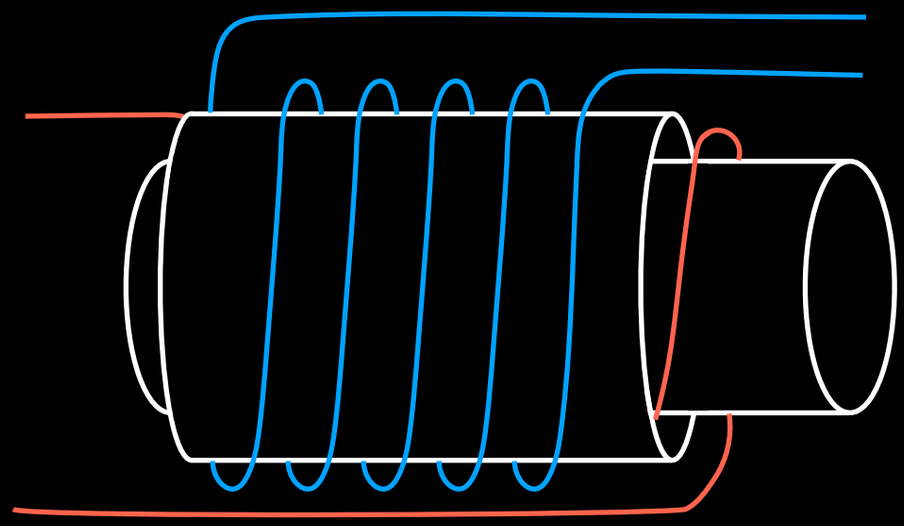
“About twenty-six feet of copper wire were wound round a cylinder of wood as a helix.”

The first experiment



“This helix was covered with cotton cloth …”

The first experiment



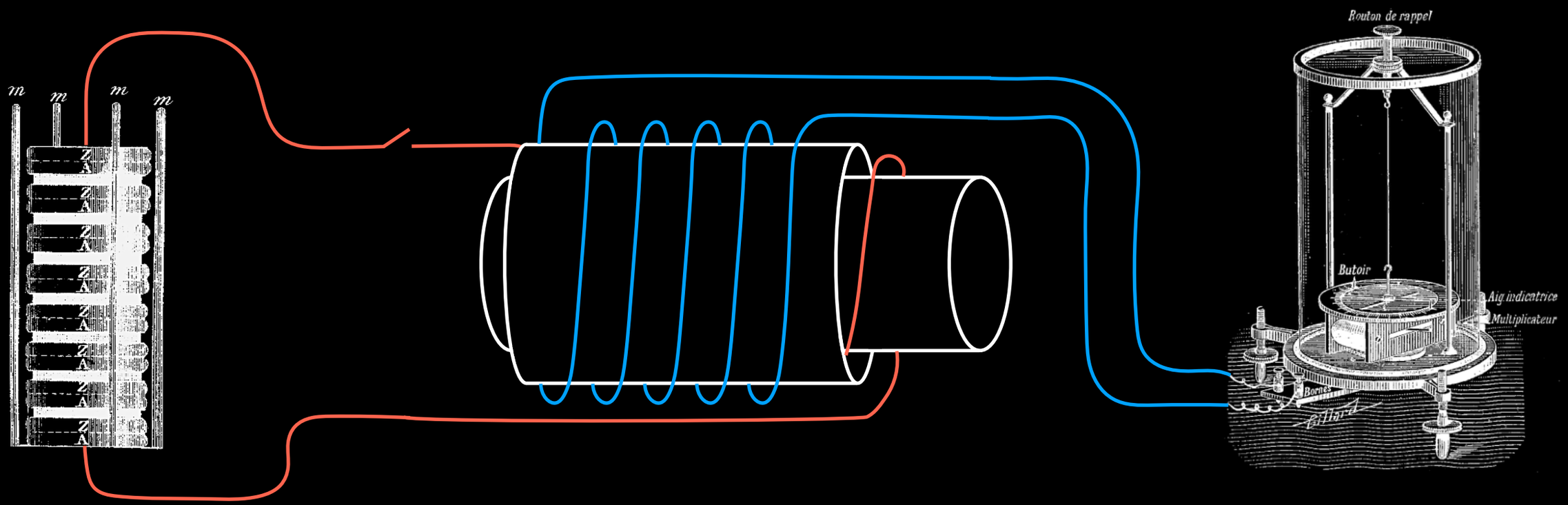
“… and then a second wire applied in the same manner.”

“This produced two principal helices, closely interposed, having the same direction, and not touching anywhere.”

The first experiment

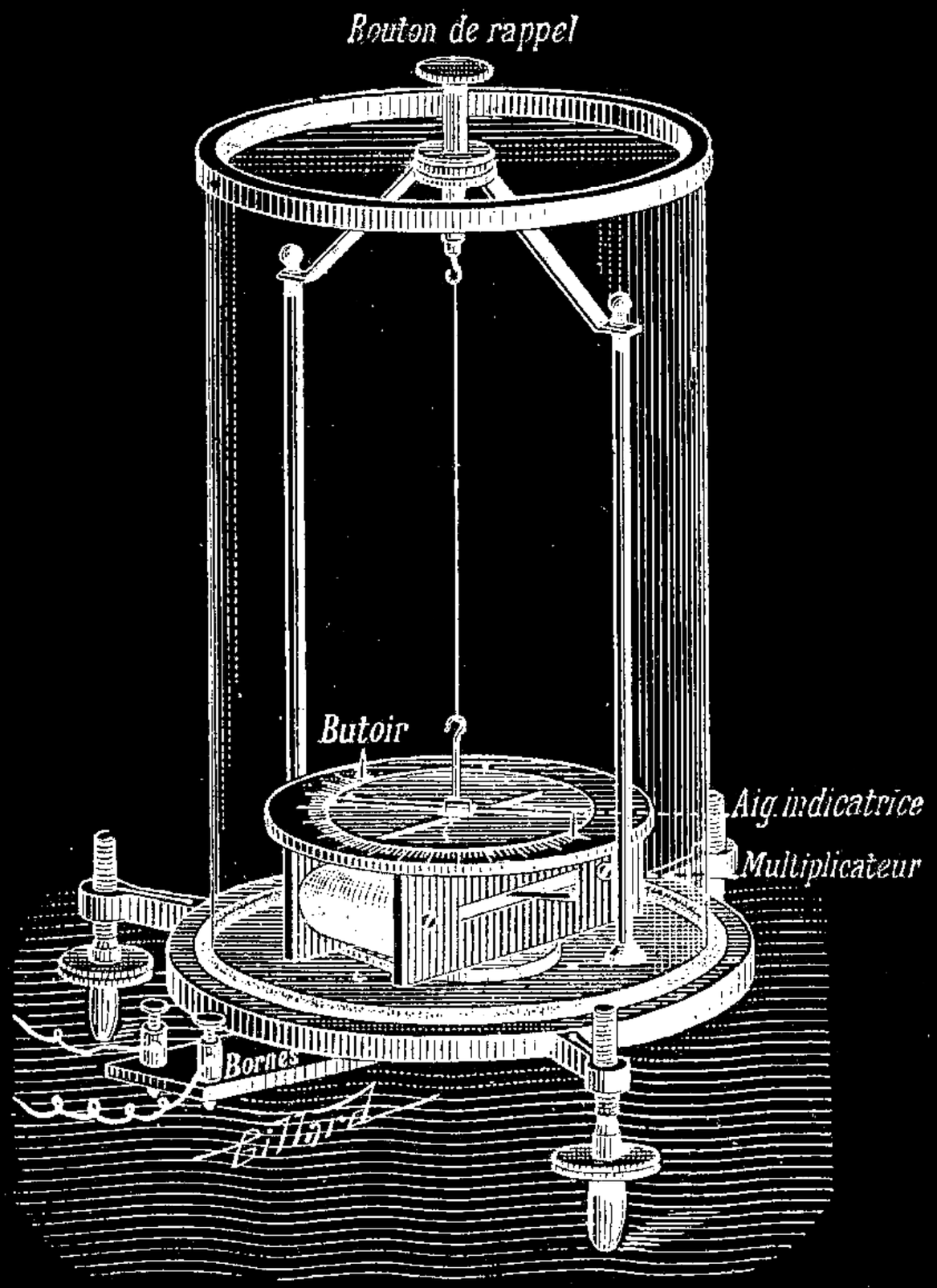
Voltaic pile

Galvanometer

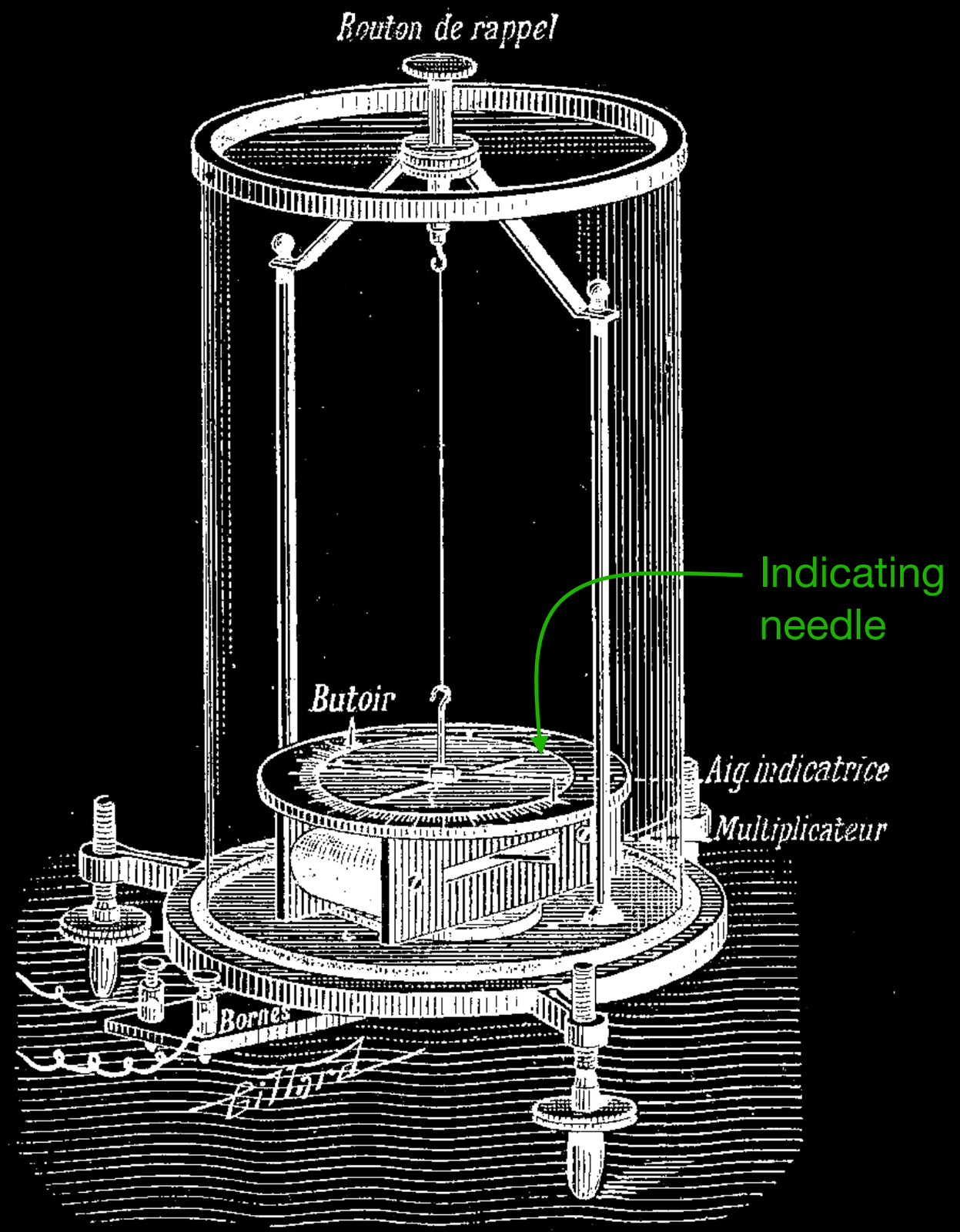


“One of these helices was connected with a galvanometer, the other with a voltaic battery.”

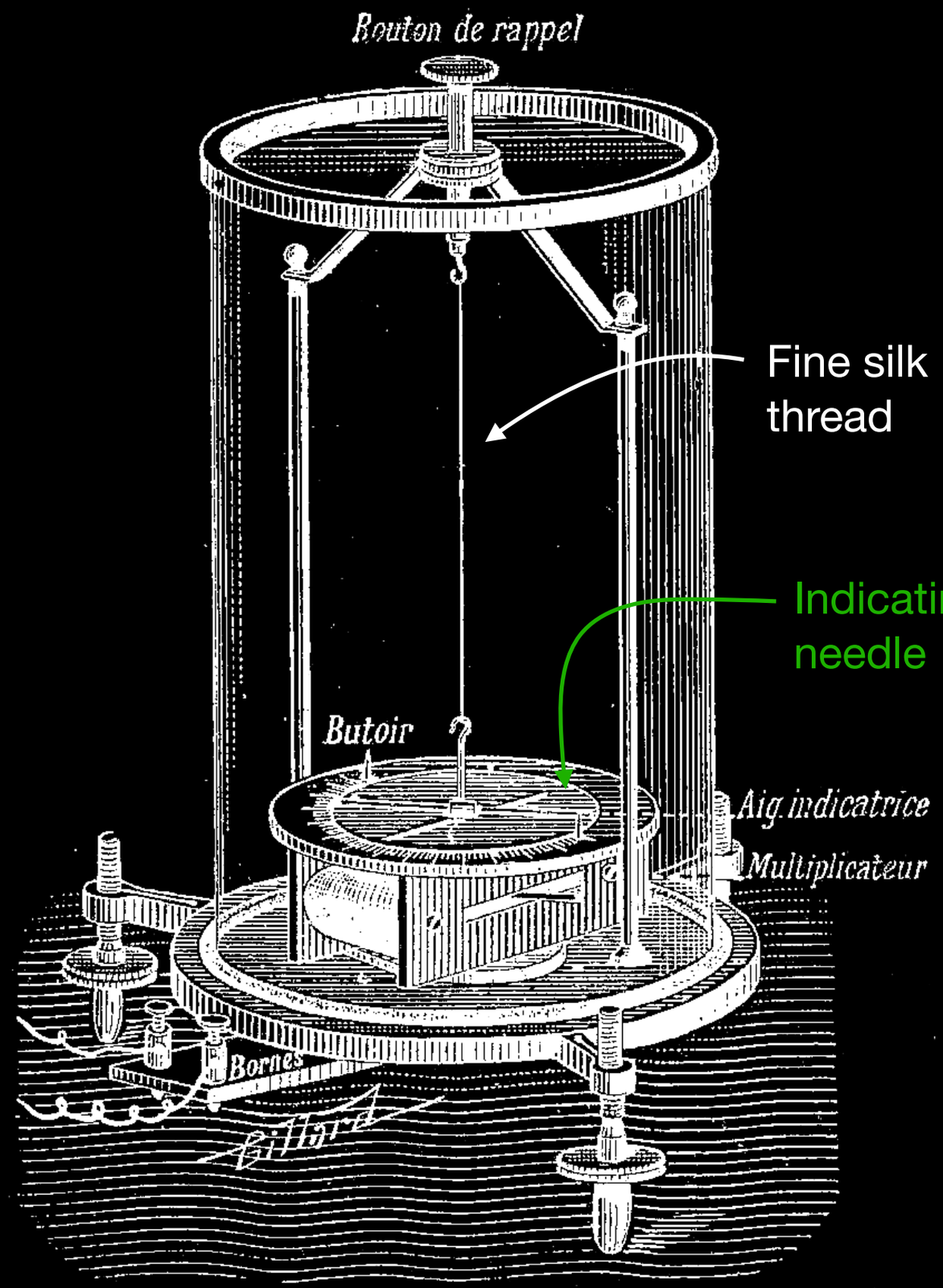
Faraday's Galvanometer



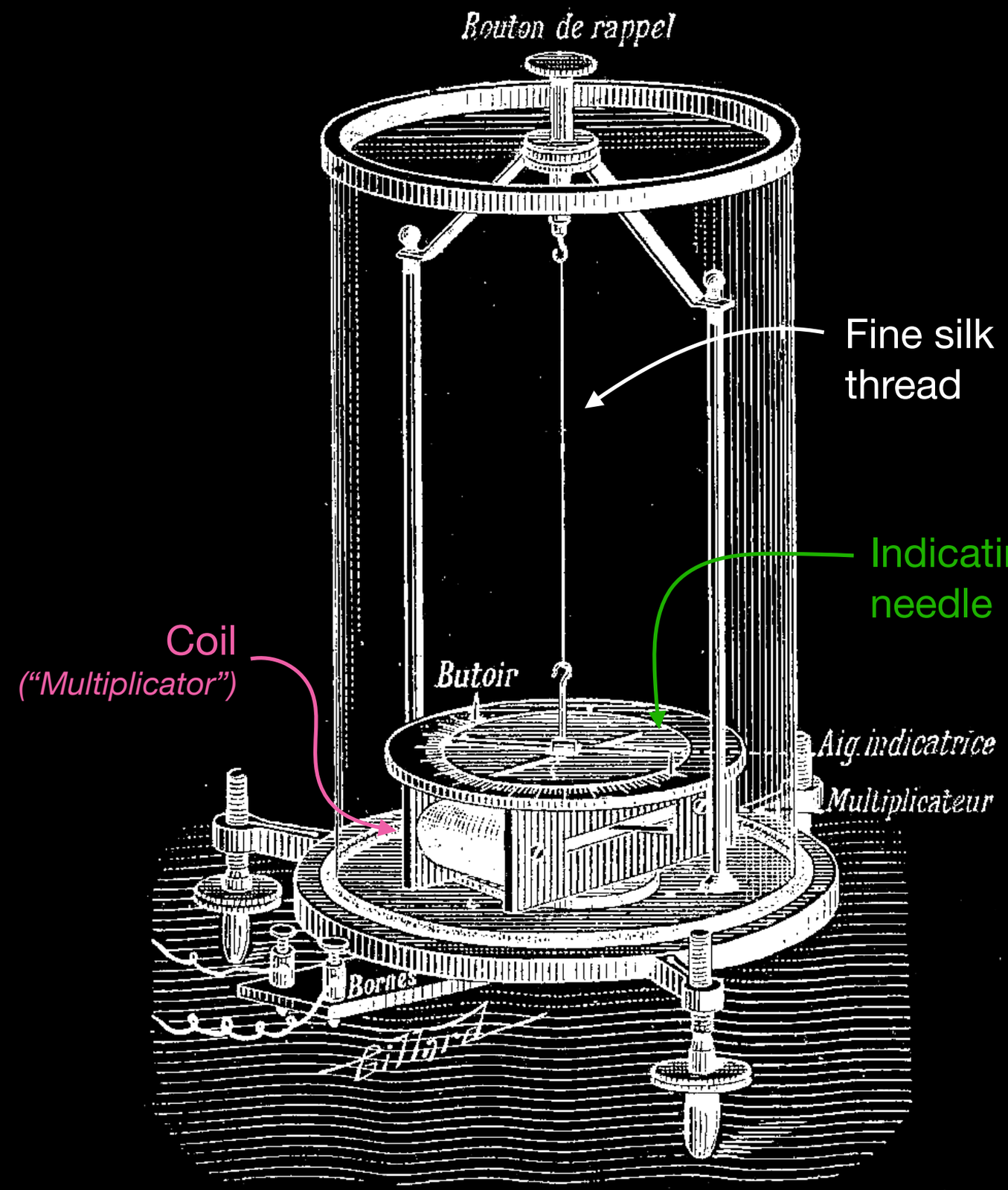
Faraday's Galvanometer



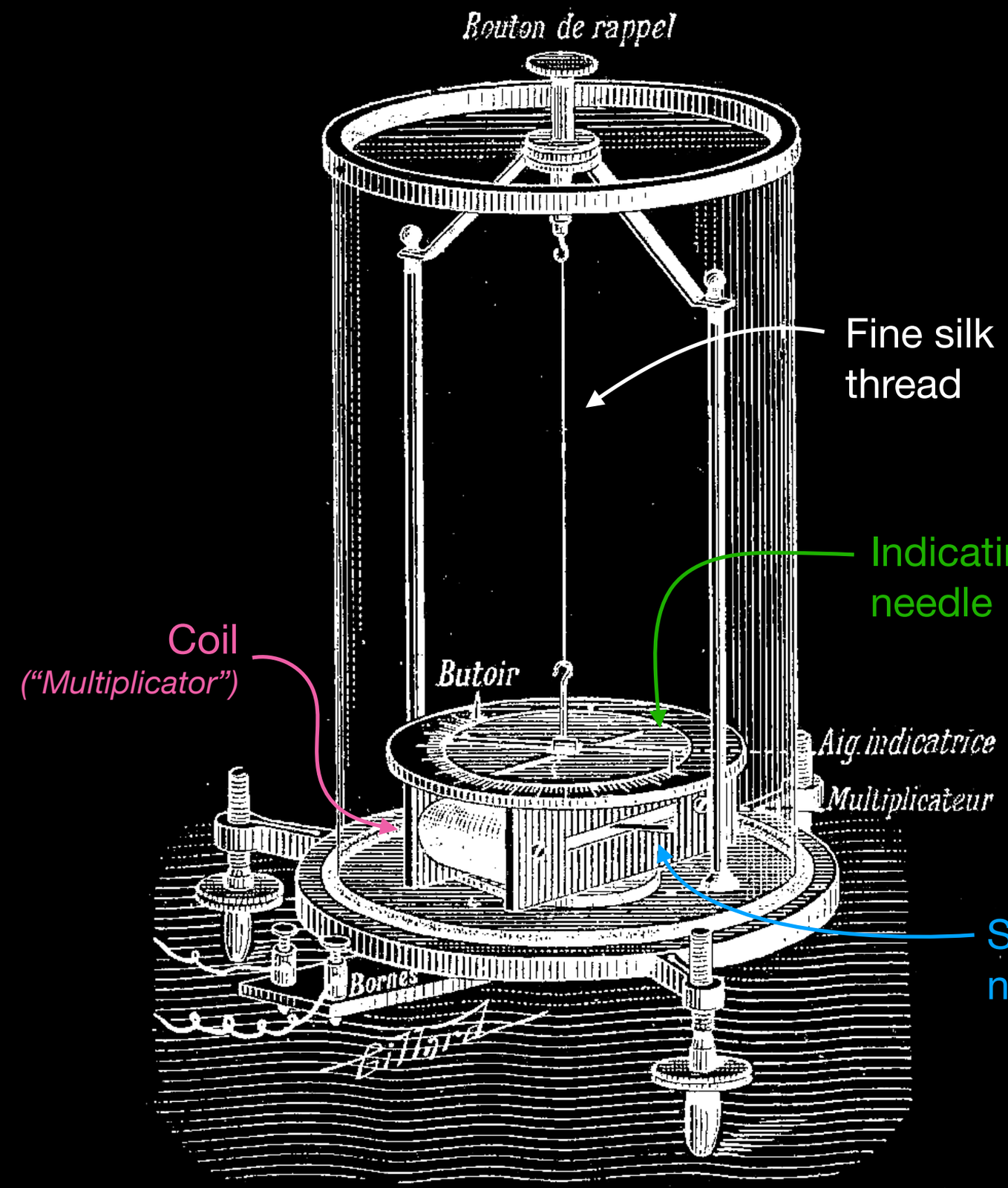
Faraday's Galvanometer



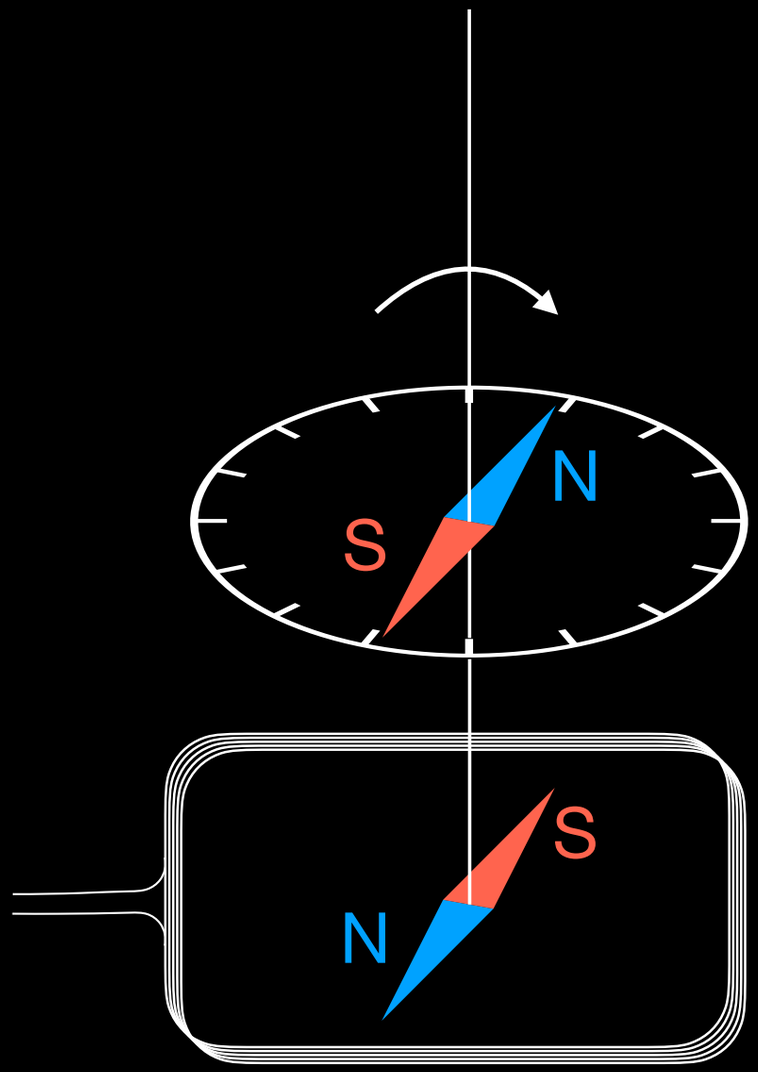
Faraday’s Galvanometer

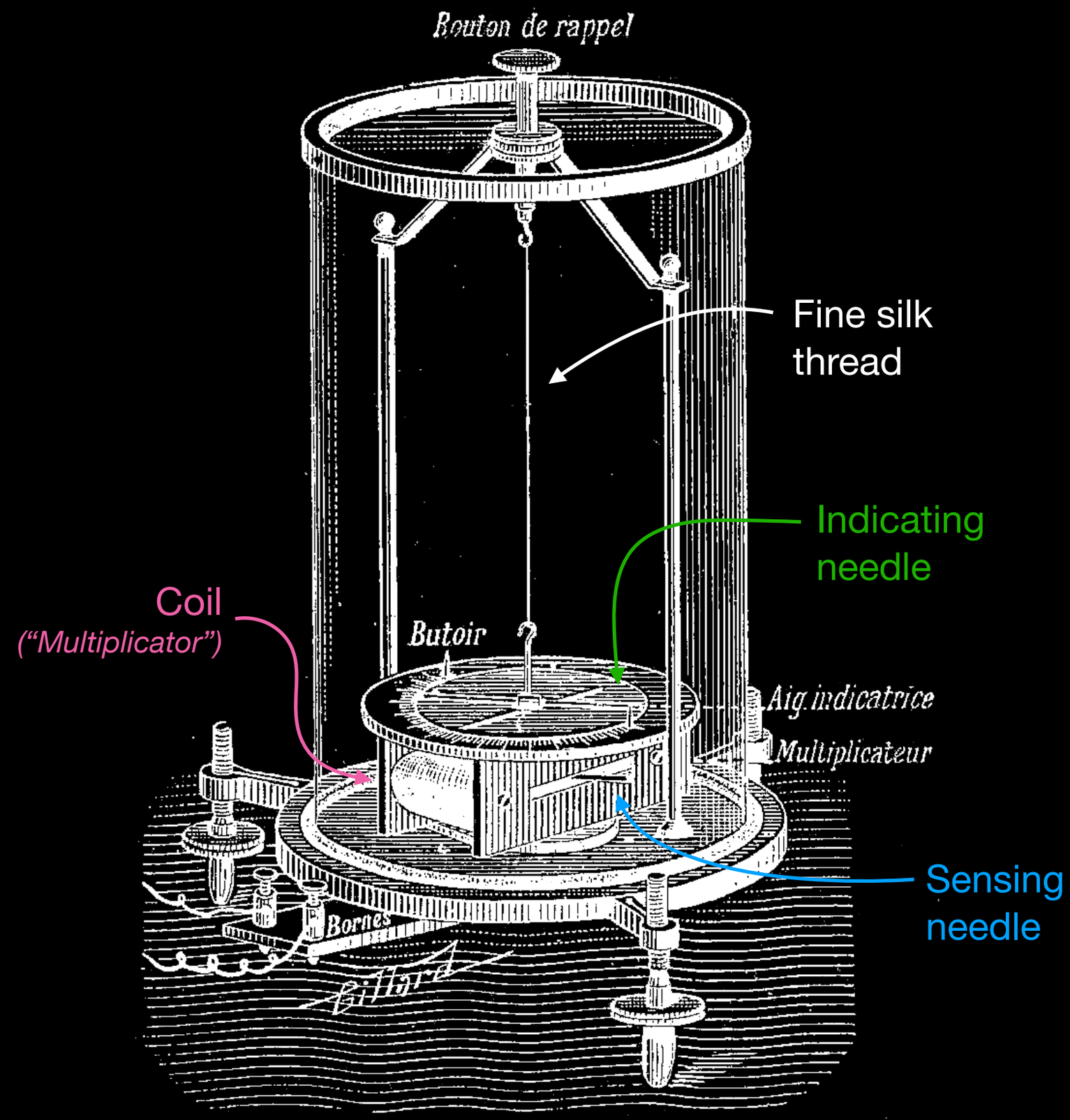


Faraday’s Galvanometer

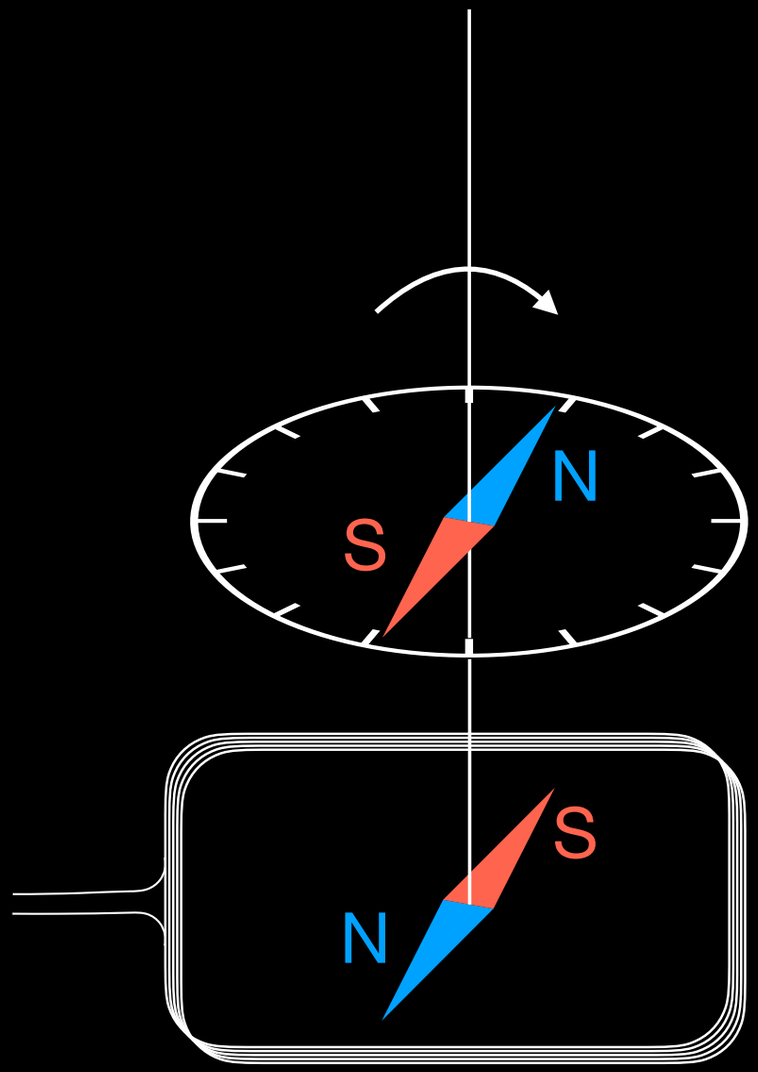


Faraday's Galvanometer



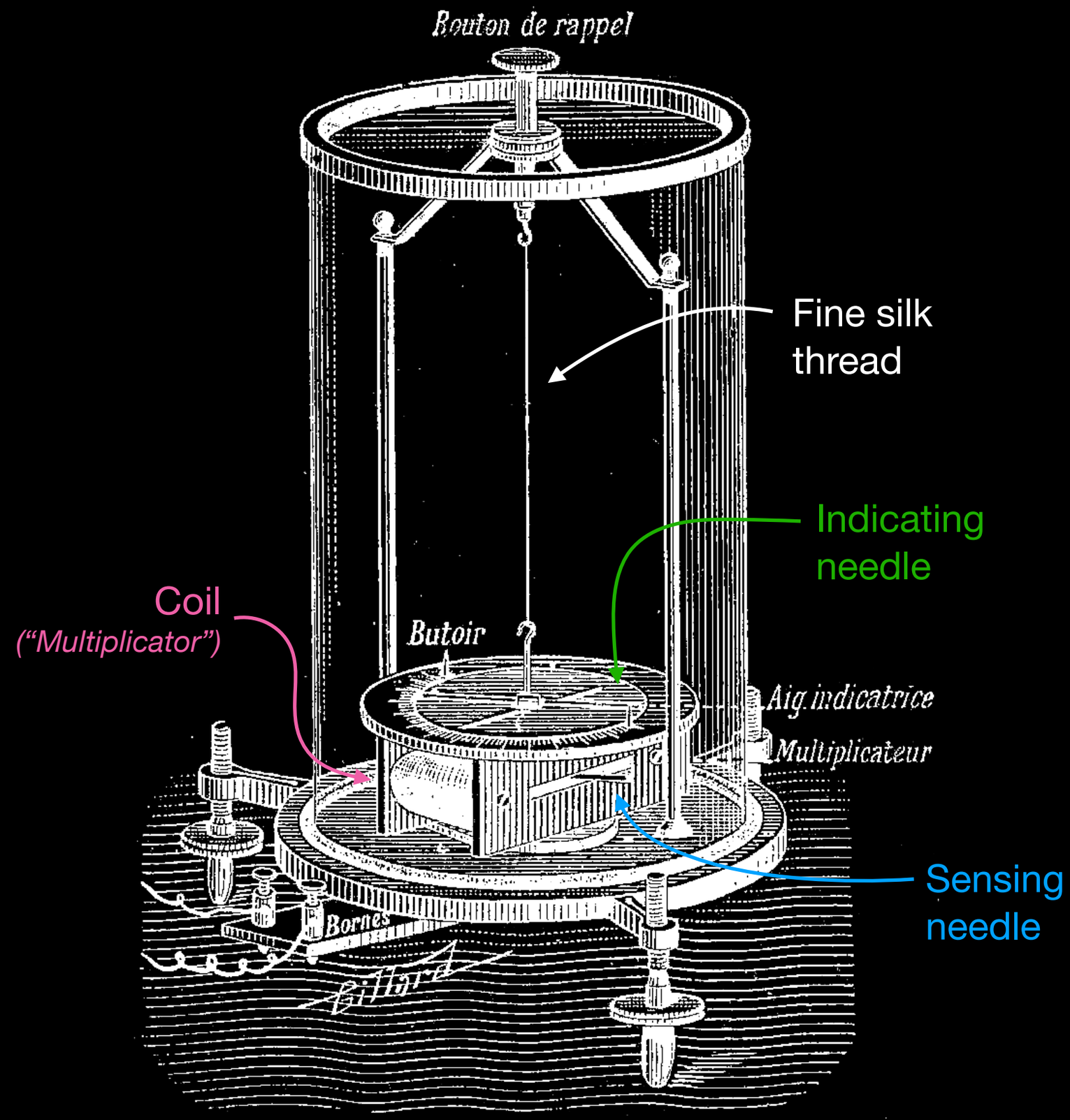


Faraday's Galvanometer



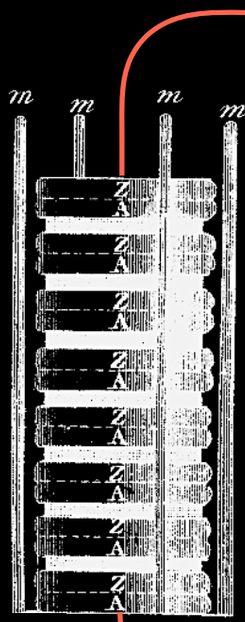
Two magnetic needles in opposite orientation:

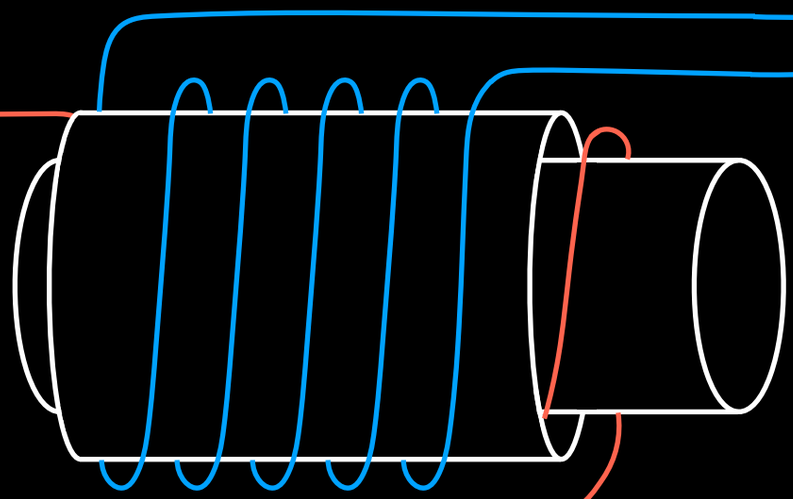
Compensation of Earth's magnetic field

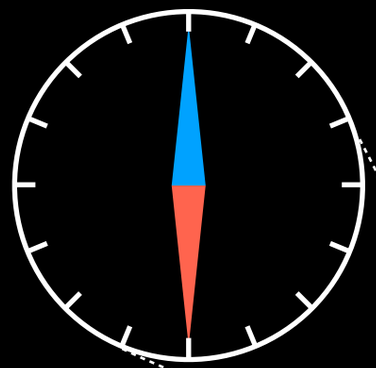


The first experiment

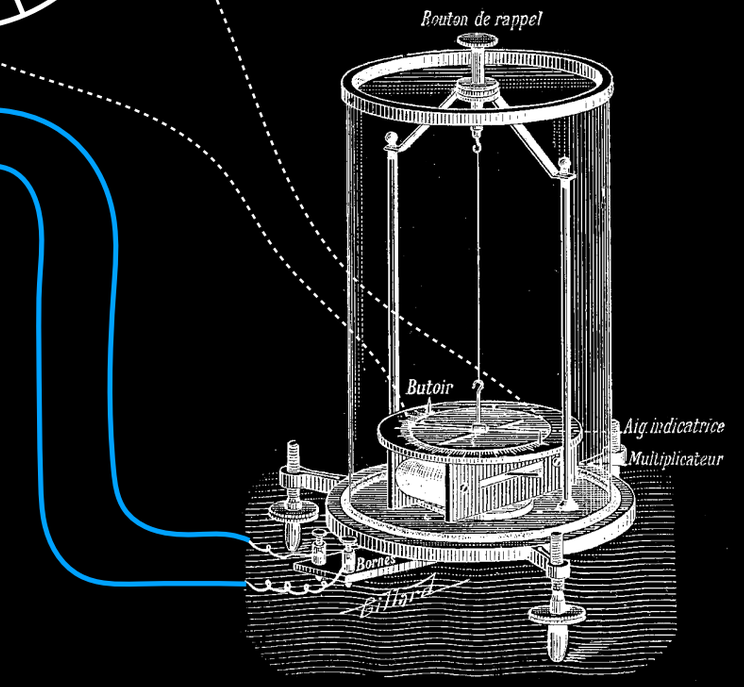
Voltaic pile





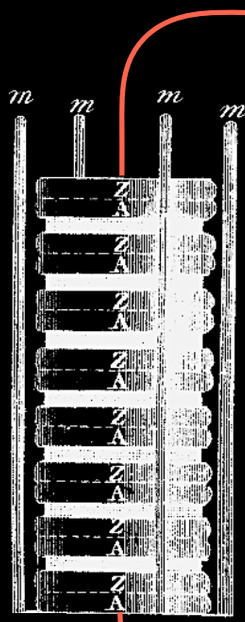


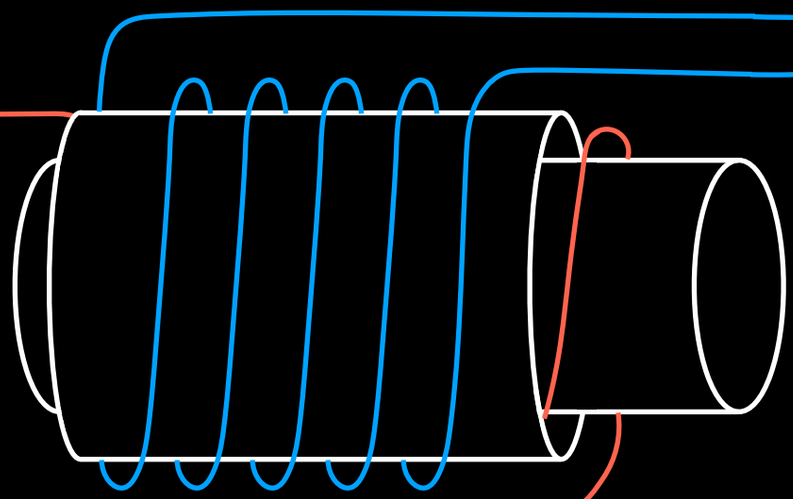
Galvanometer

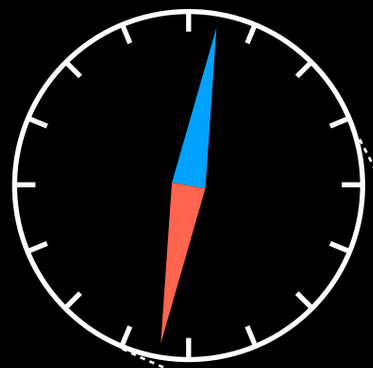


The first experiment

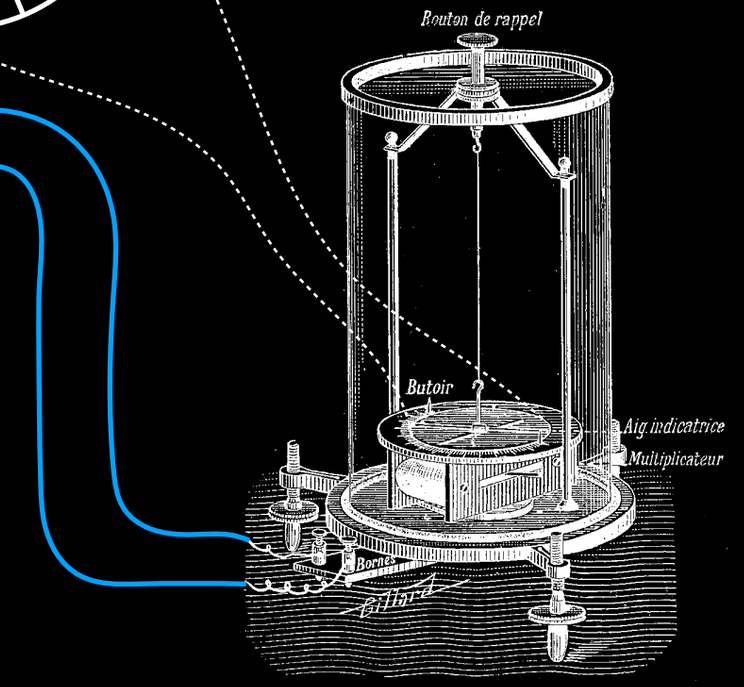
Voltaic pile







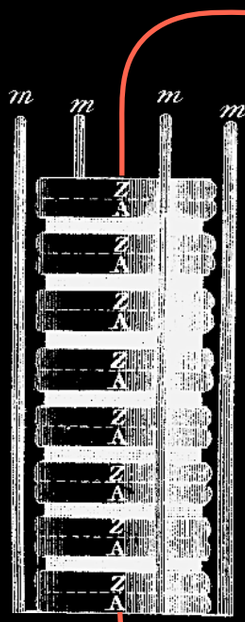
Galvanometer

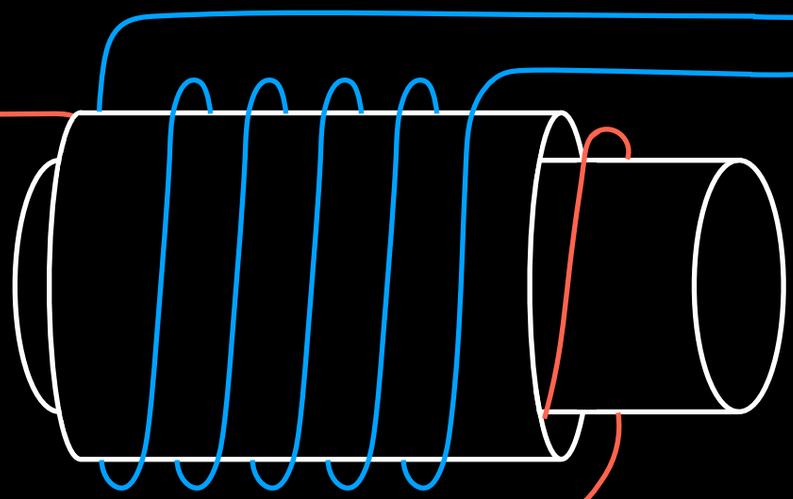


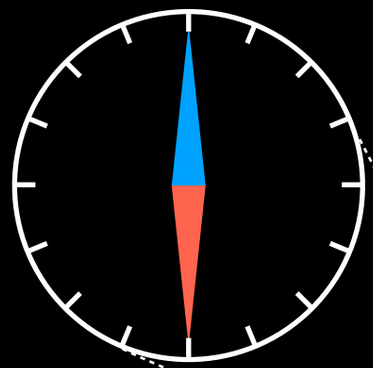
“When the contact was made, there was a sudden and very slight effect at the galvanometer.”

The first experiment

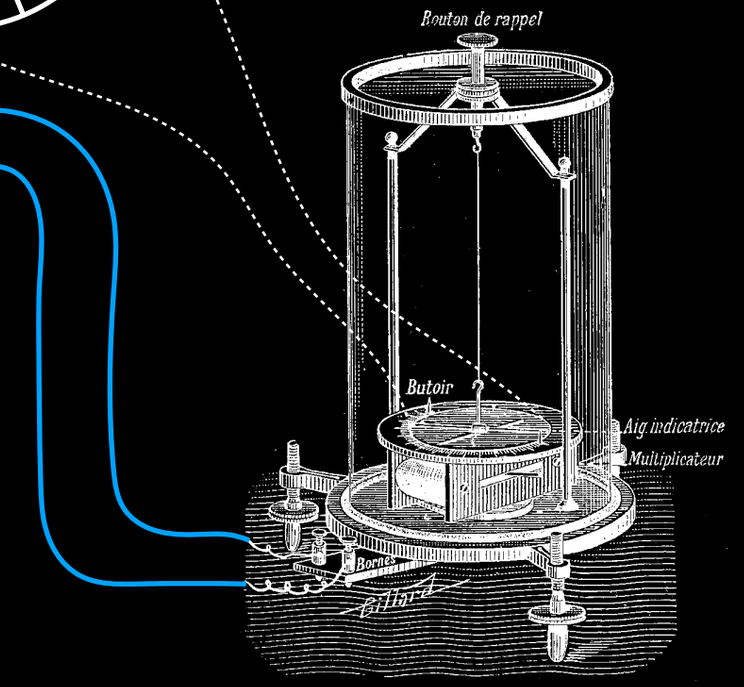
Voltaic pile







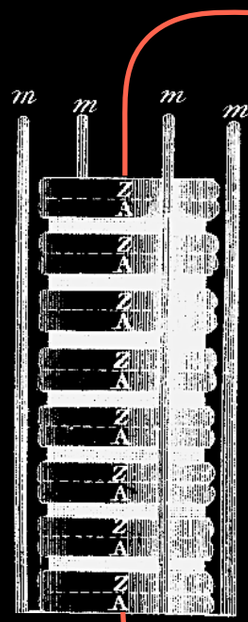
Galvanometer

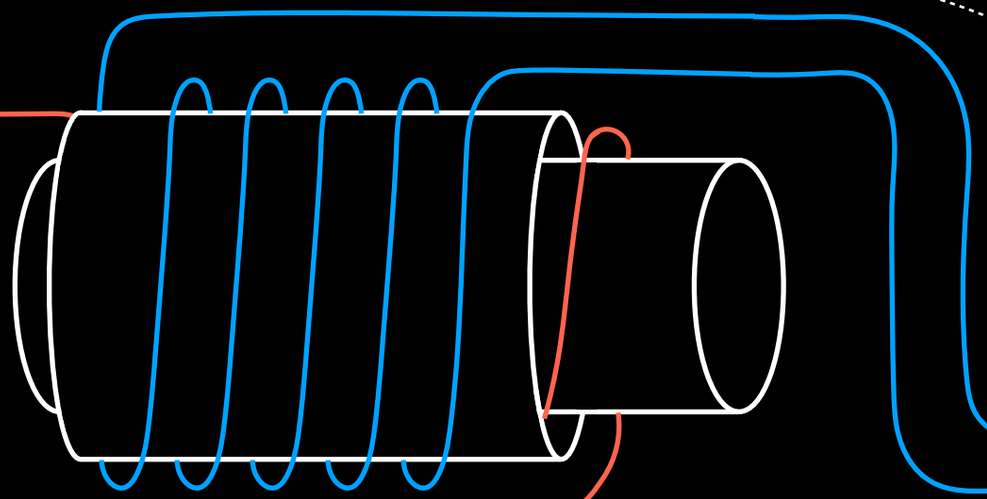


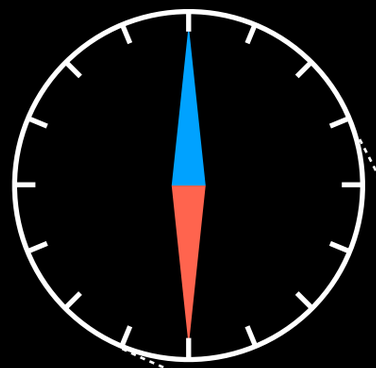
“When the contact was made, there was a sudden and very slight effect at the galvanometer.”

The first experiment

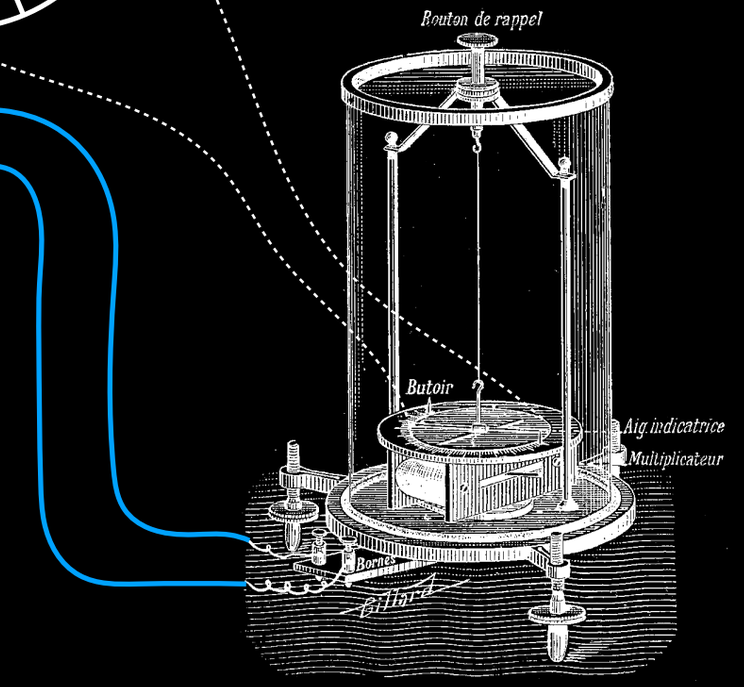
Voltaic pile







Galvanometer

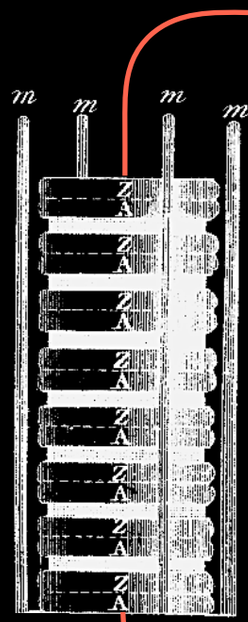


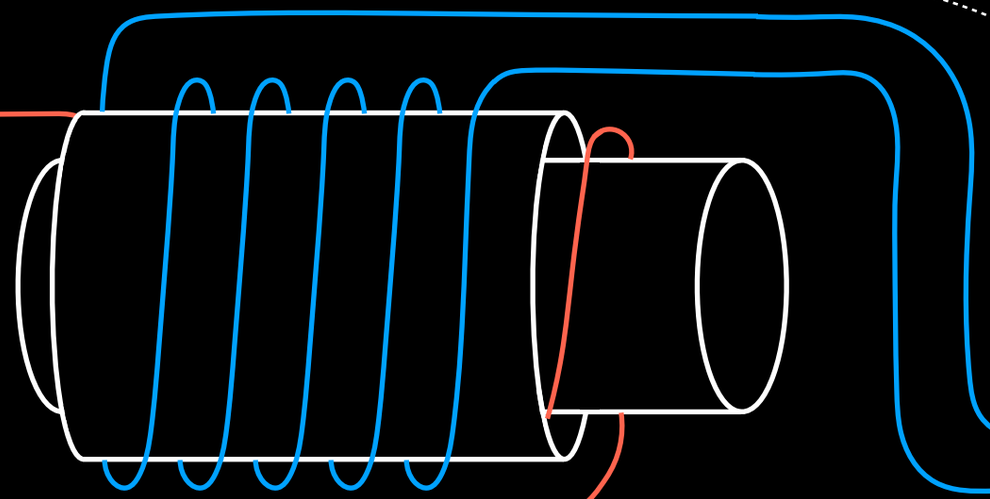
“When the contact was made, there was a sudden and very slight effect at the galvanometer.”

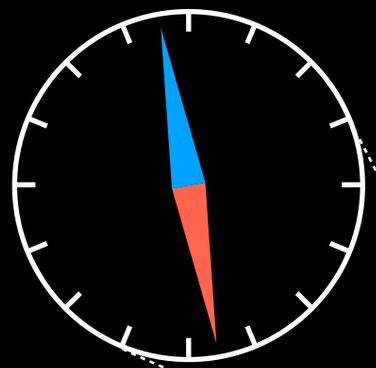
“But whilst the voltaic current was continuing to pass through the one helix, no galvanometrical appearances of any effect could be perceived,
although the active power of the battery was proved to be great.”

The first experiment

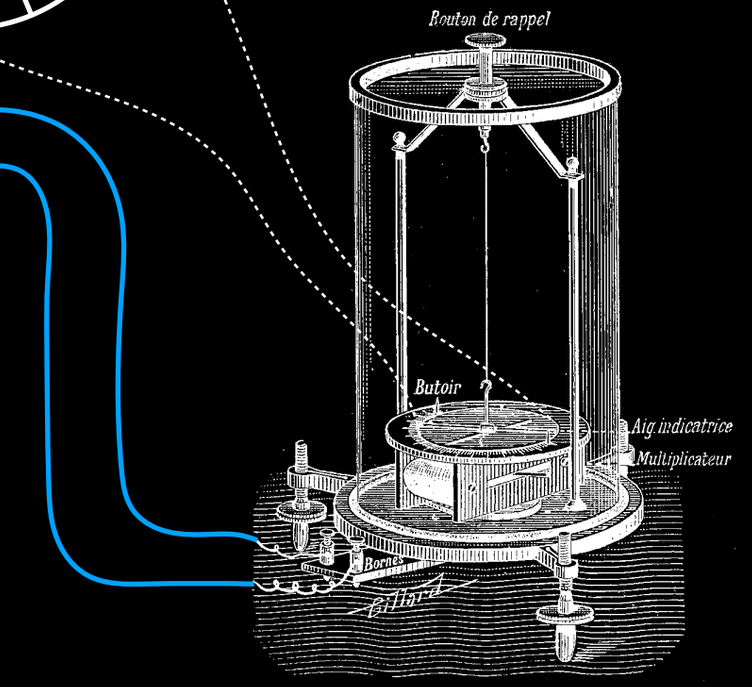
Voltaic pile







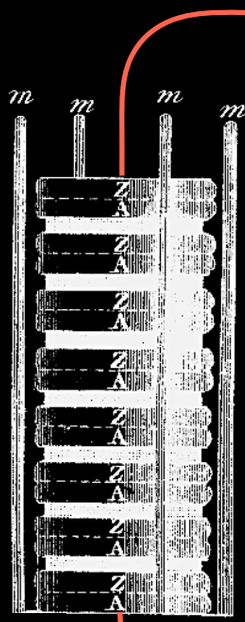
Galvanometer

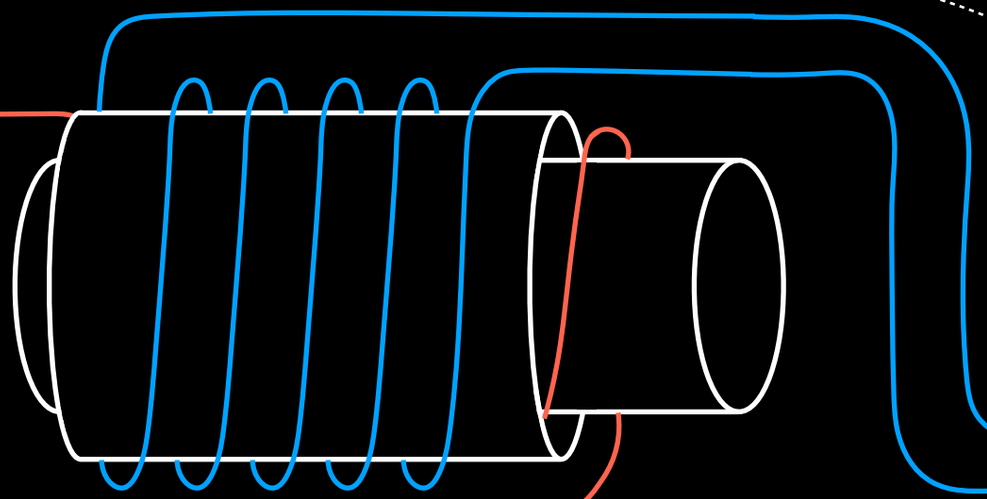


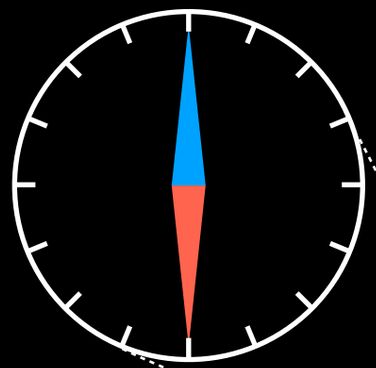
“There was also a similar slight effect, but in the opposite direction, when the contact with the battery was broken.”

The first experiment

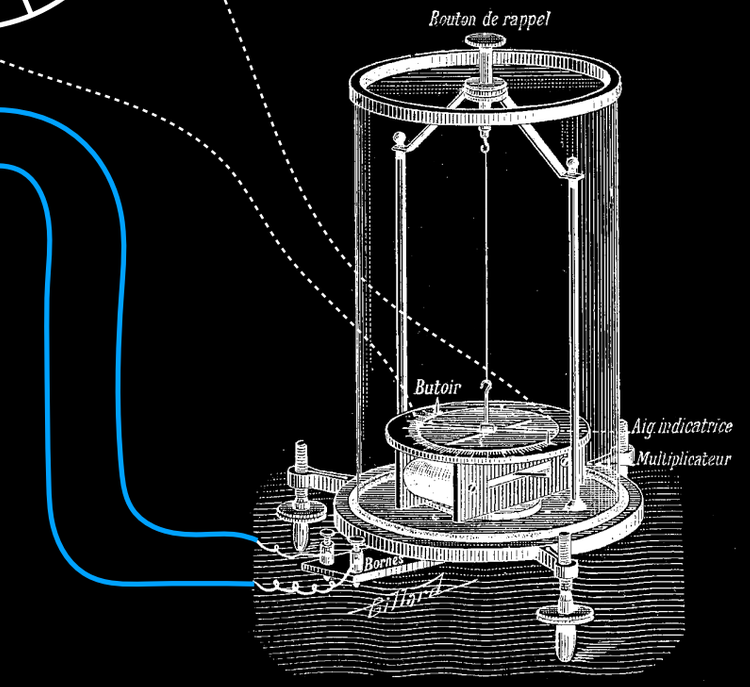
Voltaic pile







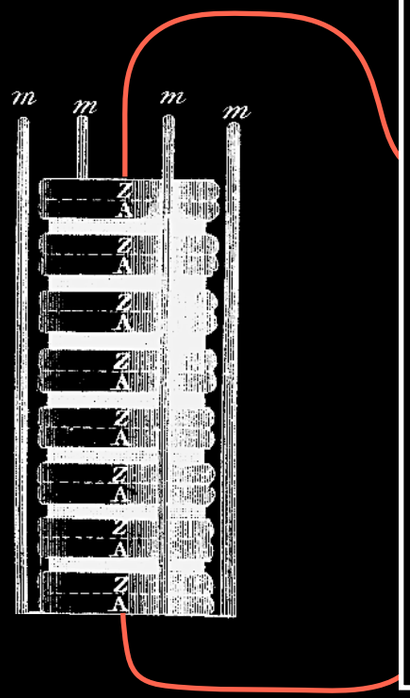
Galvanometer



“There was also a similar slight effect, but in the opposite direction, when the contact with the battery was broken.”

The first experiment

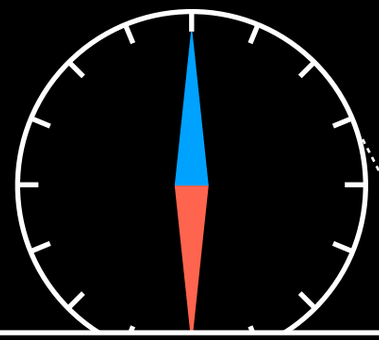
Voltaic pile

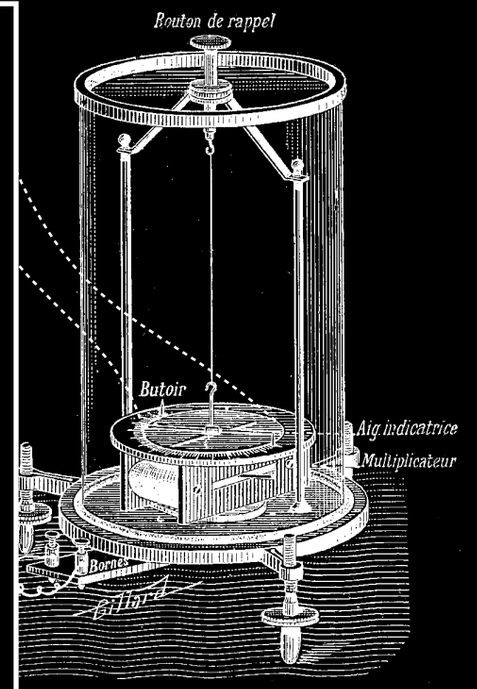


“It continued for an instant only, and partook more of the nature of the shock of a common Leyden jar than of that from a voltaic battery.”

“I could obtain no evidence by the tongue, by spark, or by heating fine wire, of the electricity passing through the wire under induction.”

Galvanometer





“There was also a similar slight effect, but in the opposite direction, when the contact with the battery was broken.”

William Sturgeon

Shoemaker, gunner, instrument maker, lecturer

William Sturgeon

Shoemaker, gunner, instrument maker, lecturer

Posted as gunner
to Newfoundland
[source]

William Sturgeon

Shoemaker, gunner, instrument maker, lecturer

Posted as gunner
to Newfoundland
[source]

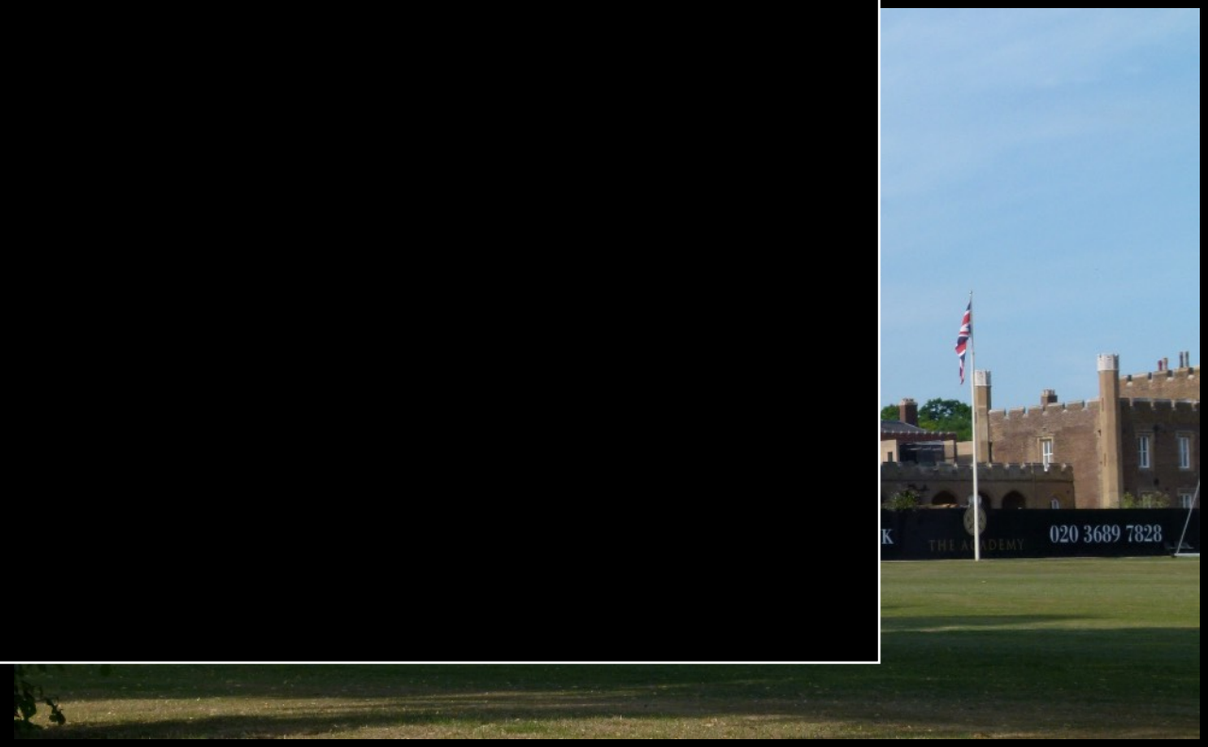
Royal military academy at Woolwich

William Sturgeon

Shoemaker, gunner, instrument maker, lecturer

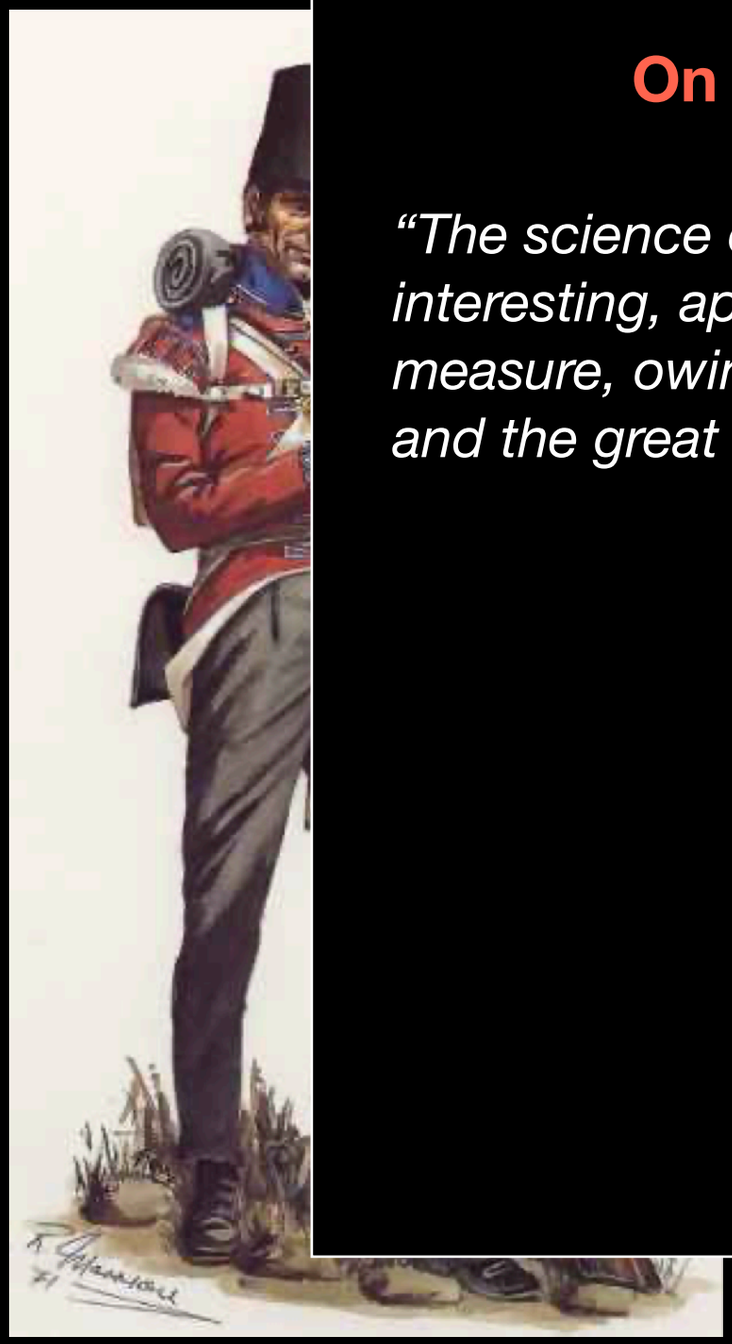
On the science of electromagnetism:

at Woolwich



William Sturgeon

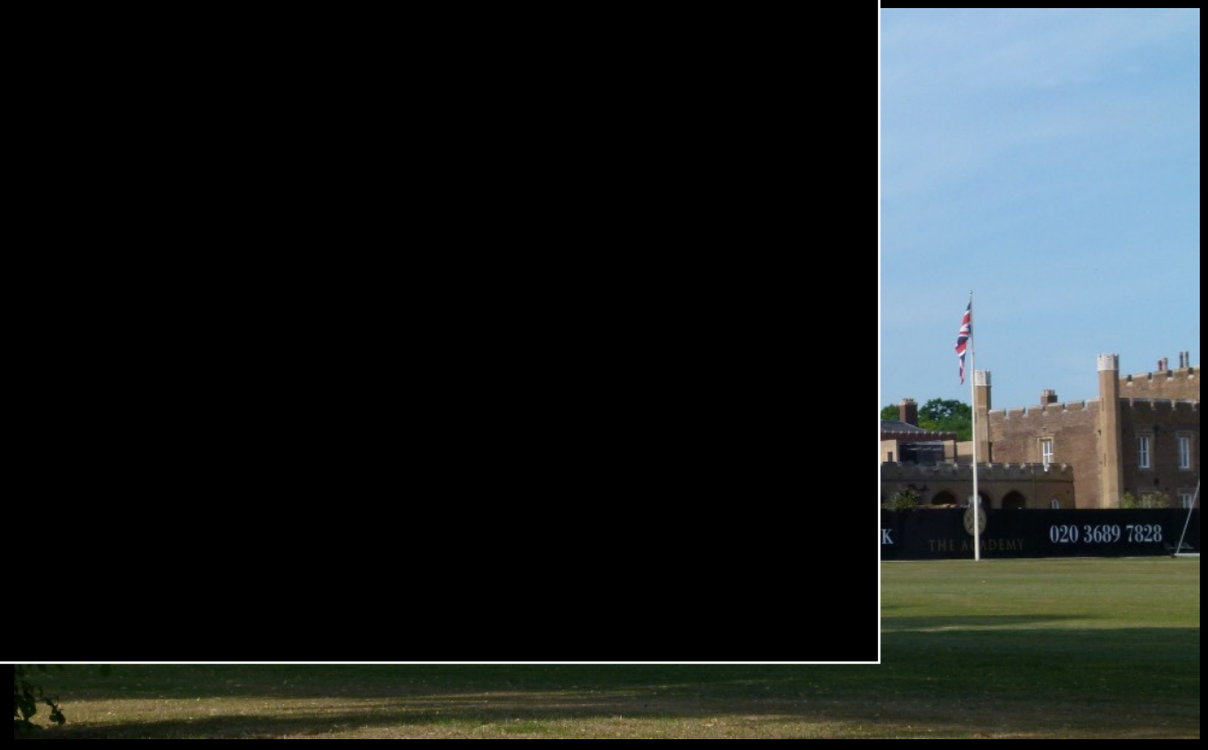
Shoemaker, gunner, instrument maker, lecturer



On the science of electromagnetism:

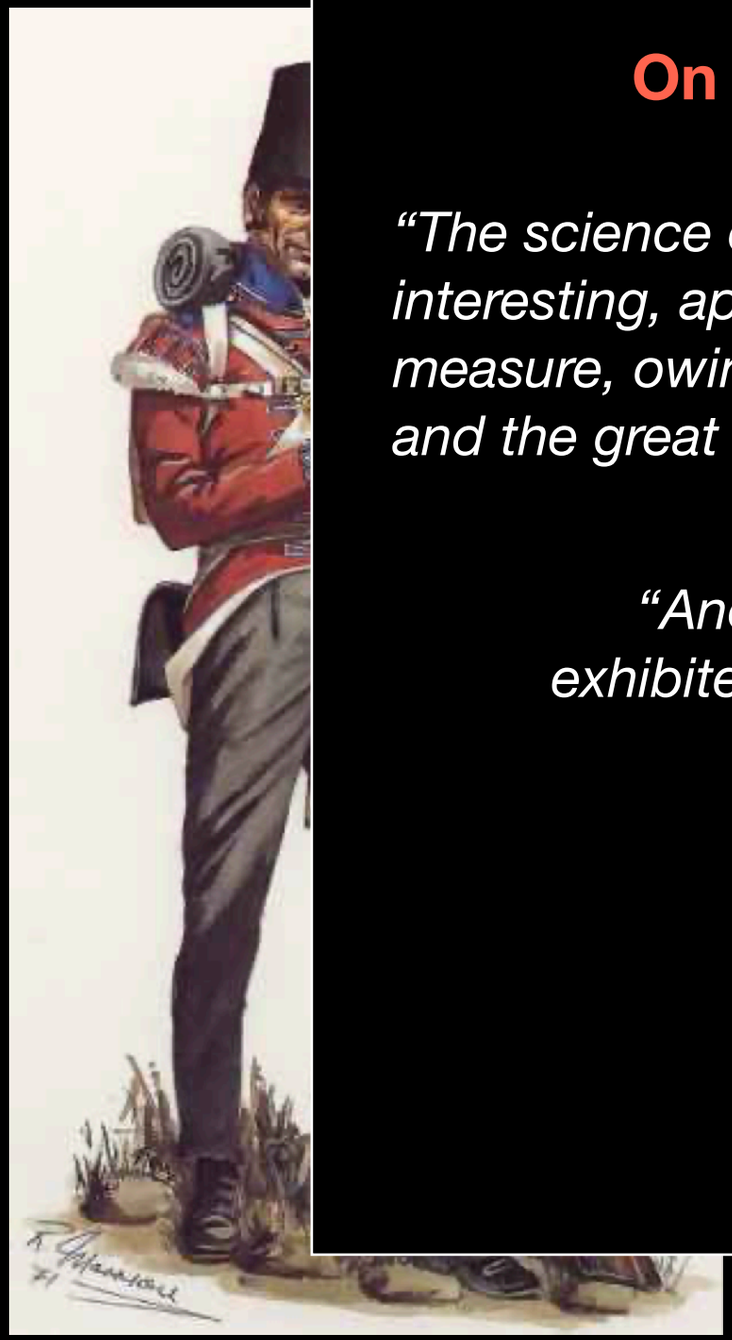
"The science of electro-magnetism, although so generally interesting, appears to be very little understood, in a great measure, owing to the difficulty of making the experiments, and the great expense attending the process."

at Woolwich



William Sturgeon

Shoemaker, gunner, instrument maker, lecturer

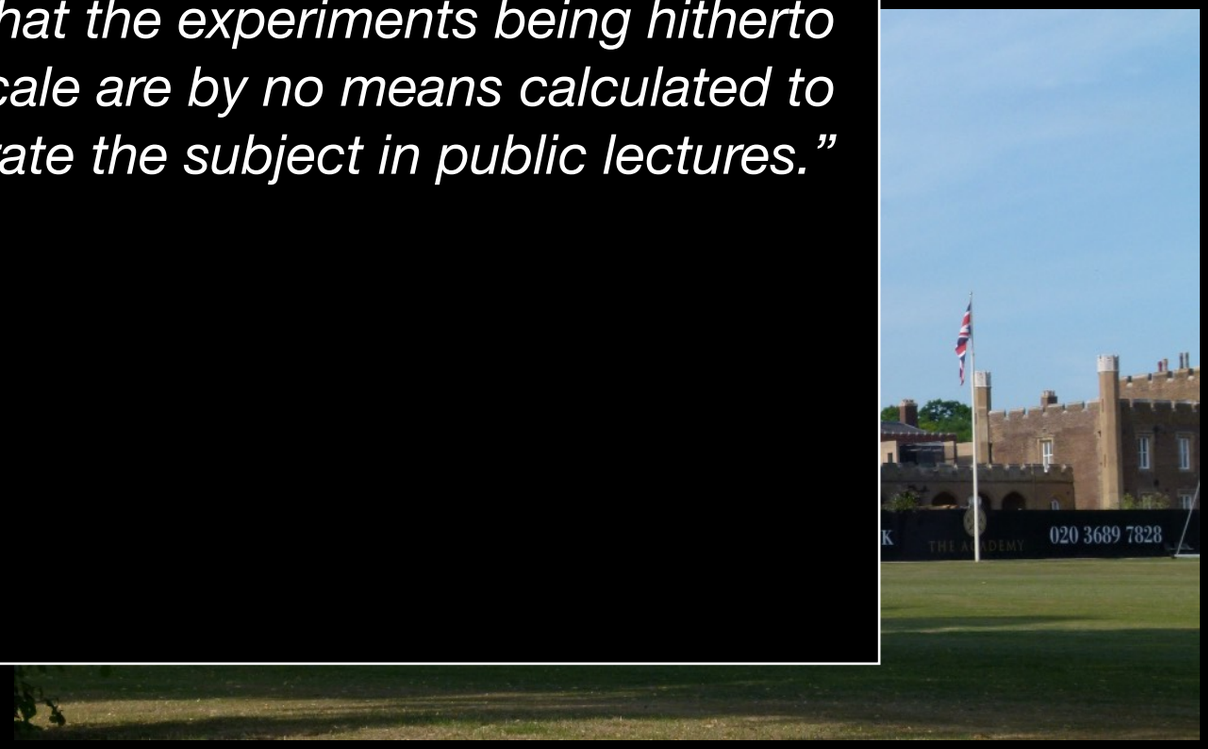


On the science of electromagnetism:

"The science of electro-magnetism, although so generally interesting, appears to be very little understood, in a great measure, owing to the difficulty of making the experiments, and the great expense attending the process."

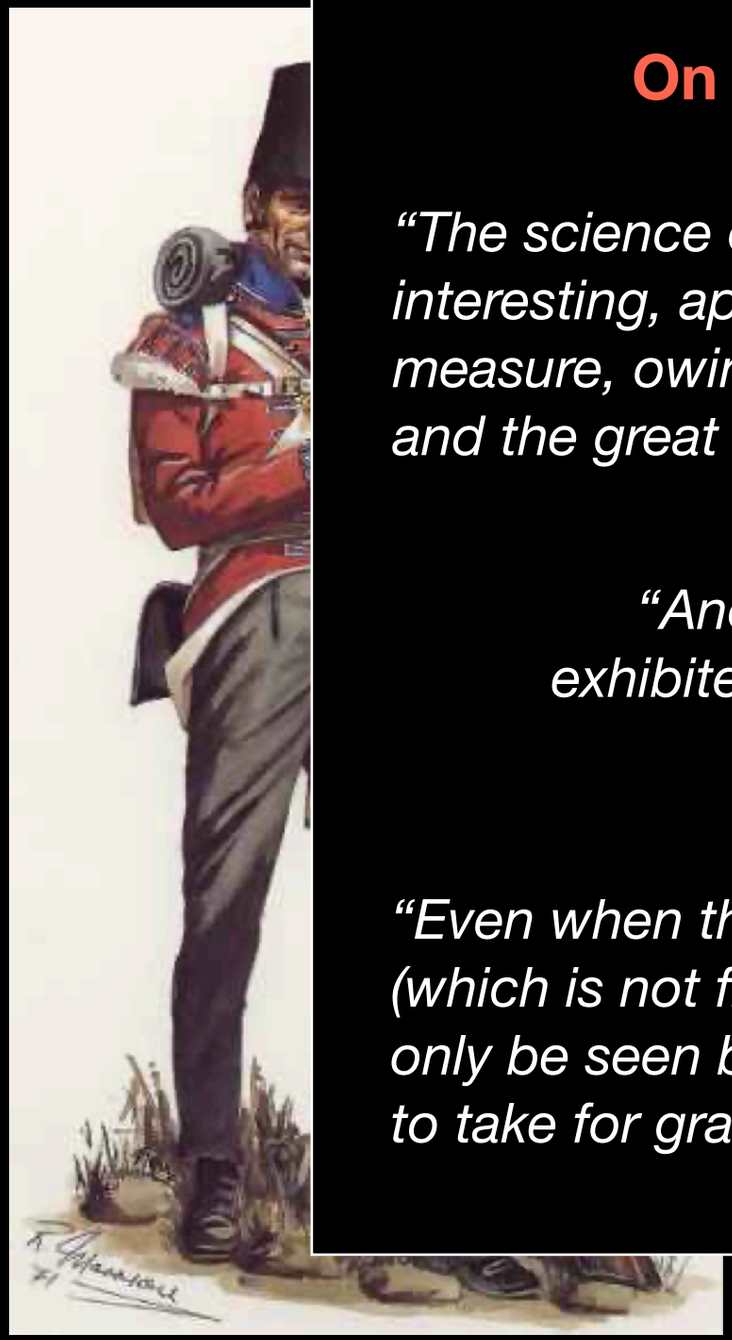
"Another obstacle is that the experiments being hitherto exhibited on so small a scale are by no means calculated to illustrate the subject in public lectures."

at Woolwich



William Sturgeon

Shoemaker, gunner, instrument maker, lecturer



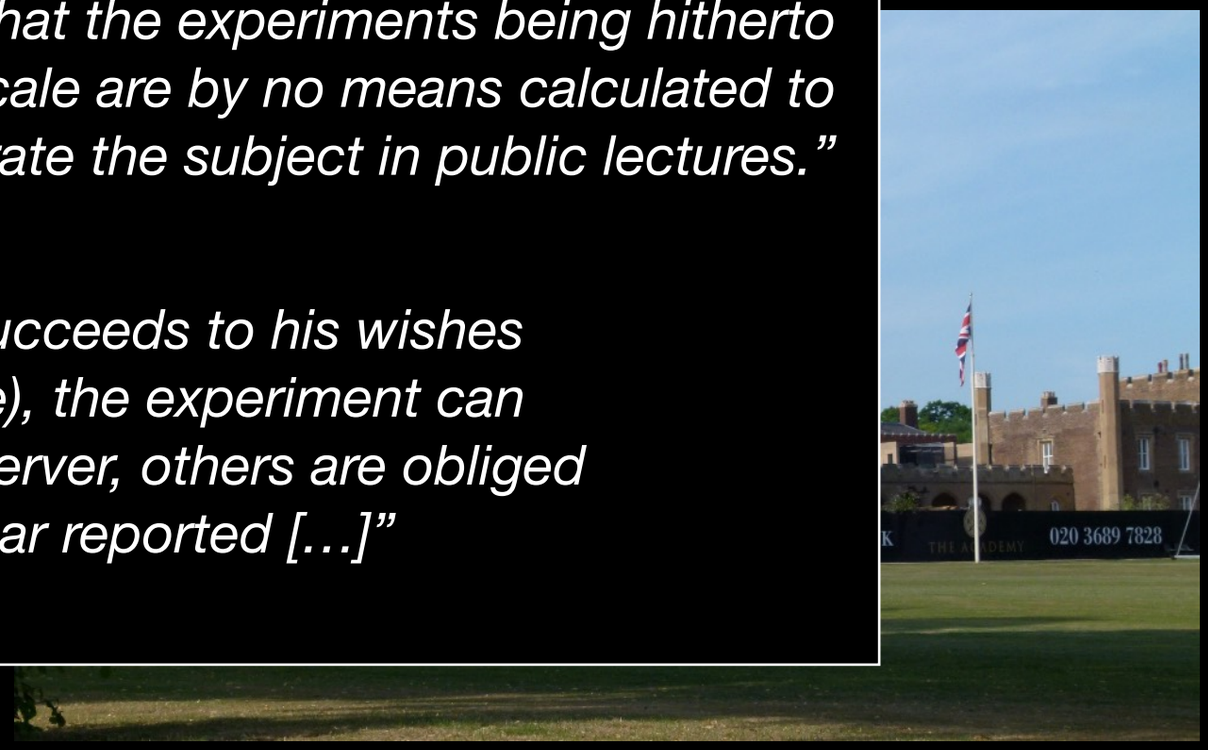
On the science of electromagnetism:

“The science of electro-magnetism, although so generally interesting, appears to be very little understood, in a great measure, owing to the difficulty of making the experiments, and the great expense attending the process.”

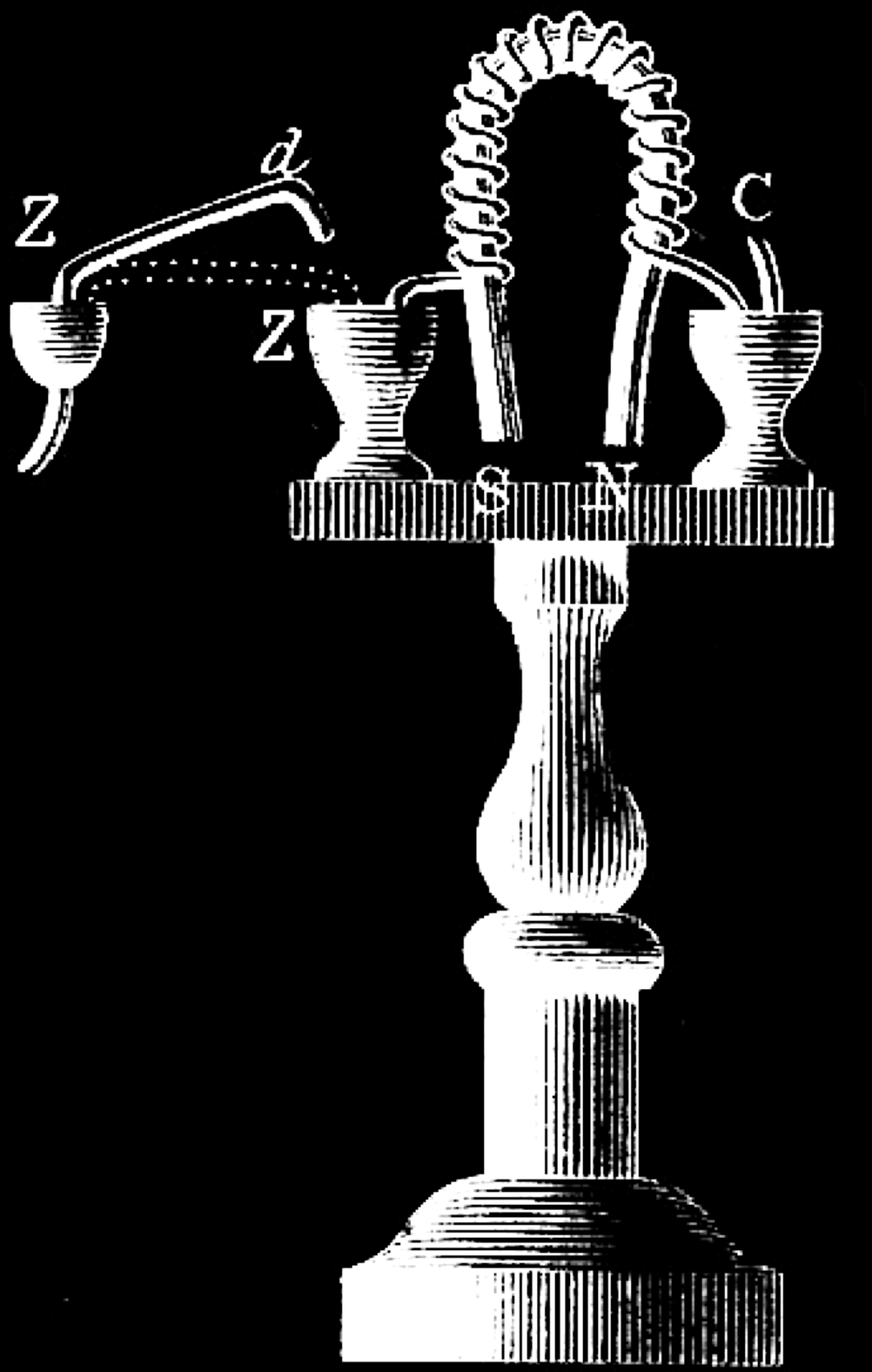
“Another obstacle is that the experiments being hitherto exhibited on so small a scale are by no means calculated to illustrate the subject in public lectures.”

“Even when the experimenter succeeds to his wishes (which is not frequently the case), the experiment can only be seen by a very near observer, others are obliged to take for granted what they hear reported […]”

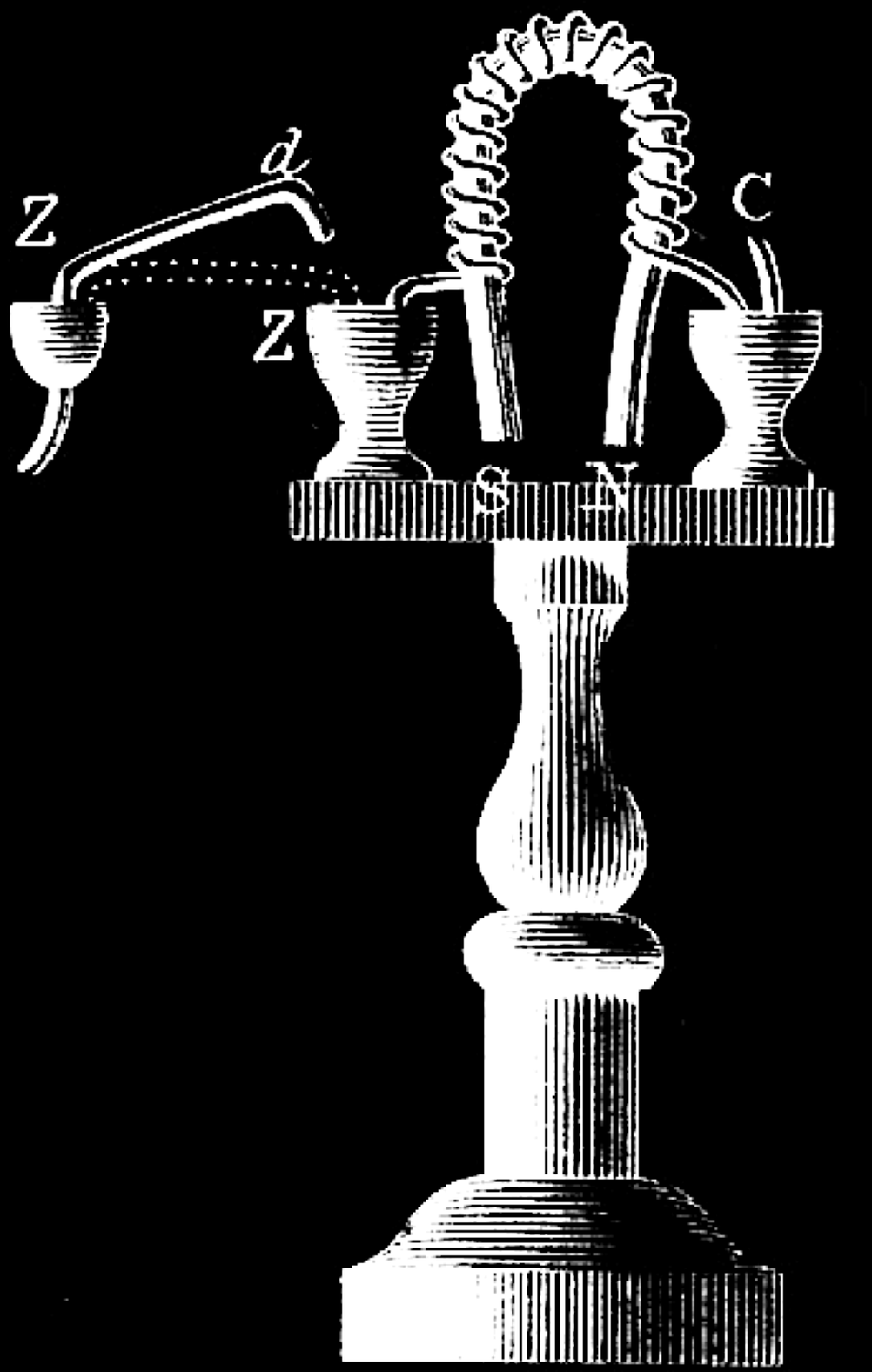
at Woolwich



The first electromagnet (1826)

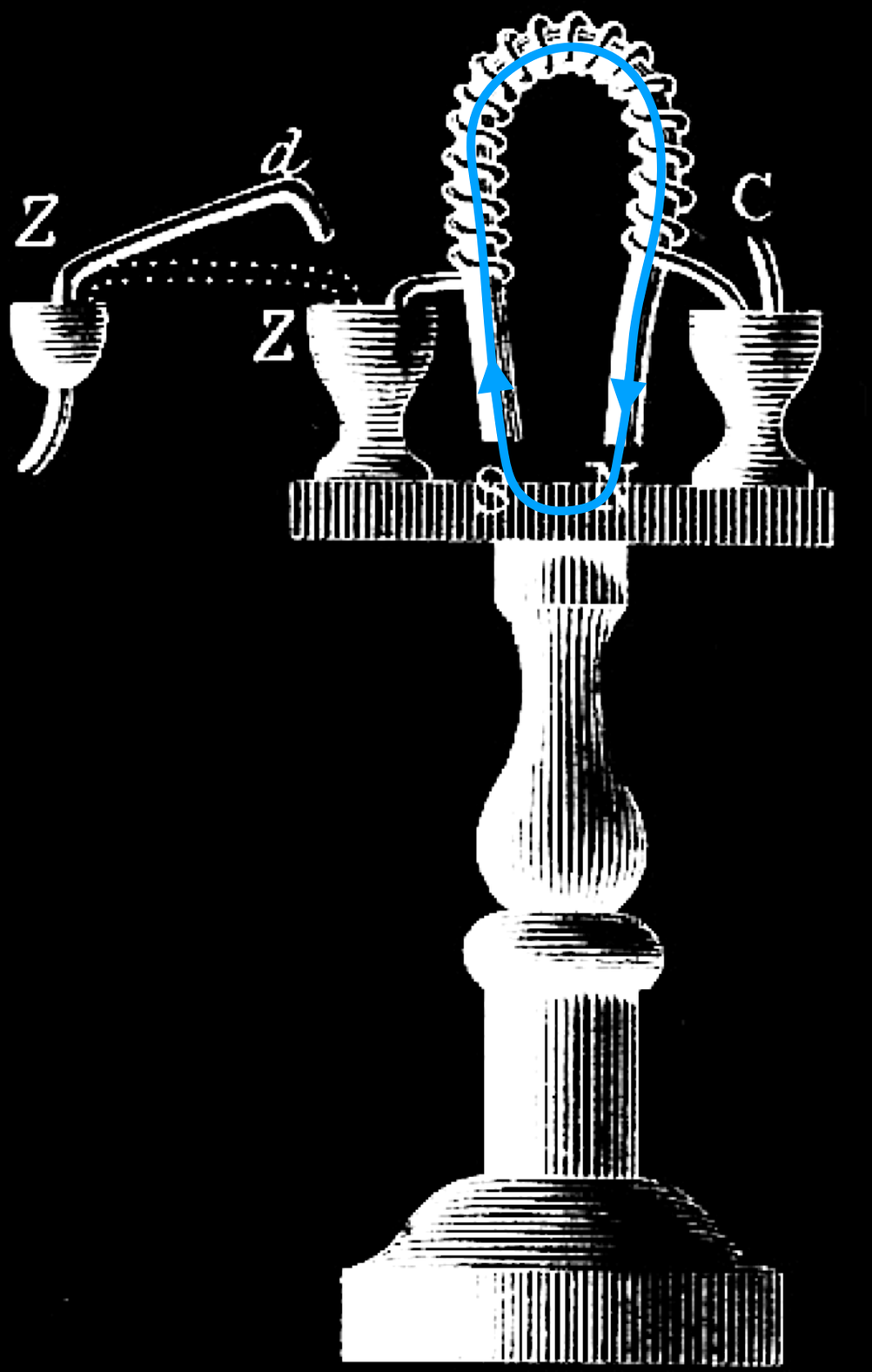


The first electromagnet (1826)



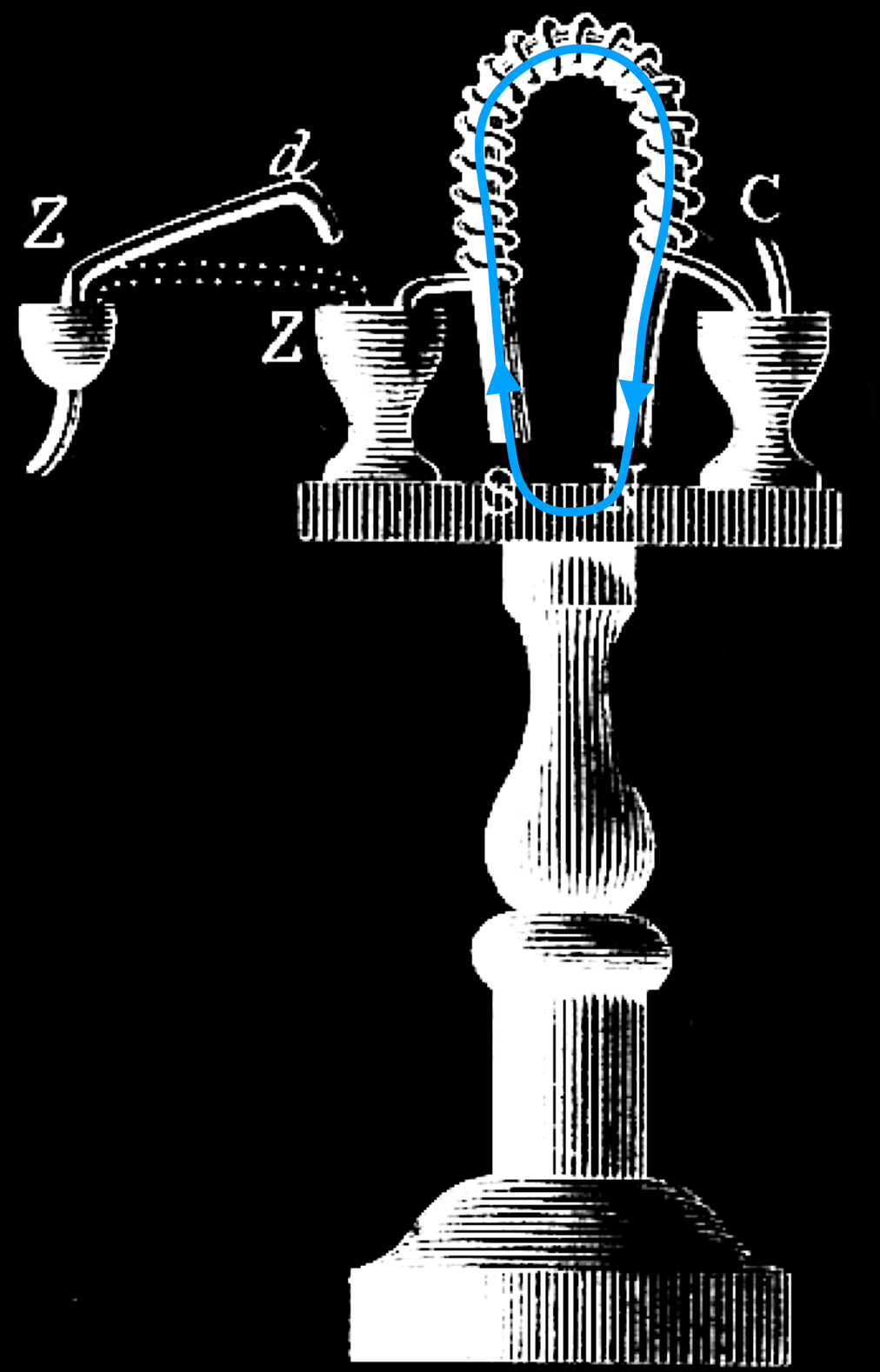
“On making the galvanic connexion through the copper wire, the iron wire becomes a strong horse-shoe magnet, and will support a heavy bar of iron; but on lifting the connecting wire, the weight immediately drops.”

The first electromagnet (1826)

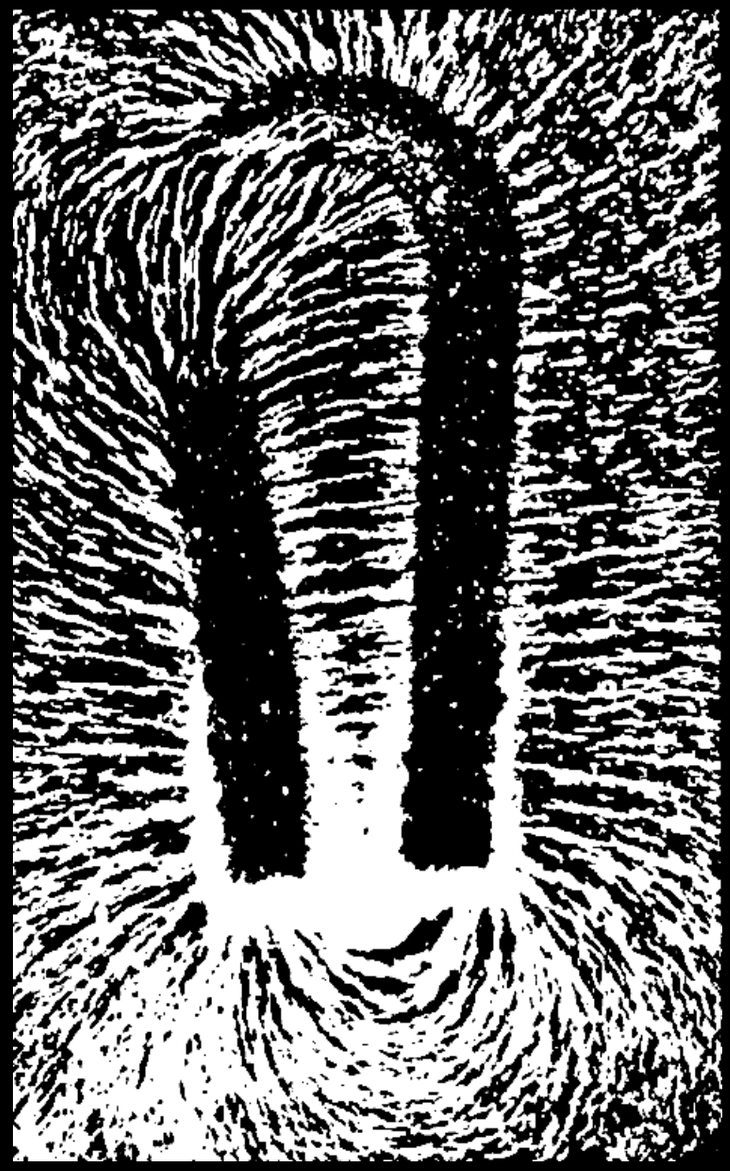


"On making the galvanic connexion through the copper wire, the iron wire becomes a strong horse-shoe magnet, and will support a heavy bar of iron; but on lifting the connecting wire, the weight immediately drops."

The first electromagnet (1826)

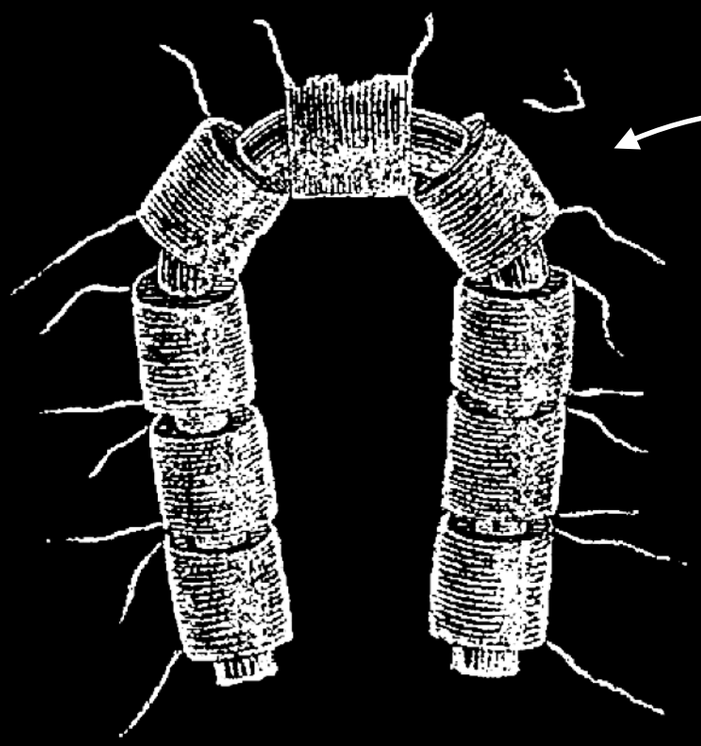


"On making the galvanic connexion through the copper wire, the iron wire becomes a strong horse-shoe magnet, and will support a heavy bar of iron; but on lifting the connecting wire, the weight immediately drops."



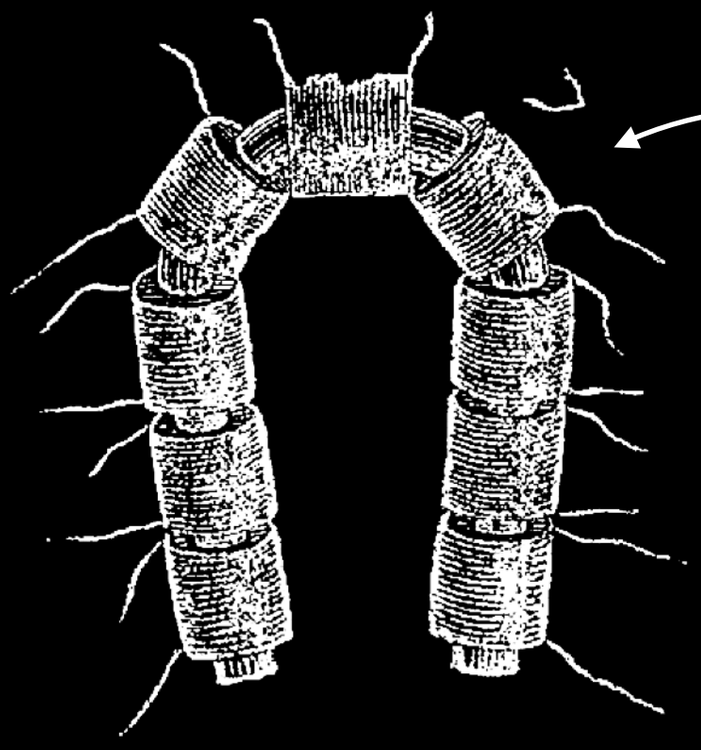
Larger magnets: Joseph Henry

Larger magnets: Joseph Henry



Horseshoe magnet with nine coils
(Insulated wire!)

Larger magnets: Joseph Henry

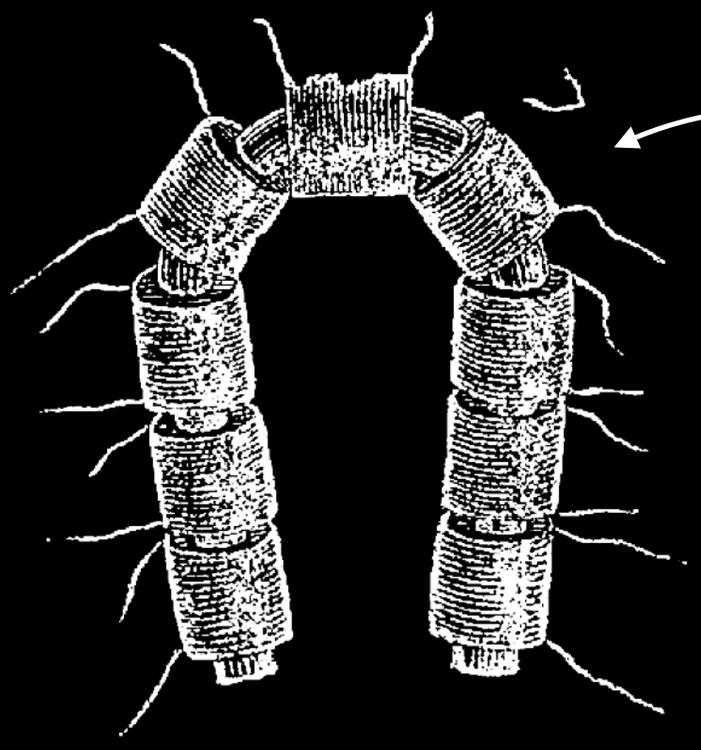


Horseshoe magnet with nine coils
(Insulated wire!)

Battery

Additional weights

Larger magnets: Joseph Henry



Horseshoe magnet with nine coils
(Insulated wire!)

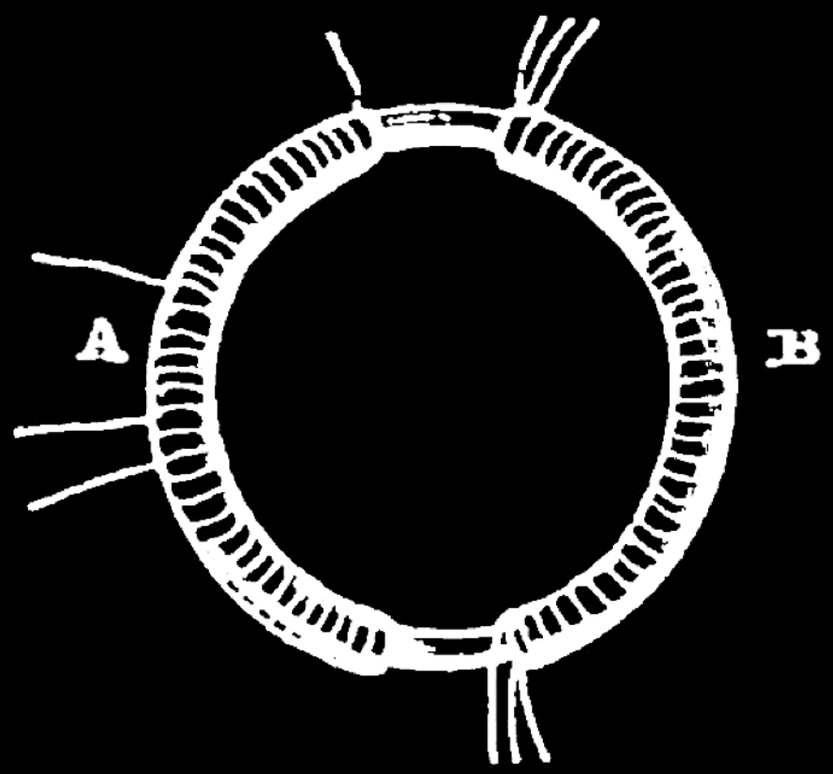
Battery

Additional weights

"Experiment 13
All nine coils:
lifted 650 lbs"

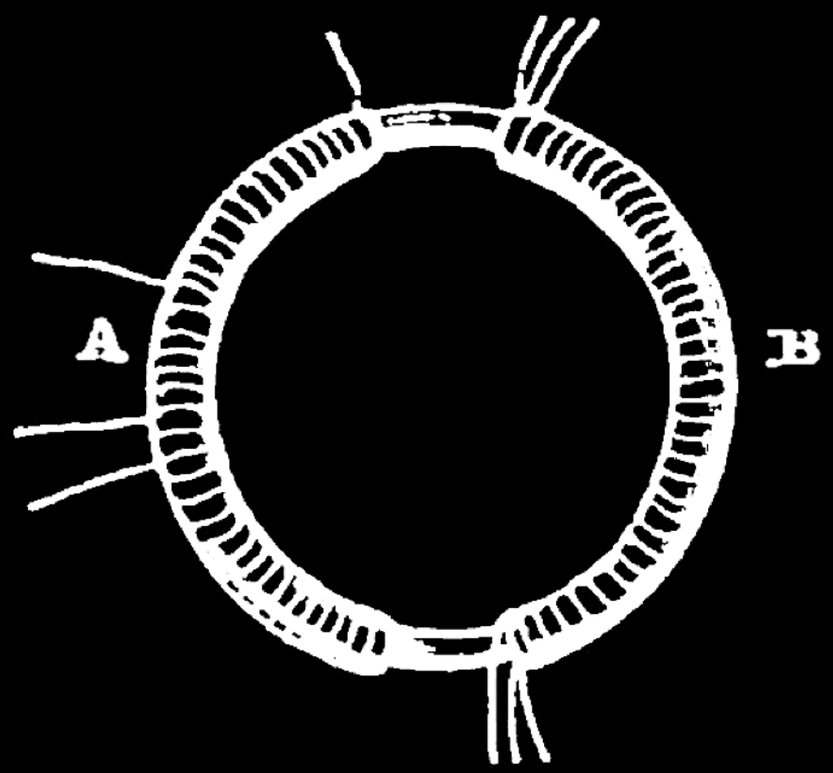
Back to Faraday: increasing the strength

Back to Faraday: increasing the strength



Back to Faraday: increasing the strength

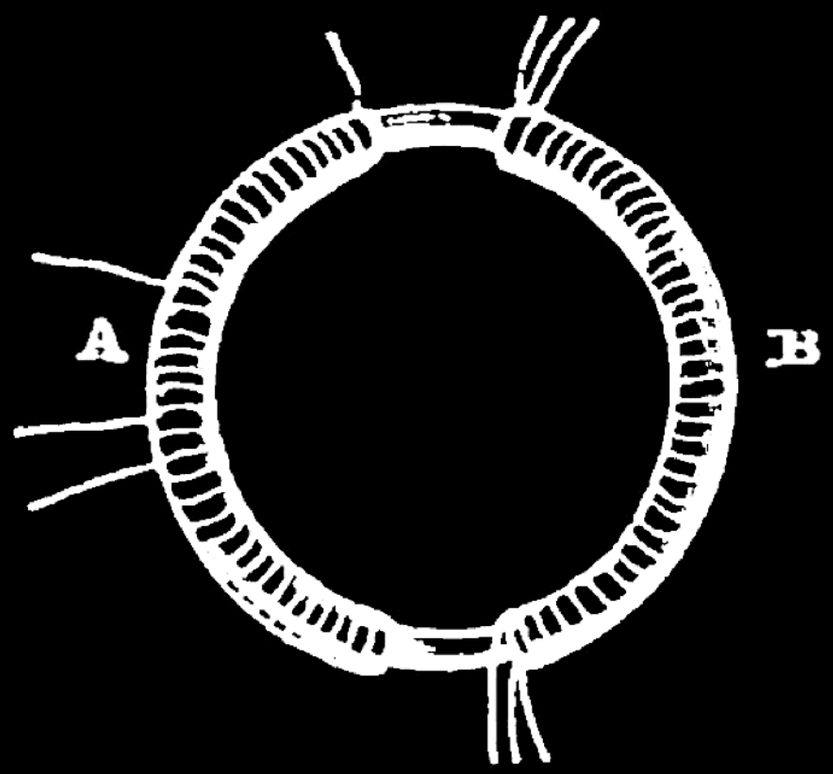
“A welded ring was made of soft round bar-iron, several helices were put round the ring.”



Back to Faraday: increasing the strength

“A welded ring was made of soft round bar-iron, several helices were put round the ring.”

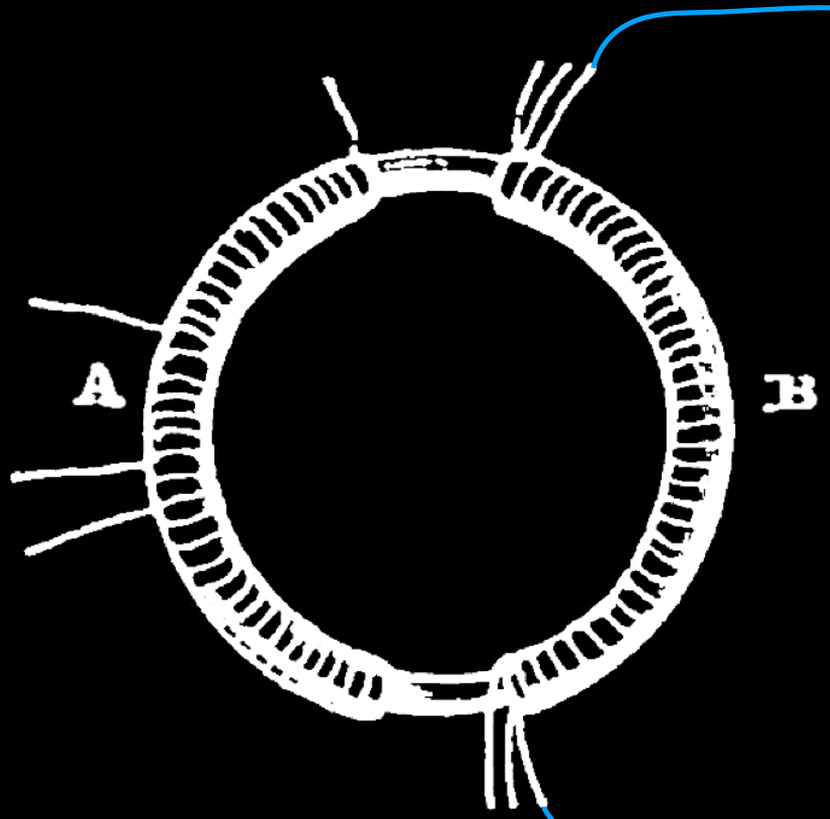
“The helix B was connected by copper wires with a galvanometer;
the wires of A were connected with a battery of ten pairs of plates.”

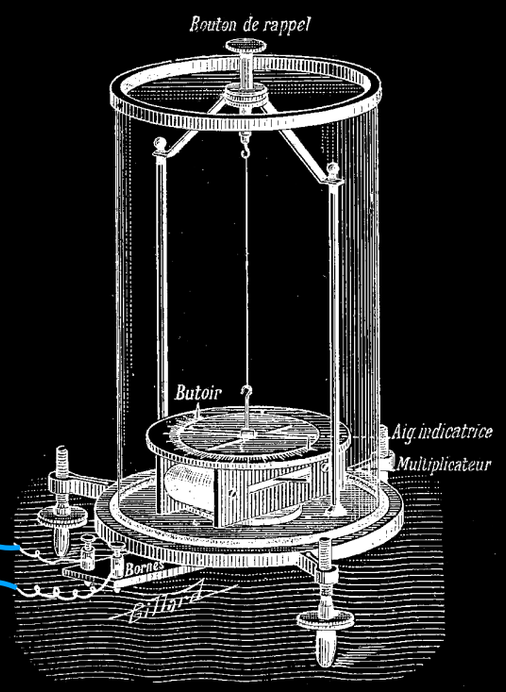


Back to Faraday: increasing the strength

“A welded ring was made of soft round bar-iron, several helices were put round the ring.”

“The helix B was connected by copper wires with a galvanometer;
the wires of A were connected with a battery of ten pairs of plates.”

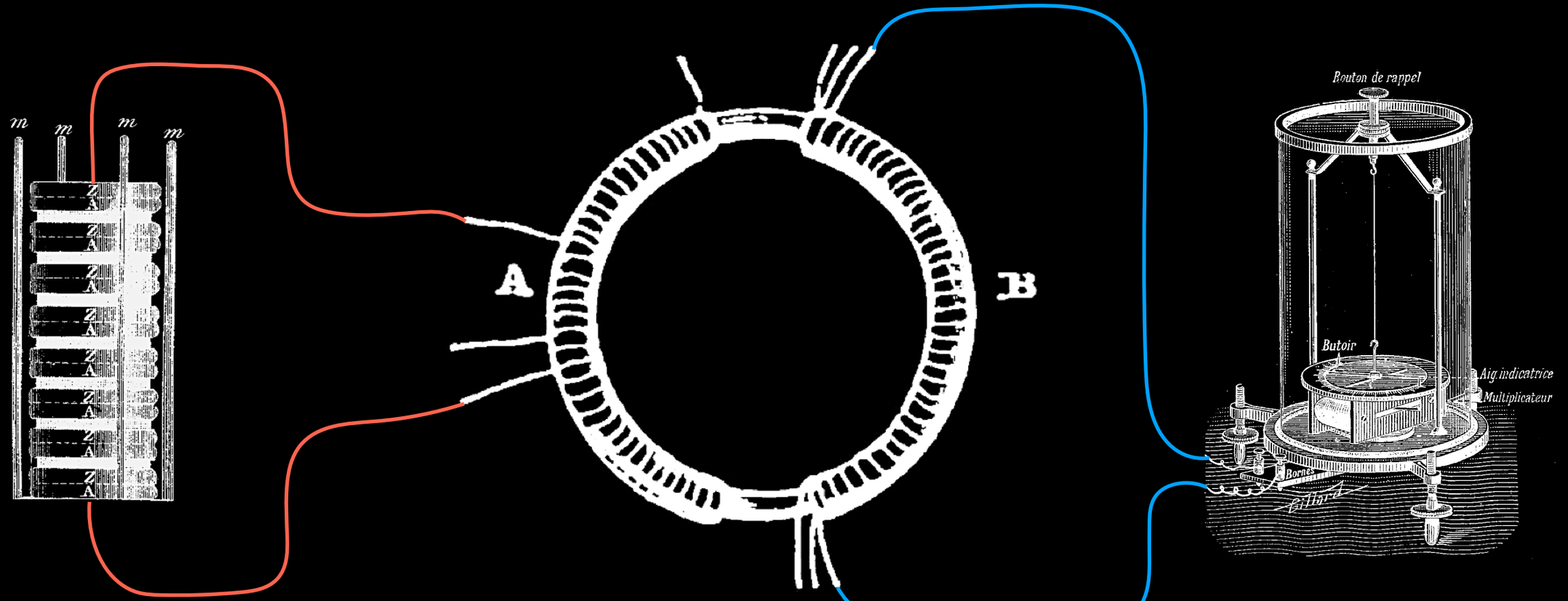




Back to Faraday: increasing the strength

“A welded ring was made of soft round bar-iron, several helices were put round the ring.”

“The helix B was connected by copper wires with a galvanometer;
the wires of A were connected with a battery of ten pairs of plates.”

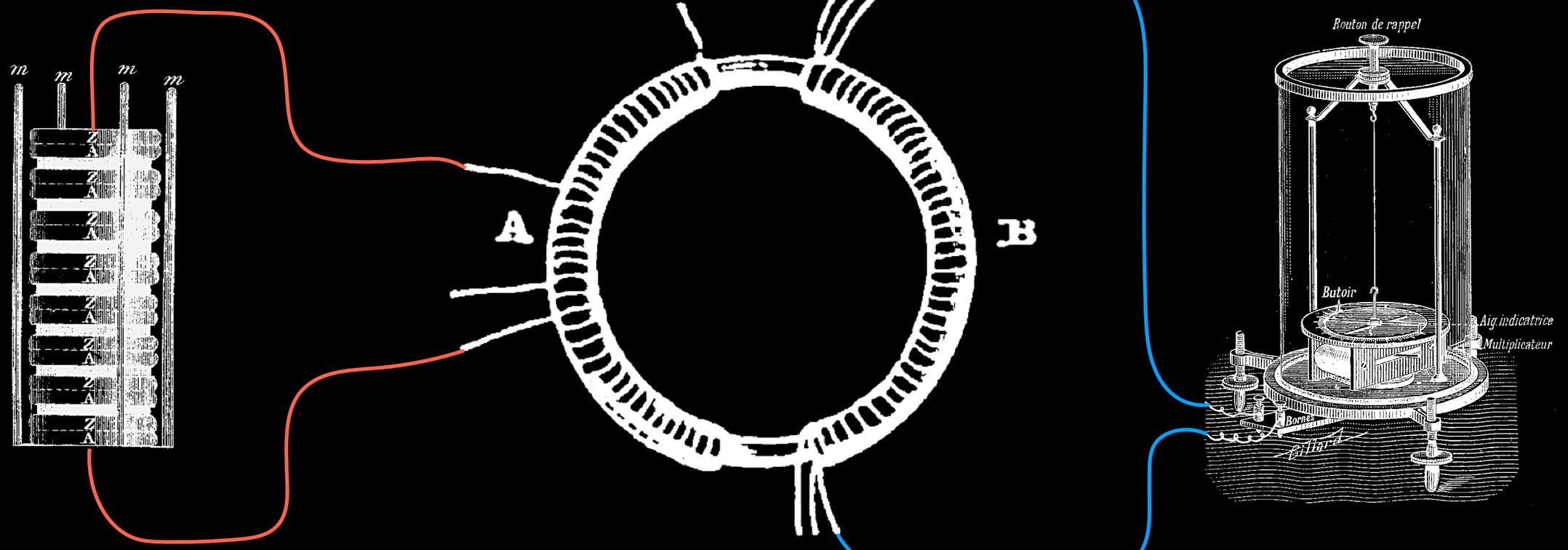


Back to Faraday: increasing the strength

“A welded ring was made of soft round bar-iron, several helices were put round the ring.”

“The helix B was connected by copper wires with a galvanometer;
the wires of A were connected with a battery of ten pairs of plates.”

“The galvanometer was immediately affected,
and to a degree far beyond what has been described.”



Back to Faraday: increasing the strength

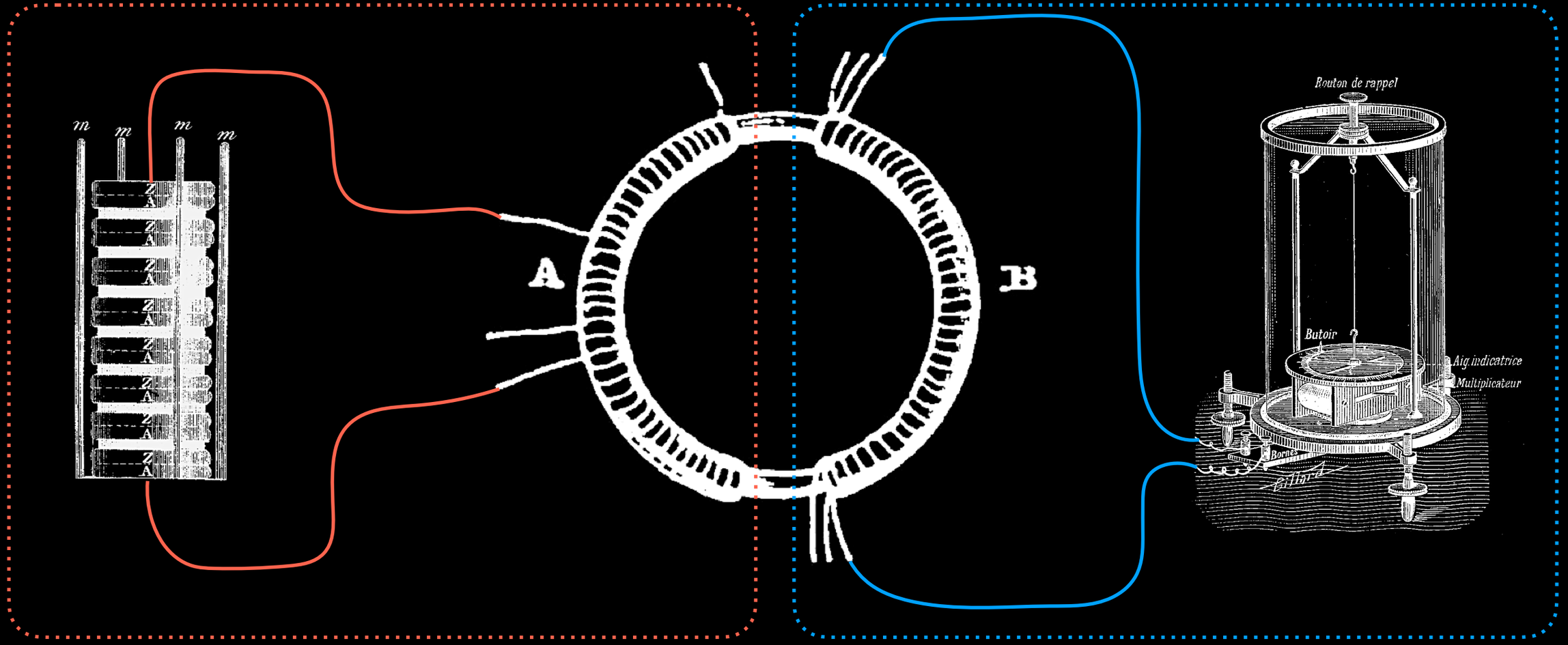
“A welded ring was made of soft round bar-iron, several helices were put round the ring.”

*“The helix B was connected by copper wires with a galvanometer;
the wires of A were connected with a battery of ten pairs of plates.”*

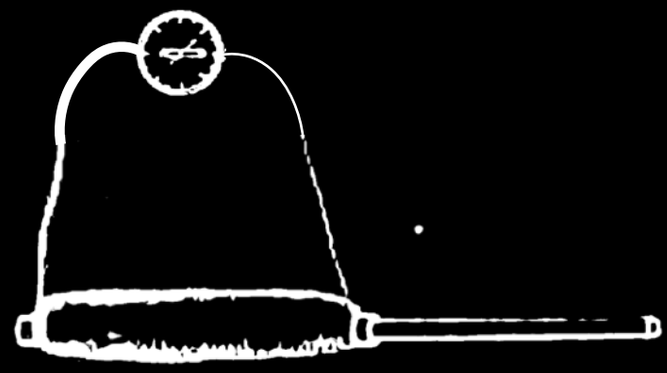
*“The galvanometer was immediately affected,
and to a degree far beyond what has been described.”*

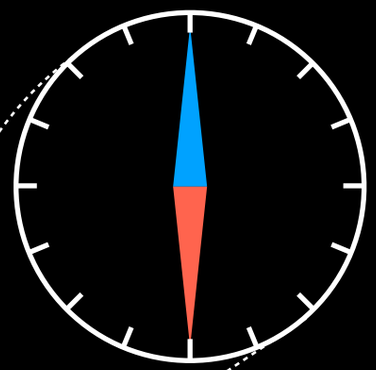
Electromagnet: *“transmitter”*

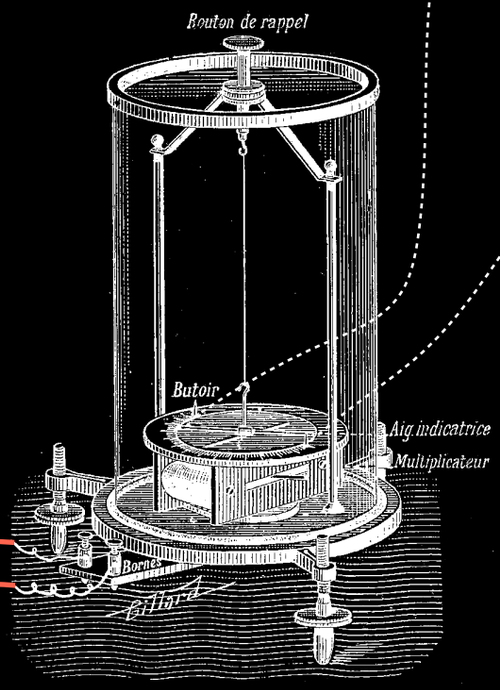
Coil: *“receiver”*



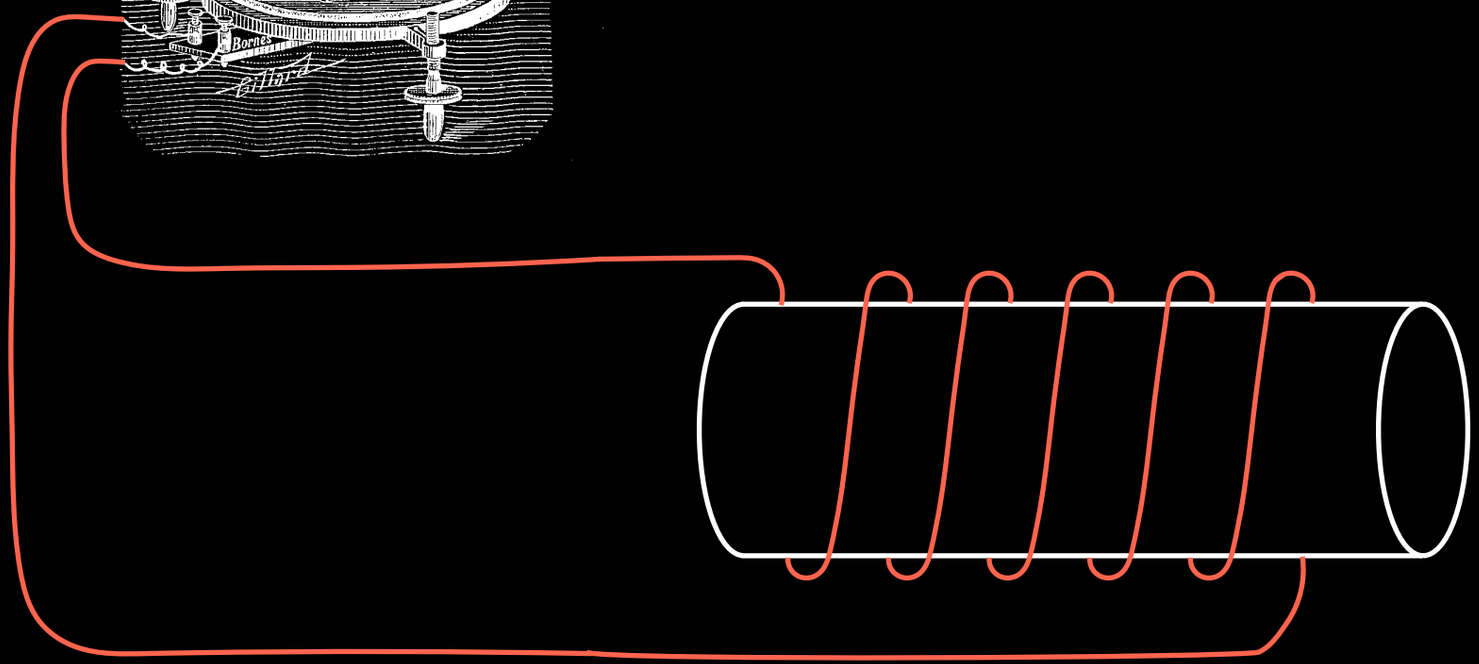
Electricity from motion



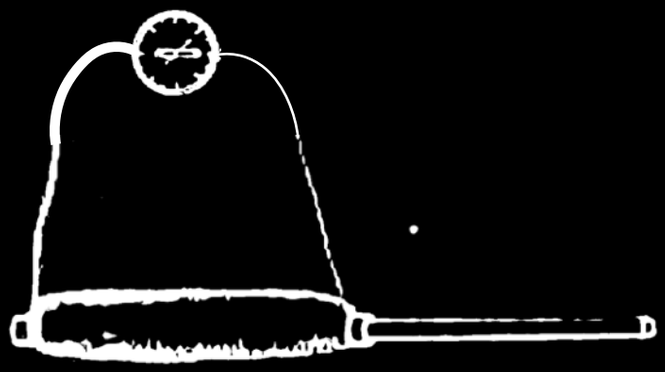


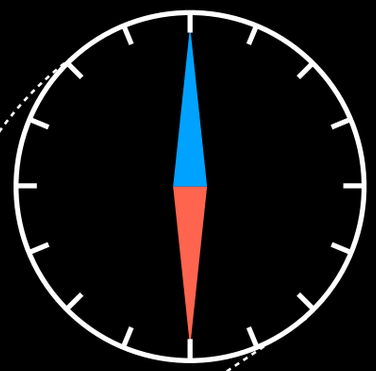


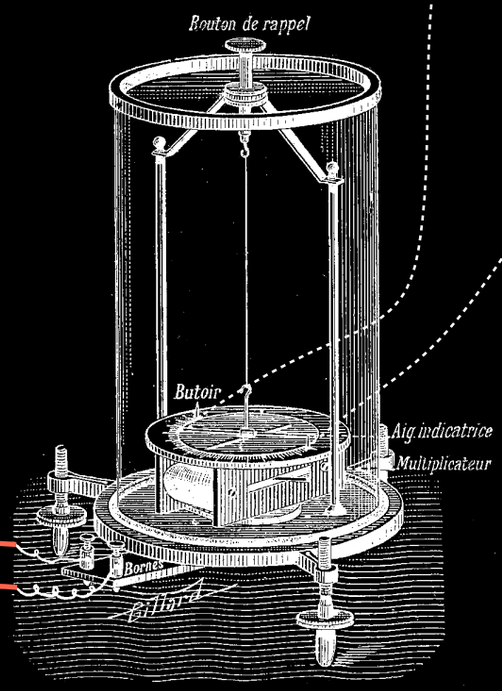
“A helix was constructed upon a hollow cylinder of pasteboard, and connected with the galvanometer.”



Electricity from motion

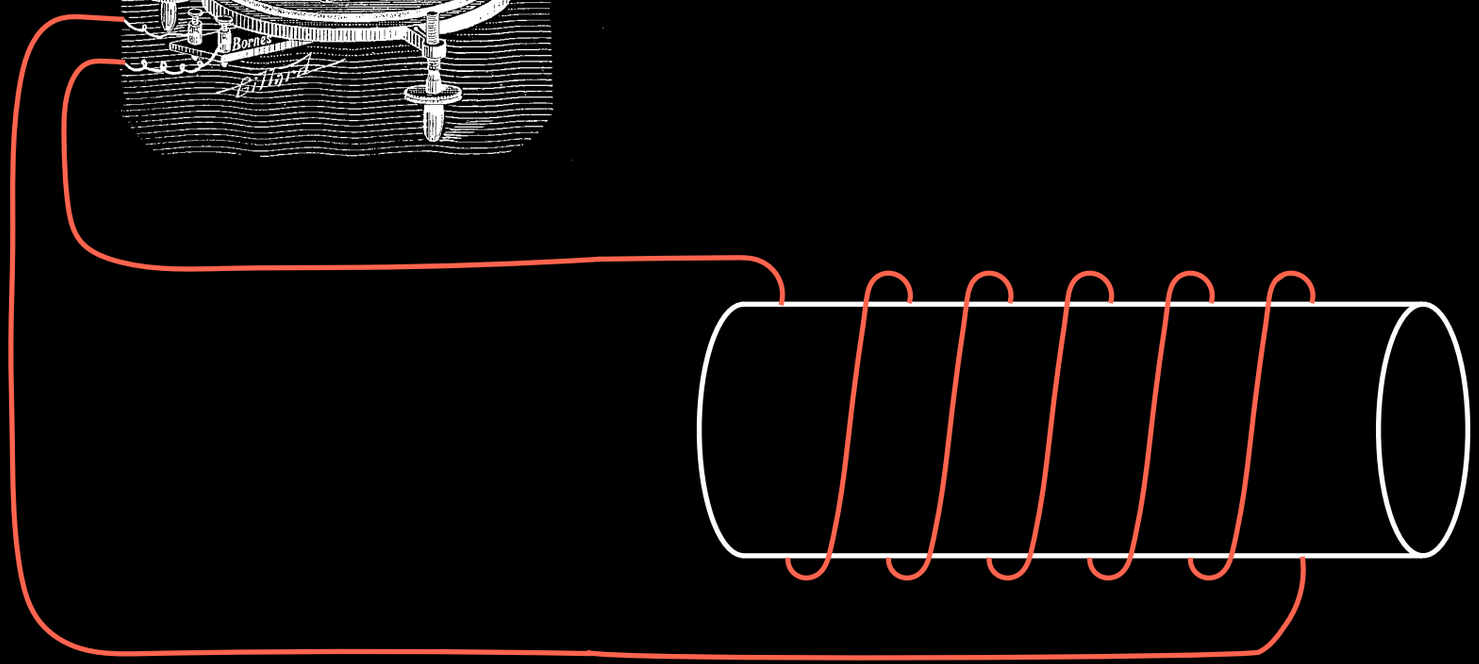




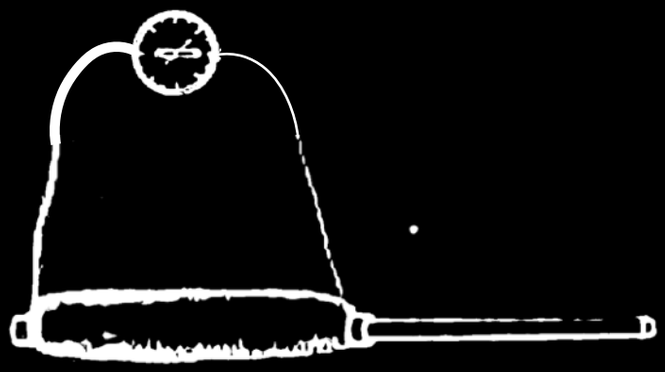


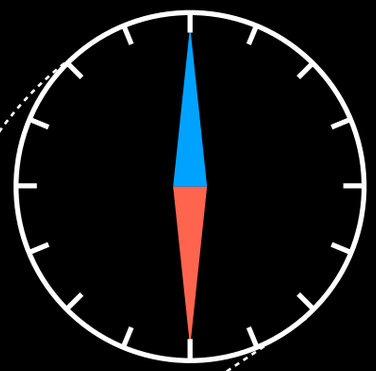
"A helix was constructed upon a hollow cylinder of pasteboard, and connected with the galvanometer."

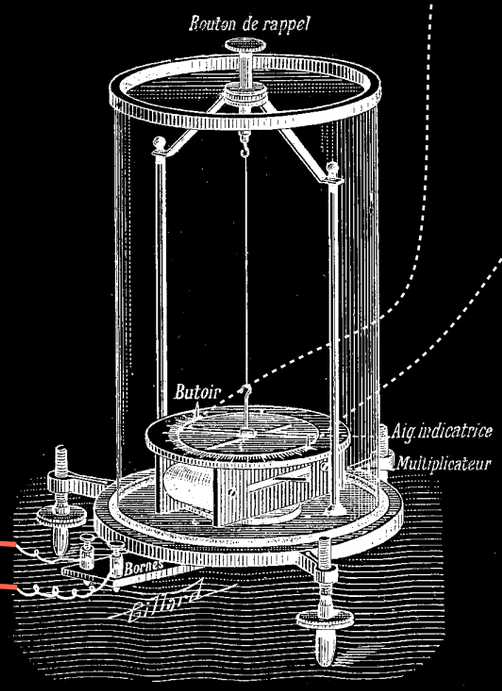
"One end of a cylindrical magnet was introduced into the axis of the helix, and then, the galvanometer-needle being stationary, the magnet was suddenly thrust in."



Electricity from motion

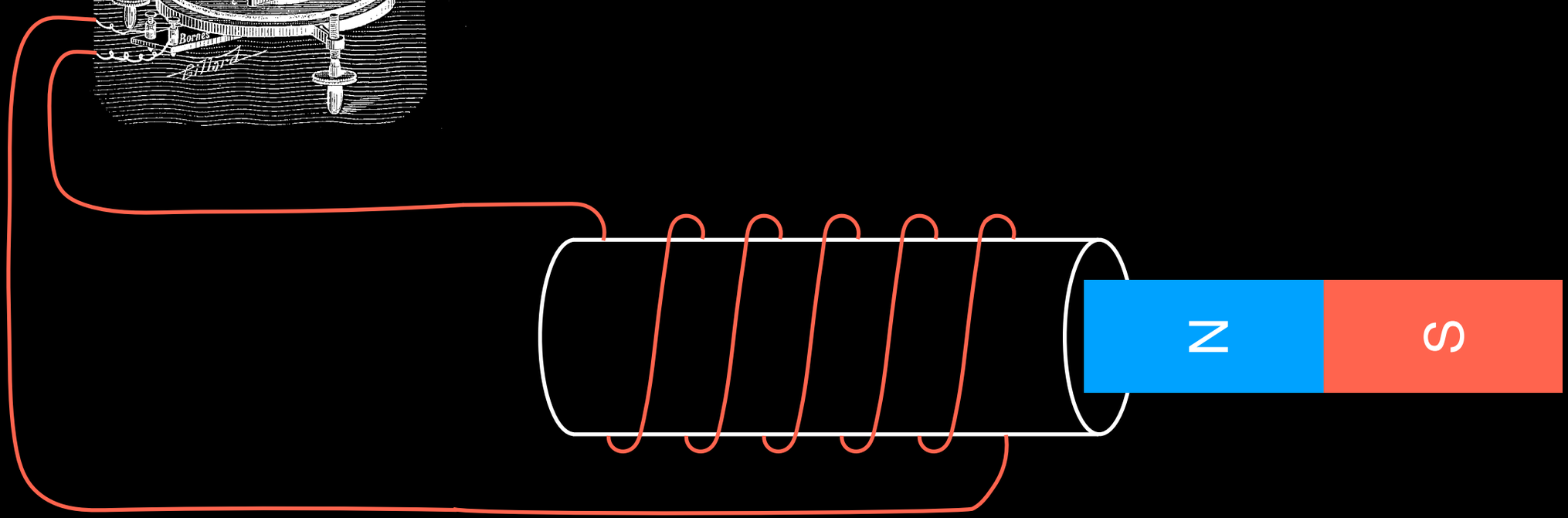




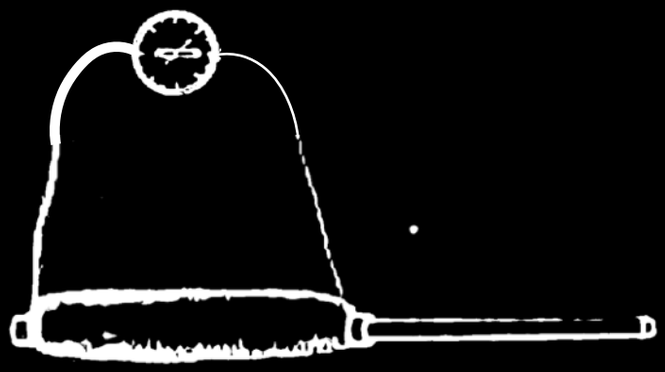


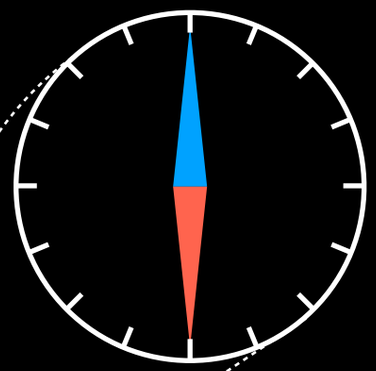
"A helix was constructed upon a hollow cylinder of pasteboard, and connected with the galvanometer."

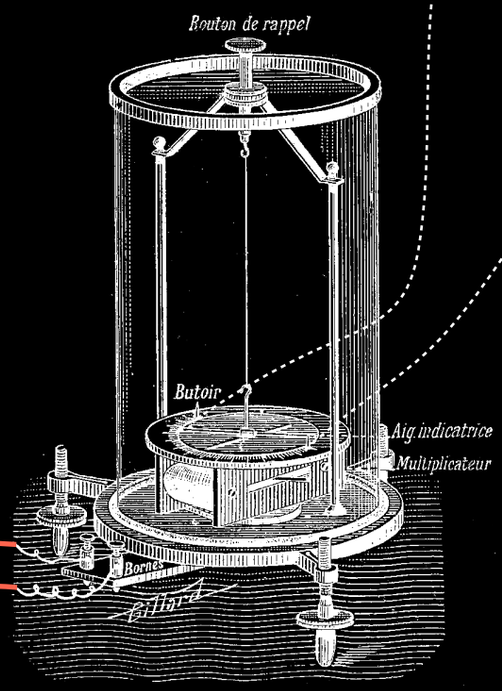
"One end of a cylindrical magnet was introduced into the axis of the helix, and then, the galvanometer-needle being stationary, the magnet was suddenly thrust in."



Electricity from motion

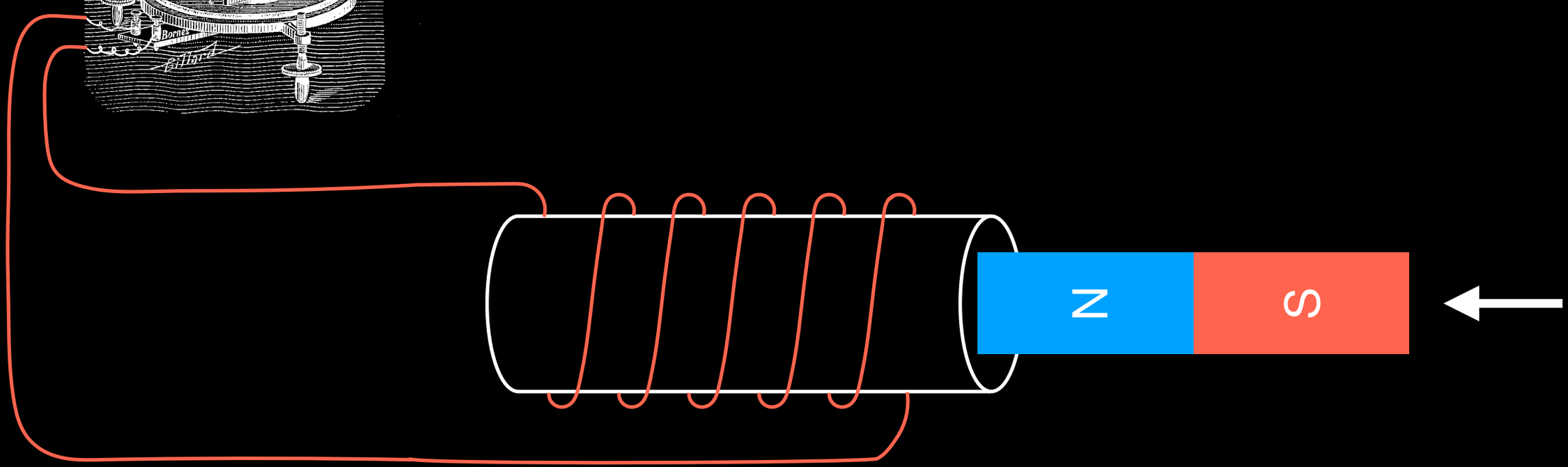




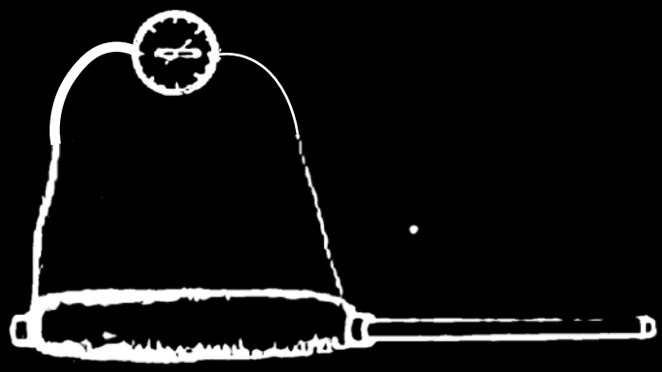


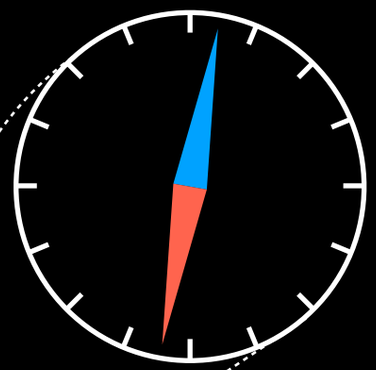
"A helix was constructed upon a hollow cylinder of pasteboard, and connected with the galvanometer."

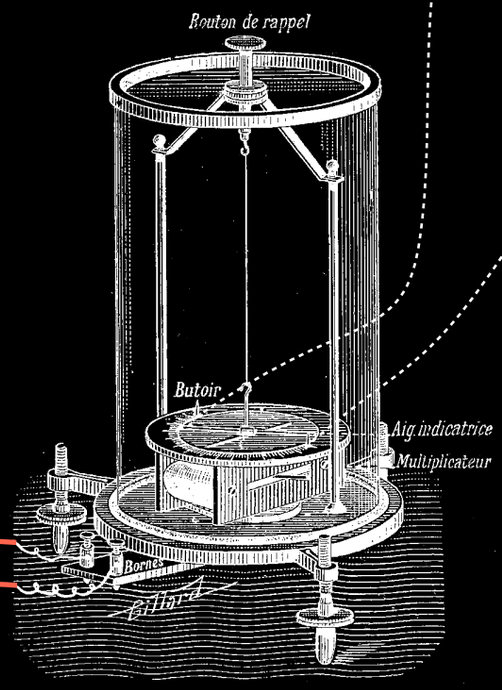
"One end of a cylindrical magnet was introduced into the axis of the helix, and then, the galvanometer-needle being stationary, the magnet was suddenly thrust in."



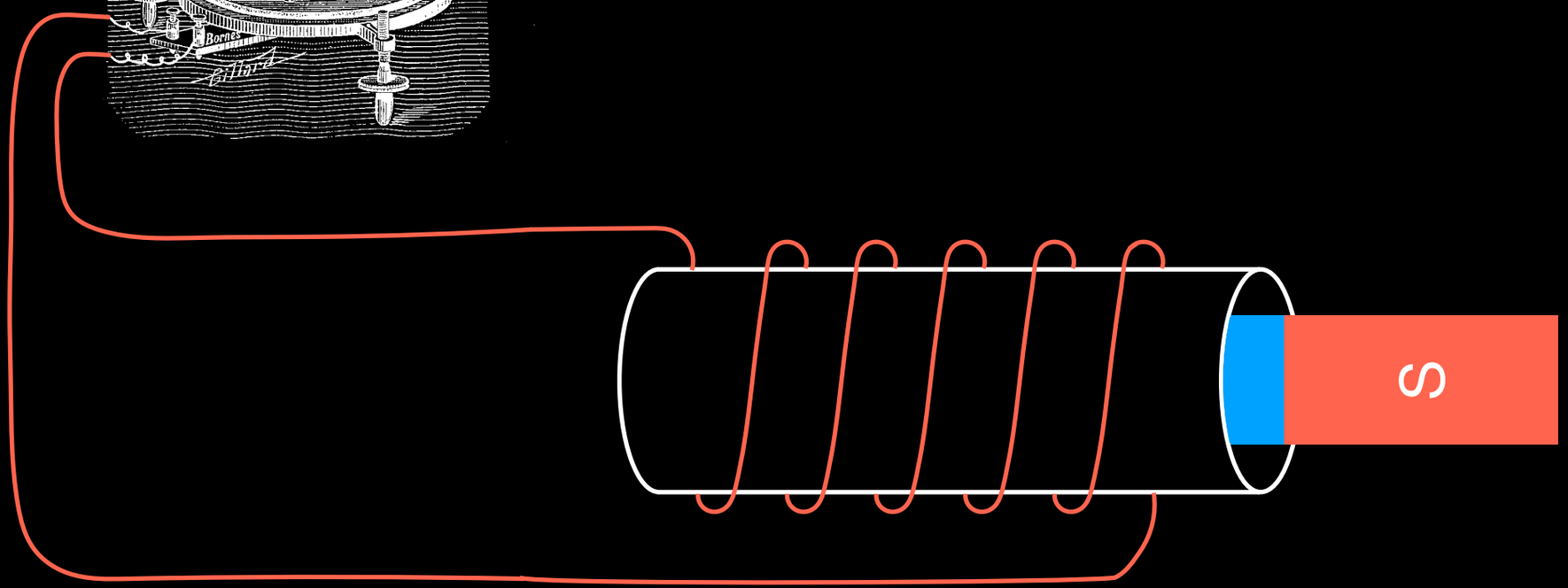
Electricity from motion



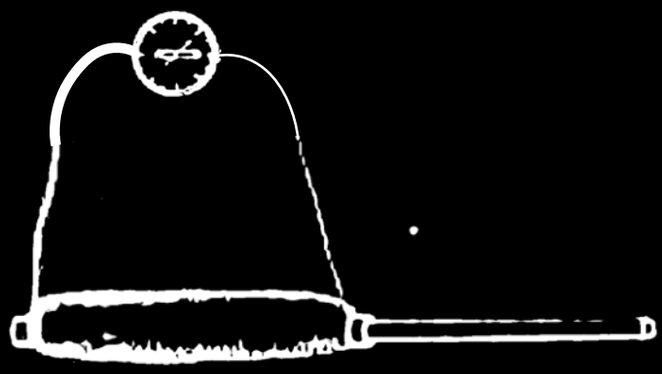


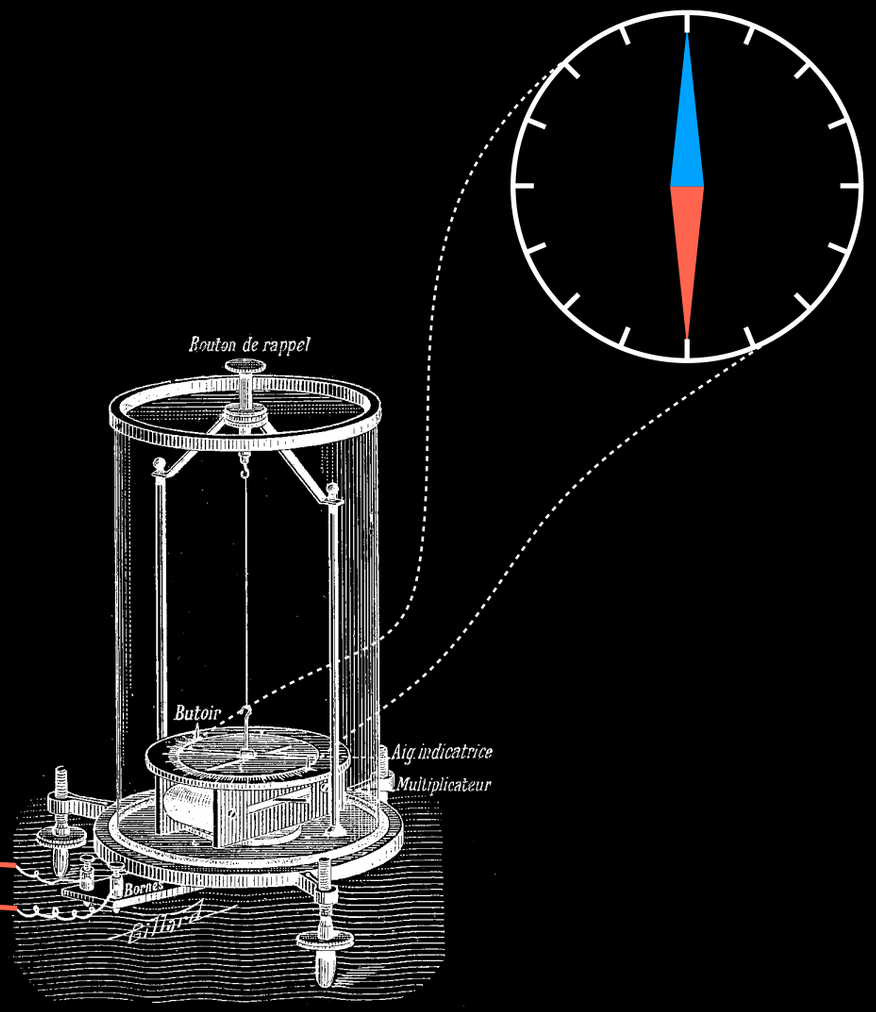


“Immediately the needle was deflected.”



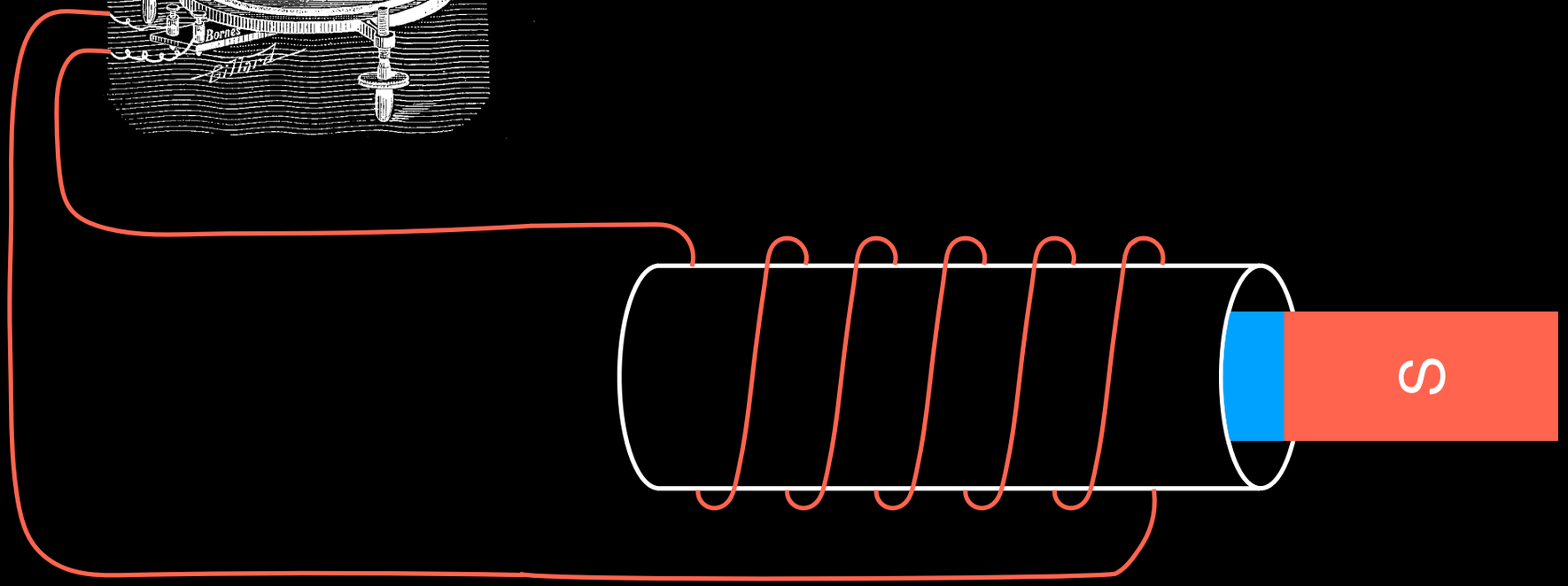
Electricity from motion



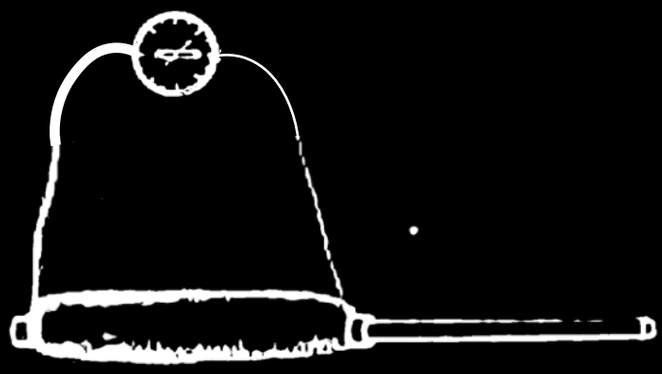


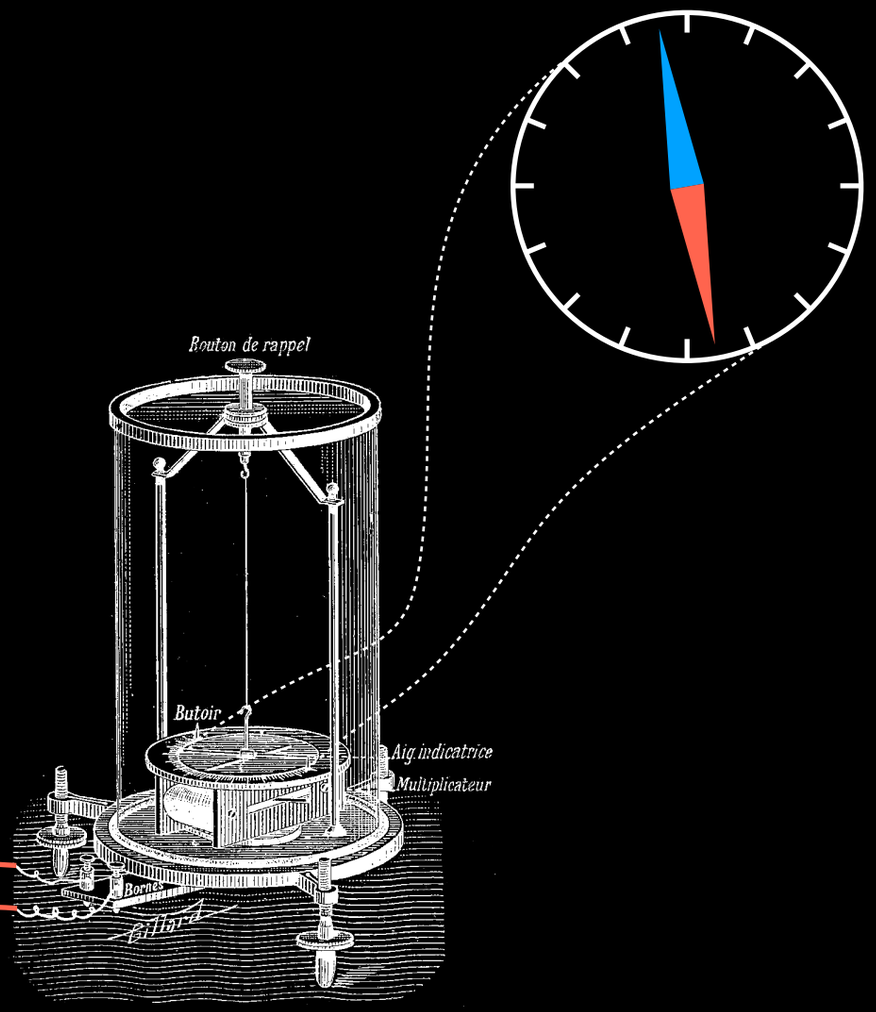
“Immediately the needle was deflected.”

“Being left in, the needle resumed its first position …”



Electricity from motion

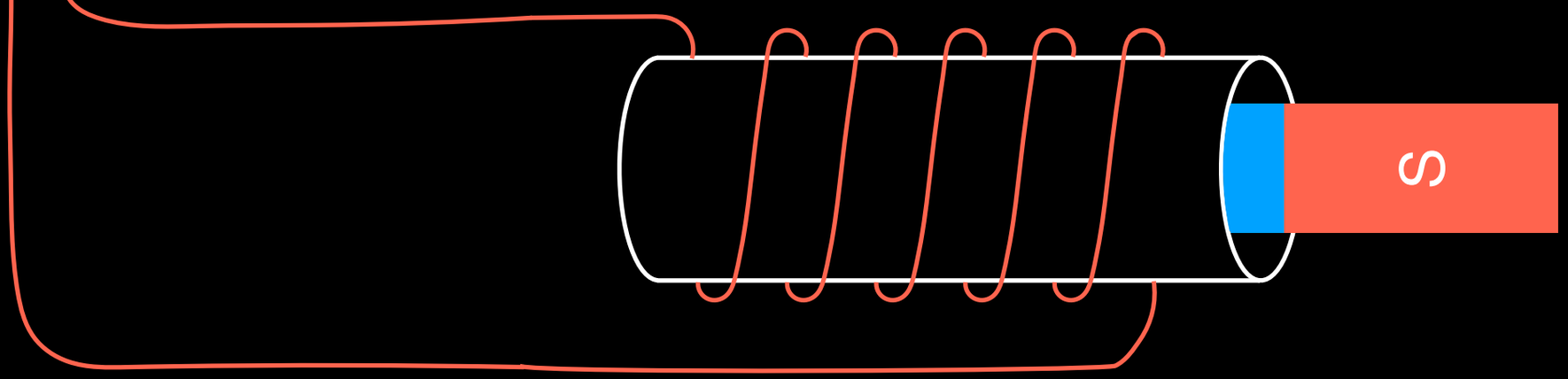




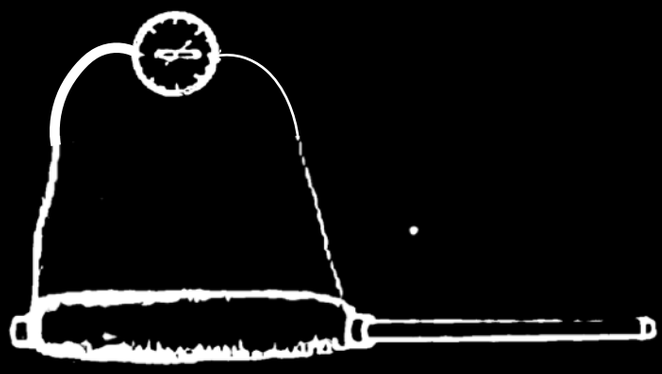
“Immediately the needle was deflected.”

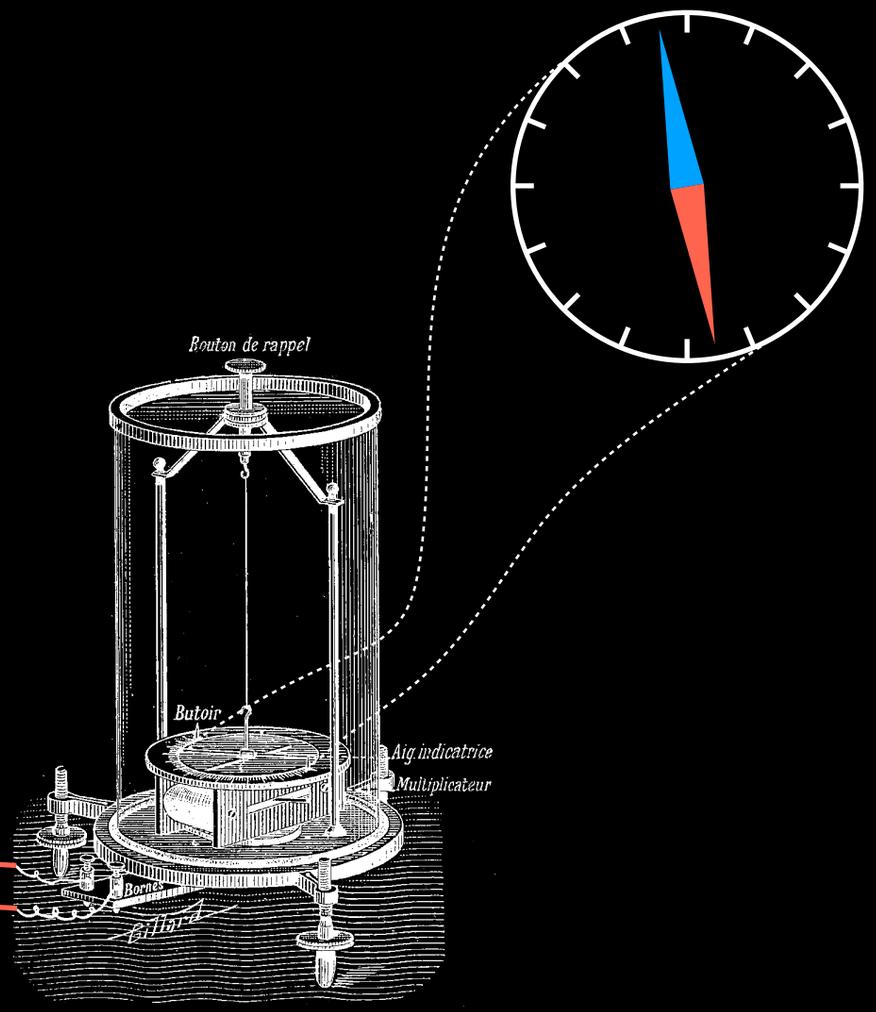
“Being left in, the needle resumed its first position …”

“… and then the magnet being withdrawn the needle was deflected in the opposite direction.”



Electricity from motion

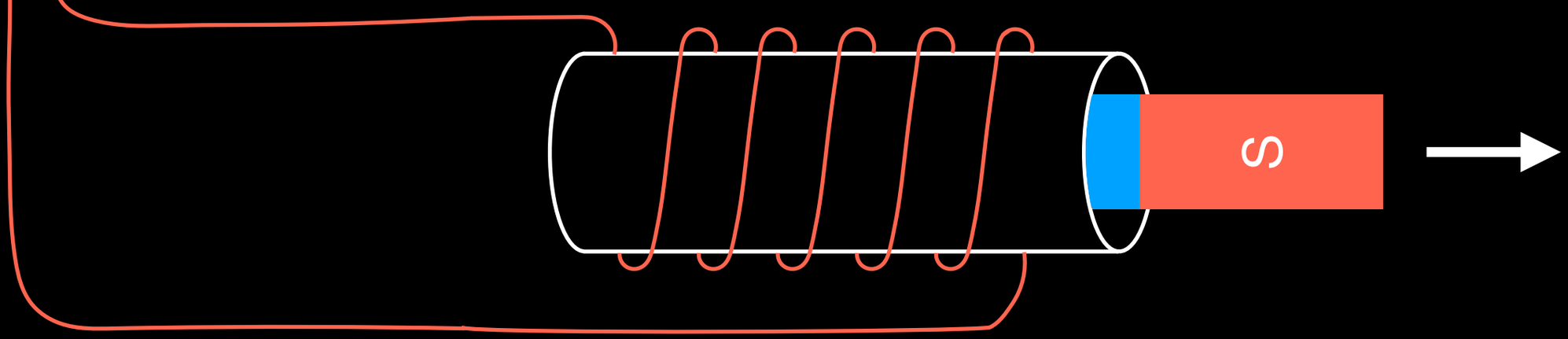




“Immediately the needle was deflected.”

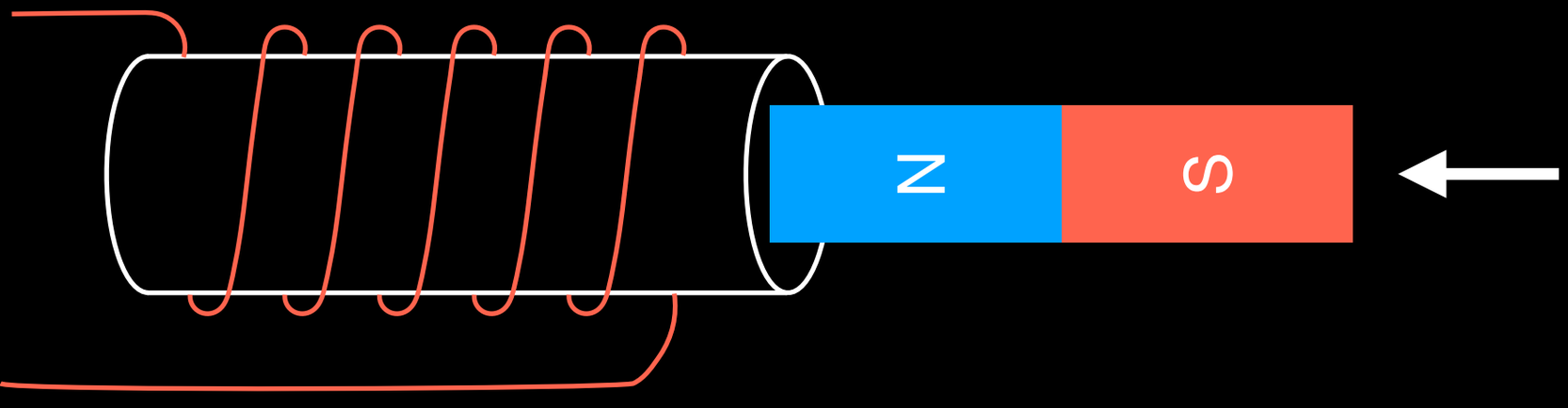
“Being left in, the needle resumed its first position …”

“… and then the magnet being withdrawn the needle was deflected in the opposite direction.”

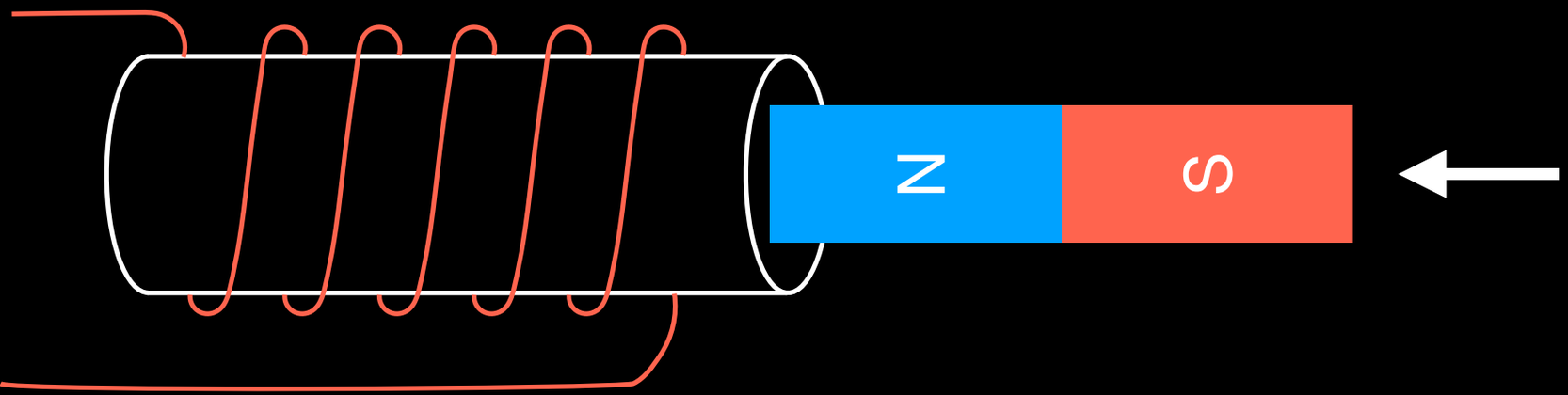


The law of induction

The law of induction

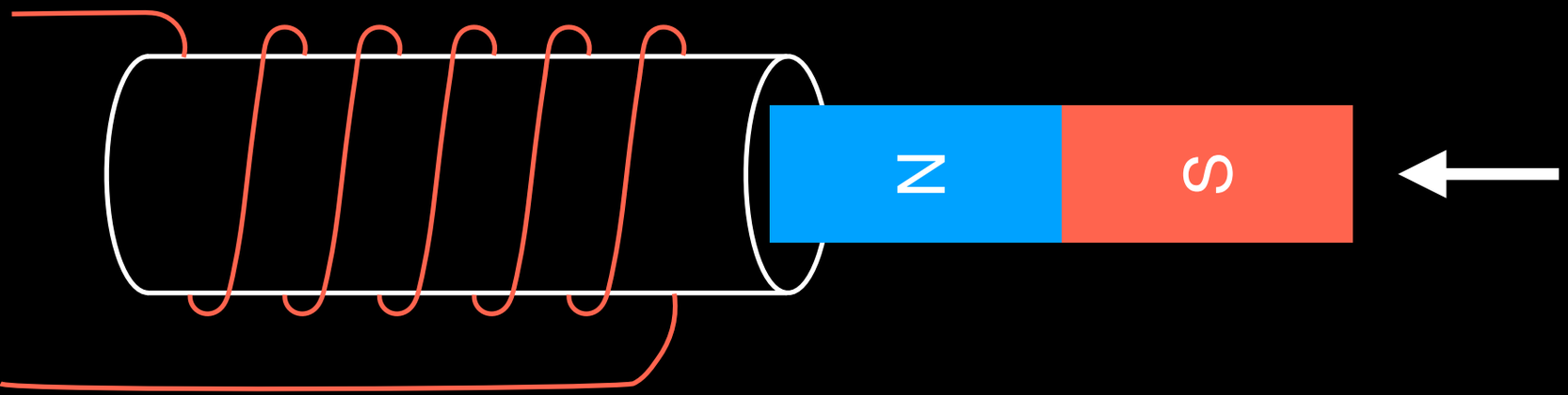


The law of induction



“The law which governs the evolution of electricity by magneto-electric induction is very simple, although rather difficult to express.”

The law of induction



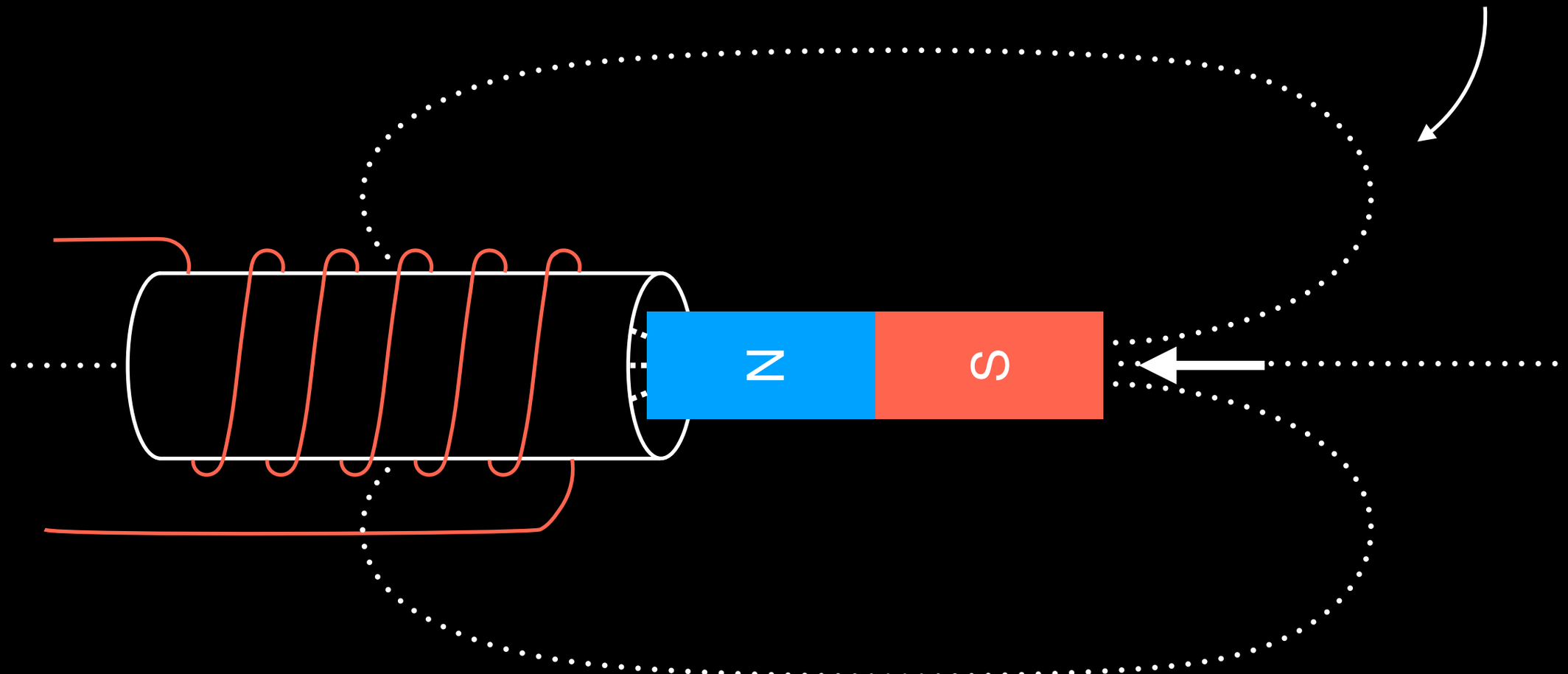
“The law which governs the evolution of electricity by magneto-electric induction is very simple, although rather difficult to express.”

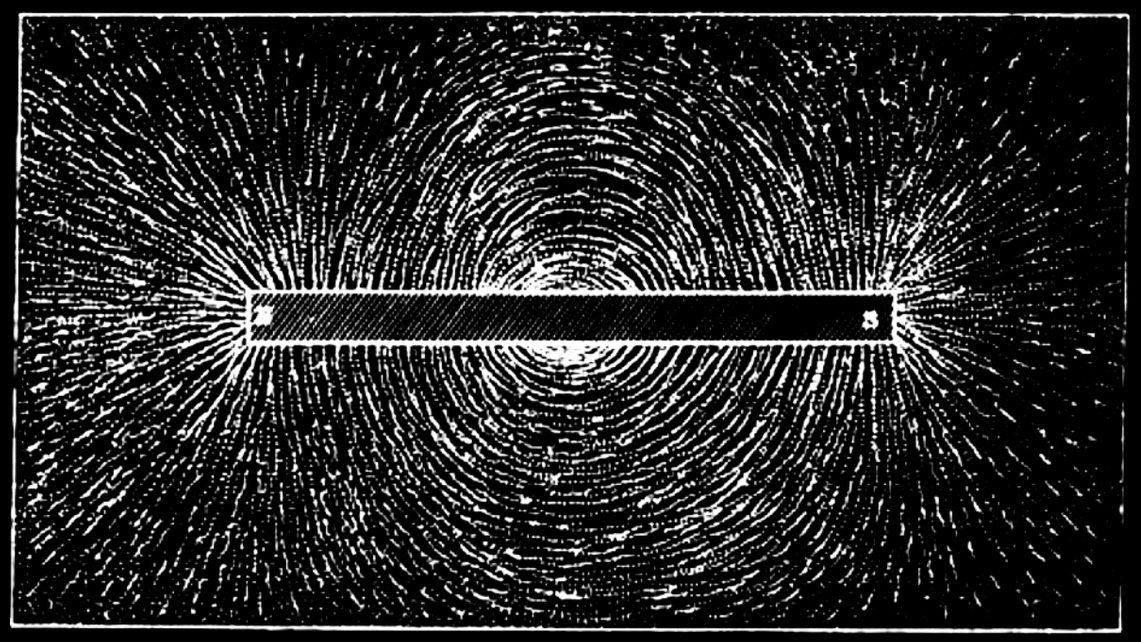
“If the wire moves so as to cut the magnetic curves, then a current of electricity is evolved in the wire.”

(Abridged version)

The law of induction

“By magnetic curves, I mean the lines of magnetic forces, which would be depicted by iron filings.”



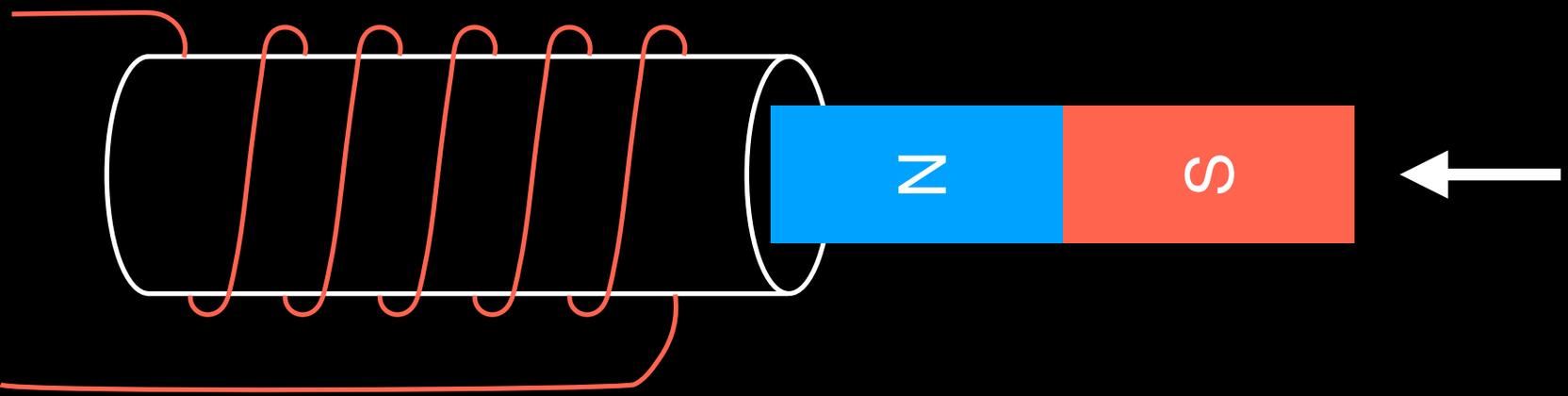


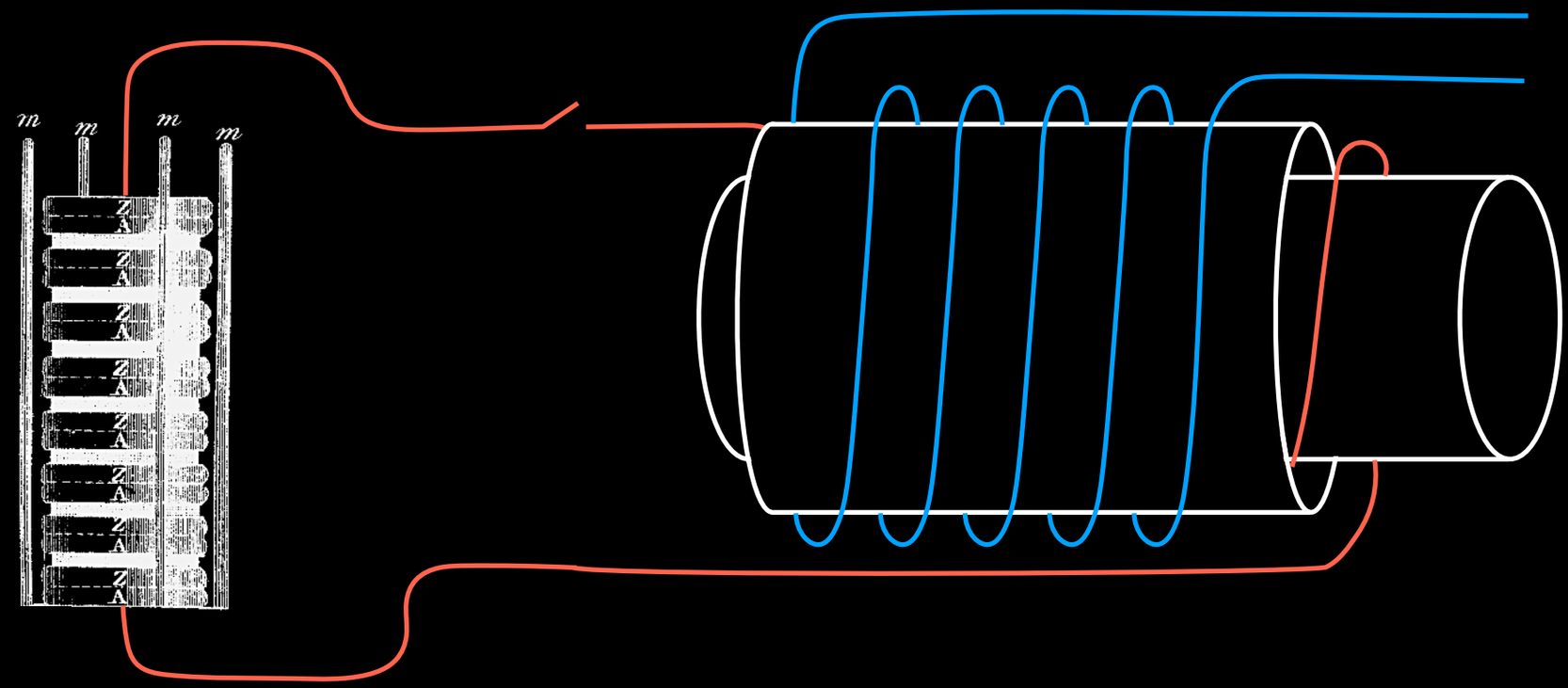
“The law which governs the evolution of electricity by magneto-electric induction is very simple, although rather difficult to express.”

“If the wire moves so as to cut the magnetic curves, then a current of electricity is evolved in the wire.”

(Abridged version)

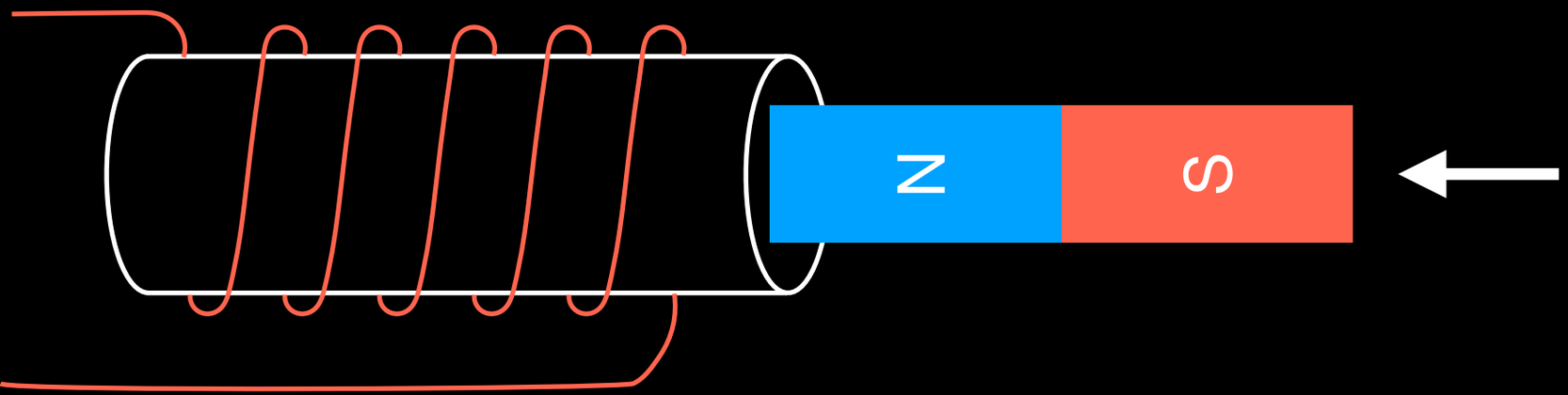
The law of induction

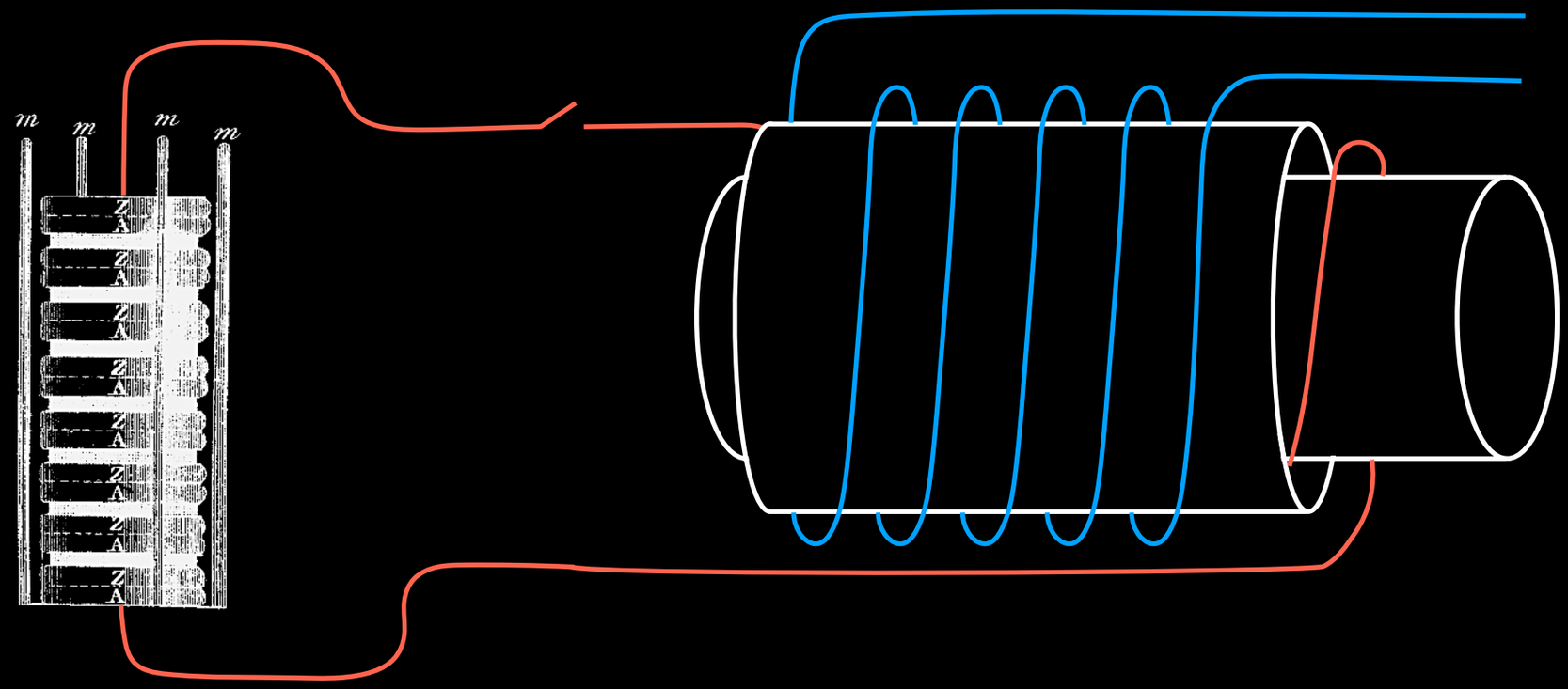




The law of induction

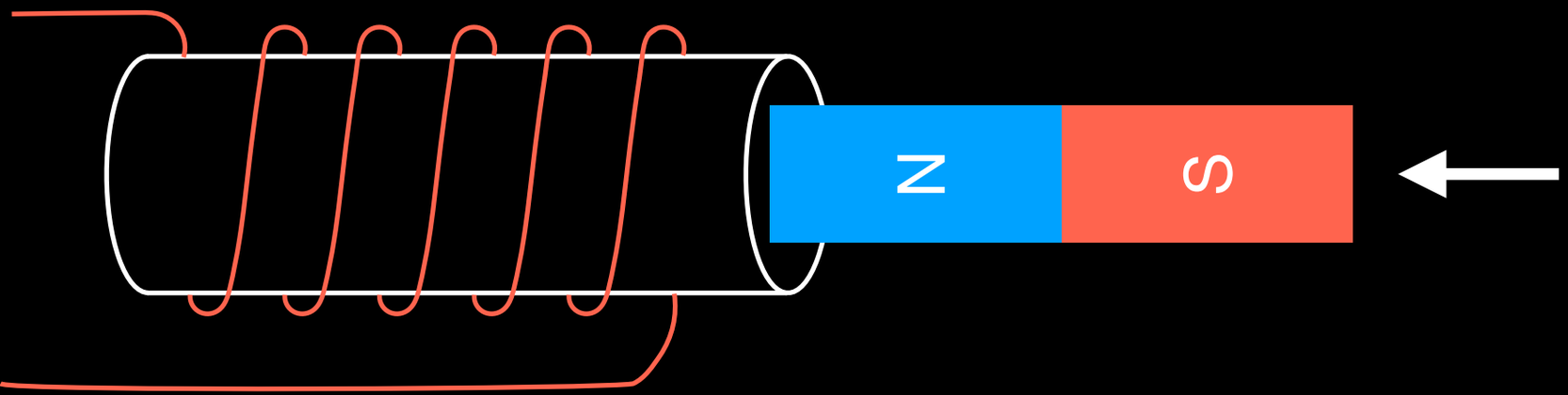
Turning on an electromagnet produces
(almost identical) **“lines of magnetic forces”**
that cut the wires

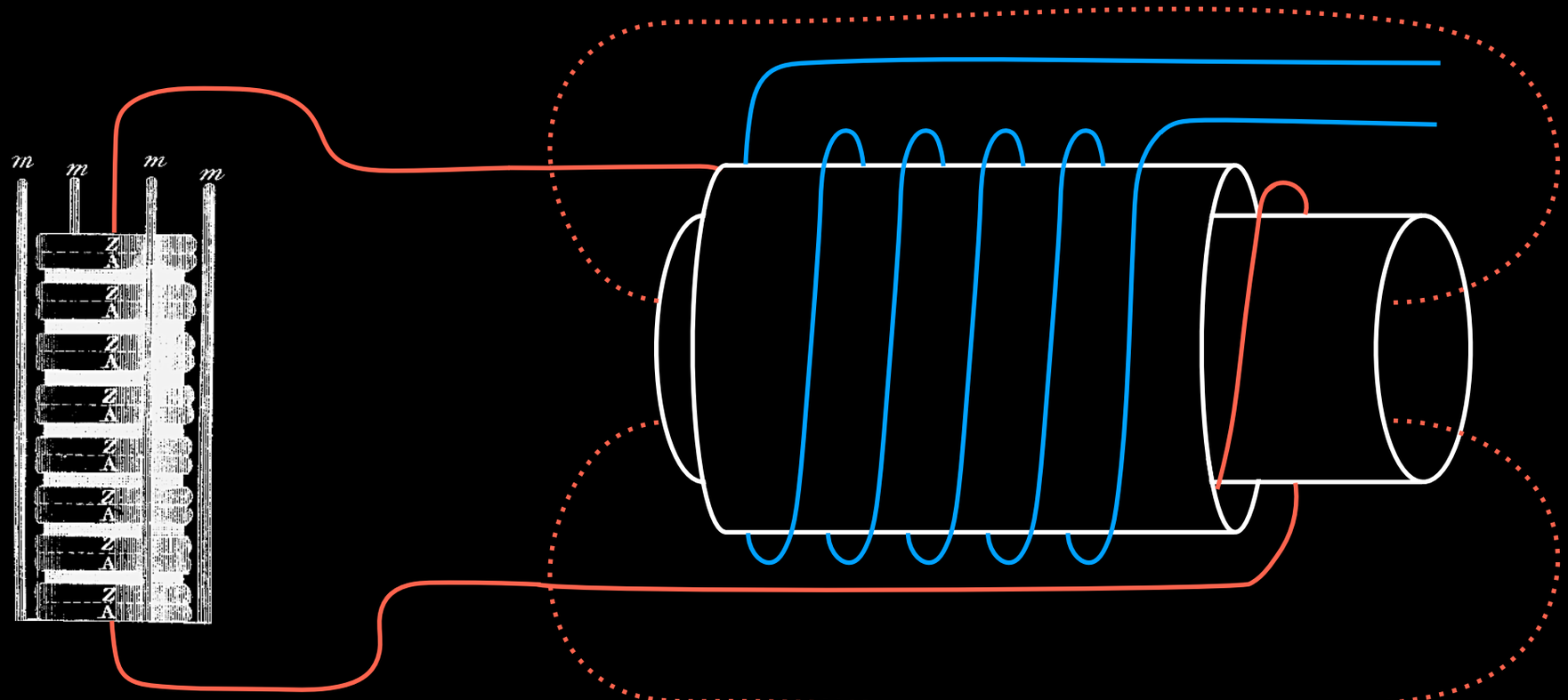




The law of induction

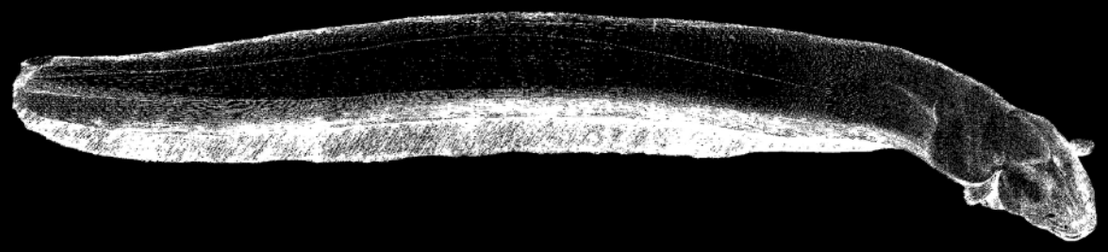
Turning on an electromagnet produces
(almost identical) **“lines of magnetic forces”**
that cut the wires

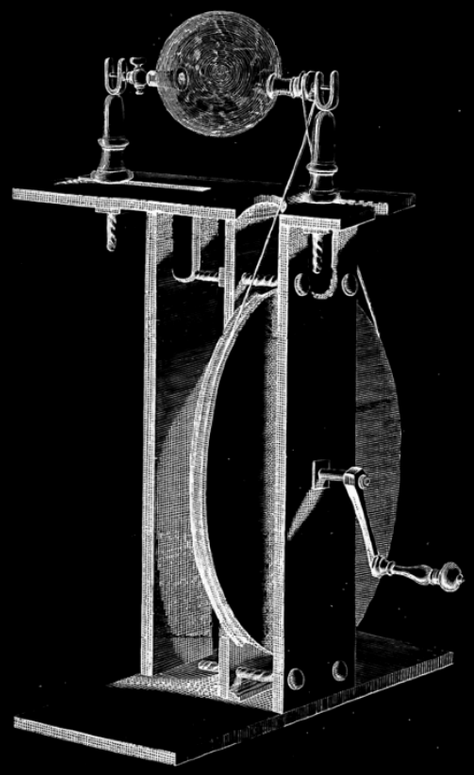




Electricity in ~~1800~~ 1820

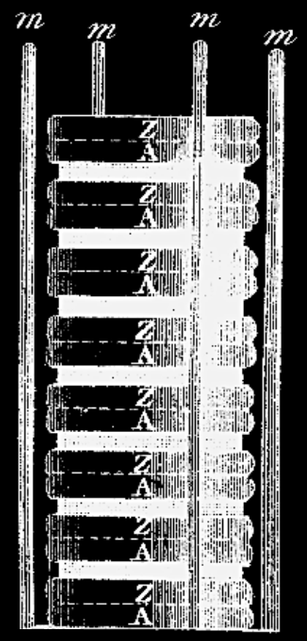
“Animal electricity”

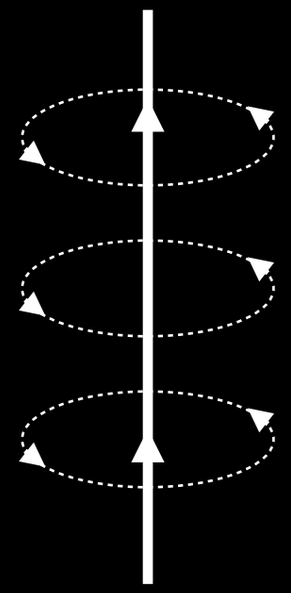




“Ordinary electricity”

“Voltaic electricity”

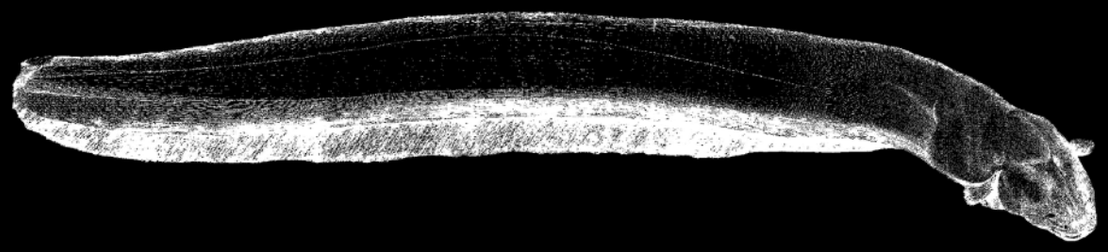




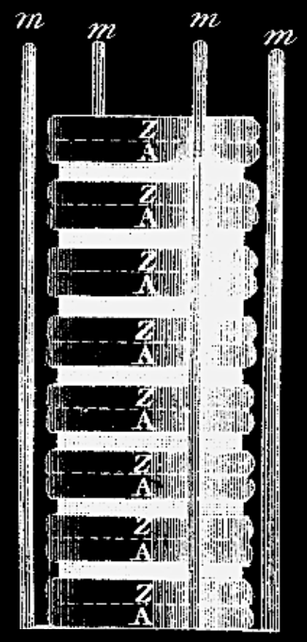
“Electro-magnetism”

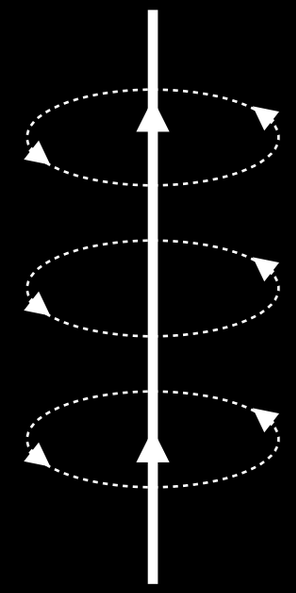
Electricity in ~~1800~~ 1830 ~~1820~~

“Animal electricity”

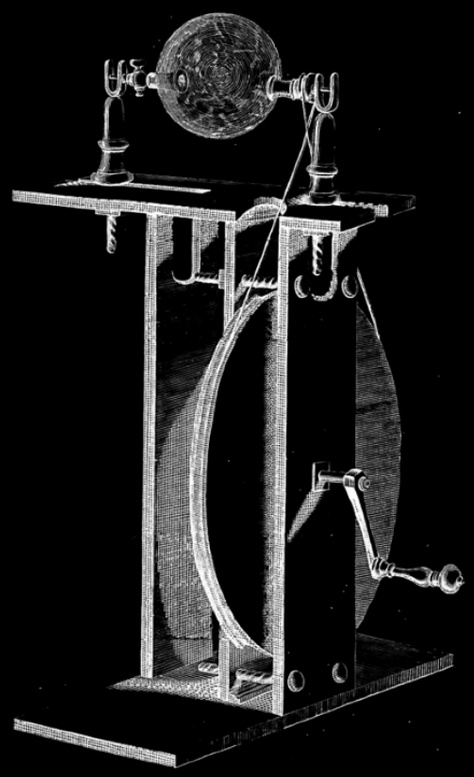


“Voltaic electricity”





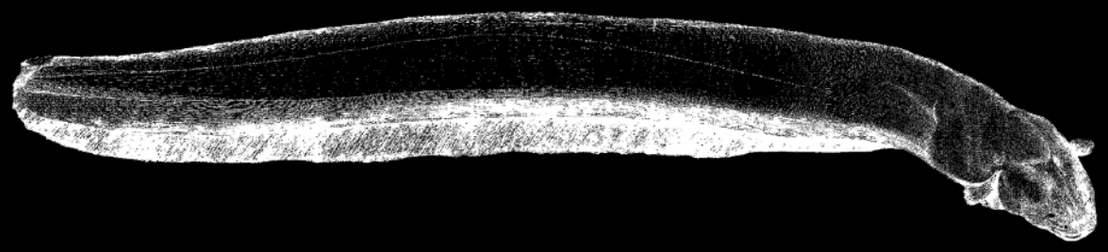
“Electro-magnetism”



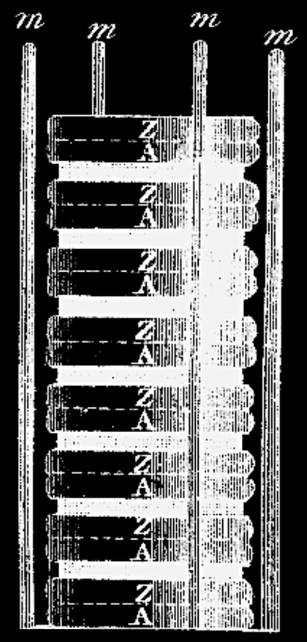
“Ordinary electricity”

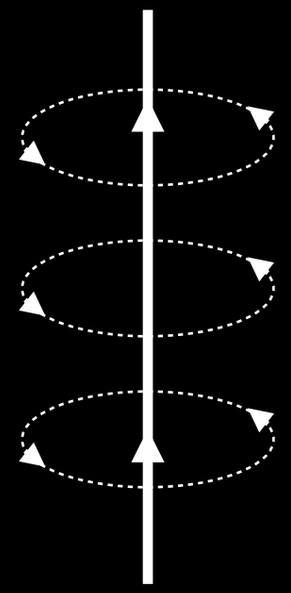
Electricity in ~~1800~~ 1830 ~~1820~~

"Animal electricity"

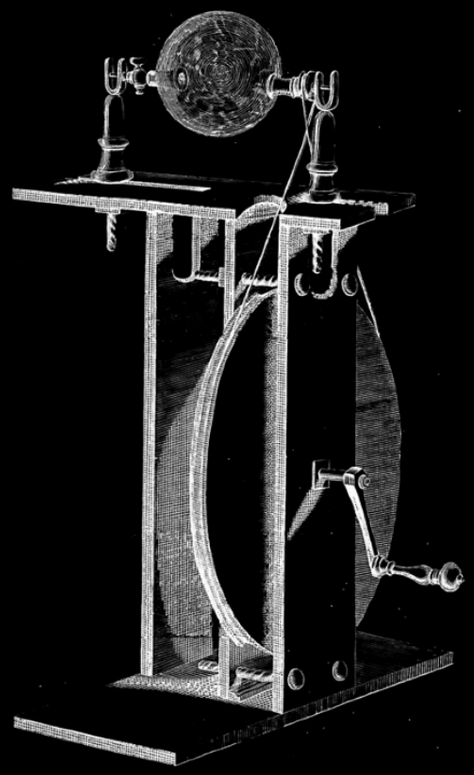


"Voltaic electricity"



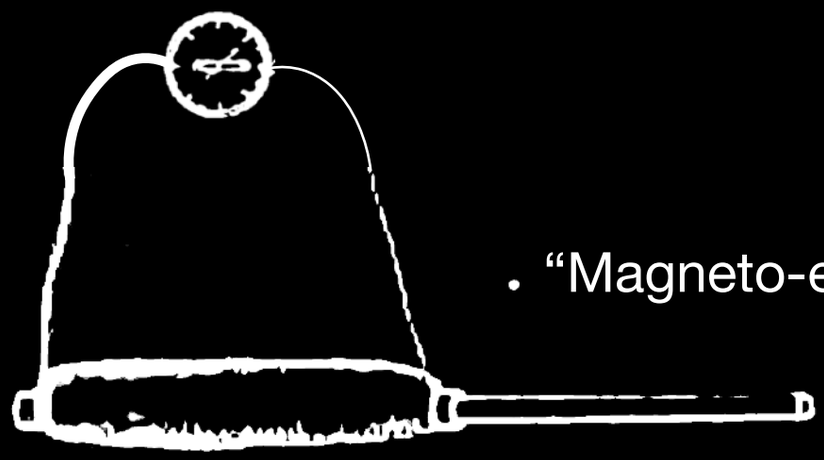


"Ordinary electricity"



"Electro-magnetism"

"Magneto-electricity"

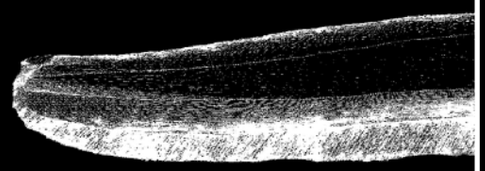


Electricity in ~~1800~~ 1830

~~1820~~

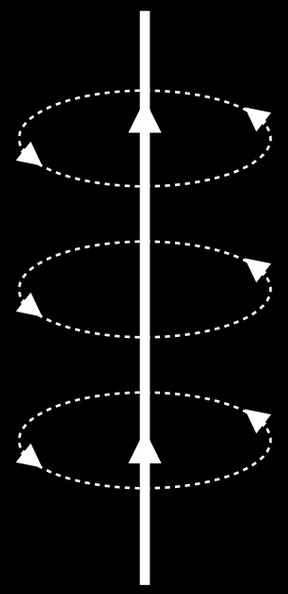
"Voltaic electricity"

"Animal electricity"

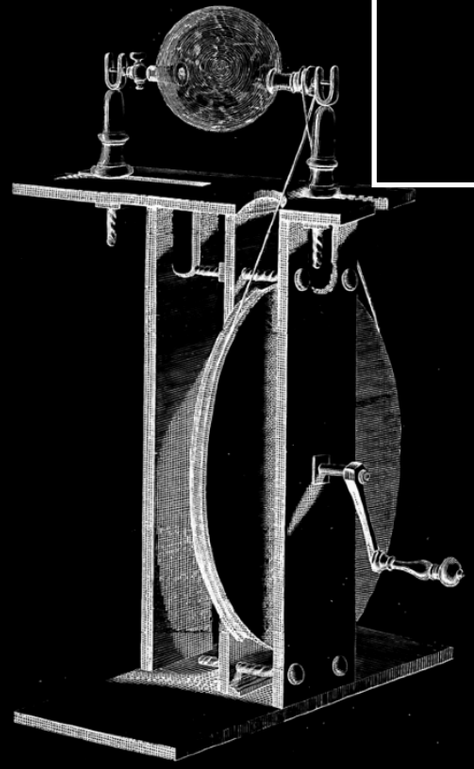


Faraday, 1830s:

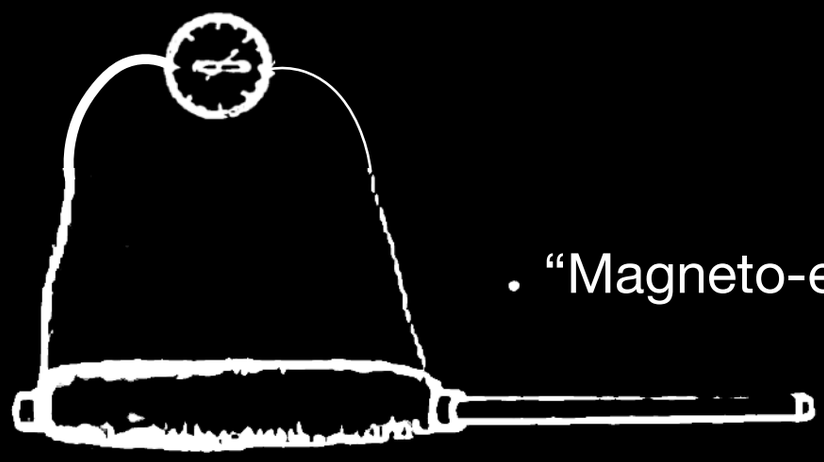
"The progress of the electrical researches brought me to a point at which it was essential that no doubt should remain of the identity or distinction of electricities excited by different means."



electricity"



"Electro-magnetism"



• "Magneto-electricity"

Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”

Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”

“Attraction or repulsion at sensible distances”

Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”

“Attraction or repulsion at sensible distances”

“Evolution of heat”

Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”

“Attraction or repulsion at sensible distances”

“Evolution of heat”

“Physiological phenomena”

Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”

“Attraction or repulsion at sensible distances”

“Evolution of heat”

“Spark”

“Physiological phenomena”

Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”

“Attraction or repulsion at sensible distances”

“Magnetism”

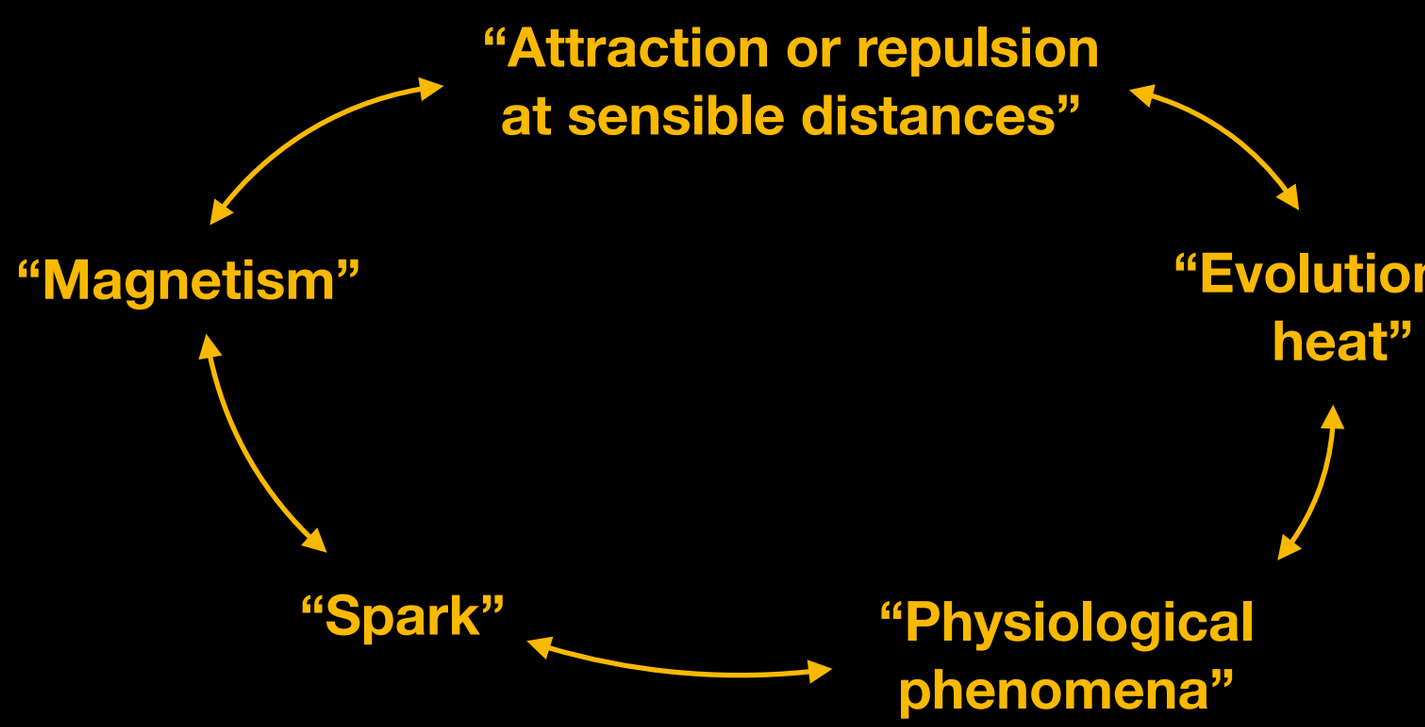
“Evolution of heat”

“Spark”

“Physiological phenomena”

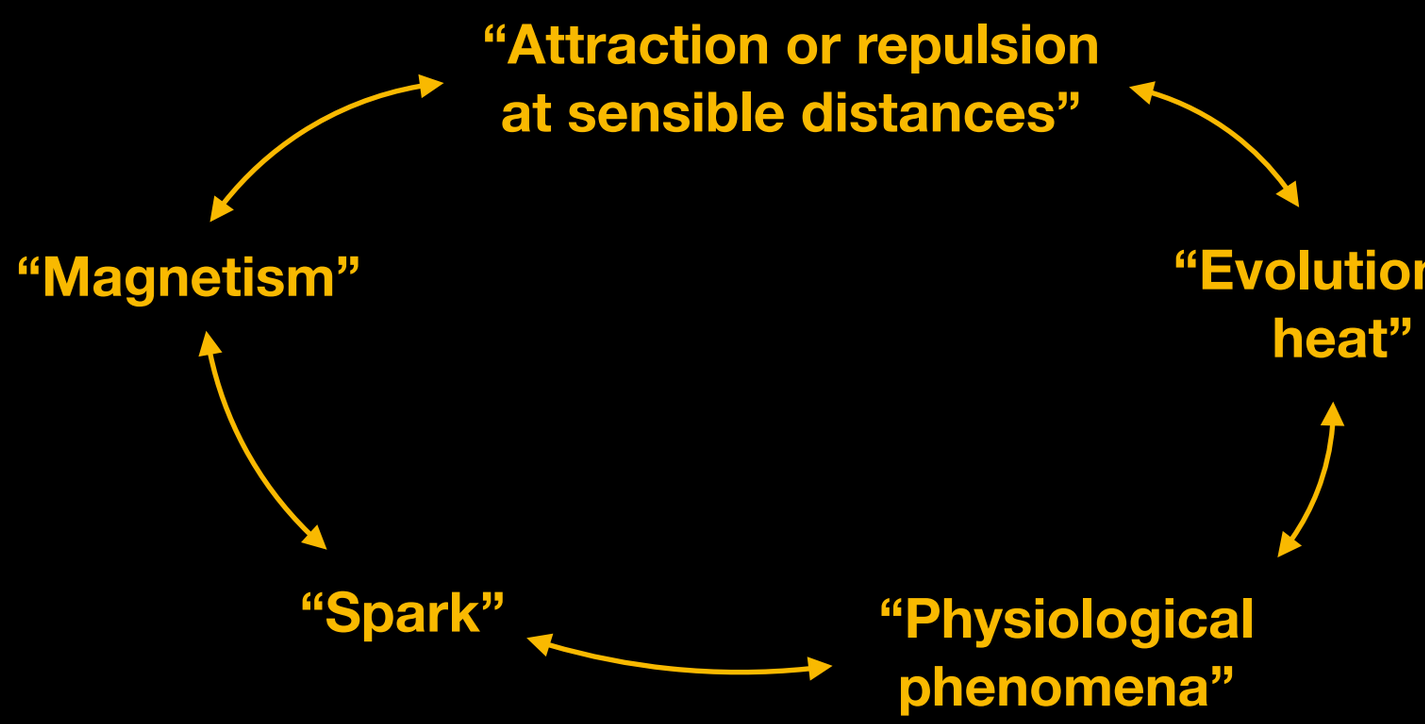
Effects of electricity

“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”



Effects of electricity

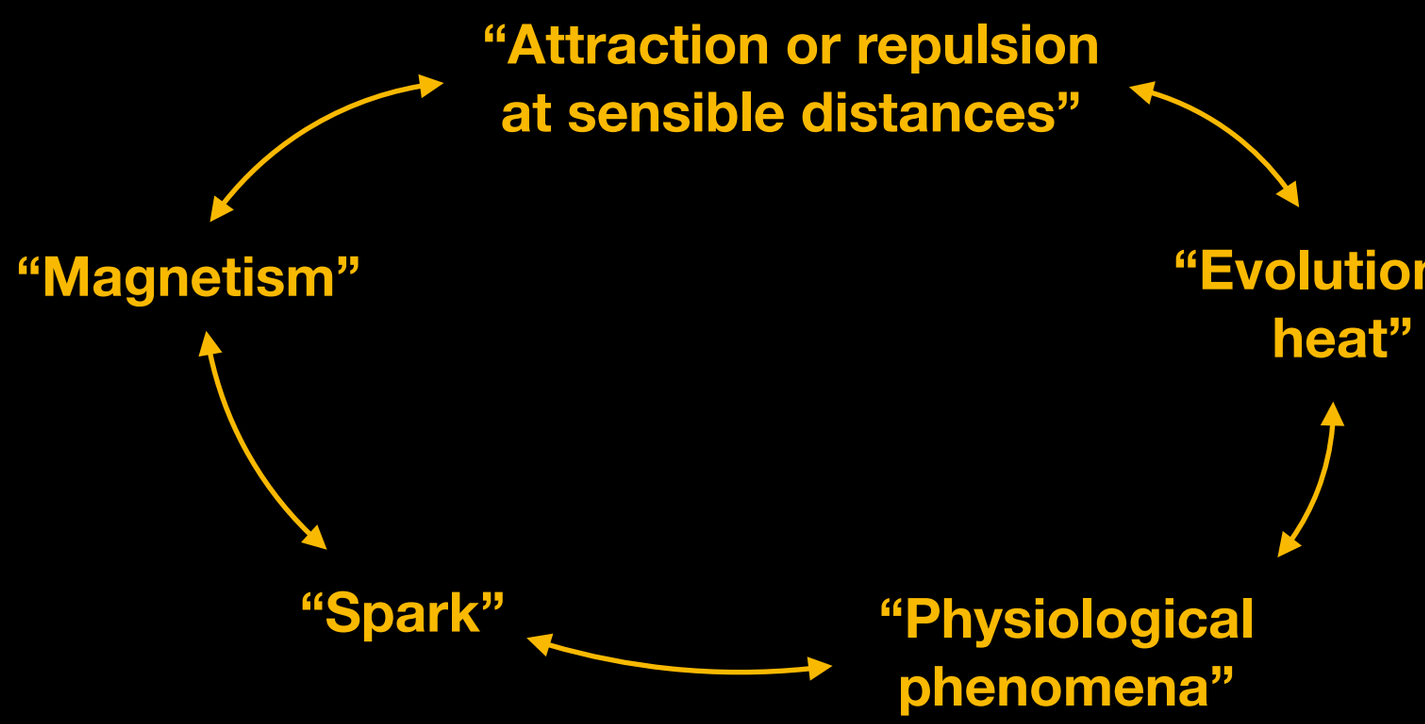
“The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized”



“It will be my object to compare electricities from different sources by their power of producing these effects.”

Effects of electricity

"The various phenomena exhibited by electricity may, for the purpose of comparison, be summarized"



"It will be my object to compare electricities from different sources by their power of producing these effects."

If it looks like a duck, swims like a duck, and quacks like a duck, then it probably is a duck!

Assembling the facts

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

Assembling the facts

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

Assembling the facts

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

Assembling the facts

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

Assembling the facts

“The brilliant star of light produced by the discharge of a voltaic battery is known to all as the most beautiful light that man can produce by art.”

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

Assembling the facts

“The positively charged surface of the Leyden jar coincided with the positive end of the voltaic apparatus; The deflections were in the same direction as if a voltaic current had been passed through the galvanometer.”

“The brilliant star of light produced by the discharge of a voltaic battery is known to all as the most beautiful light that man can produce by art.”

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

Assembling the facts

"The positively charged surface of the Leyden jar coincided with the positive end of the voltaic apparatus; The deflections were in the same direction as if a voltaic current had been passed through the galvanometer."

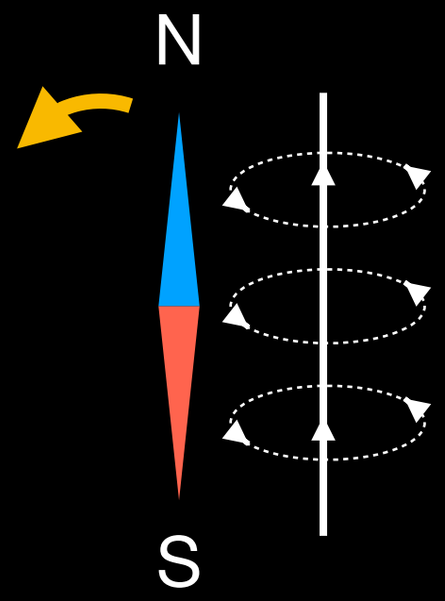
"The brilliant star of light produced by the discharge of a voltaic battery is known to all as the most beautiful light that man can produce by art."

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

"The general conclusion which must be drawn from this collection of facts is, that electricity, whatever may be its source, is identical in its nature."

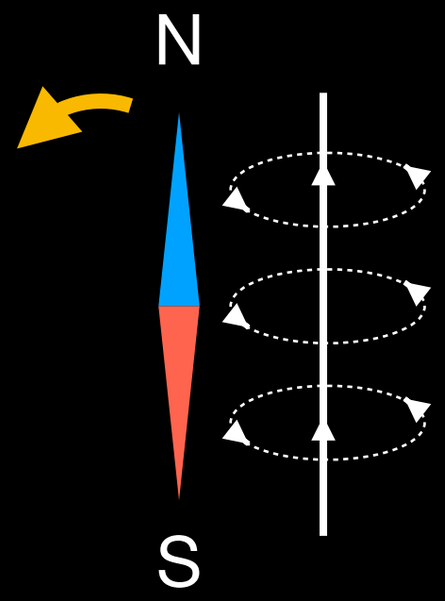
Electricity connects the world

Electricity connects the world

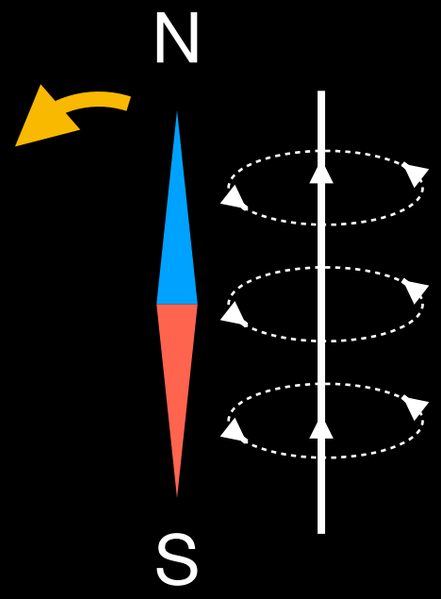


Electricity connects the world

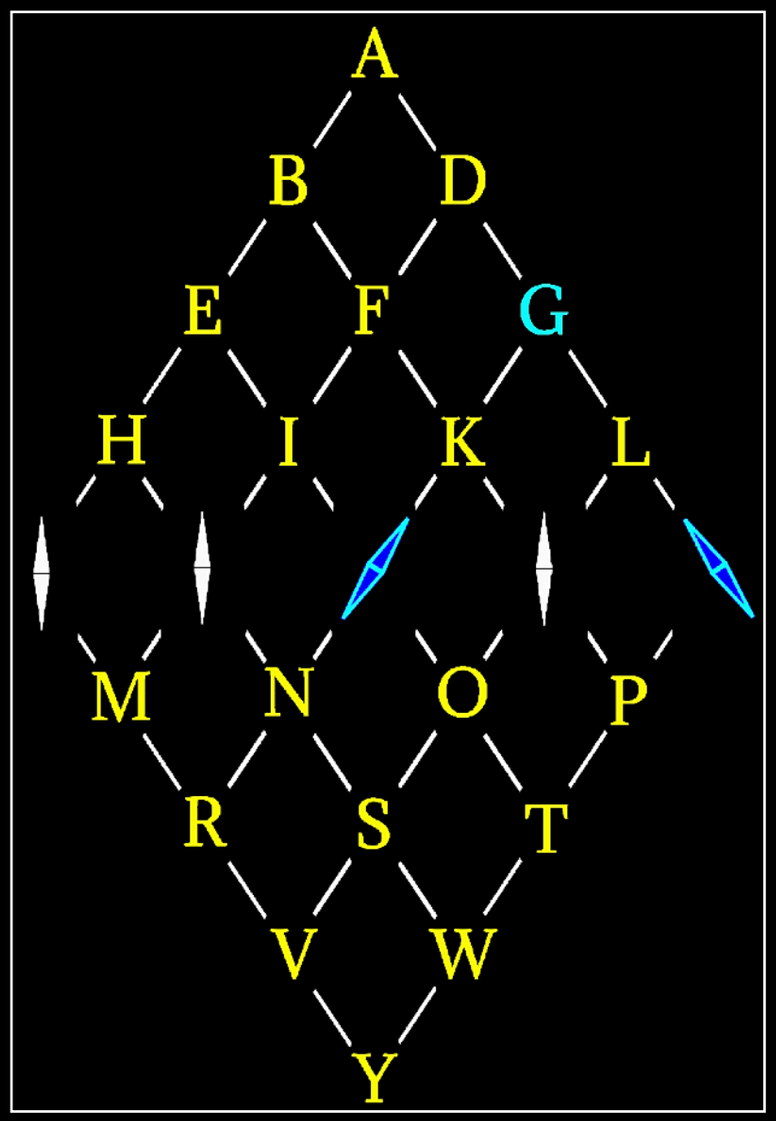
Electromagnets + wires = needle telegraph



Electricity connects the world



Electromagnets + wires = needle telegraph



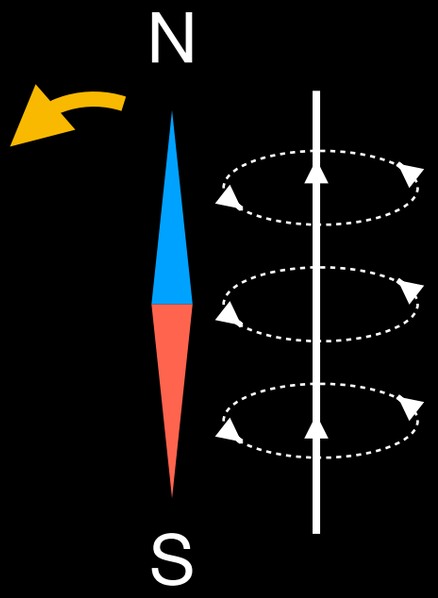
Cooke-Wheatstone telegraph (1837):

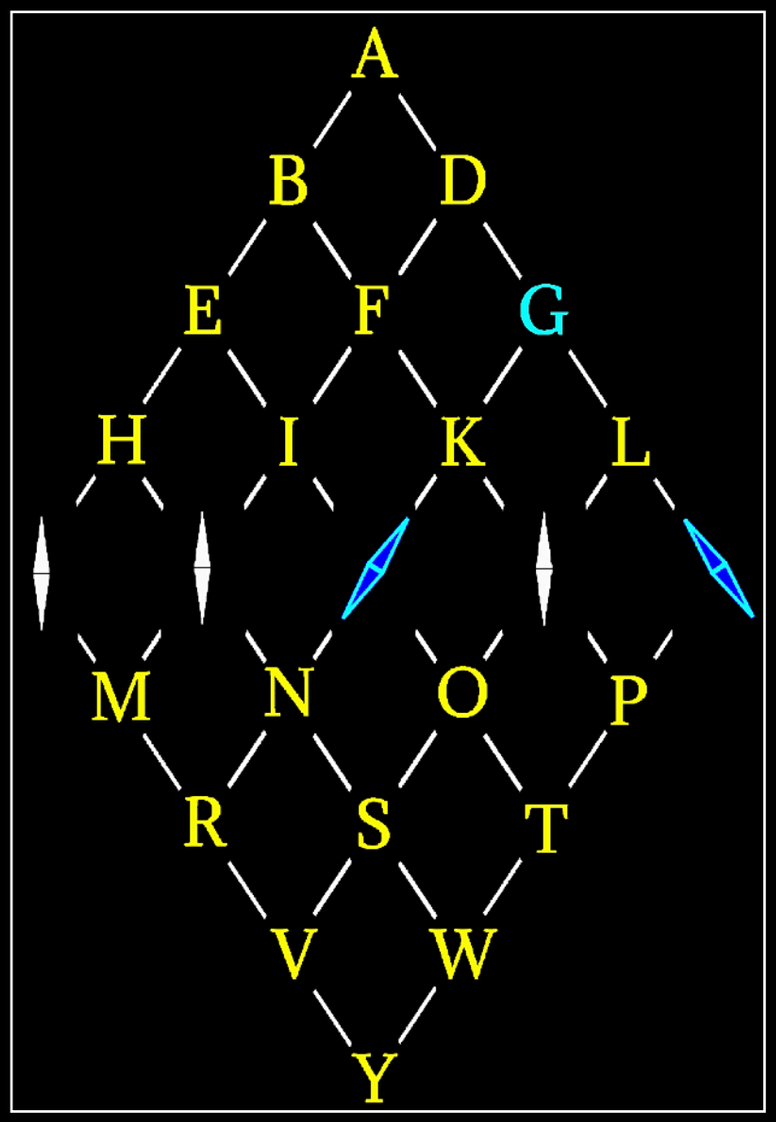
Five-needle telegraph

Used commercially along 13 miles of Great Western Railway (UK)

Electricity connects the world

Electromagnets + wires = needle telegraph





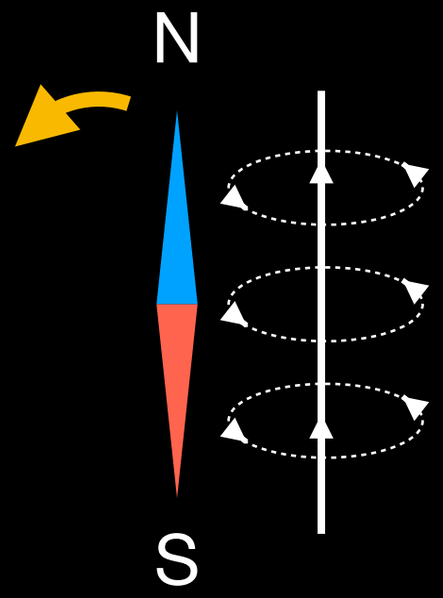
Cooke-Wheatstone telegraph (1837):

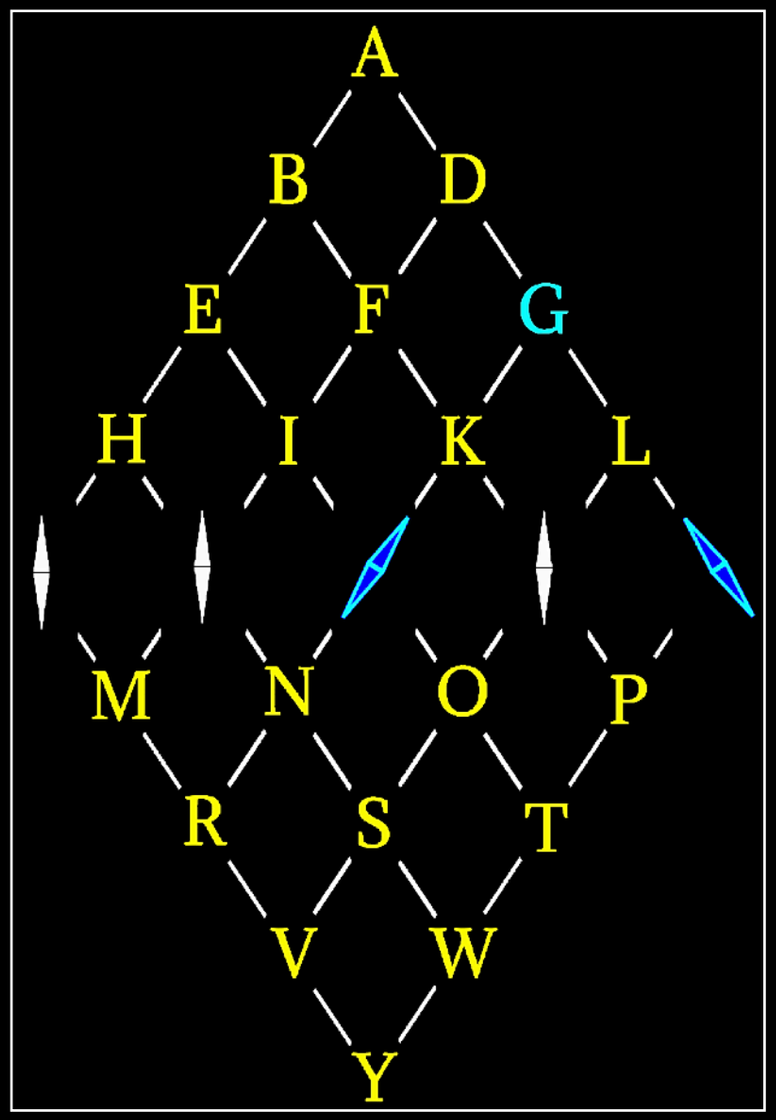
Five-needle telegraph

Used commercially along 13 miles of Great Western Railway (UK)

Electricity connects the world

Electromagnets + wires = needle telegraph



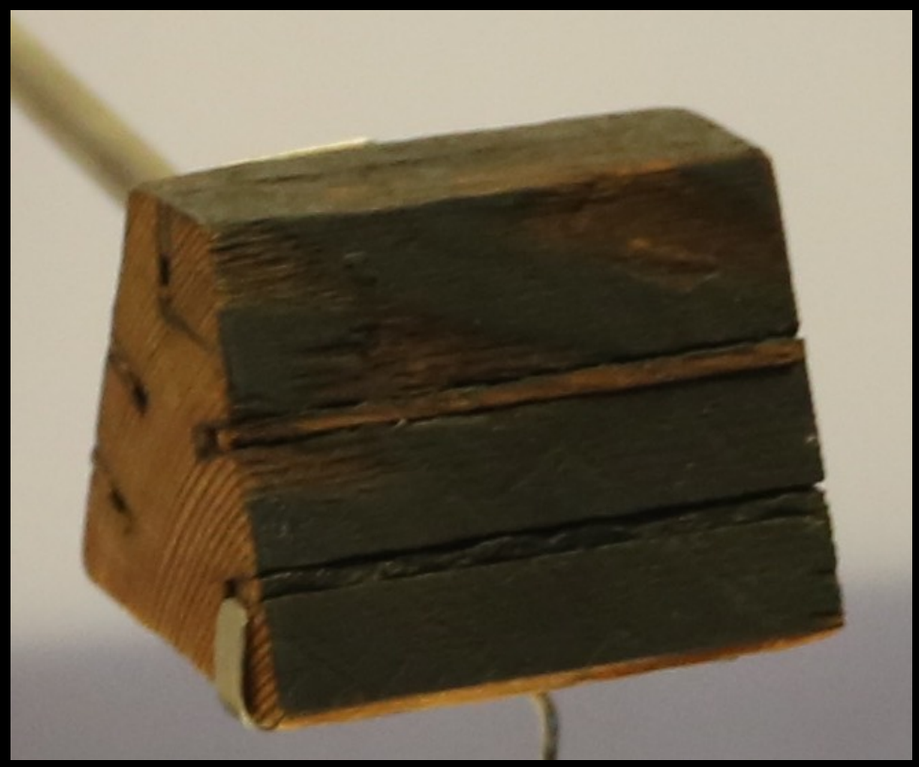


Cooke-Wheatstone telegraph (1837):

Five-needle telegraph

Used commercially along 13 miles of Great Western Railway (UK)

5-wire telegraph cable



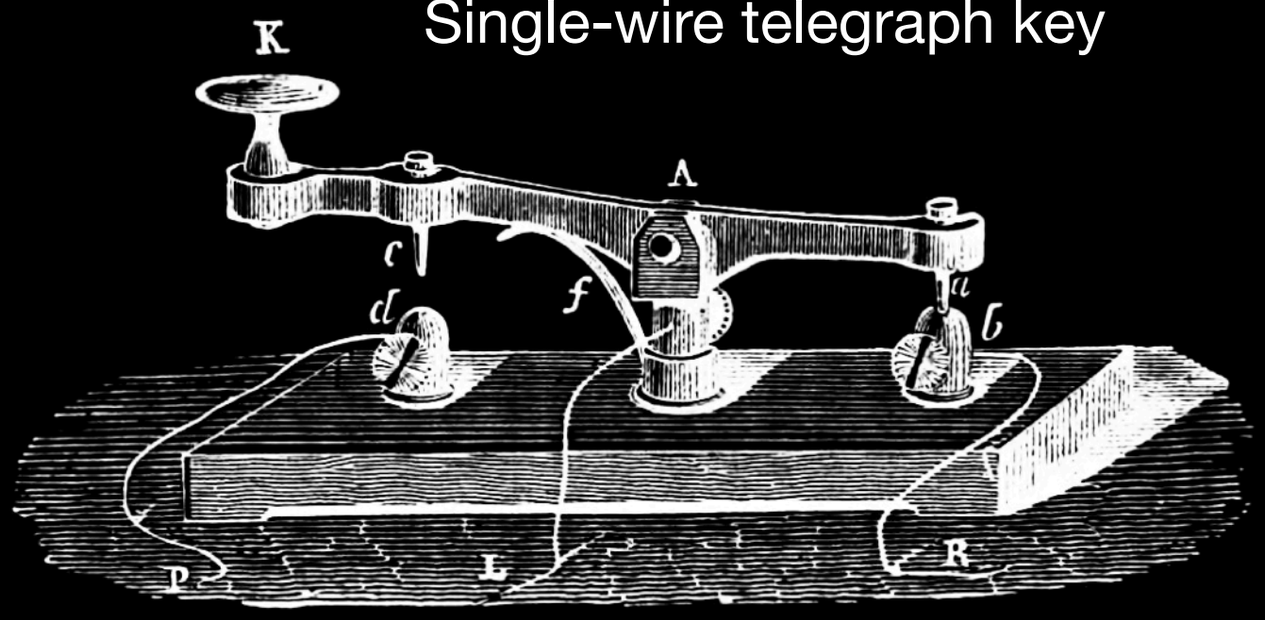
Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?

Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?

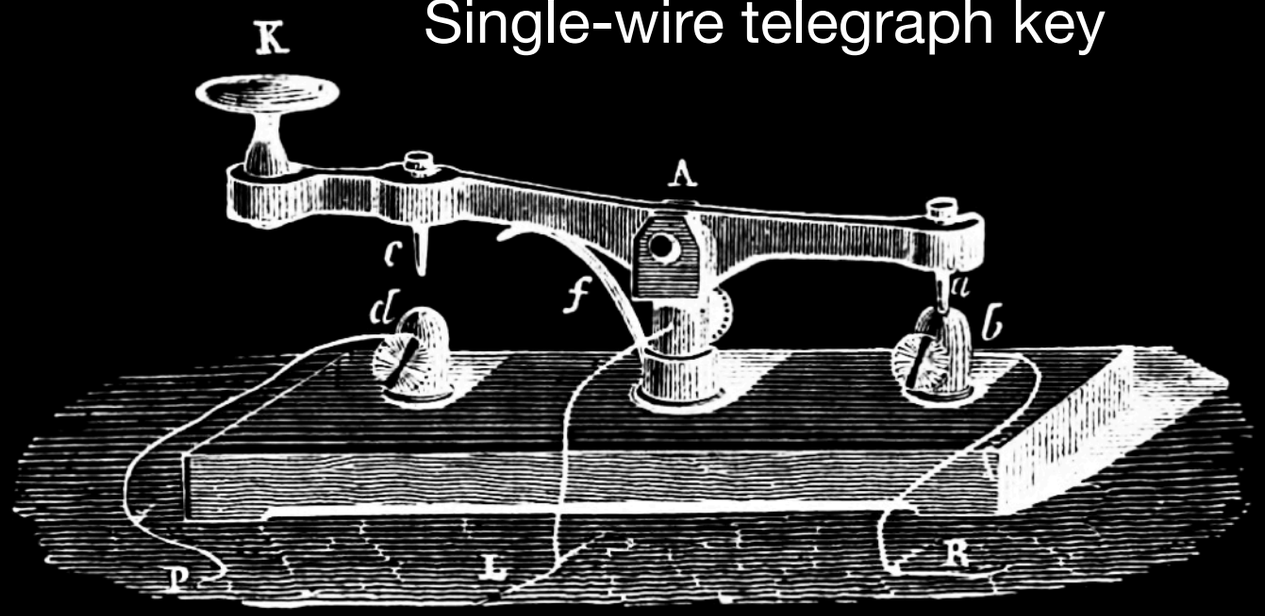
Single-wire telegraph key



Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?

Single-wire telegraph key

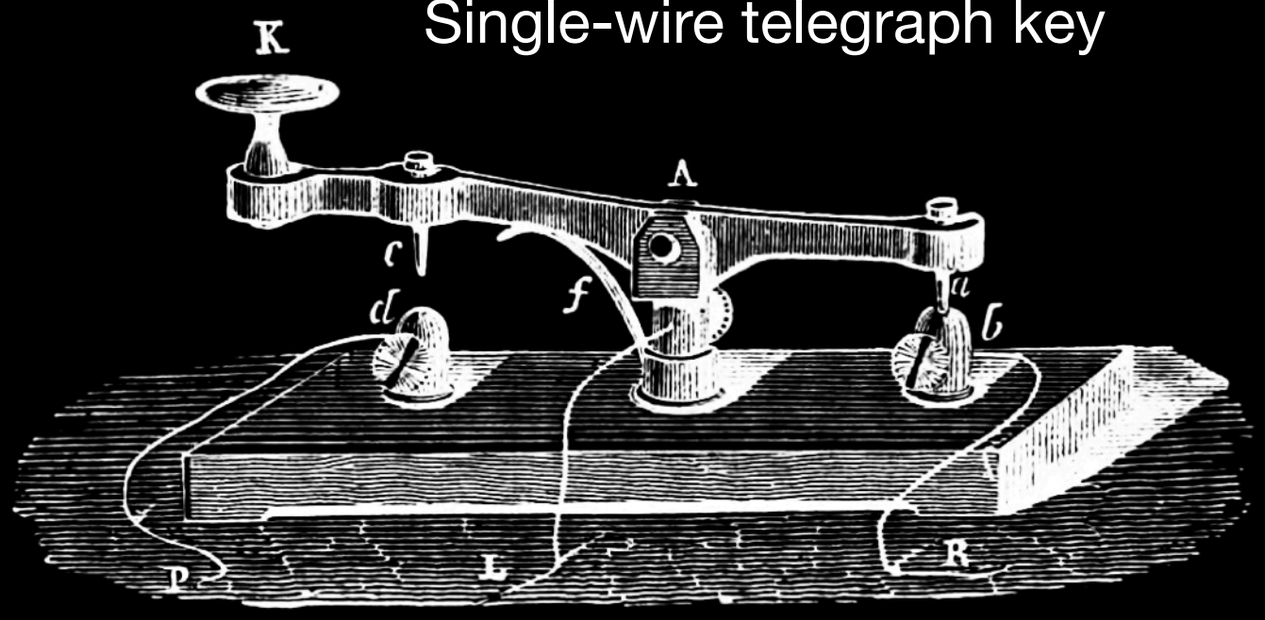


A	● ▬	U	● ● ▬
B	▬ ● ● ●	V	● ● ● ▬
C	▬ ● ▬ ●	W	● ▬ ▬
D	▬ ● ●	X	▬ ● ● ▬
E	●	Y	▬ ● ▬ ▬
F	● ● ▬ ●	Z	▬ ▬ ● ●
G	▬ ▬ ●		
H	● ● ● ●		
I	● ●		
J	● ▬ ▬ ▬		
K	▬ ● ▬	1	● ▬ ▬ ▬ ▬
L	● ▬ ● ●	2	● ● ▬ ▬ ▬
M	▬ ▬	3	● ● ● ▬ ▬
N	▬ ●	4	● ● ● ● ▬
O	▬ ▬ ▬	5	● ● ● ● ●
P	● ▬ ▬ ●	6	▬ ● ● ● ●
Q	▬ ▬ ● ▬	7	▬ ▬ ● ● ●
R	● ▬ ●	8	▬ ▬ ▬ ● ●
S	● ● ●	9	▬ ▬ ▬ ▬ ●
T	▬	0	▬ ▬ ▬ ▬ ▬

Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?

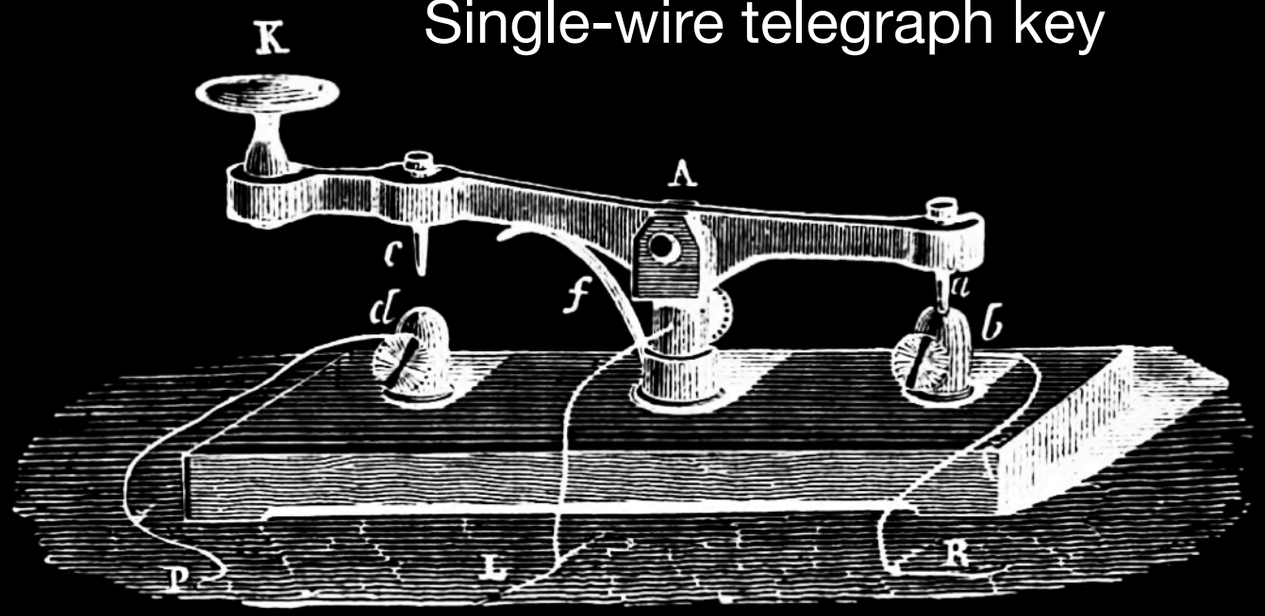
Single-wire telegraph key



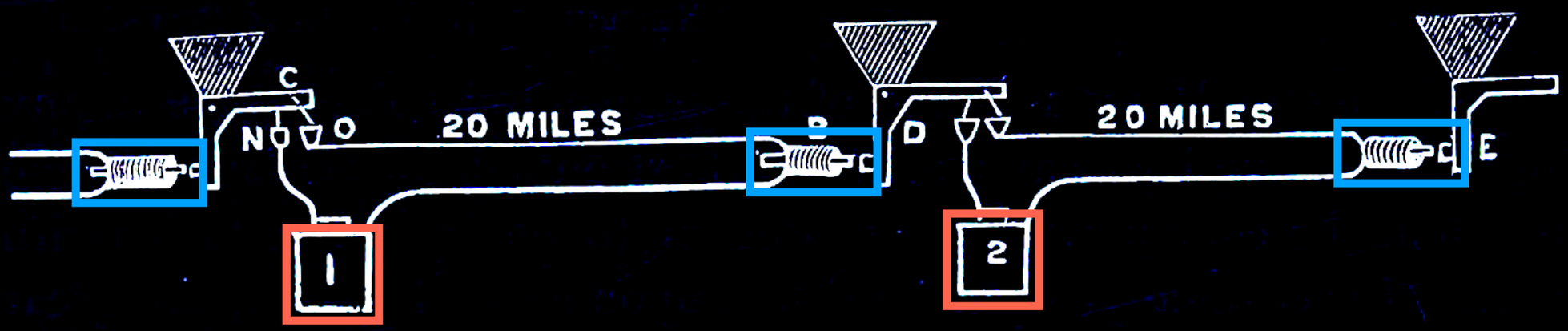
Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?

Single-wire telegraph key



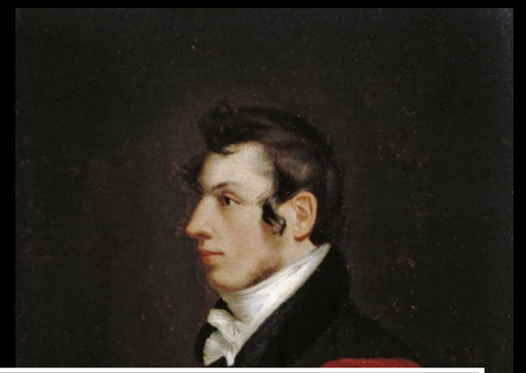
“Relay” stations



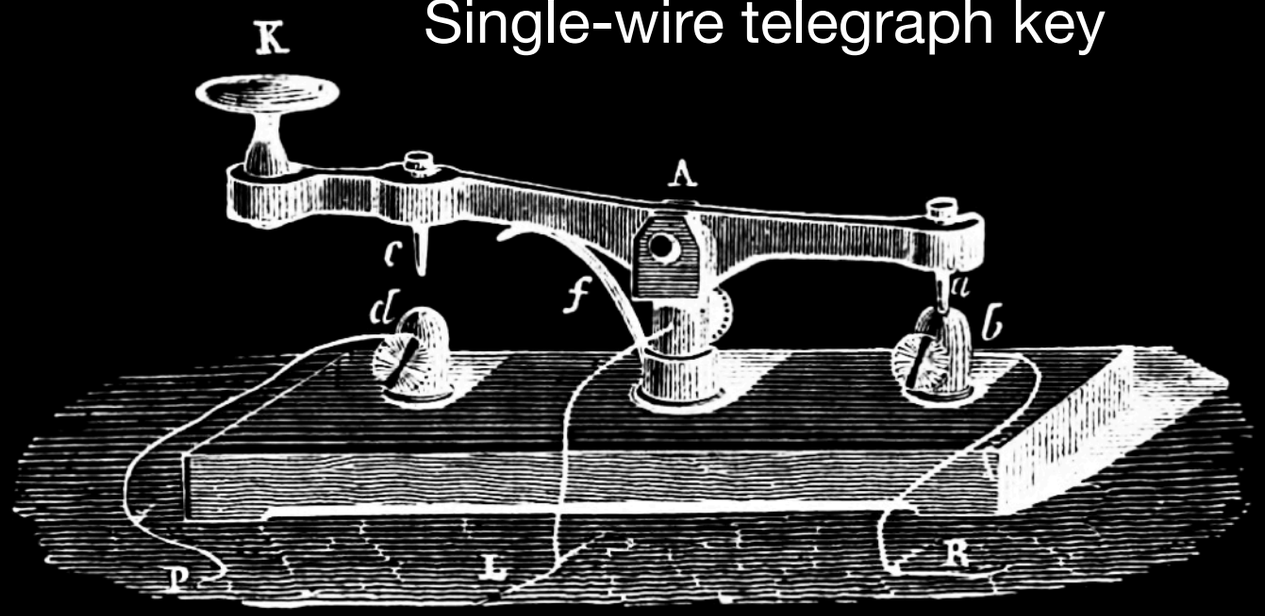
Electromagnet
Battery

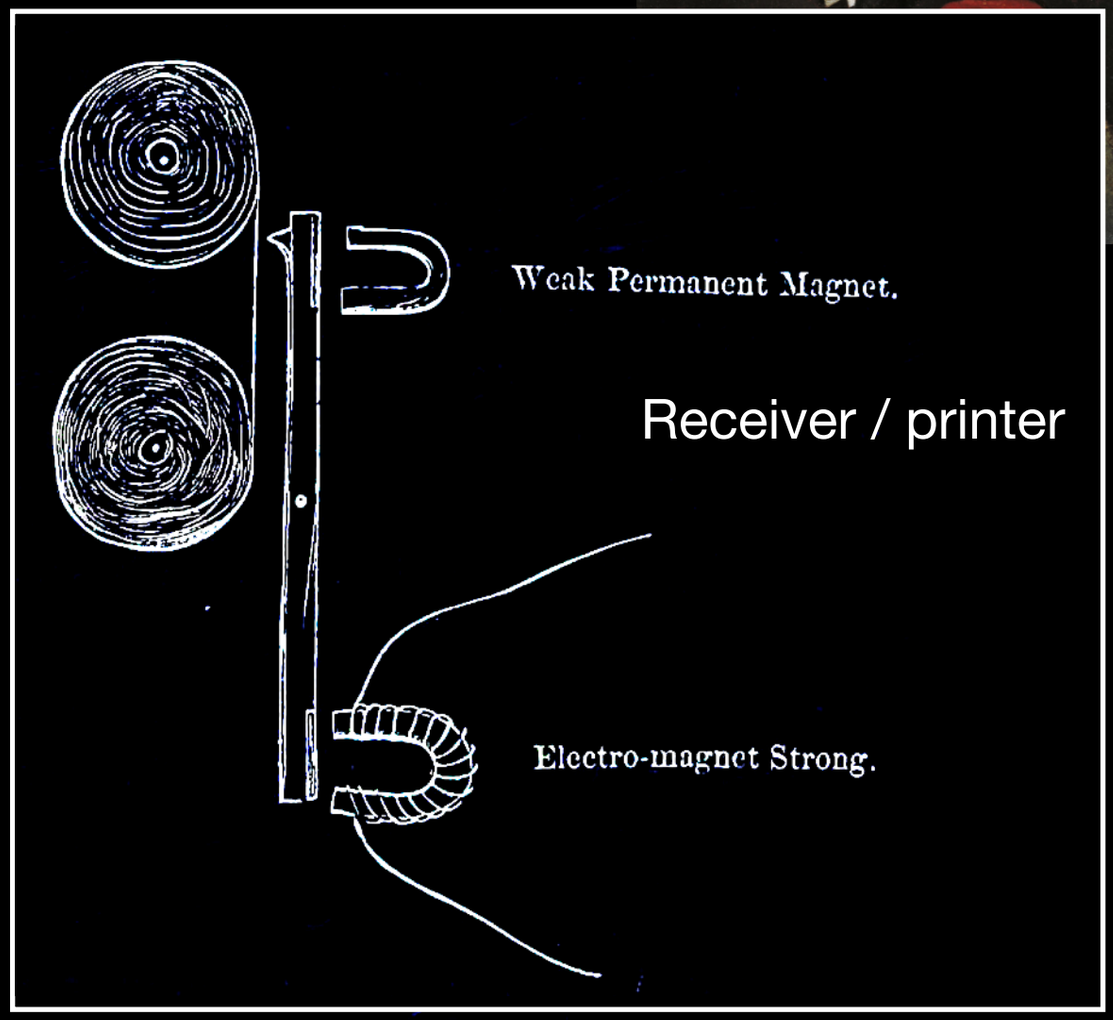
Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?



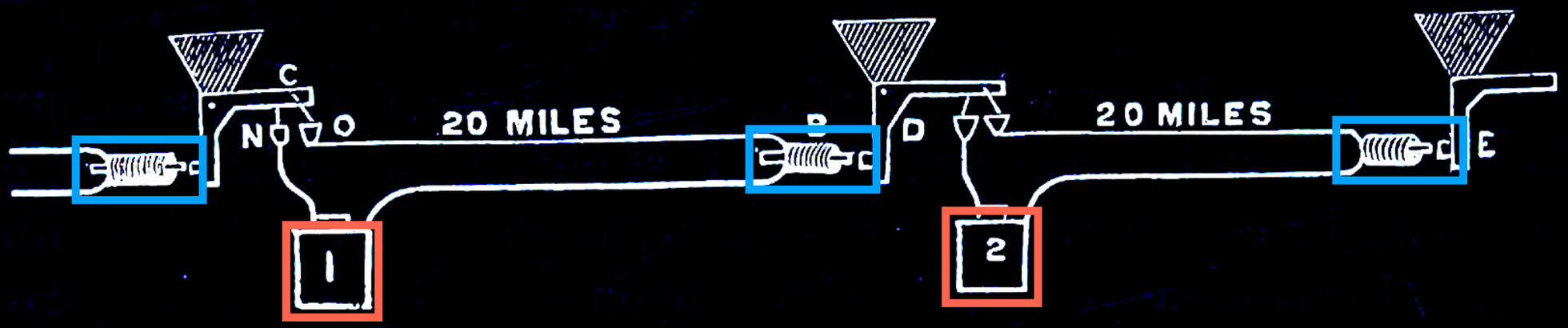
Single-wire telegraph key





Receiver / printer

"Relay" stations



Electromagnet
Battery

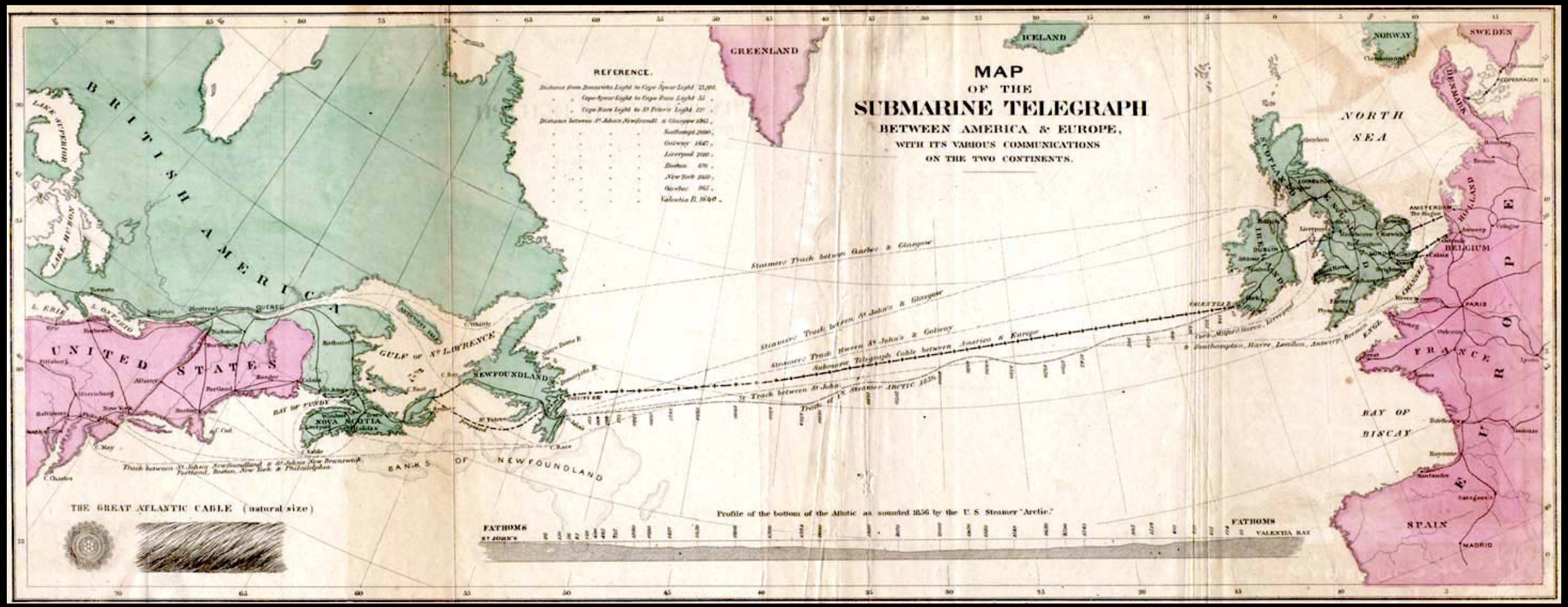
The first transatlantic telegraph cable

The first transatlantic telegraph cable

First message sent across the Atlantic in 1858:

The first transatlantic telegraph cable

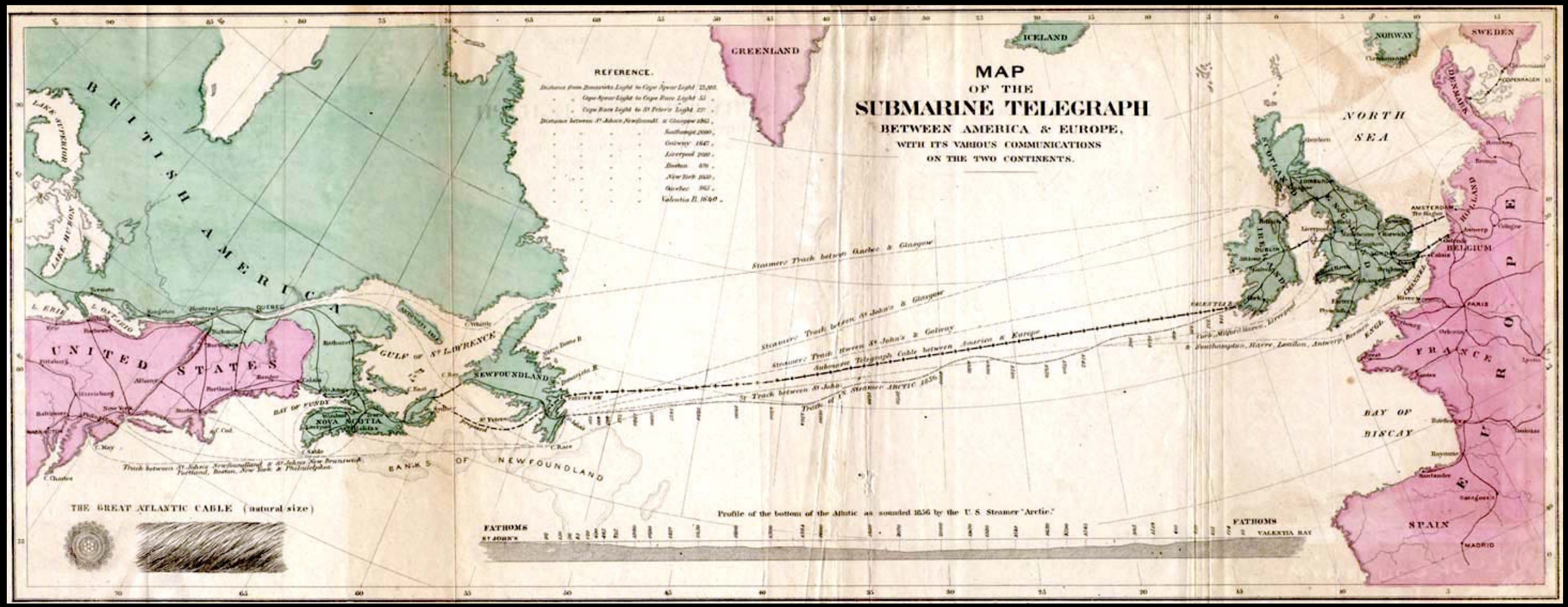
First message sent across the Atlantic in 1858:



The first transatlantic telegraph cable

First message sent across the Atlantic in 1858:

"Directors of Atlantic Telegraph Company, Great Britain, to Directors in America: Europe and America are united by telegraph. Glory to God in the highest; on earth peace, good will towards men."



Electromagnetism

Electromagnetism

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

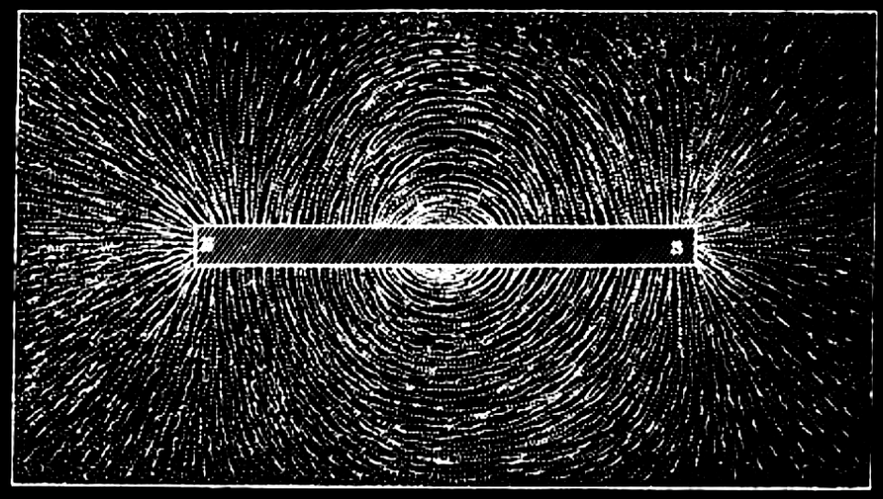
One kind of electricity

Electromagnetism

	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

One kind of electricity

“Magnetic lines of force”

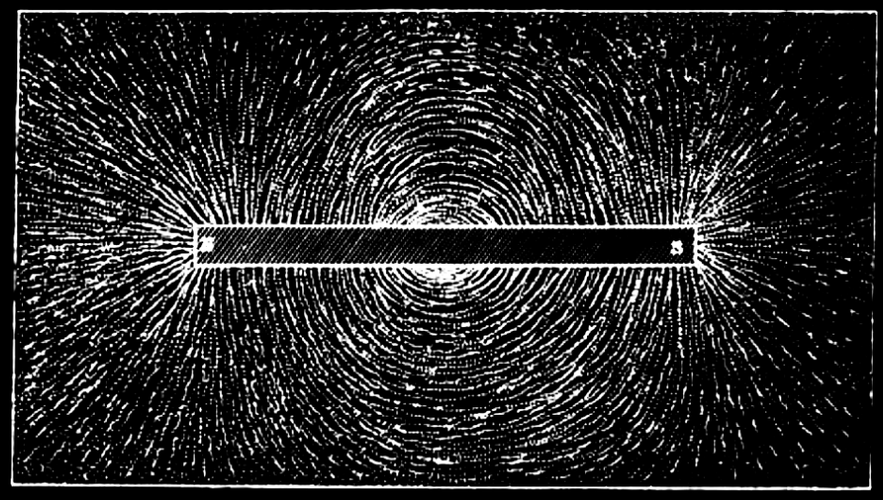


Electromagnetism

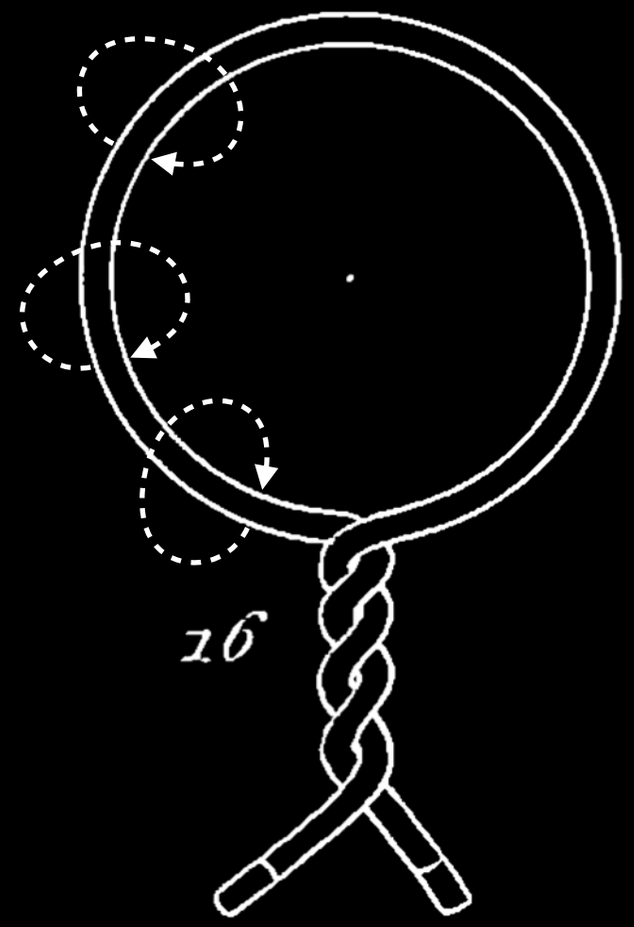
	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

One kind of electricity

“Magnetic lines of force”



Electricity → magnetism

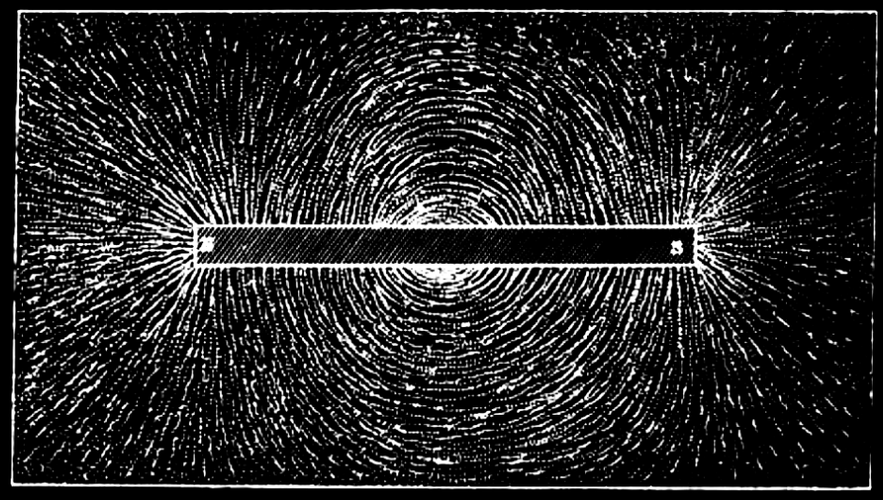


Electromagnetism

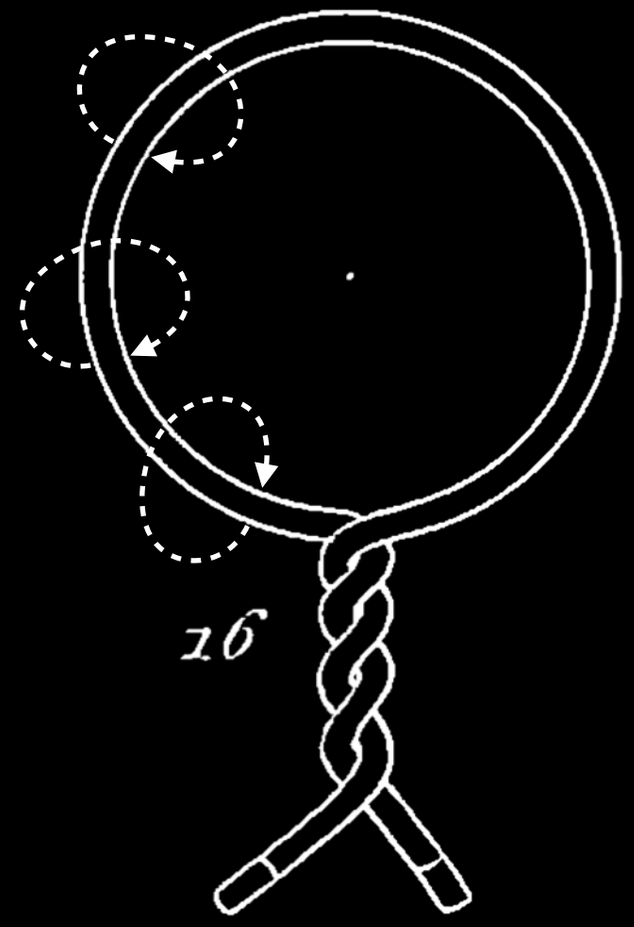
	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

One kind of electricity

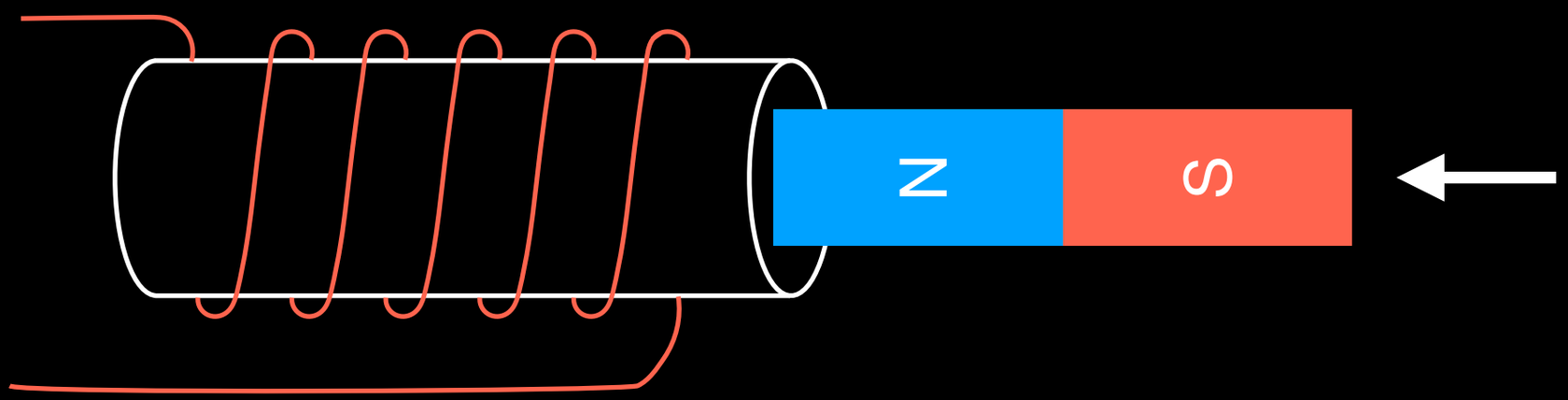
“Magnetic lines of force”



Electricity → magnetism



Magnetism → electricity

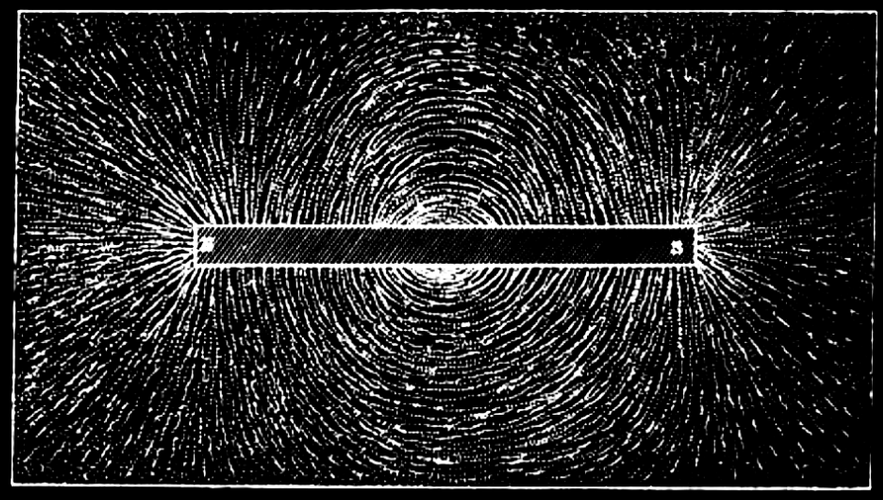


Electromagnetism

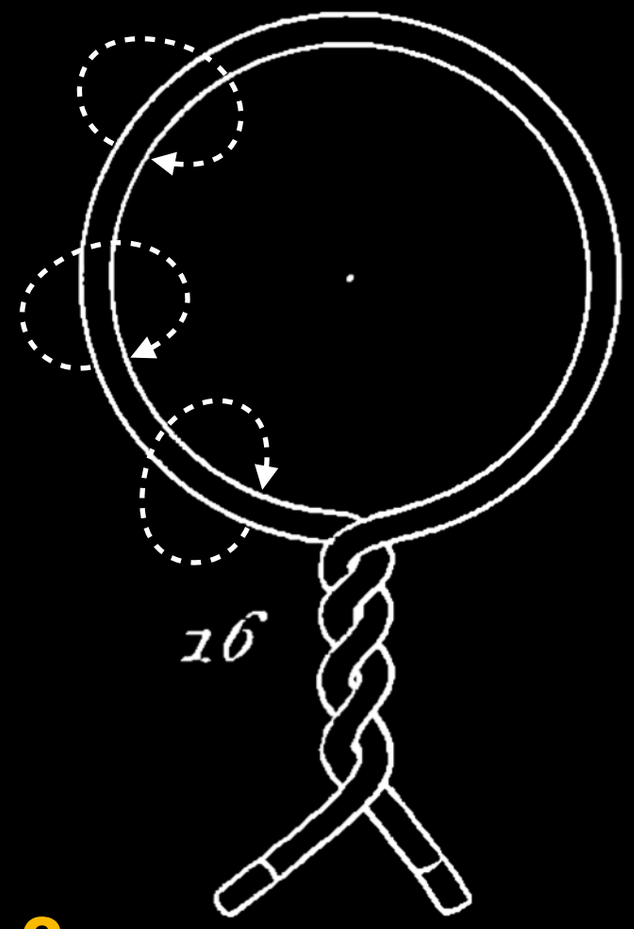
	Physiological Effects.	Magnetic Deflection.	Magnets made.	Spark.	Heating Power.	Attraction and Repulsion.	Discharge by Hot Air.
Voltaic electricity	×	×	×	×	×	×	×
Common electricity...	×	×	×	×	×	×	×
Magneto-Electricity..	×	×	×	×	×	×	
Animal Electricity...	×	×	×	+	+		

One kind of electricity

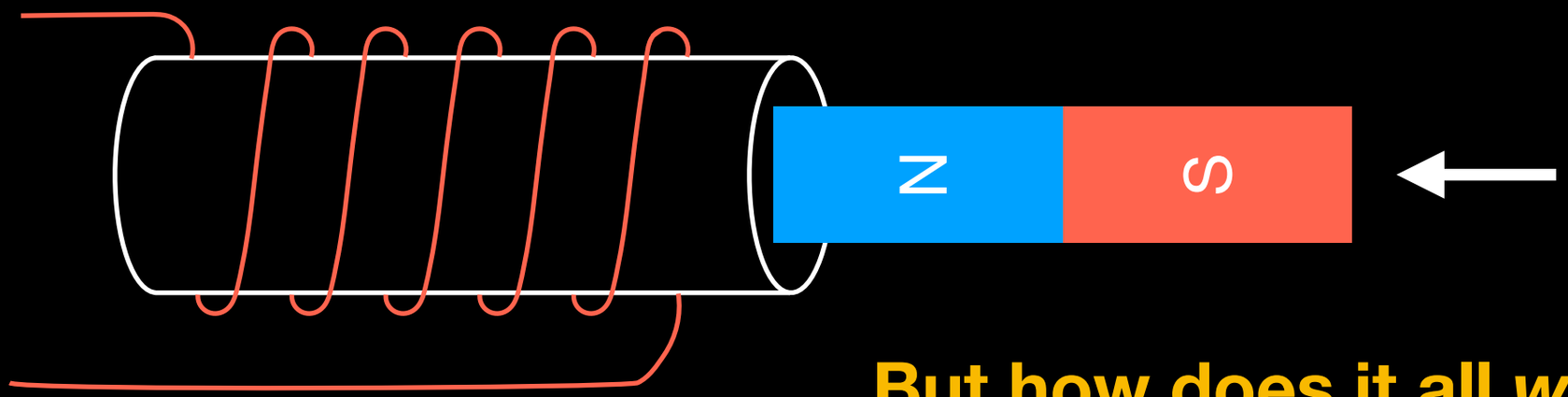
“Magnetic lines of force”



Electricity → magnetism



Magnetism → electricity



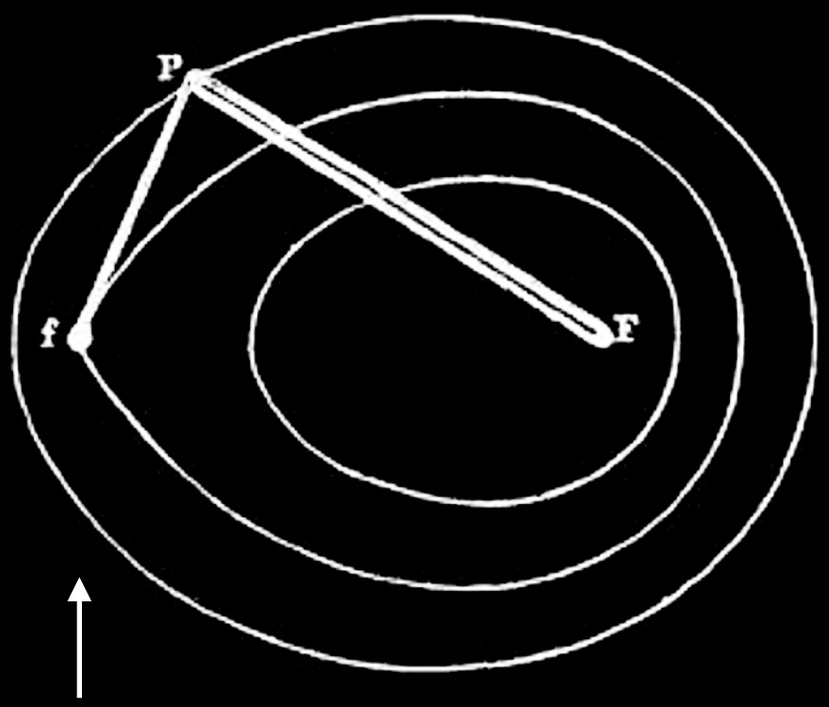
But how does it all *work*?

James Clerk Maxwell

Scottish master physicist

James Clerk Maxwell

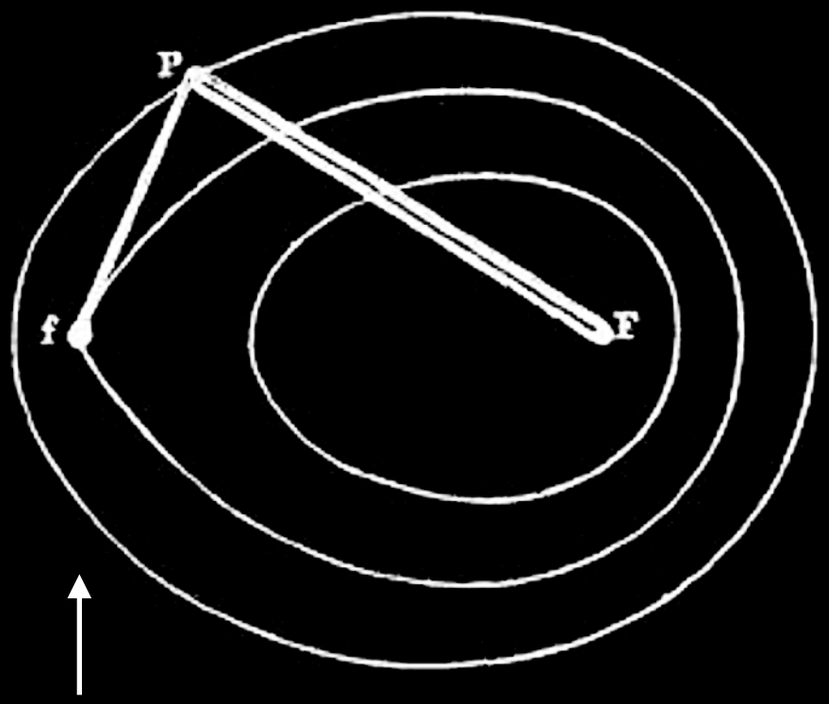
Scottish master physicist



Drawing ovals with thread and pins

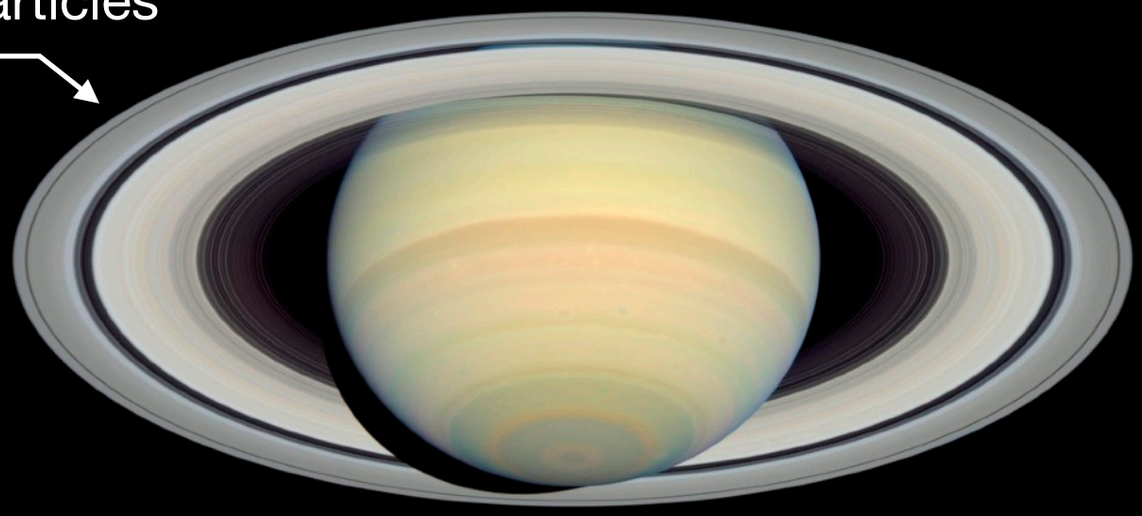
James Clerk Maxwell

Scottish master physicist



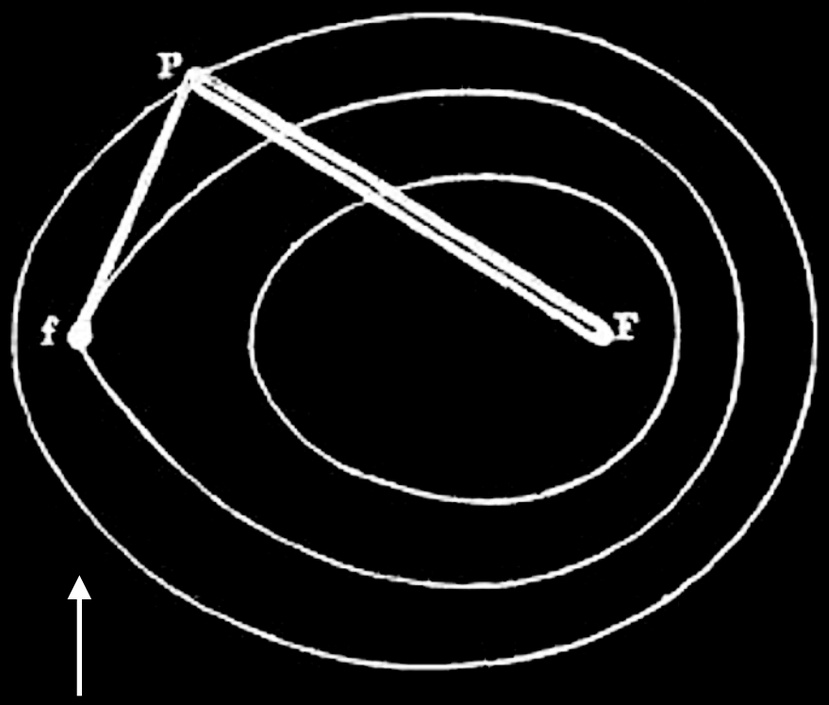
Drawing ovals with thread and pins

Saturn’s rings are made of many small particles



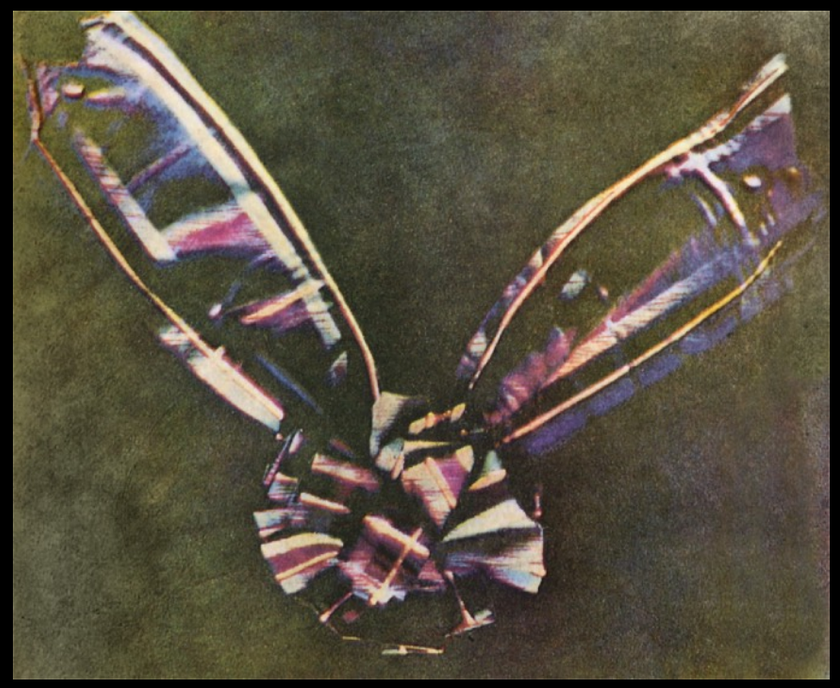
James Clerk Maxwell

Scottish master physicist

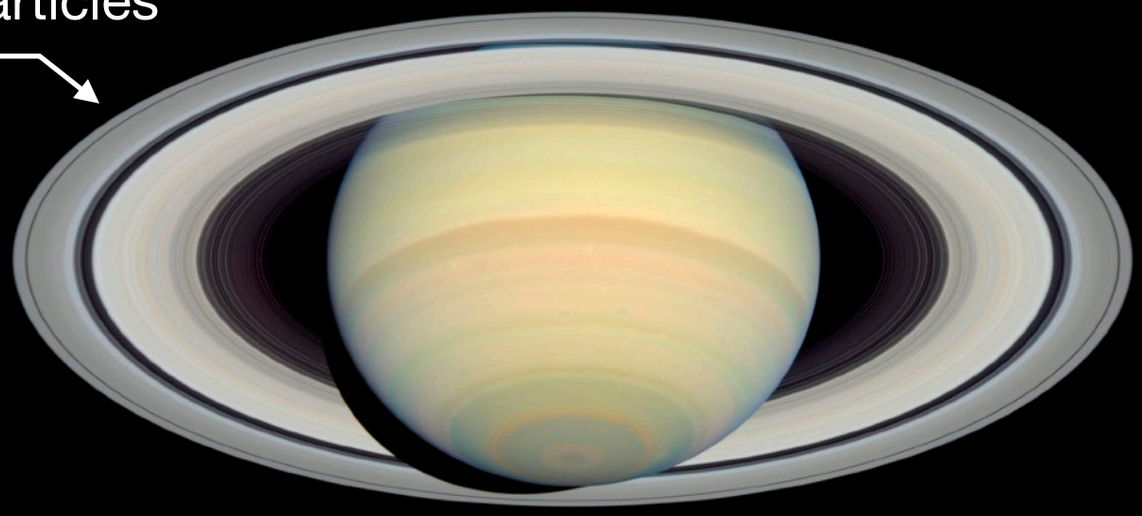


Drawing ovals with thread and pins

Color photography

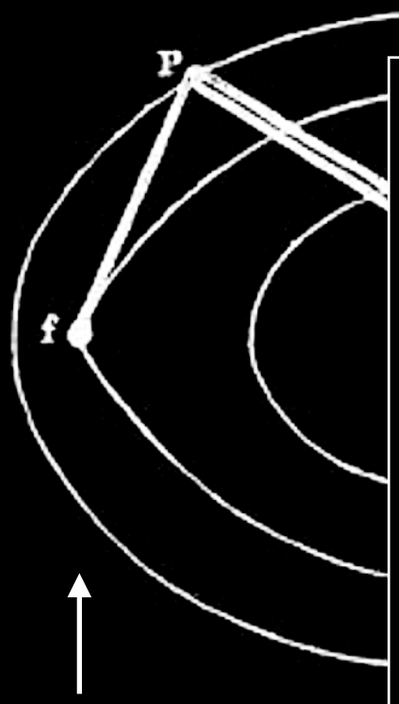


Saturn’s rings are made of many small particles



James Clerk Maxwell

Scottish master physicist

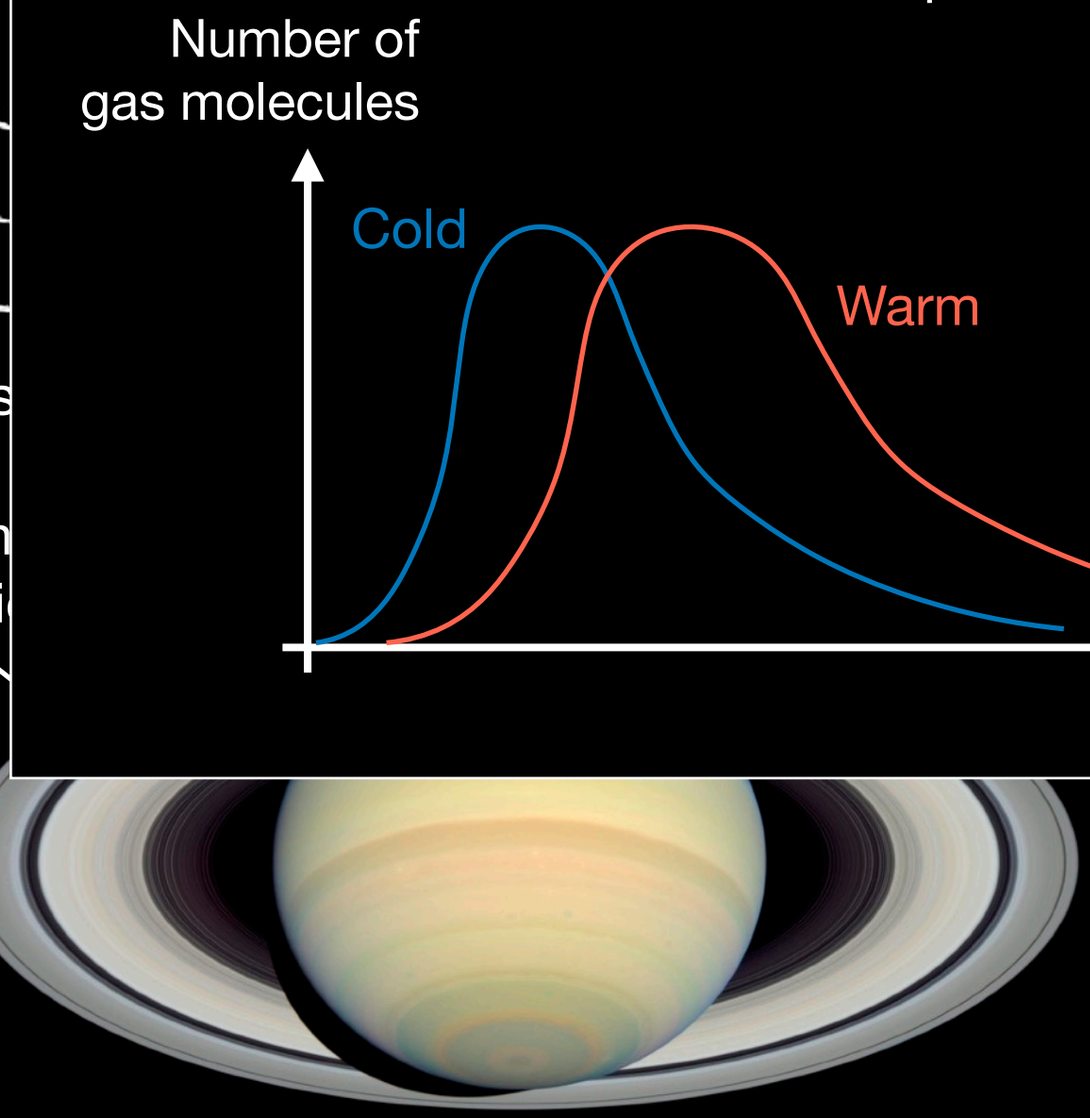


Drawing ovals

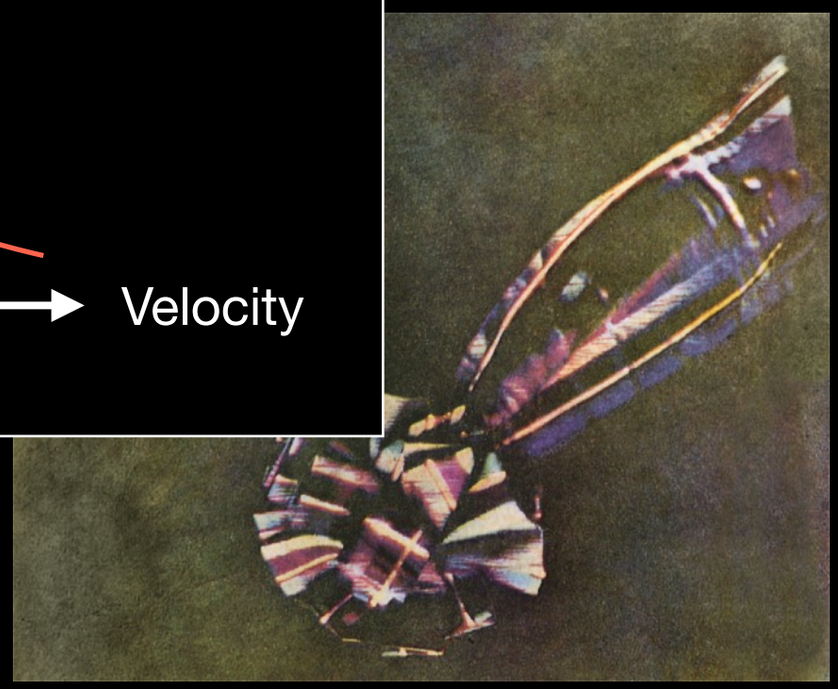
Saturn's rings are m
of many small parti

Kinetic theory of heat

Relation between temperature and speed of gas molecules

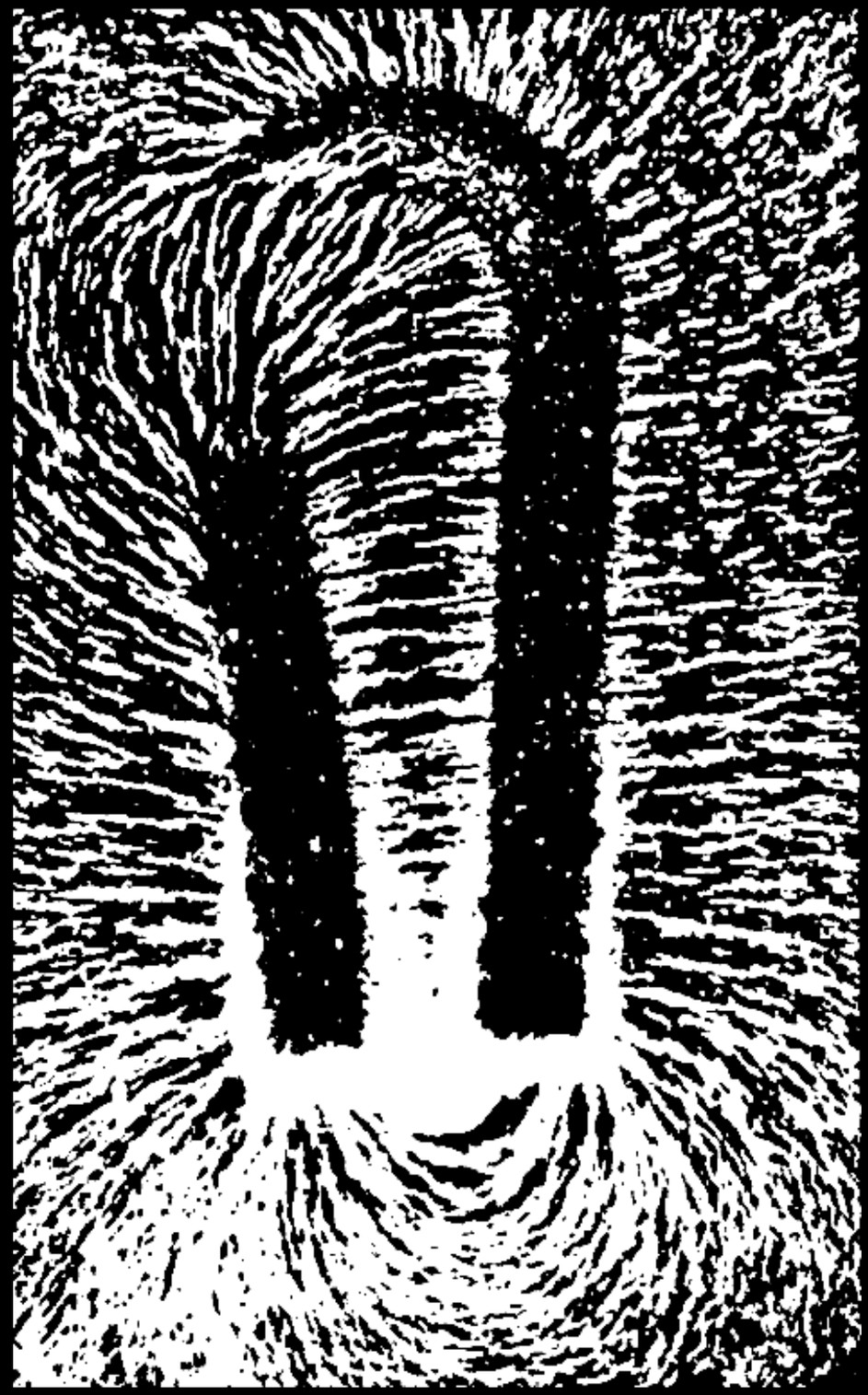


olor photography



What *really* happens around a magnet?

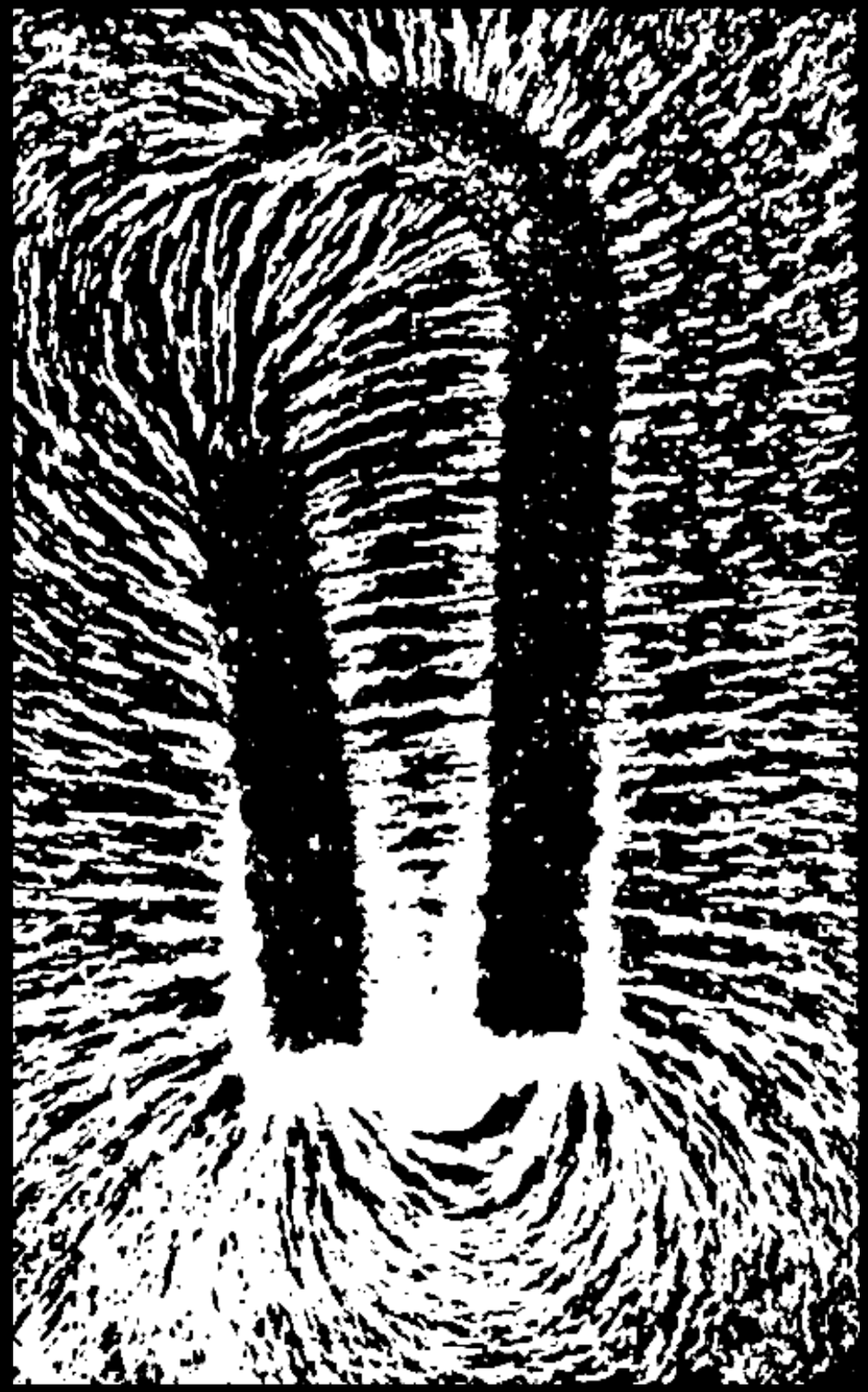
Back to magnetic “lines of force”



What *really* happens around a magnet?

Back to magnetic “lines of force”

“The beautiful illustration of the presence of magnetic force afforded by this experiment, naturally makes us think of the lines of force as something real.”

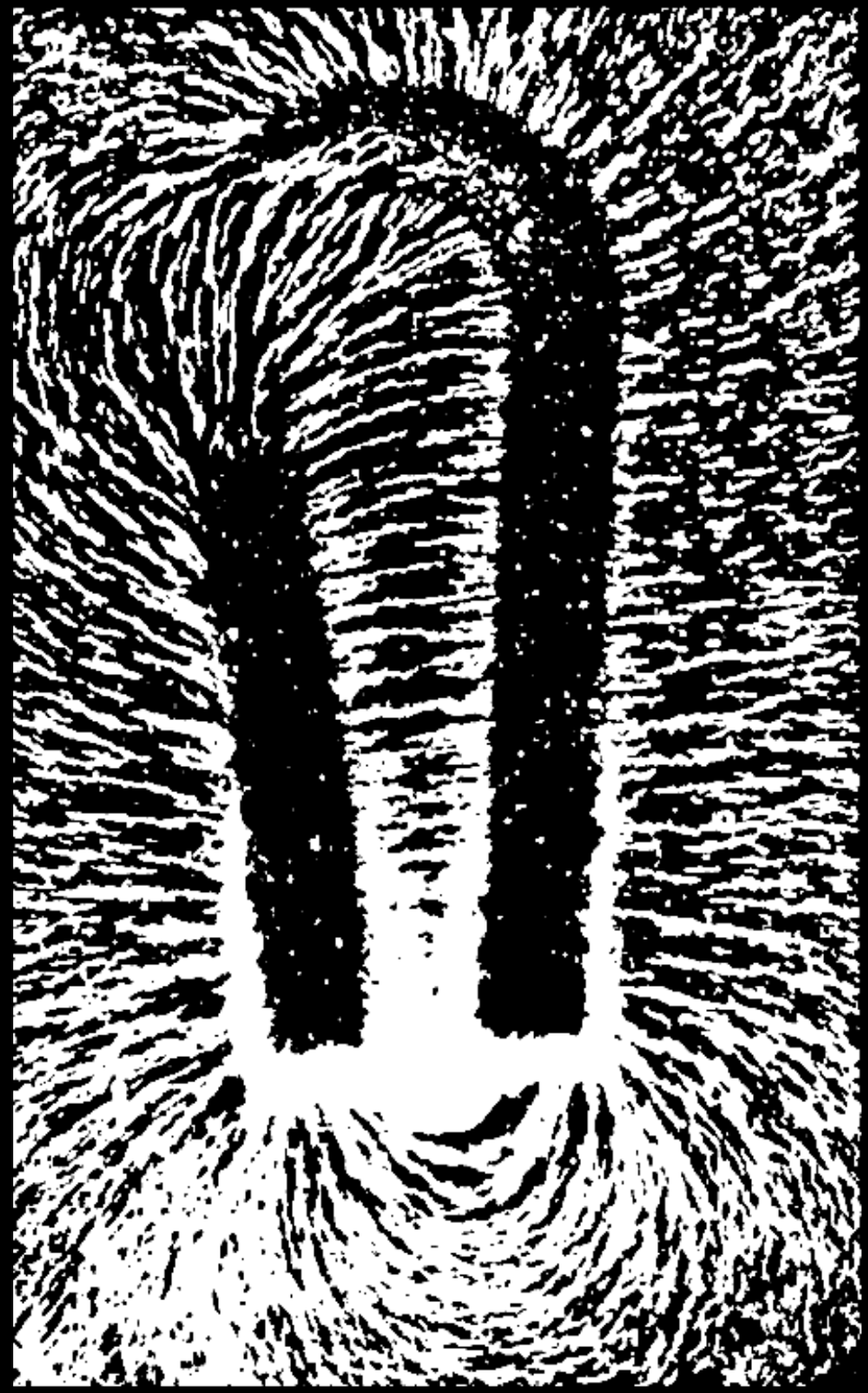


What *really* happens around a magnet?

Back to magnetic “lines of force”

“The beautiful illustration of the presence of magnetic force afforded by this experiment, naturally makes us think of the lines of force as something real.”

“We are dissatisfied with the explanation founded on the hypothesis of attractive and repellent forces directed towards the magnetic poles.”



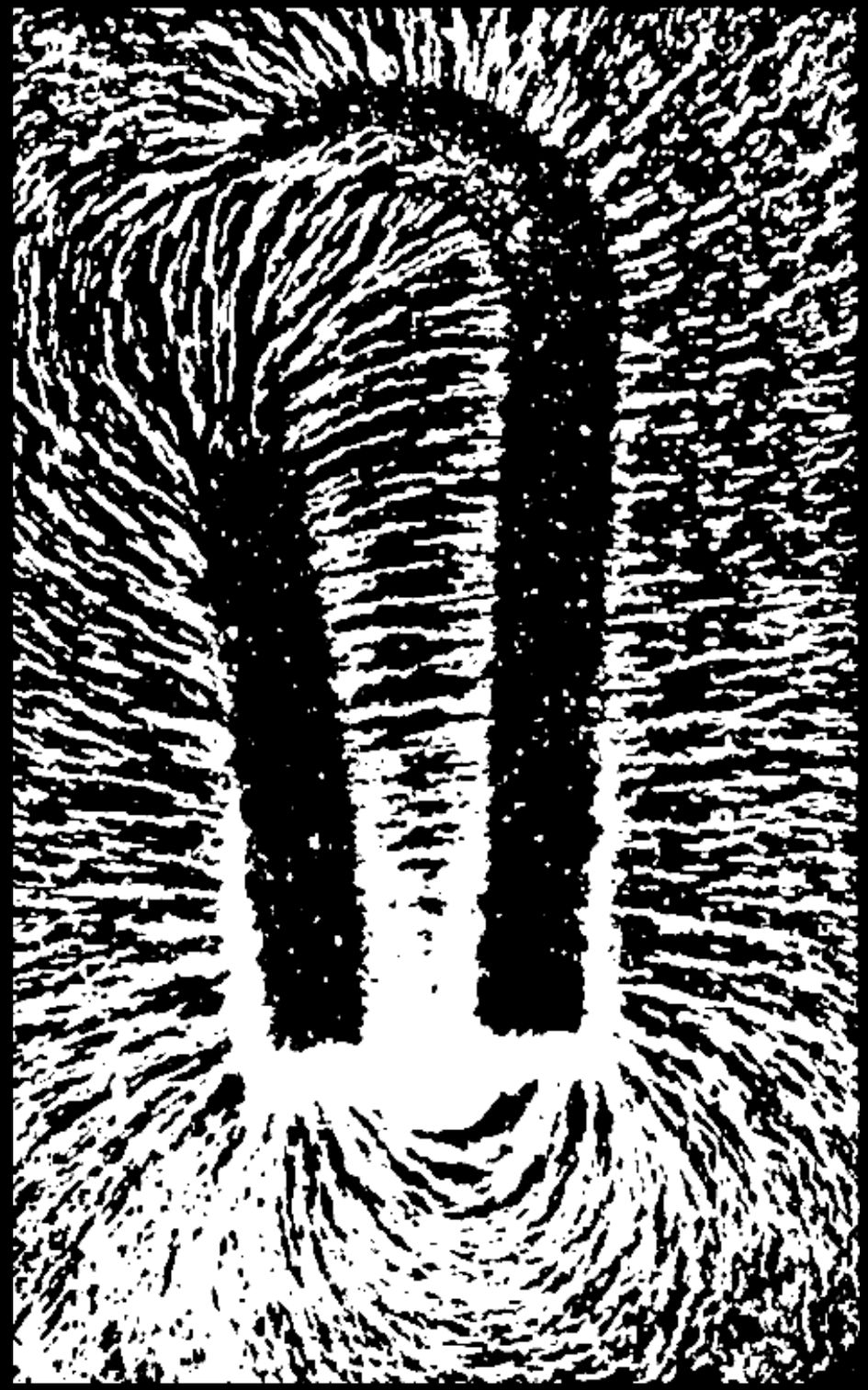
What *really* happens around a magnet?

Back to magnetic “lines of force”

“The beautiful illustration of the presence of magnetic force afforded by this experiment, naturally makes us think of the lines of force as something real.”

“We are dissatisfied with the explanation founded on the hypothesis of attractive and repellent forces directed towards the magnetic poles.”

“We cannot help thinking that in every place where we find these lines of force, some physical state or action must exist in sufficient energy to produce the actual phenomena.”



What *really* happens around a magnet?

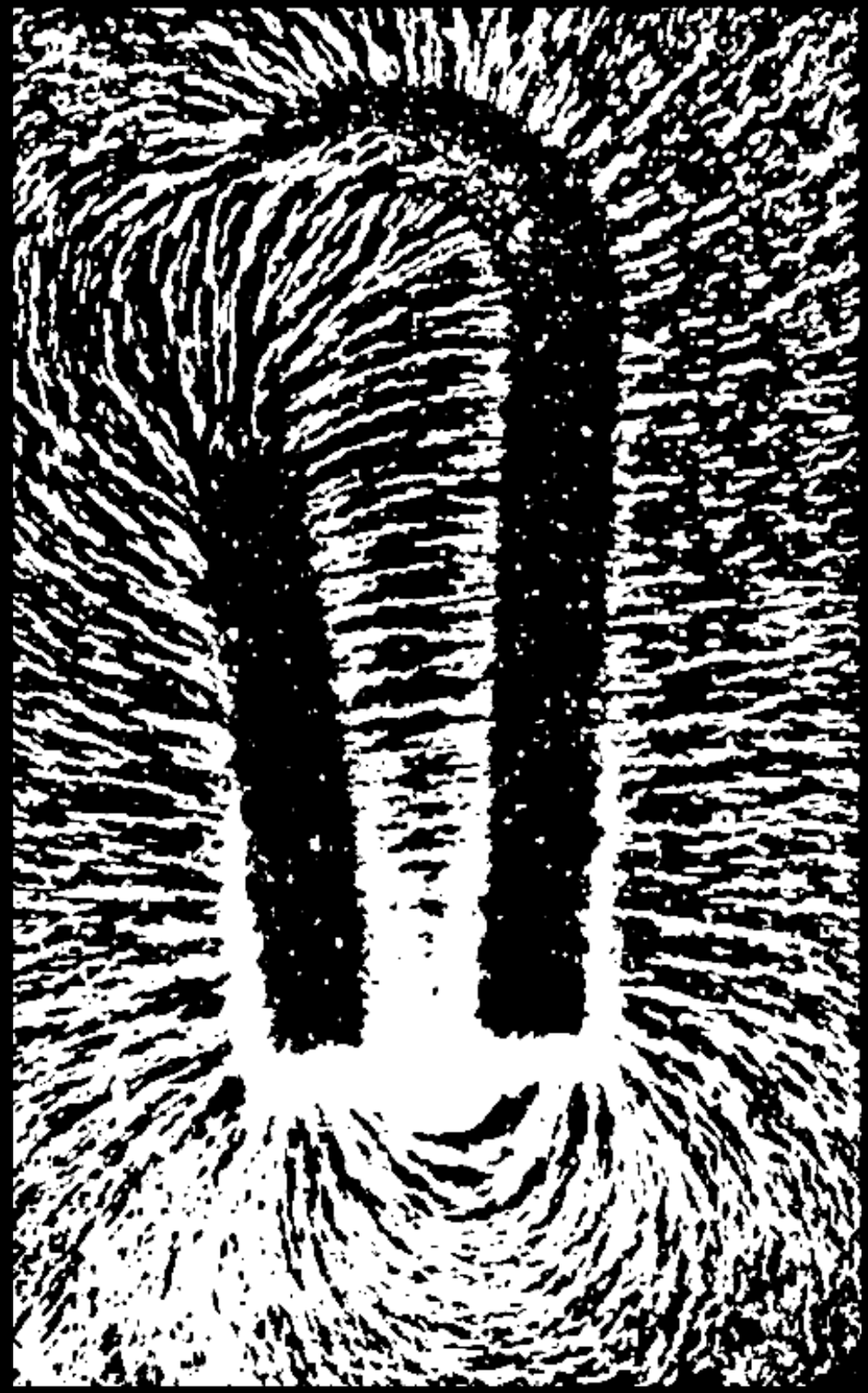
Back to magnetic “lines of force”

“The beautiful illustration of the presence of magnetic force afforded by this experiment, naturally makes us think of the lines of force as something real.”

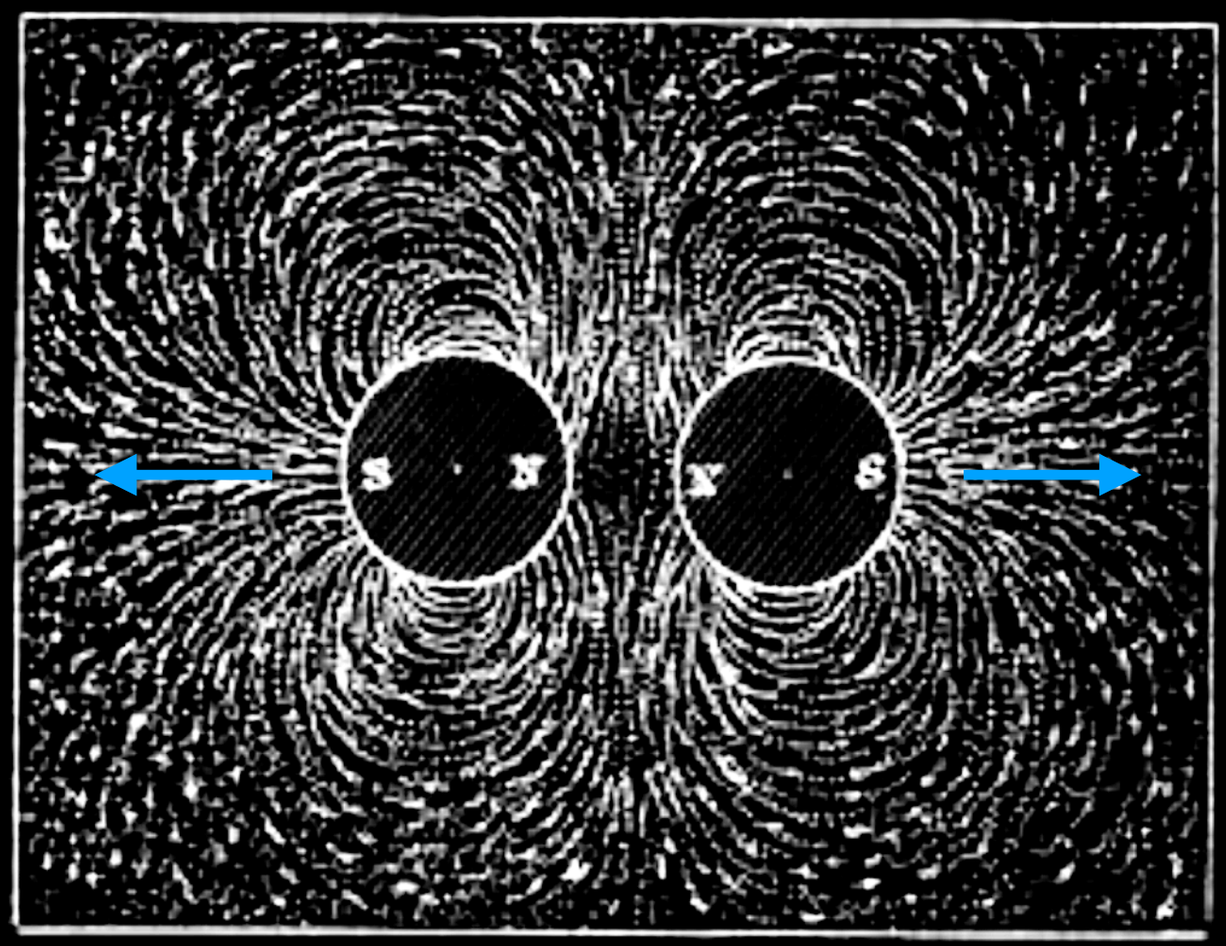
“We are dissatisfied with the explanation founded on the hypothesis of attractive and repellent forces directed towards the magnetic poles.”

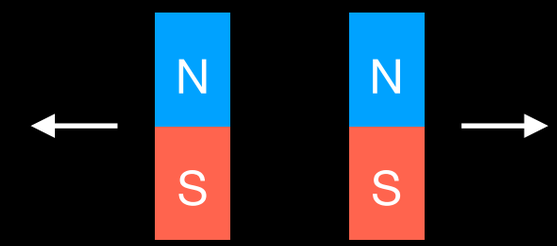
“We cannot help thinking that in every place where we find these lines of force, some physical state or action must exist in sufficient energy to produce the actual phenomena.”

“Action at a distance” again!



A “magnetic medium” (1861)



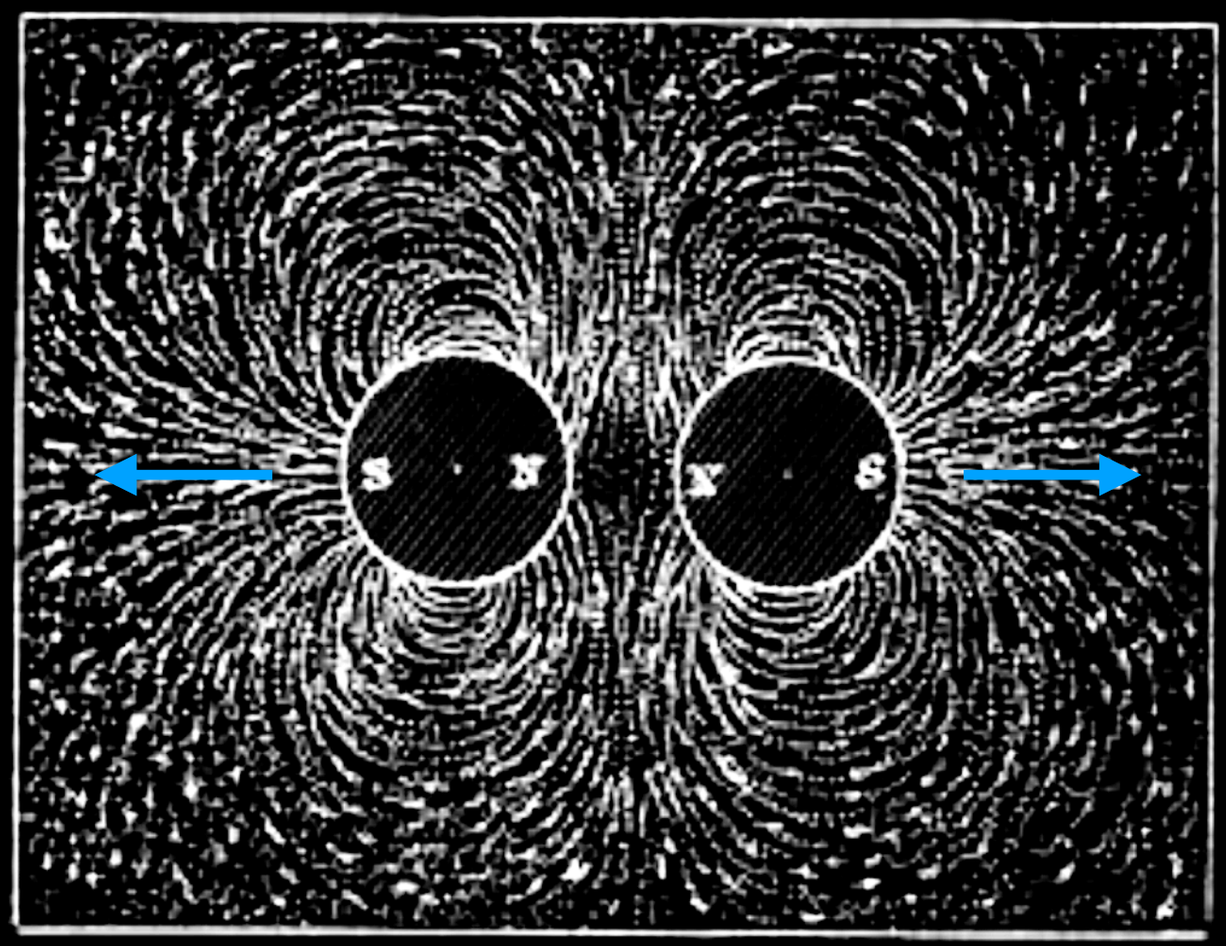


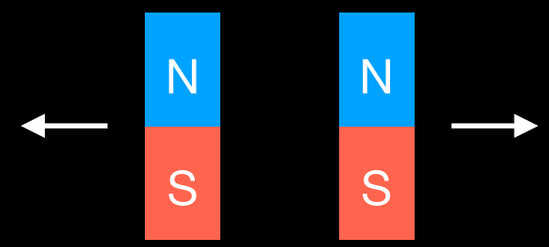
Two repelling magnets

A “magnetic medium” (1861)

“We come to consider the magnetic influence as existing in the form of some kind of pressure or tension in the medium.”

Two repelling magnets



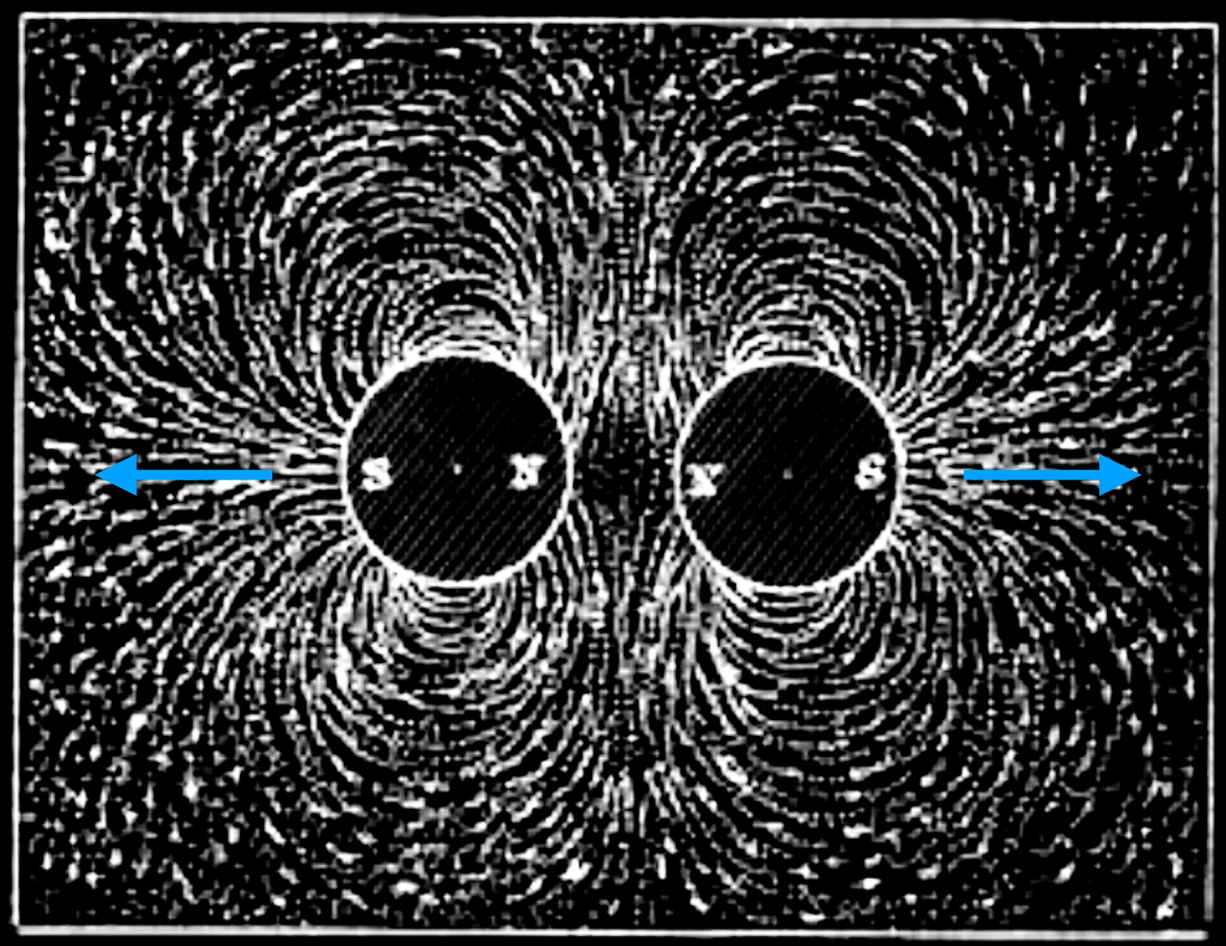


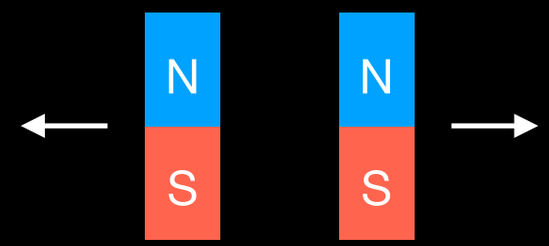
A “magnetic medium” (1861)

“We come to consider the magnetic influence as existing in the form of some kind of pressure or tension in the medium.”

“If we observe the lines of force between two magnets, we observe that where the lines from the poles avoid each other and are dispersed into space, the poles repel each other.”

Two repelling magnets





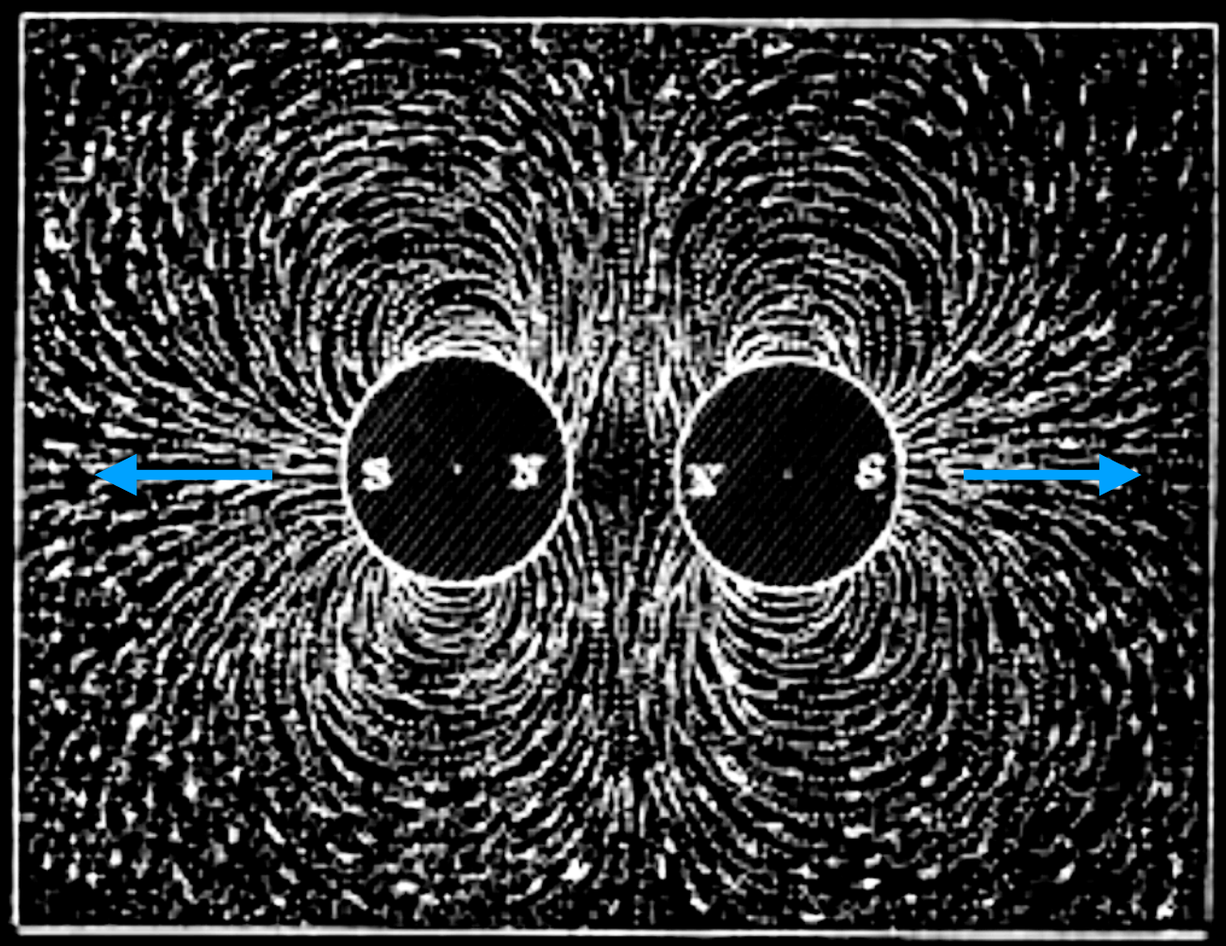
A “magnetic medium” (1861)

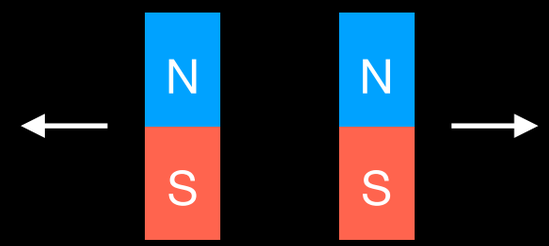
“We come to consider the magnetic influence as existing in the form of some kind of pressure or tension in the medium.”

“If we observe the lines of force between two magnets, we observe that where the lines from the poles avoid each other and are dispersed into space, the poles repel each other.”

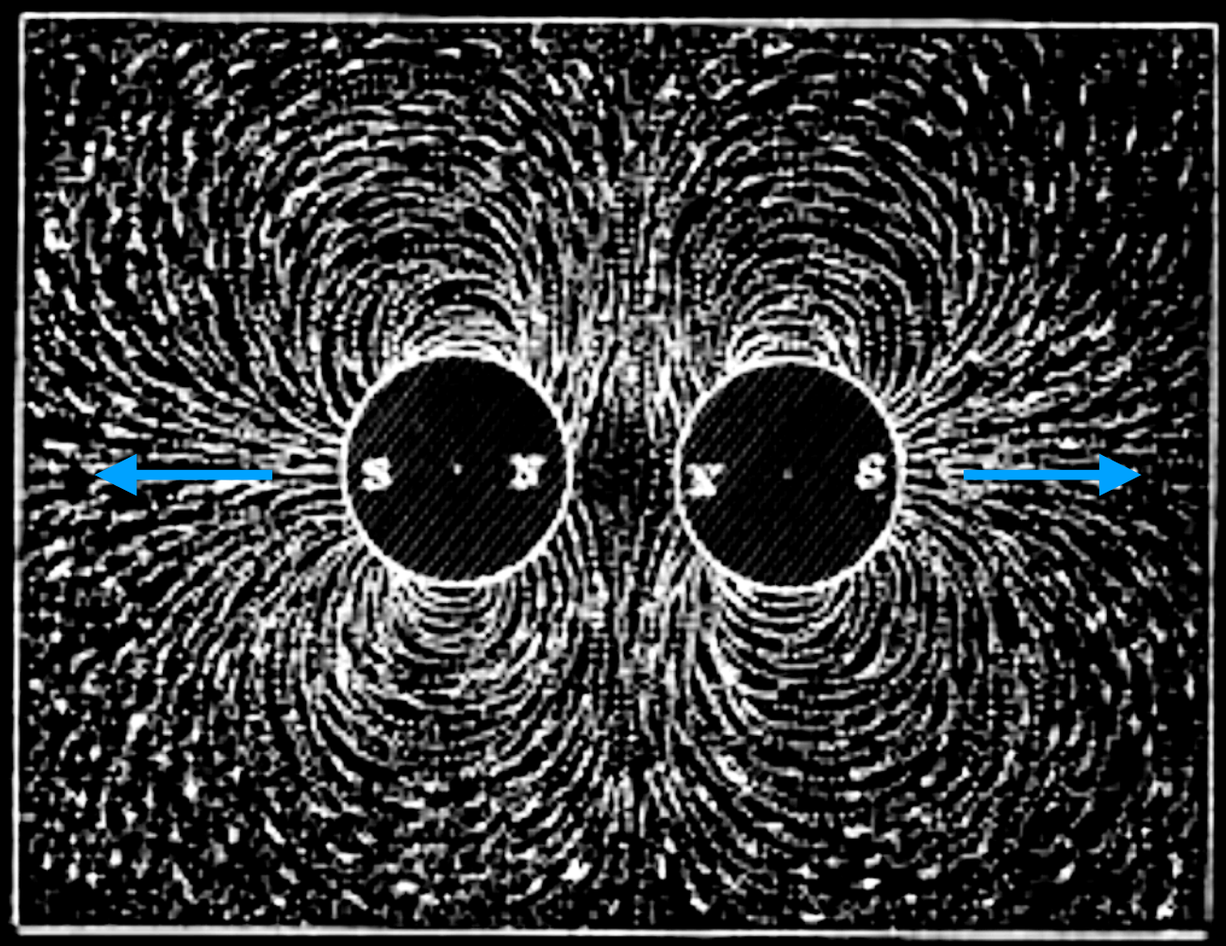
“It appears that the stress in a line of magnetic force is a tension, like that of a rope.”

Two repelling magnets

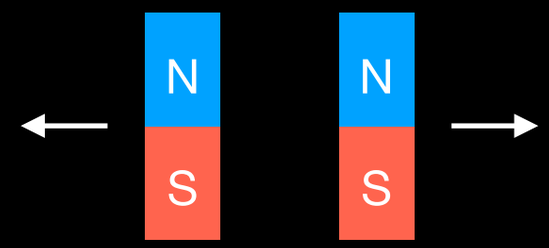




A mechanical model of magnetism

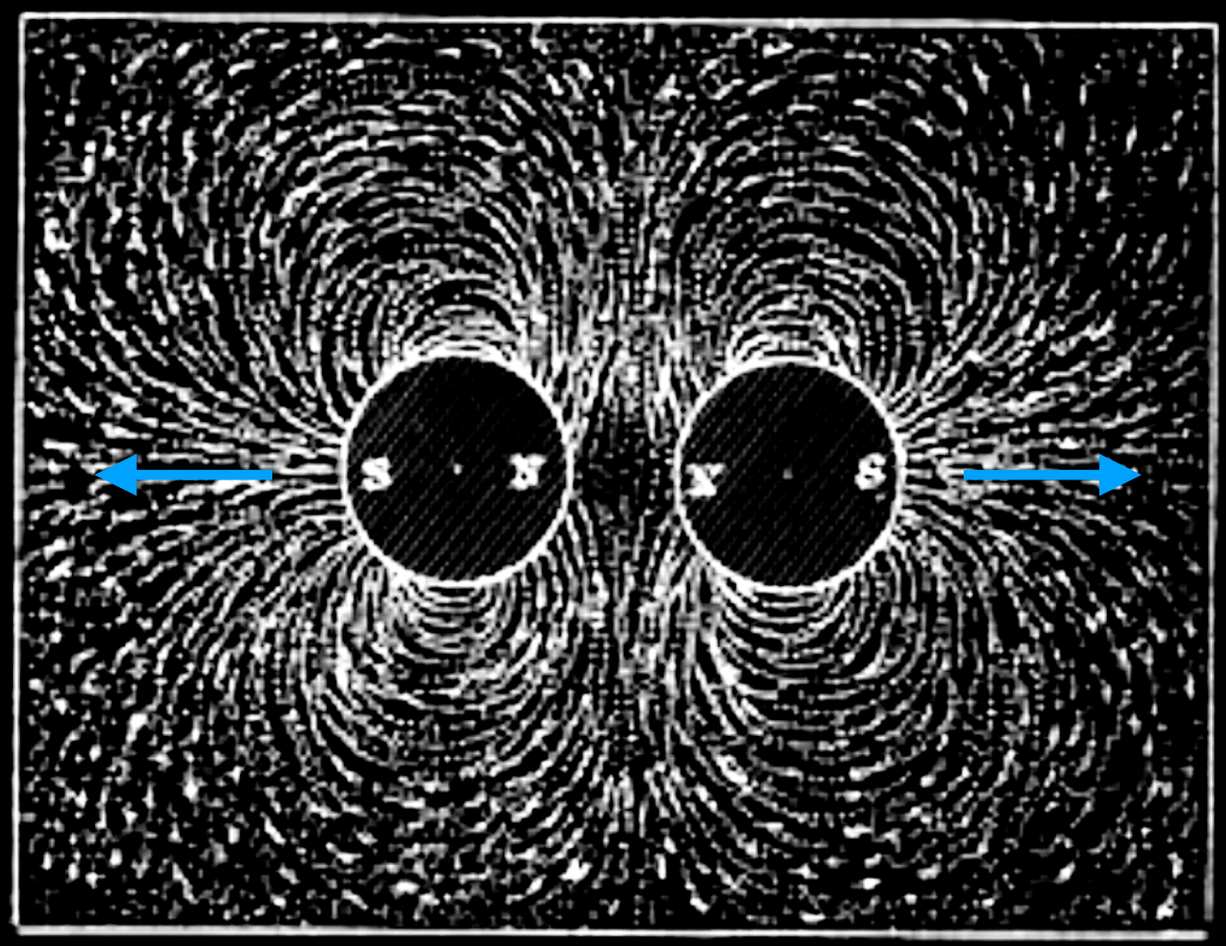


Two repelling magnets

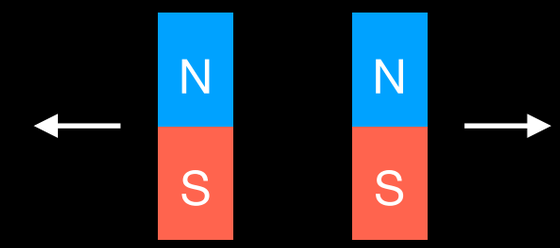


A mechanical model of magnetism

"I propose to examine magnetic phenomena from a mechanical point of view, to determine what tensions in a medium are capable of producing the mechanical phenomena observed."



Two repelling magnets

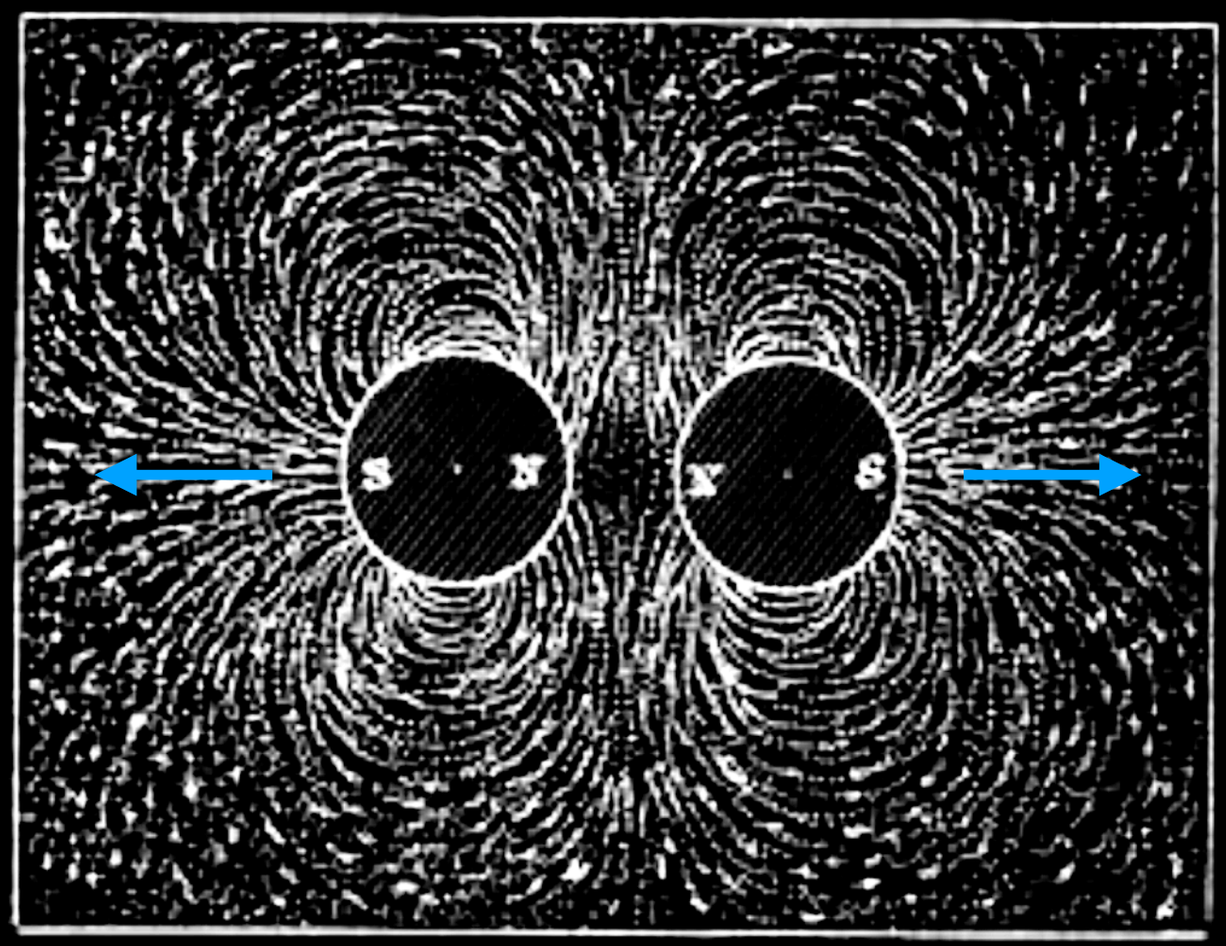


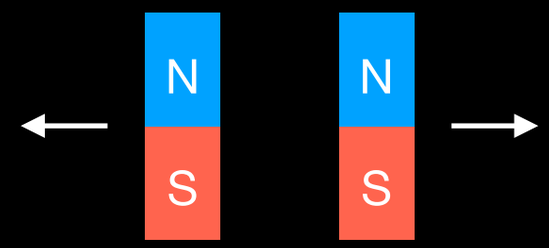
A mechanical model of magnetism

"I propose to examine magnetic phenomena from a mechanical point of view, to determine what tensions in a medium are capable of producing the mechanical phenomena observed."

A successful microscopic explanation of magnetism "will greatly enlarge our knowledge of this part of physics".

Two repelling magnets





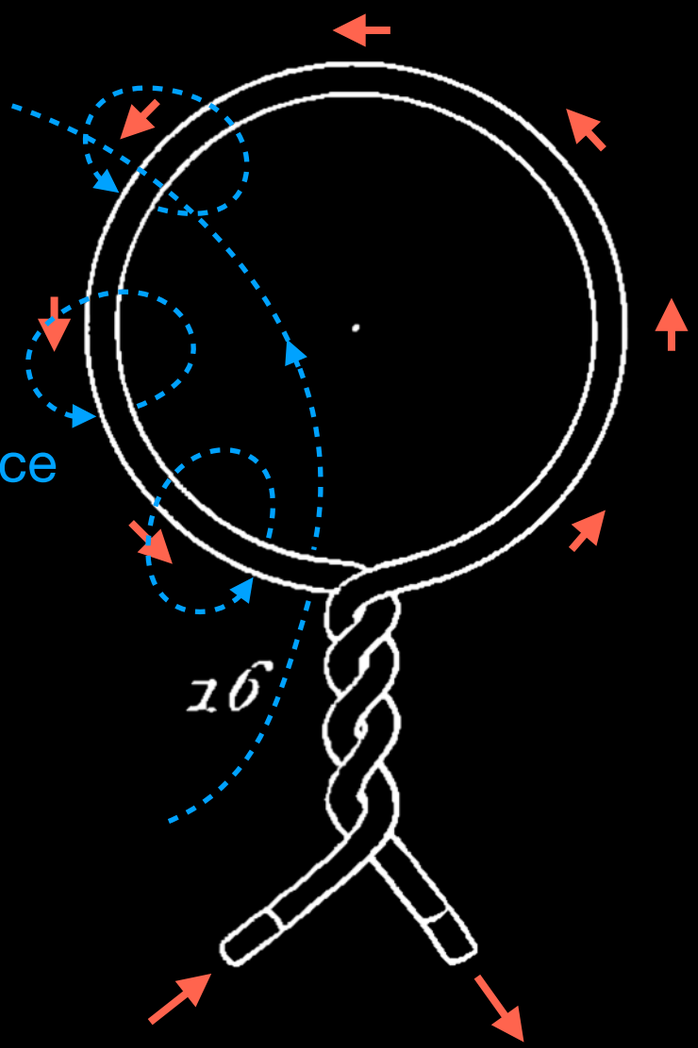
Magnetic “vortices”

Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”

Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”



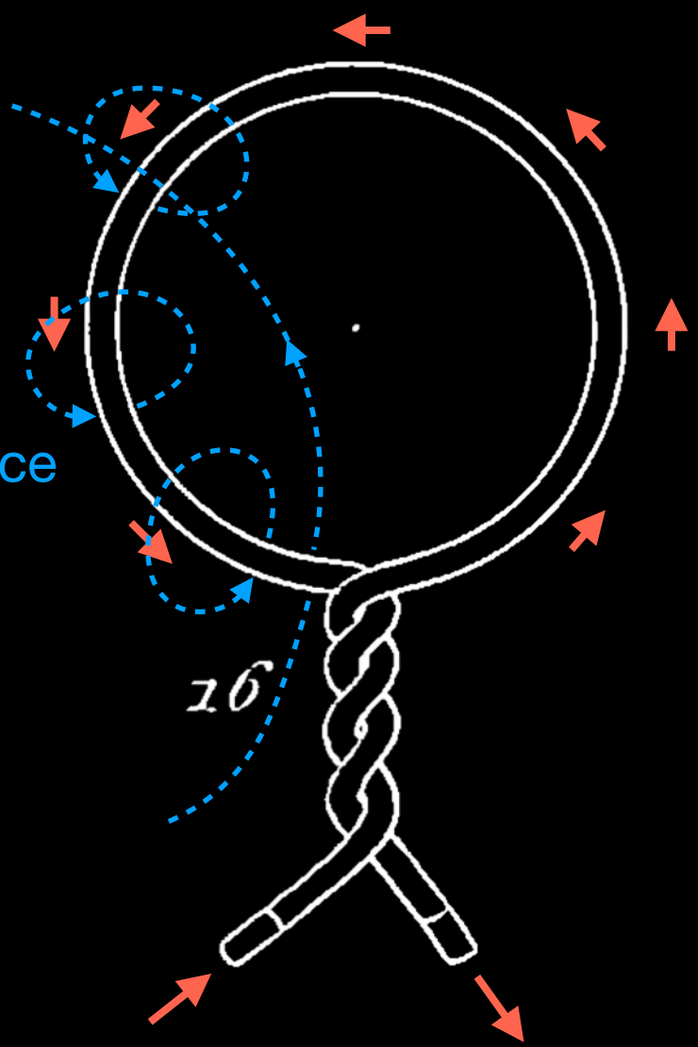
Lines of magnetic force

Faraday’s observation

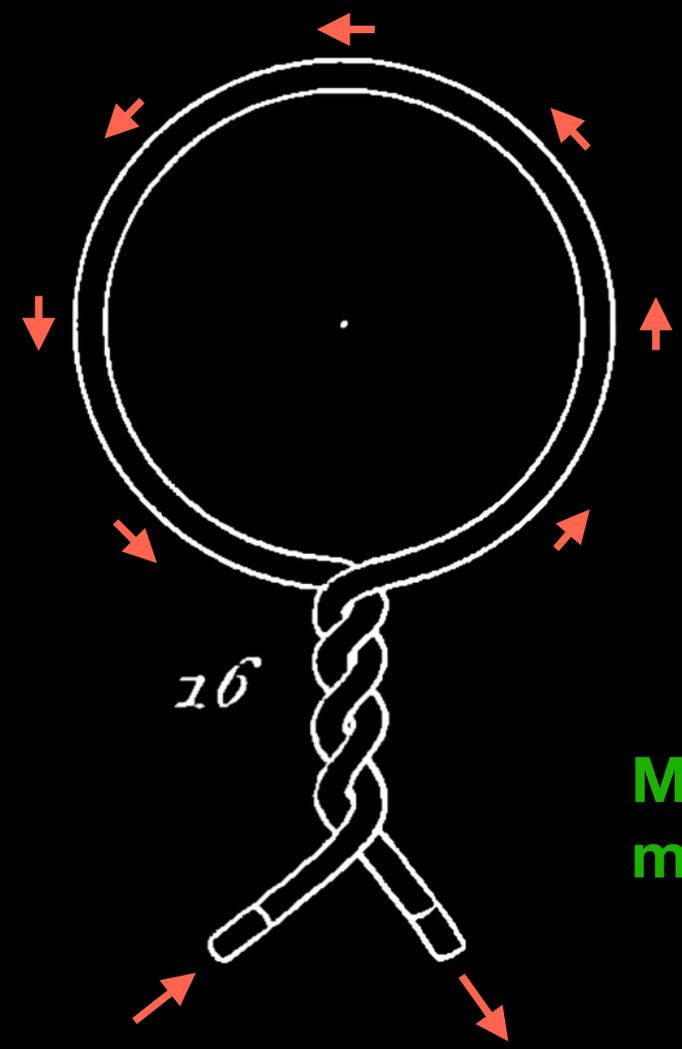
Current

Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”



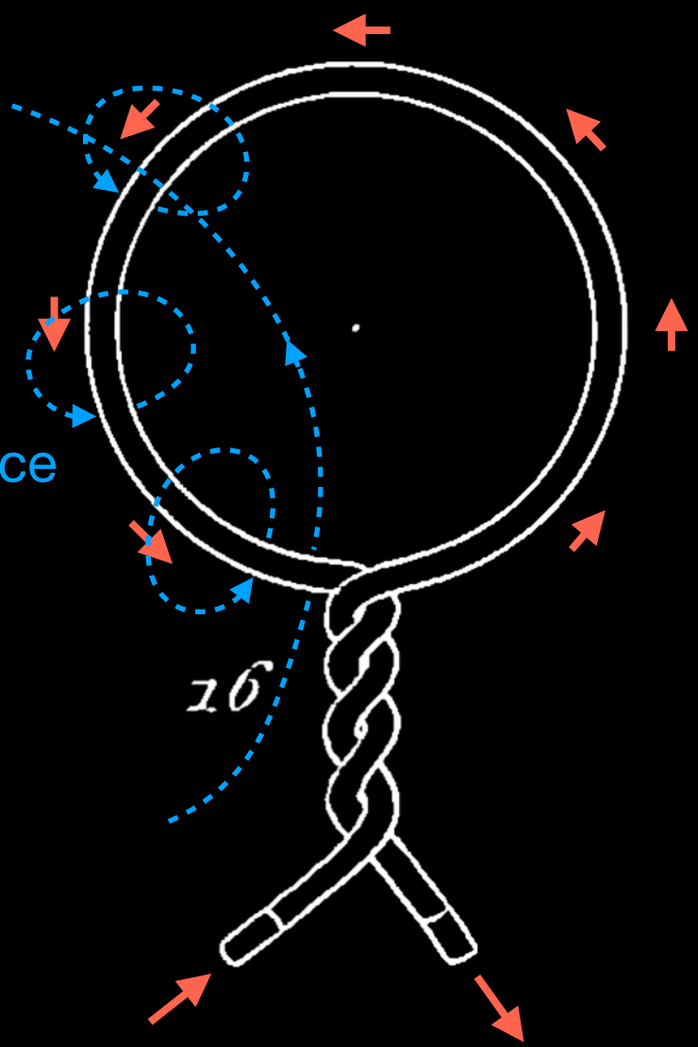
Faraday’s observation



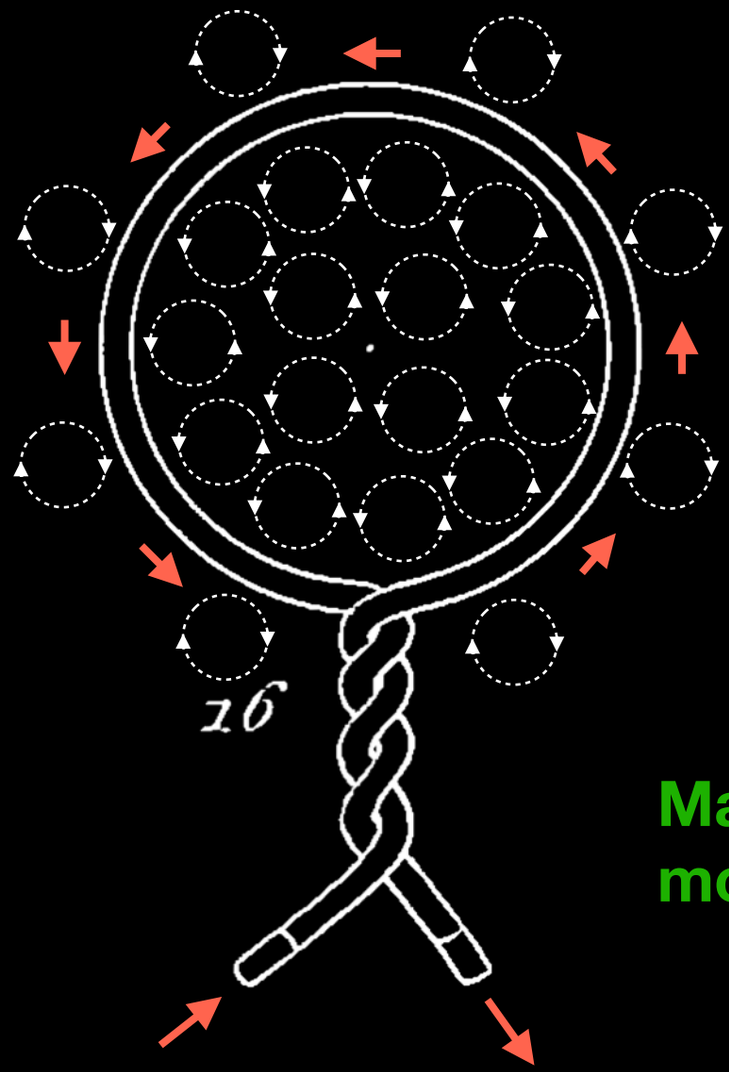
Maxwell’s model

Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”



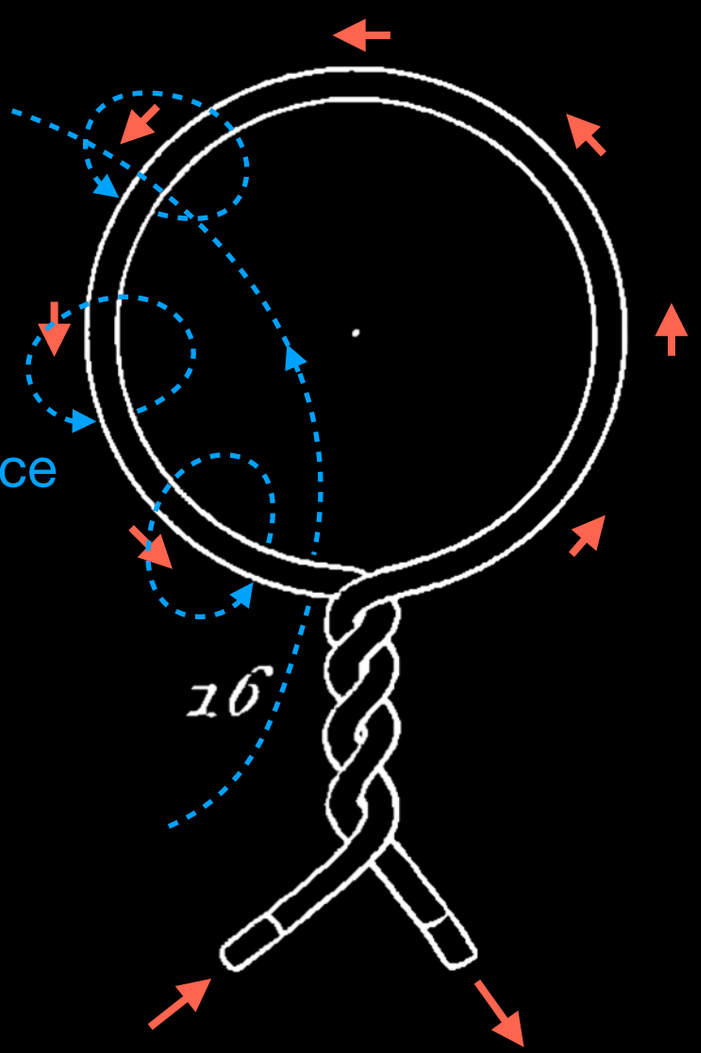
Faraday’s observation



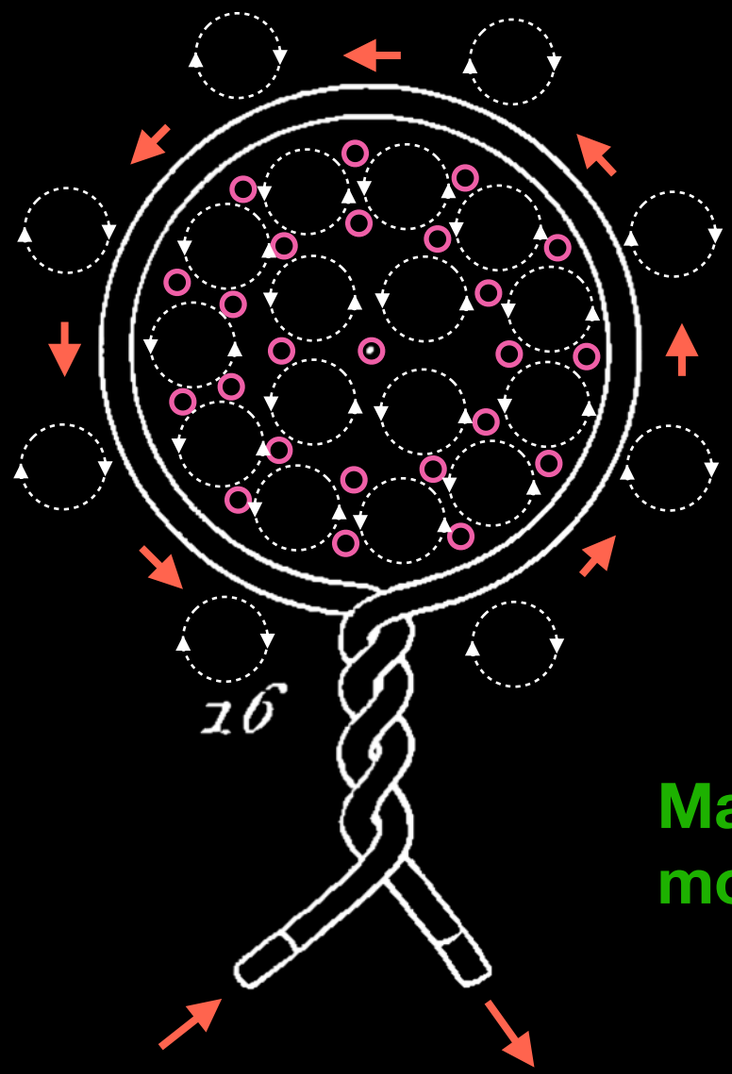
Maxwell’s model

Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”



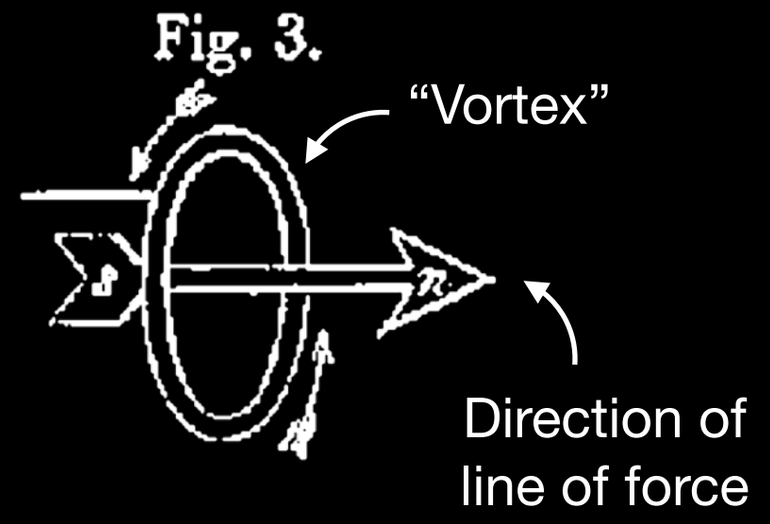
Faraday’s observation

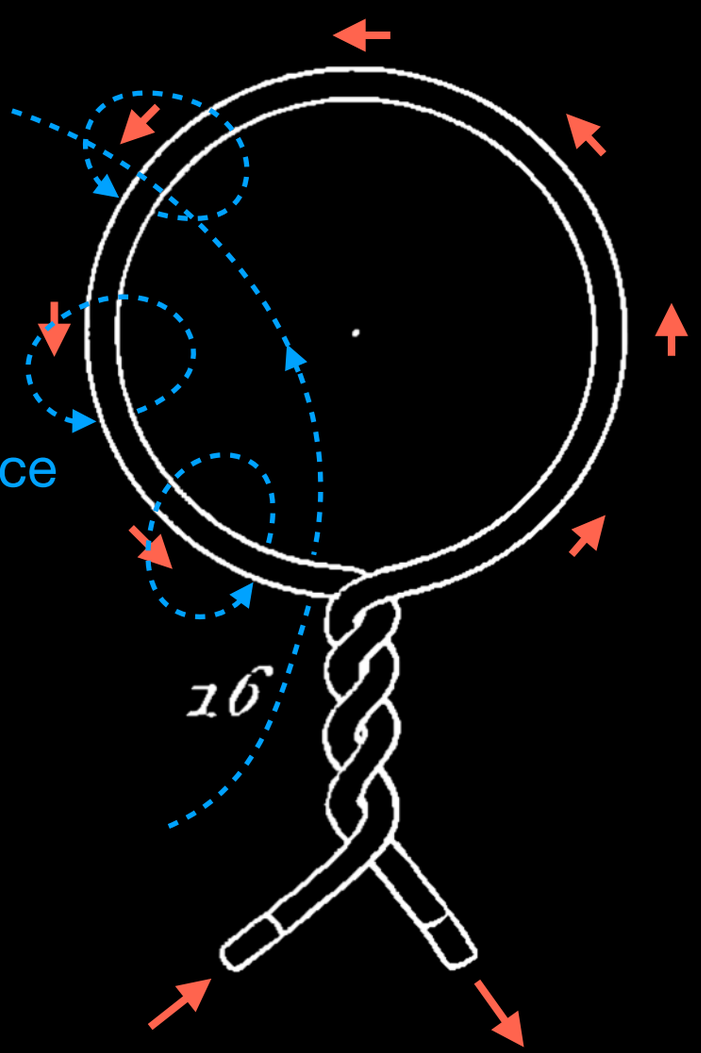


Maxwell’s model

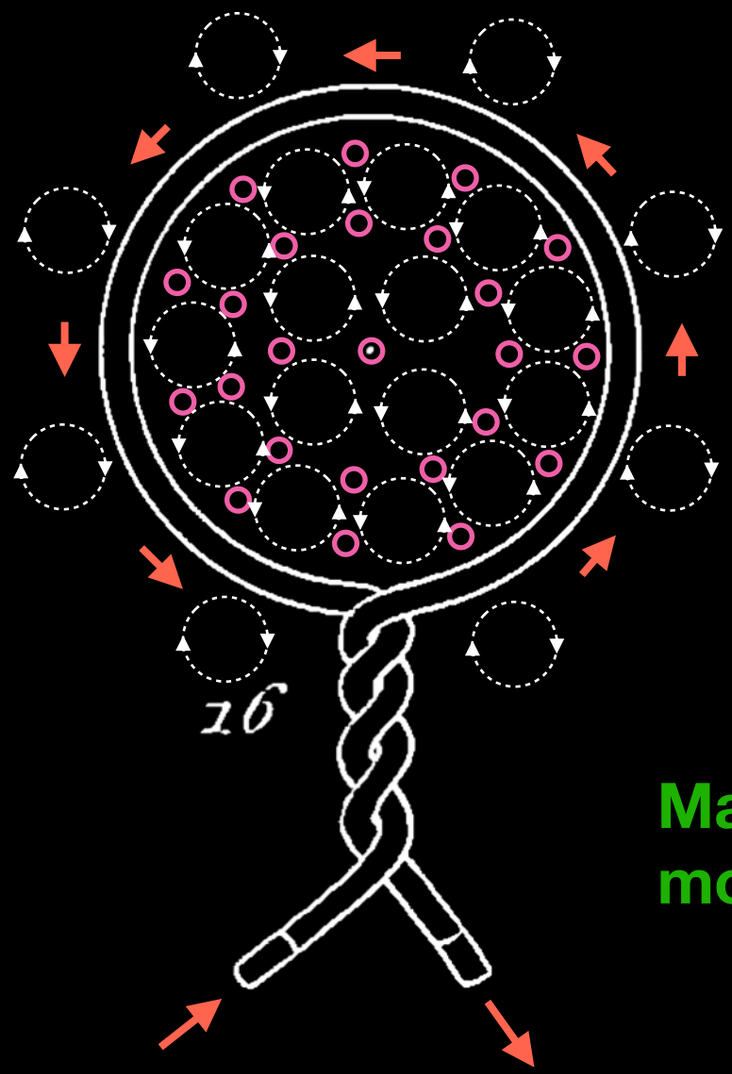
Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”





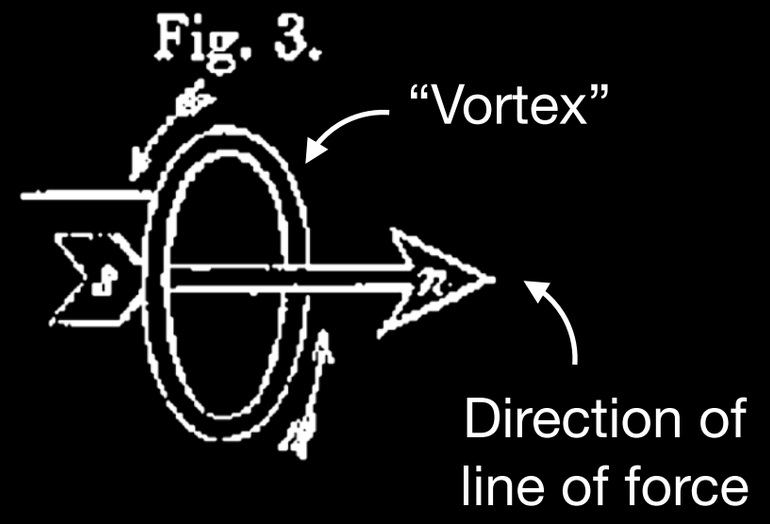
Faraday’s observation

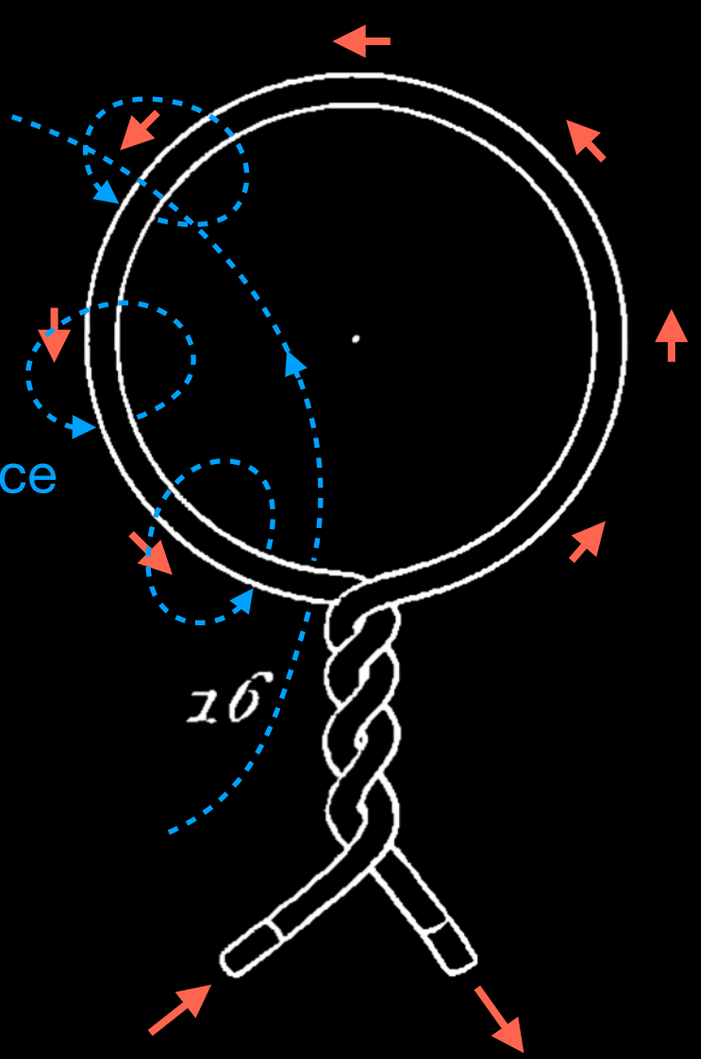


Maxwell’s model

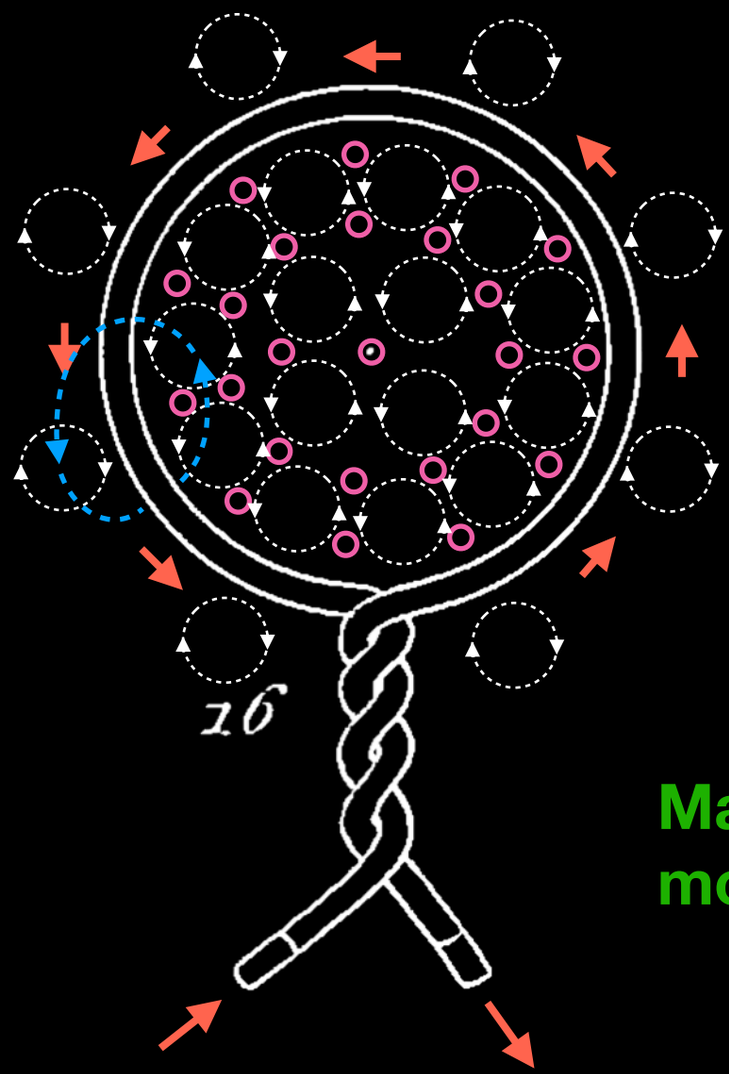
Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”





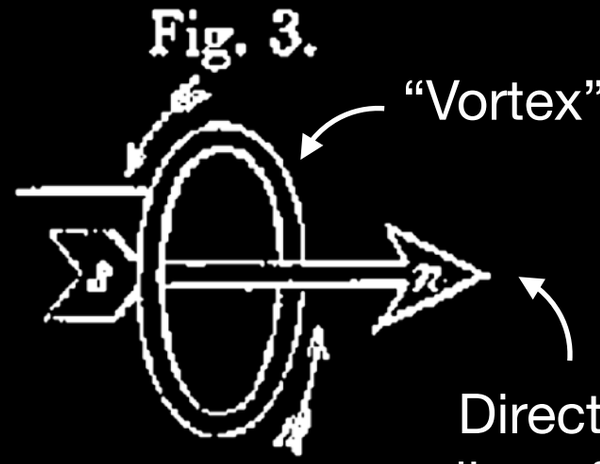
Faraday’s observation

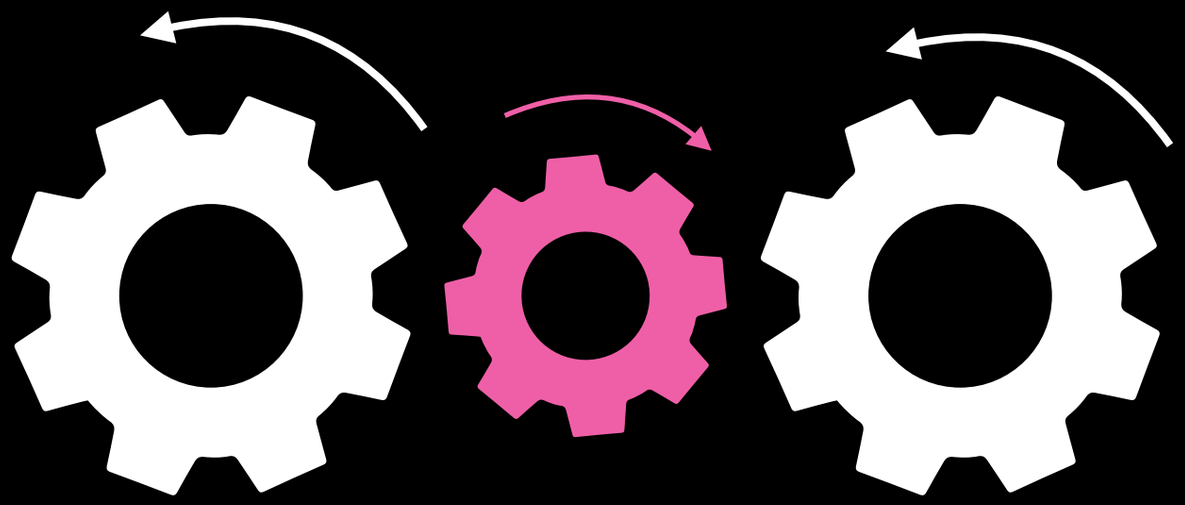


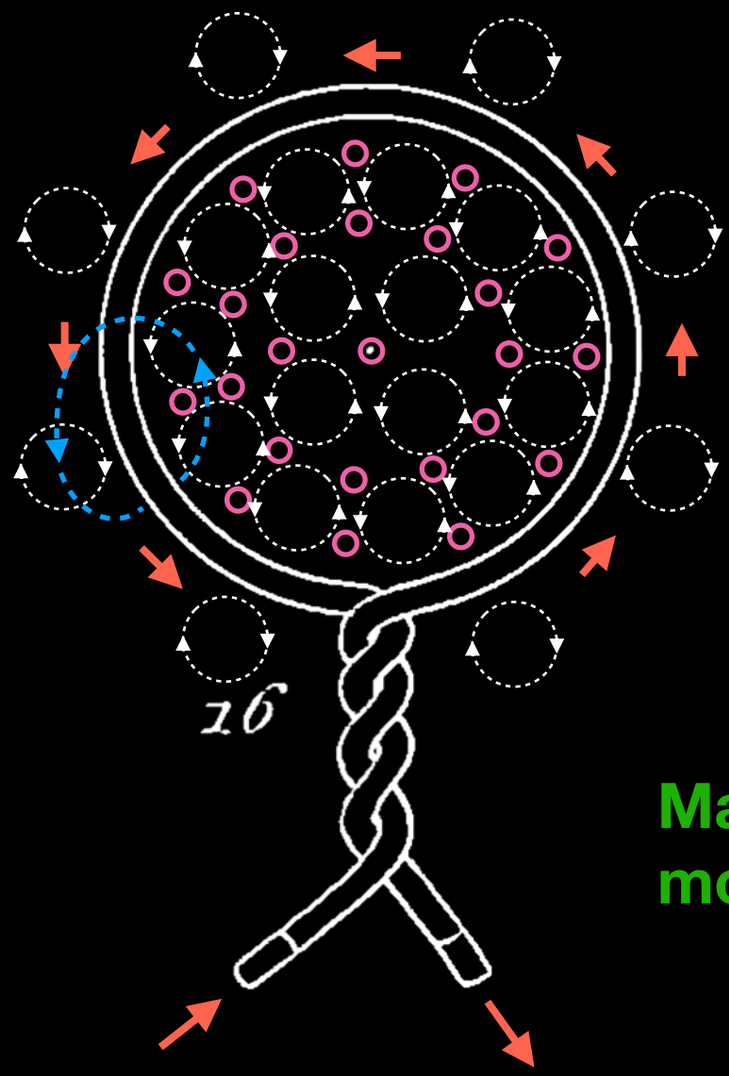
Maxwell’s model

Magnetic “vortices”

“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”

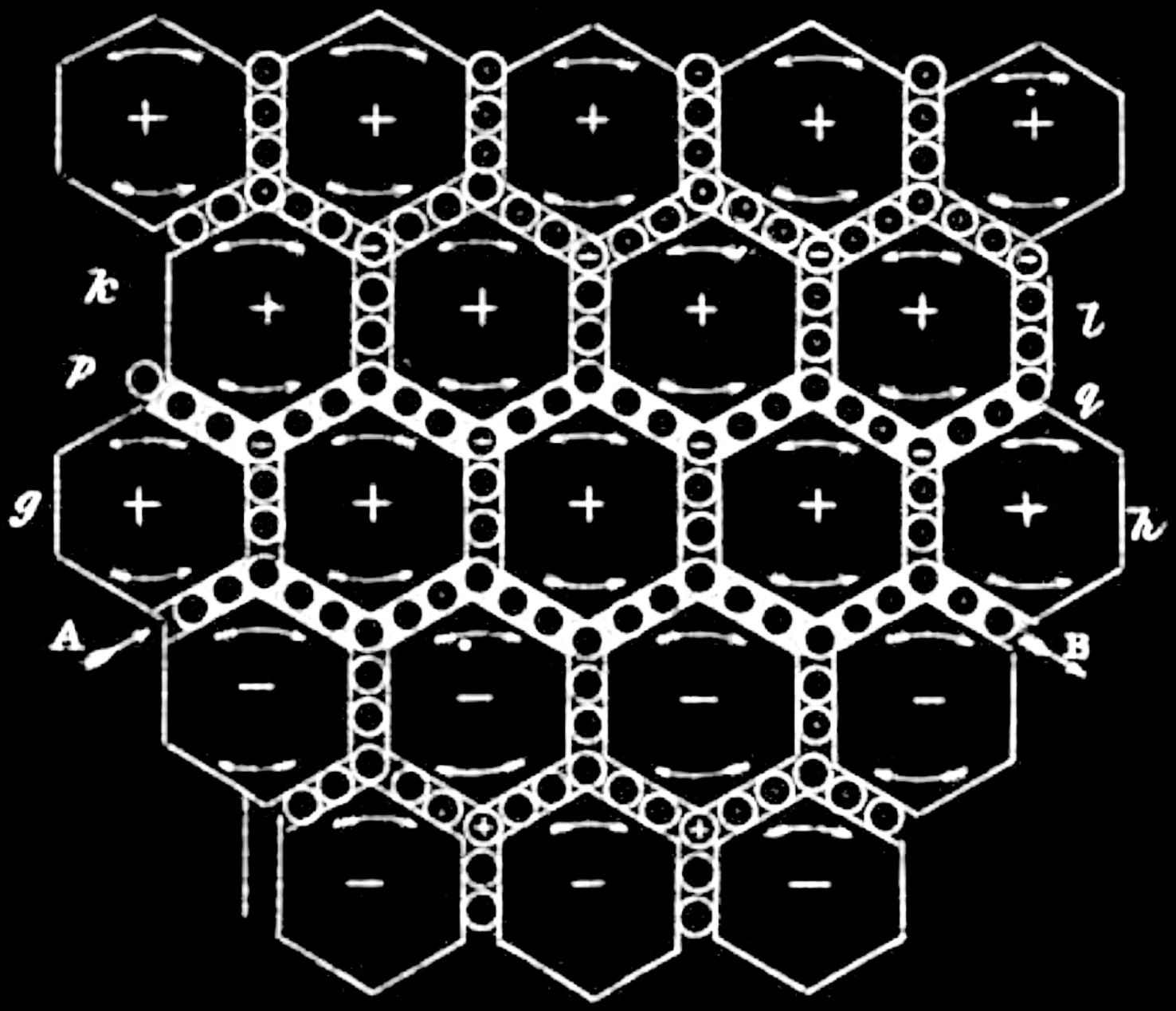




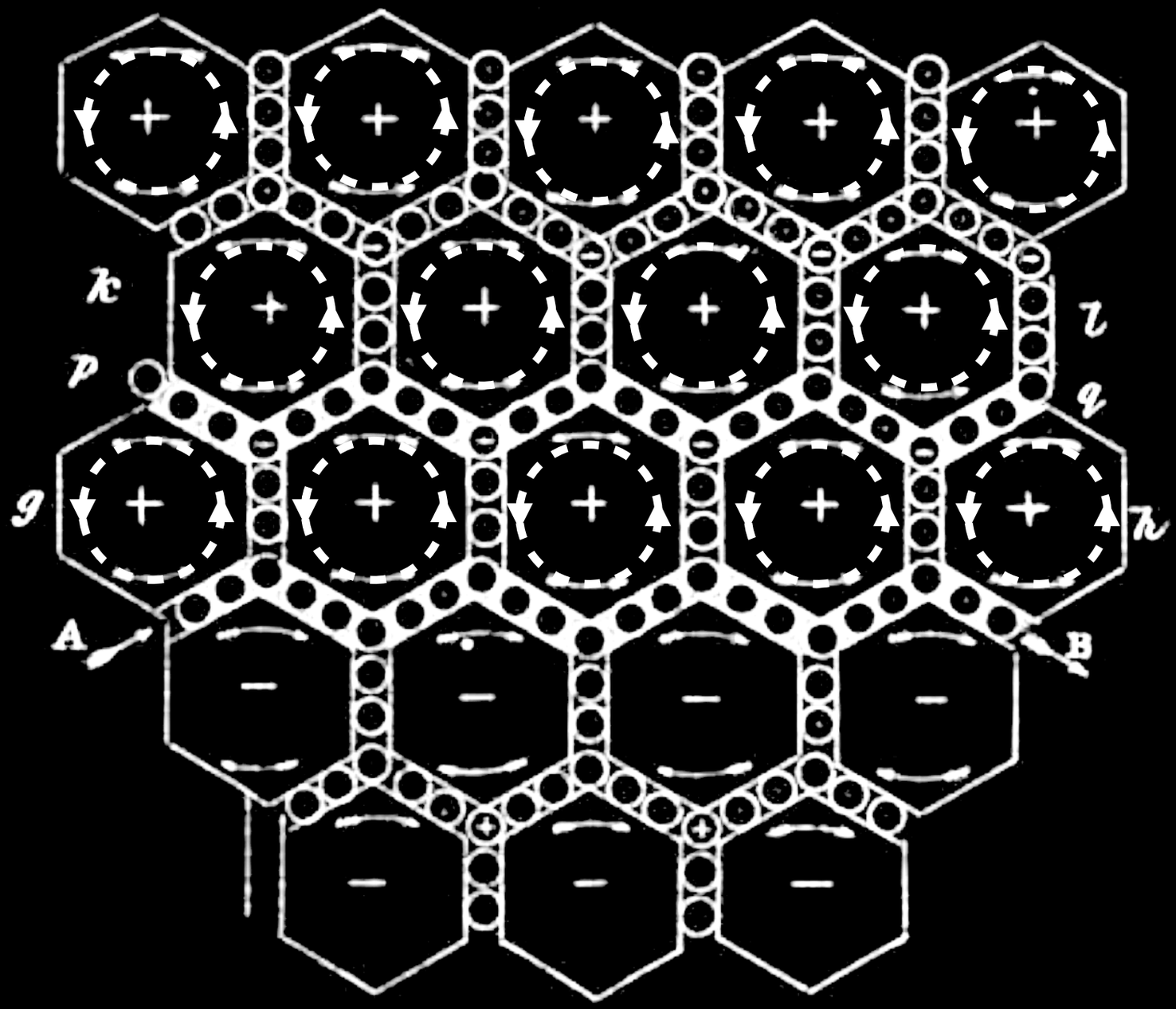


Maxwell’s model

Maxwell’s rules

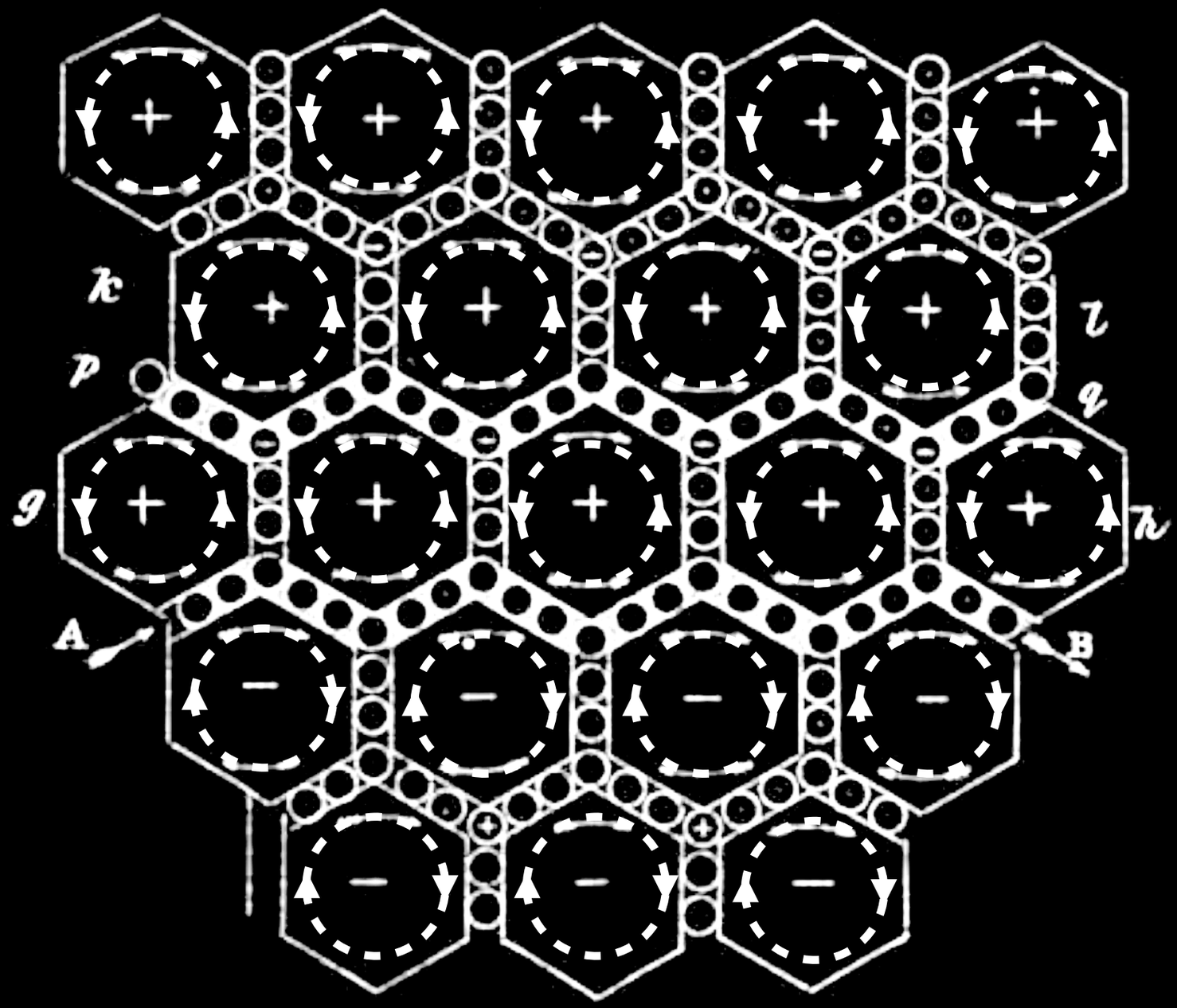


Maxwell’s rules



Vortices rotating
counter-clockwise

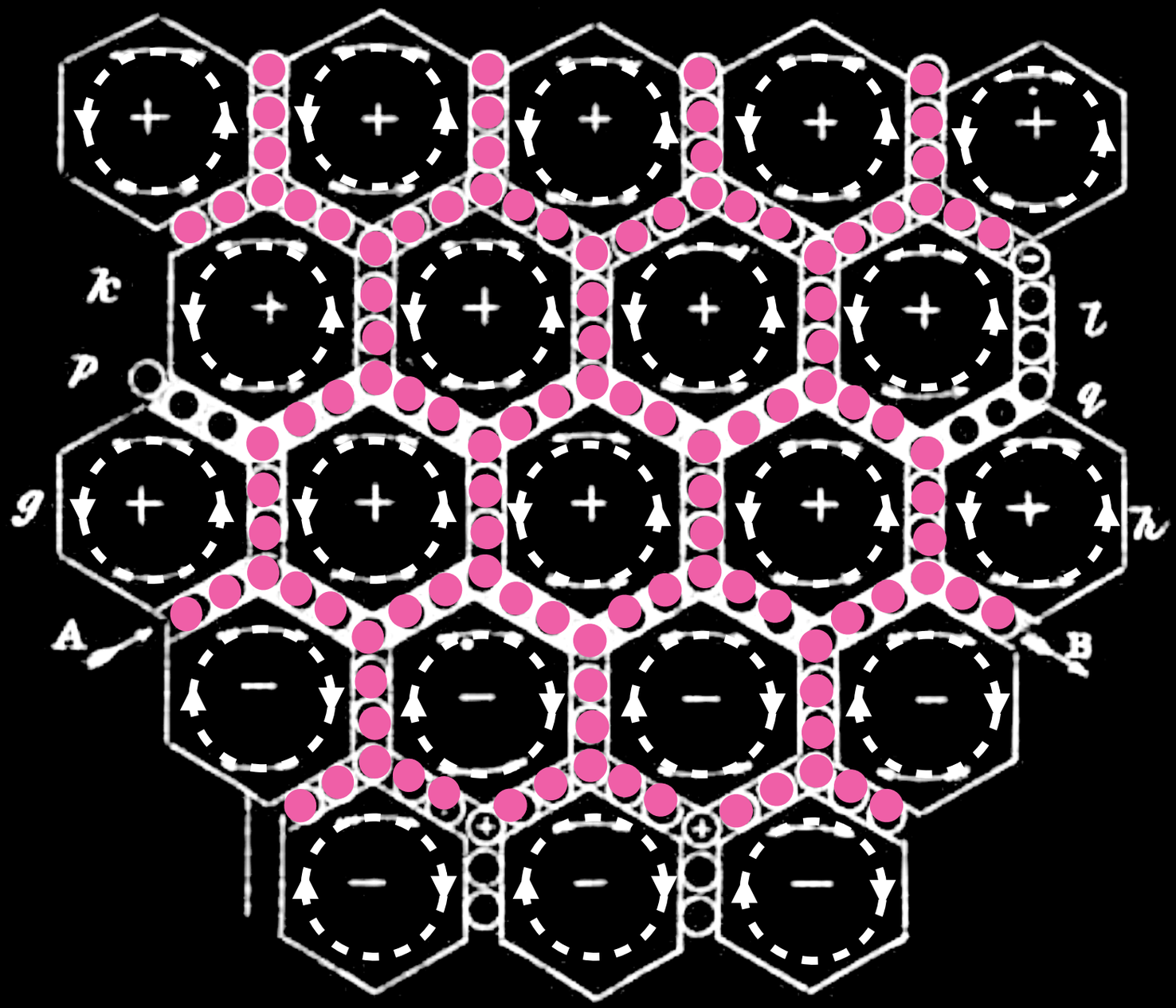
Maxwell’s rules



Vortices rotating
counter-clockwise

Vortices rotating
clockwise

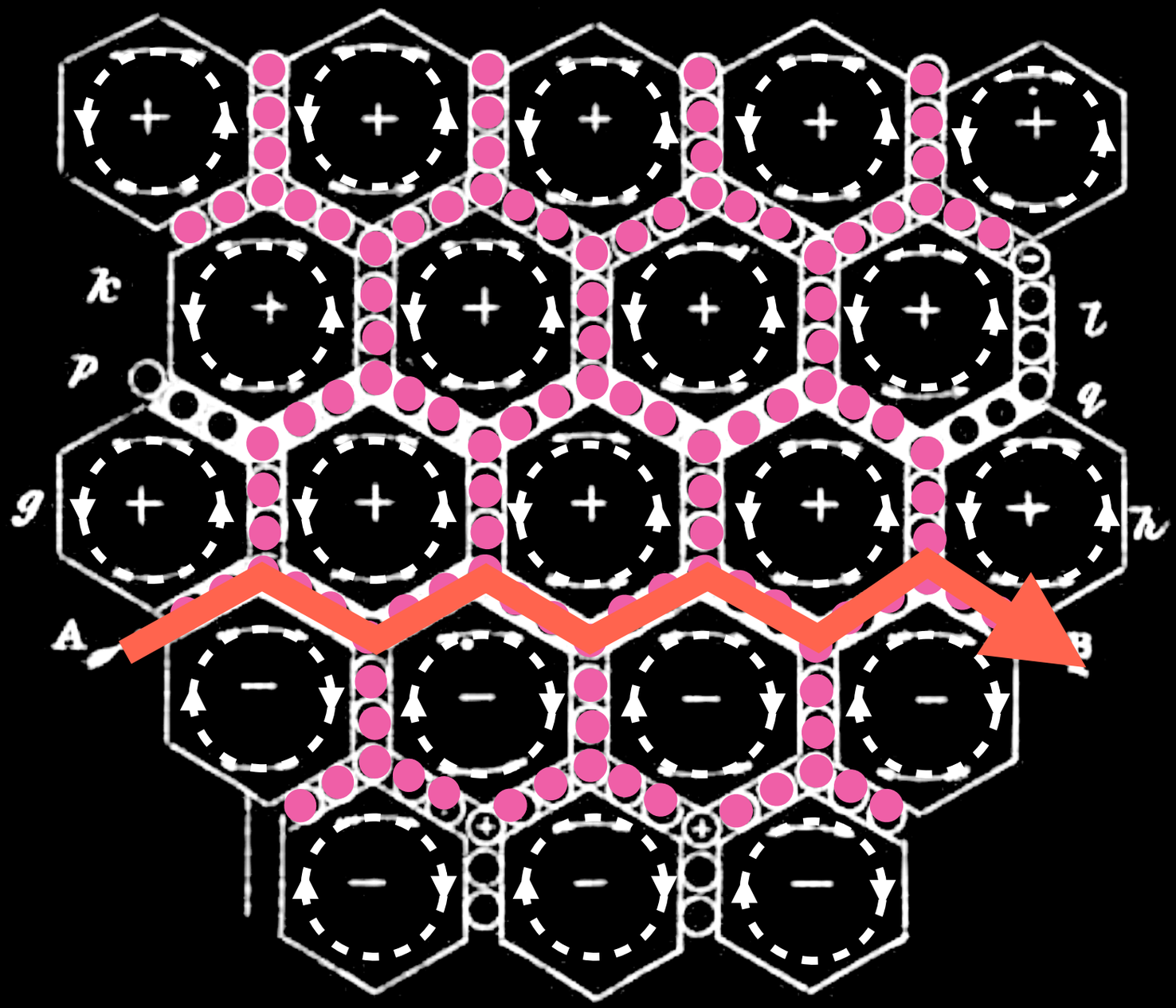
Maxwell’s rules



Vortices rotating
counter-clockwise

Vortices rotating
clockwise

Maxwell’s rules

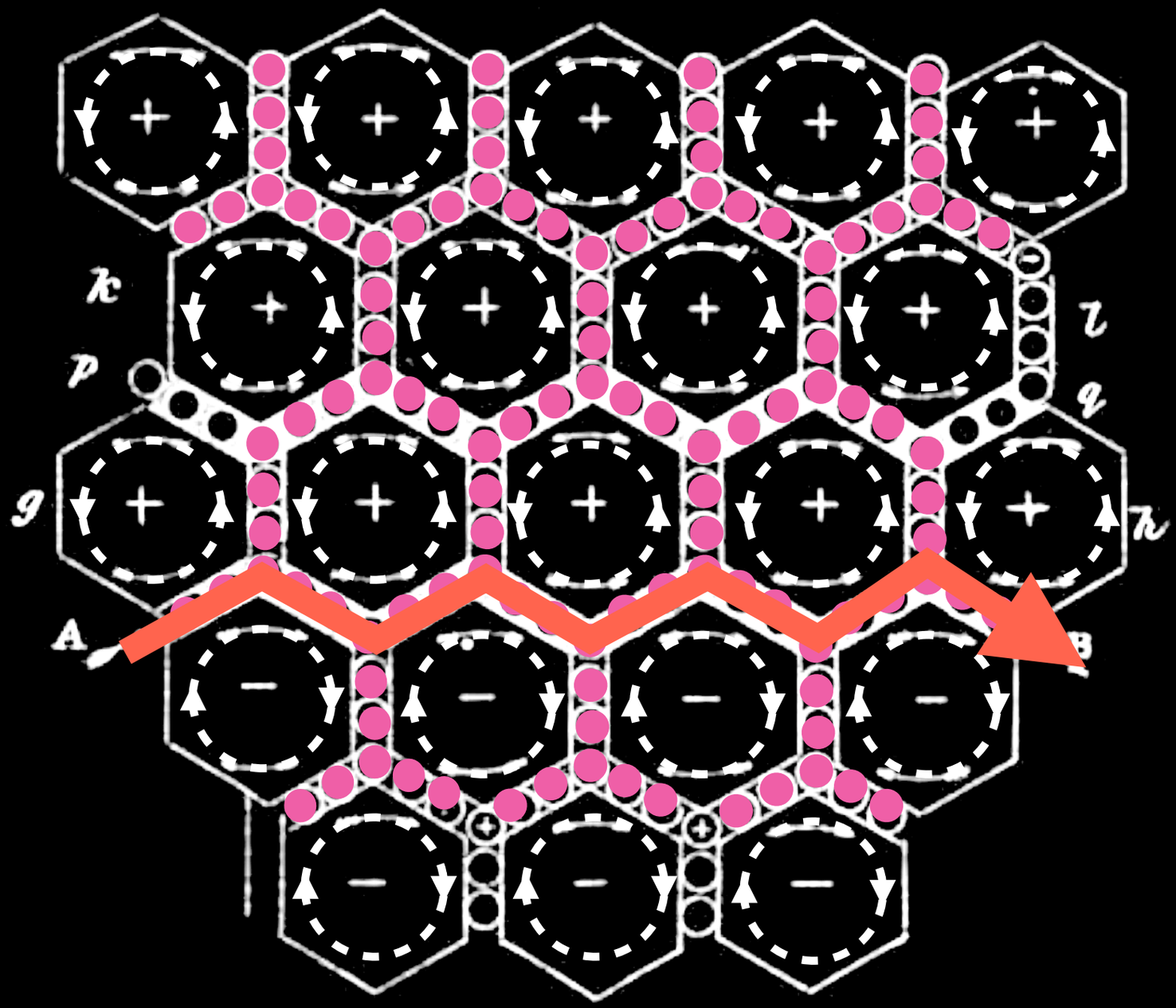


Vortices rotating
counter-clockwise

Electric current

Vortices rotating
clockwise

Maxwell’s rules



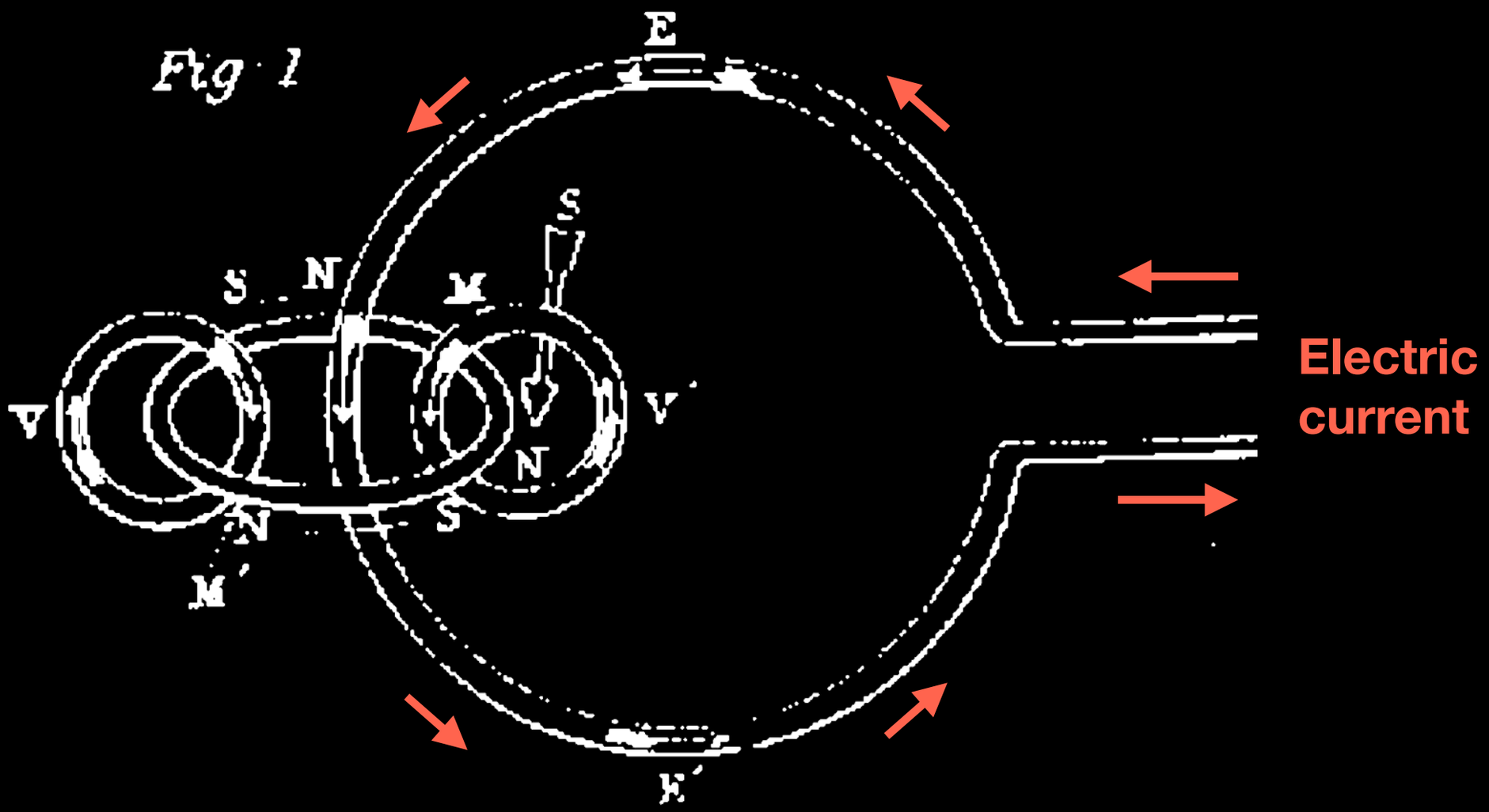
Vortices rotating
counter-clockwise

Electric current

Vortices rotating
clockwise

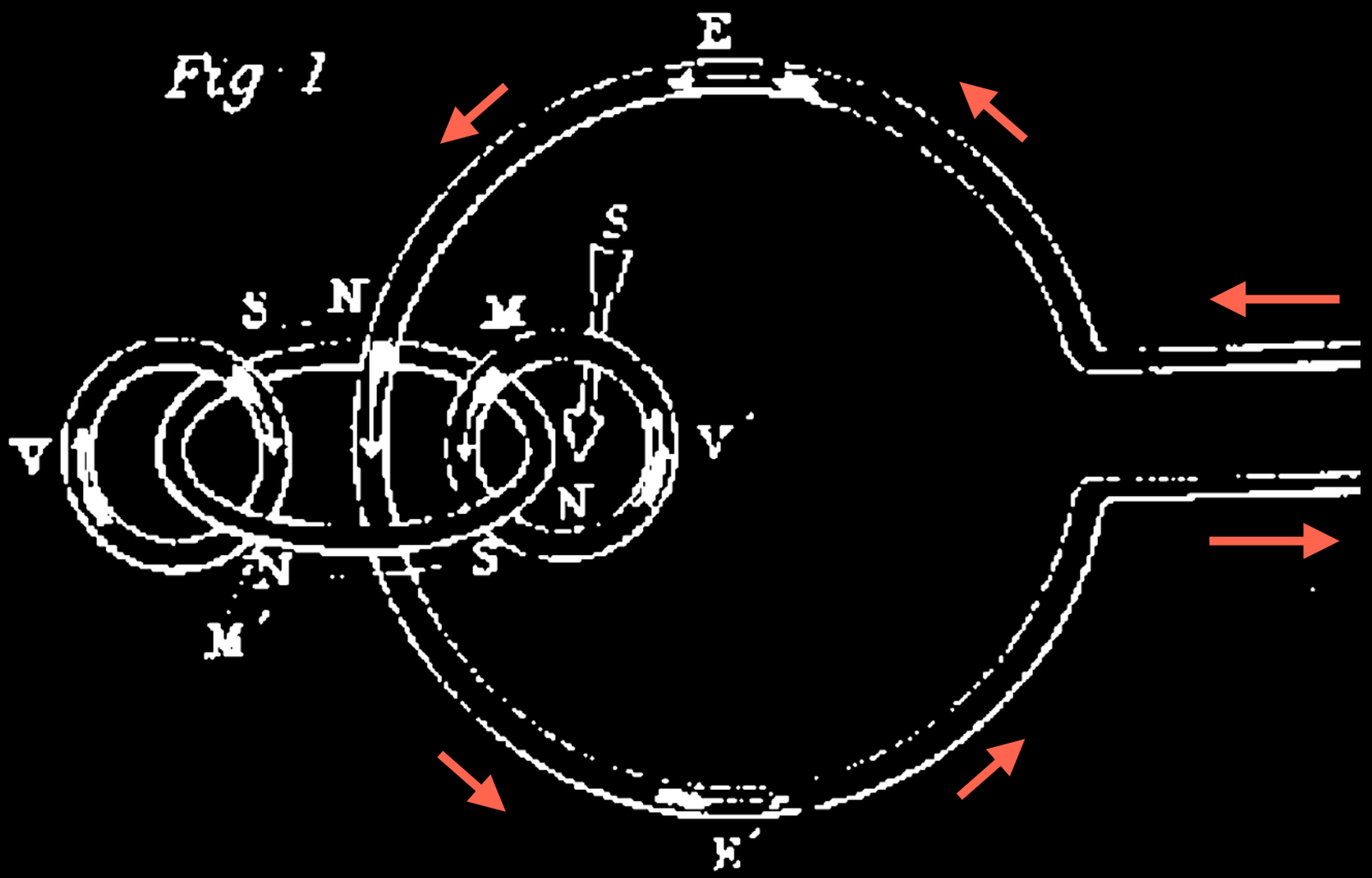
“I have found great difficulty in conceiving of the existence of vortices in a medium, side by side, revolving in the same direction about parallel axes.”

Vortices create vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

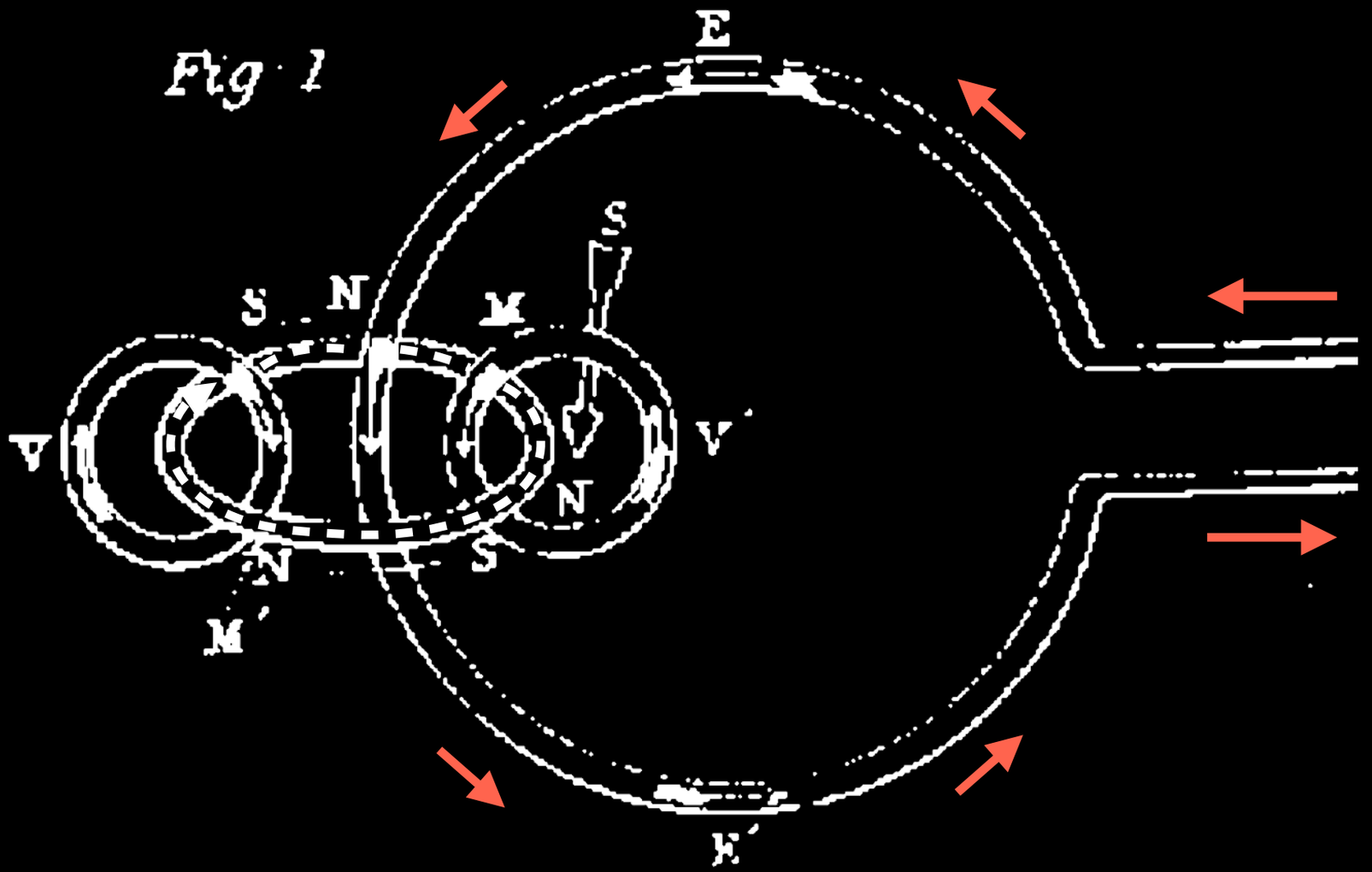
Vortices create vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

Vortices create vortices

Electric current



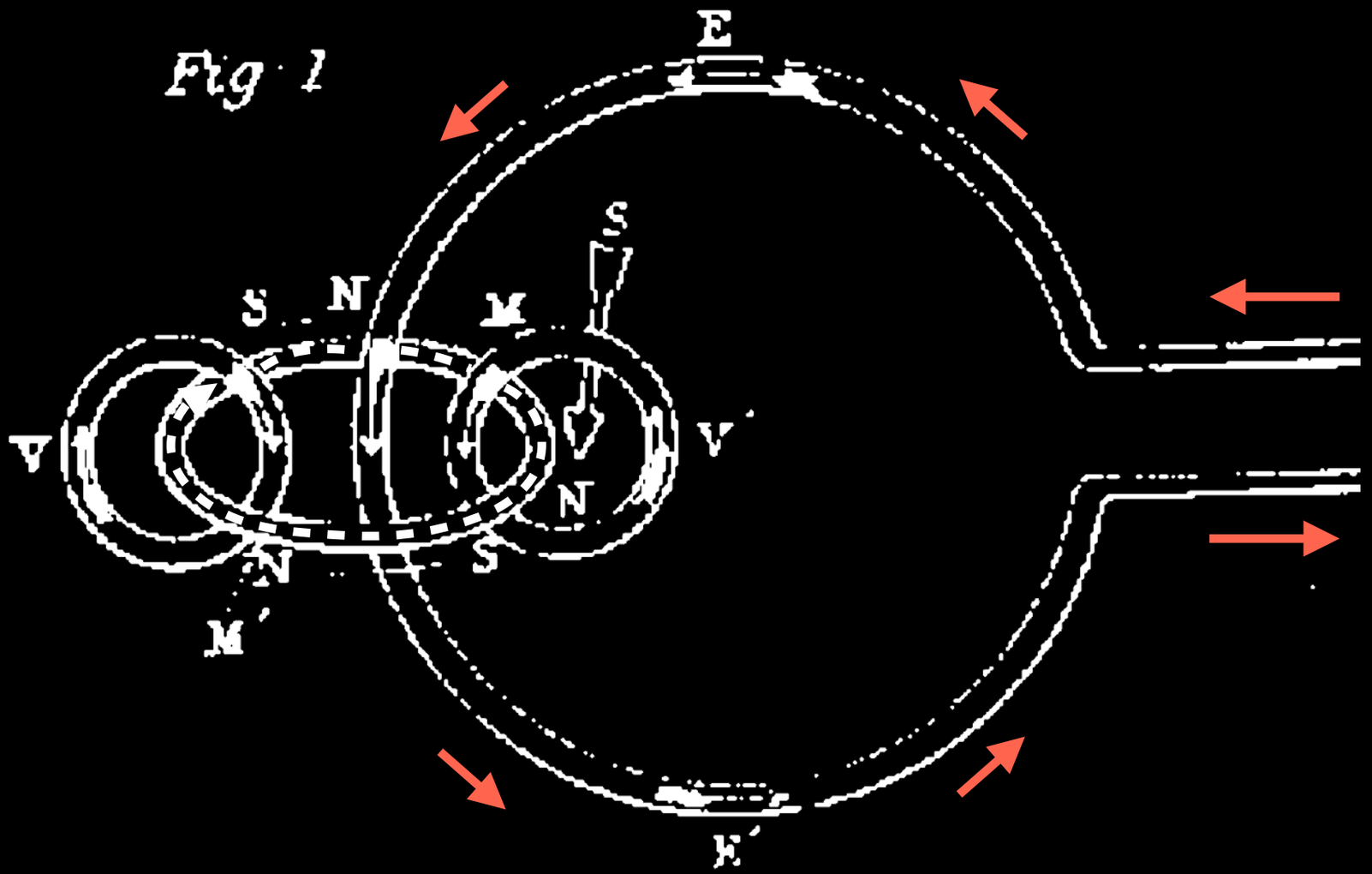
Maxwell: under the right conditions, vortices *themselves* create vortices

Vortices create vortices

Electric current

↓

Vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

Vortices create vortices

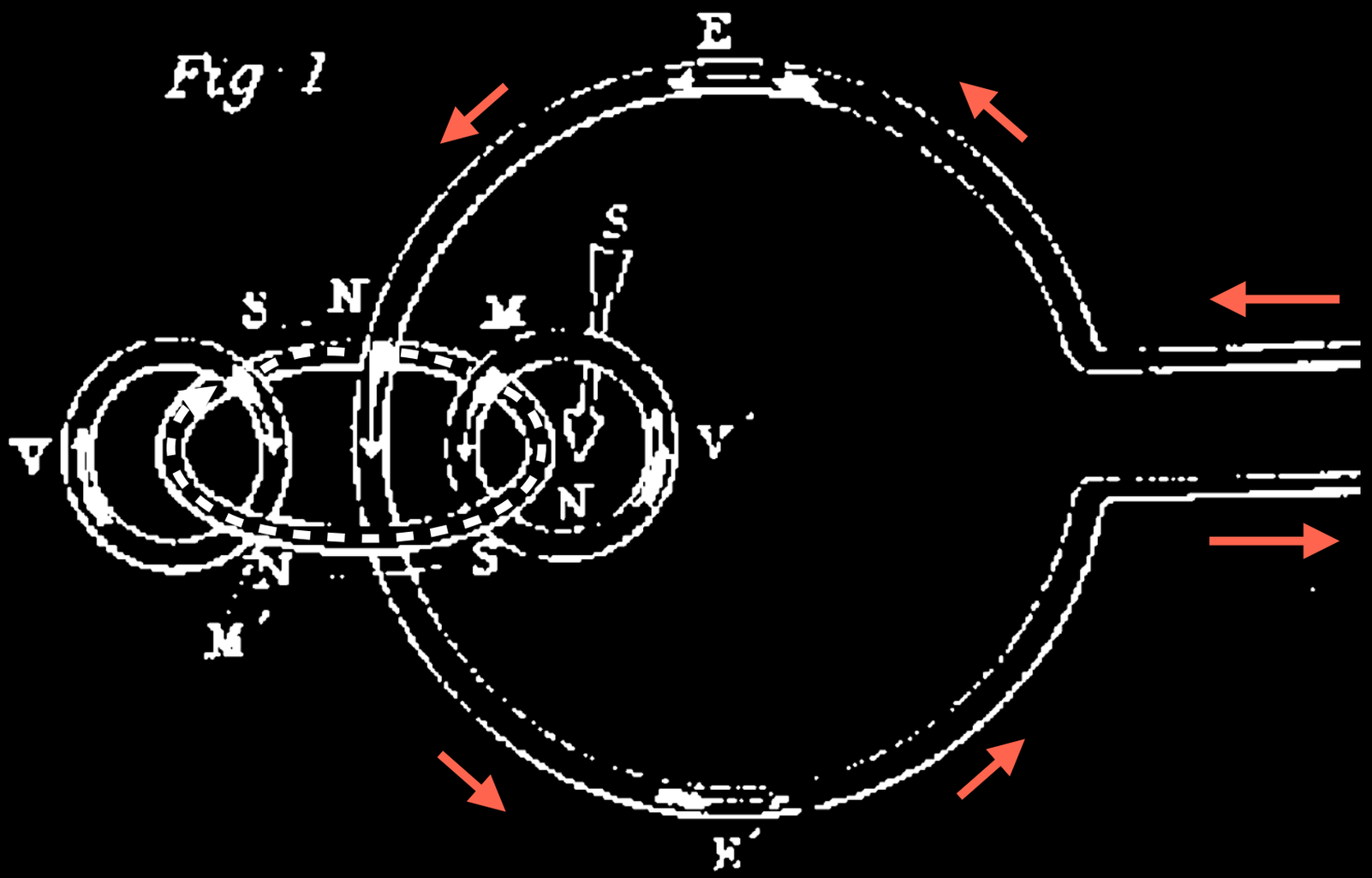
Electric current

↓

Vortices

↓

Vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

Vortices create vortices

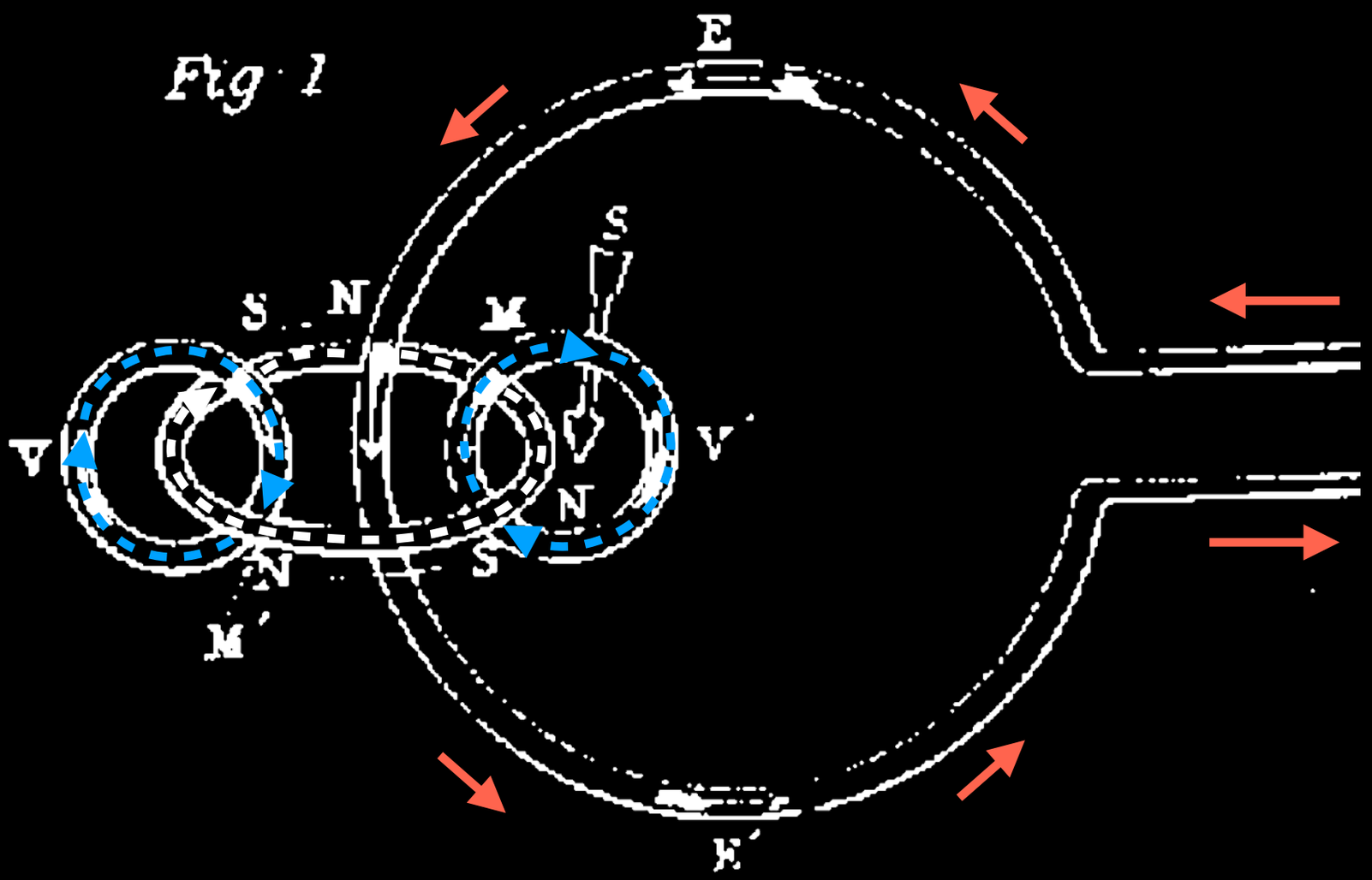
Electric current

↓

Vortices

↓

Vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

Vortices create vortices

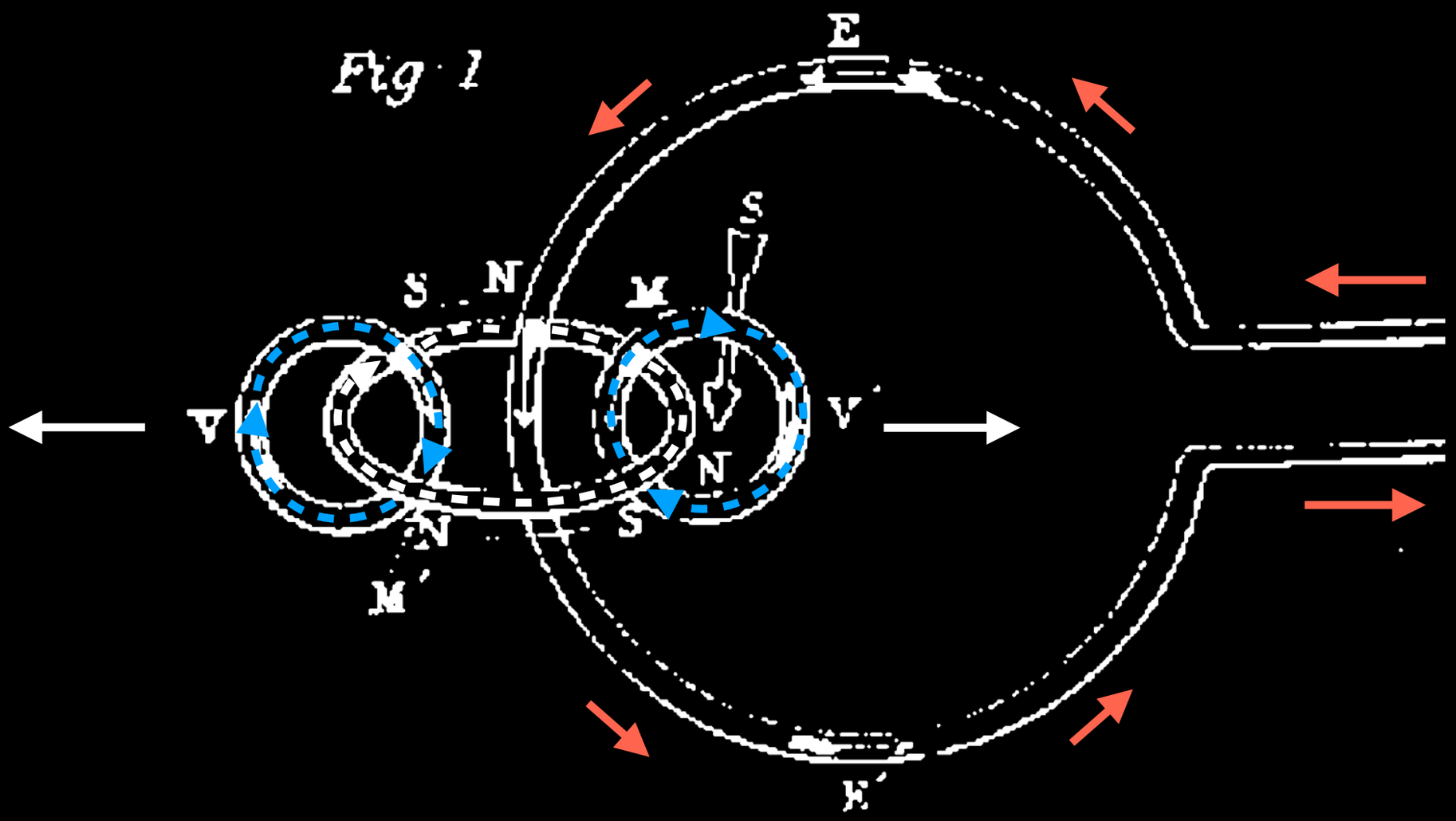
Electric current

↓

Vortices

↓

Vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

Vortices create vortices

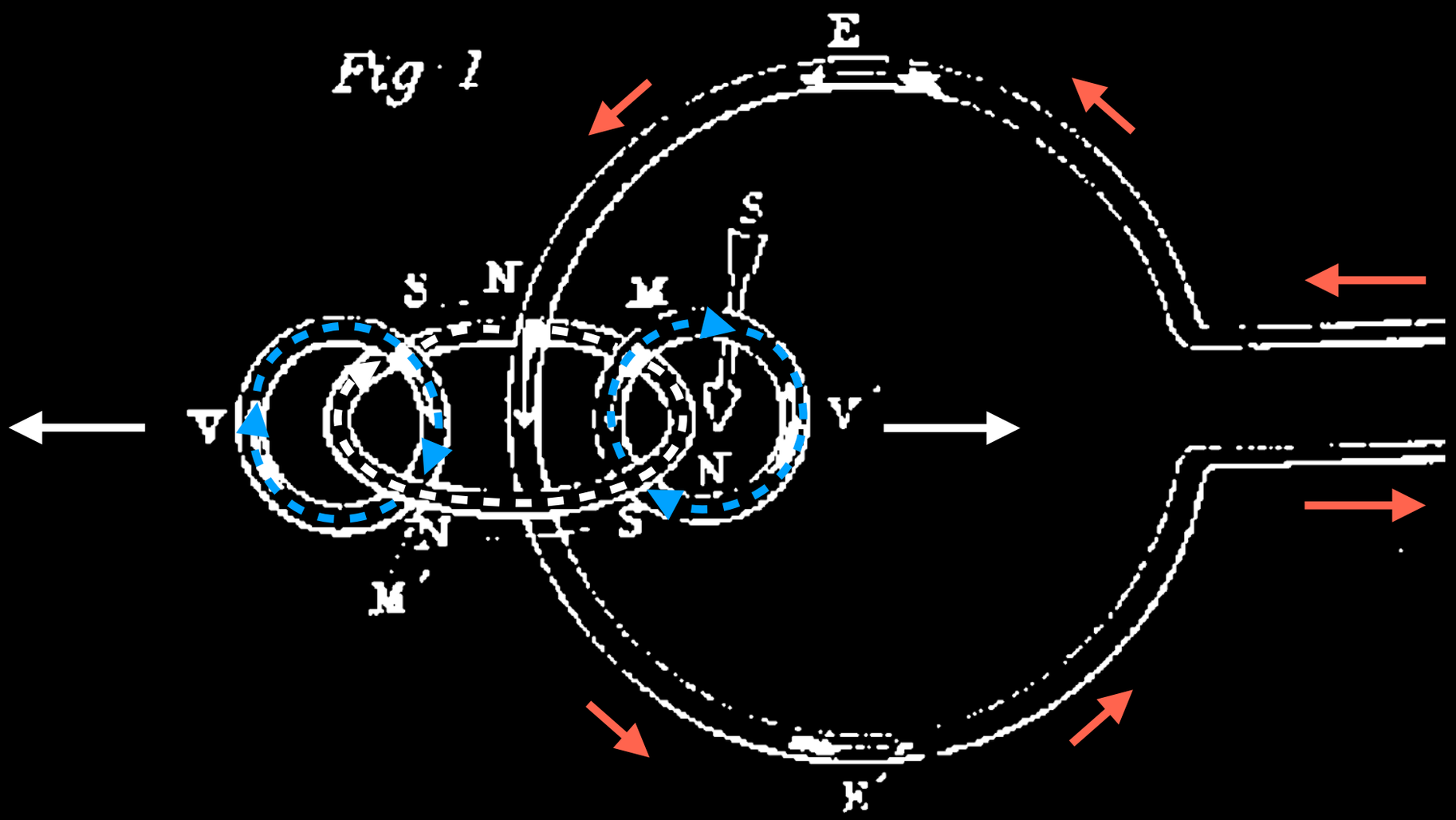
Electric current

↓

Vortices

↓

Vortices



Maxwell: under the right conditions, vortices *themselves* create vortices

“Disturbance” in the magnetic medium can propagate far away from the current

Electromagnetic “waves”

Electromagnetic “waves”

In air or vacuum $\mu = 1$, and therefore

$$\left.\begin{aligned} V &= E, \\ &= 310{,}740{,}000{,}000 \text{ millimetres per second}, \\ &= 193{,}088 \text{ miles per second.} \end{aligned}\right\} \quad . \quad (136)$$

Electromagnetic “waves”

In air or vacuum $\mu = 1$, and therefore

$$\left.\begin{aligned} V &= E, \\ &= 310{,}740{,}000{,}000 \text{ millimetres per second}, \\ &= 193{,}088 \text{ miles per second.} \end{aligned}\right\} \quad . \quad (136)$$

The velocity of light in air, as determined by M. Fizeau*, is 70,843 leagues per second (25 leagues to a degree) which gives

$$\begin{aligned} V &= 314{,}858{,}000{,}000 \text{ millimetres} \\ &= 195{,}647 \text{ miles per second.} \quad . \quad . \quad . \quad . \quad (137) \end{aligned}$$

Electromagnetic “waves”

In air or vacuum $\mu = 1$, and therefore

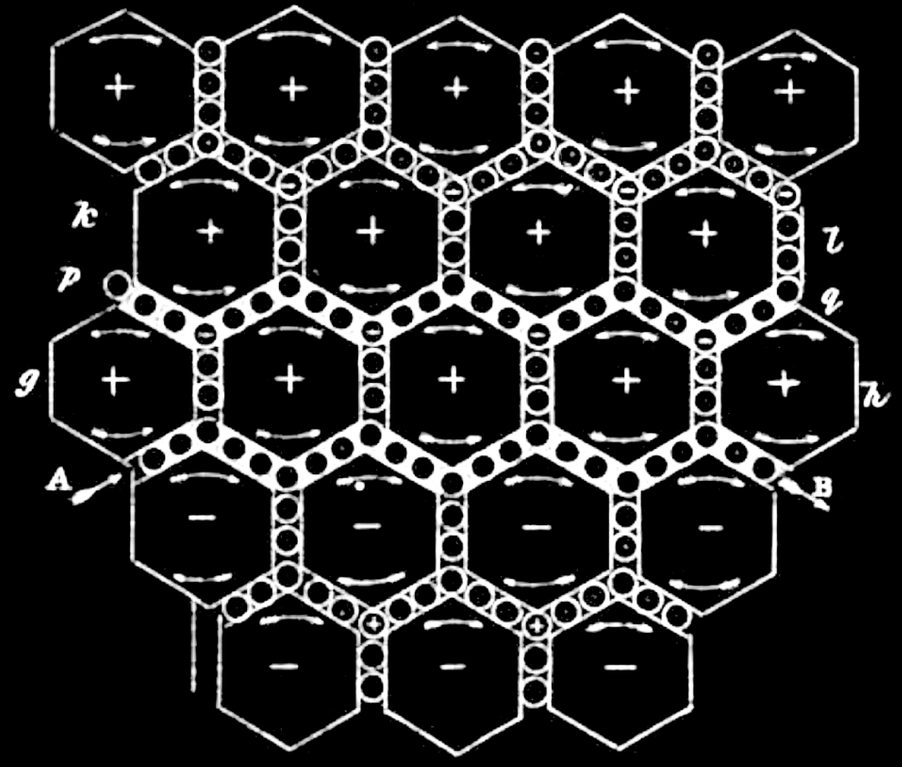
$$\left.\begin{aligned} V &= E, \\ &= 310{,}740{,}000{,}000 \text{ millimetres per second}, \\ &= 193{,}088 \text{ miles per second.} \end{aligned}\right\} \quad . \quad (136)$$

The velocity of light in air, as determined by M. Fizeau*, is 70,843 leagues per second (25 leagues to a degree) which gives

$$\begin{aligned} V &= 314{,}858{,}000{,}000 \text{ millimetres} \\ &= 195{,}647 \text{ miles per second.} \quad . \quad . \quad . \quad . \quad (137) \end{aligned}$$

“The velocity of undulations in our hypothetical medium agrees so exactly with the velocity of light that we can scarcely avoid the inference that light consists in the undulations of the same medium which is the cause of electric and magnetic phenomena.”

Vortices



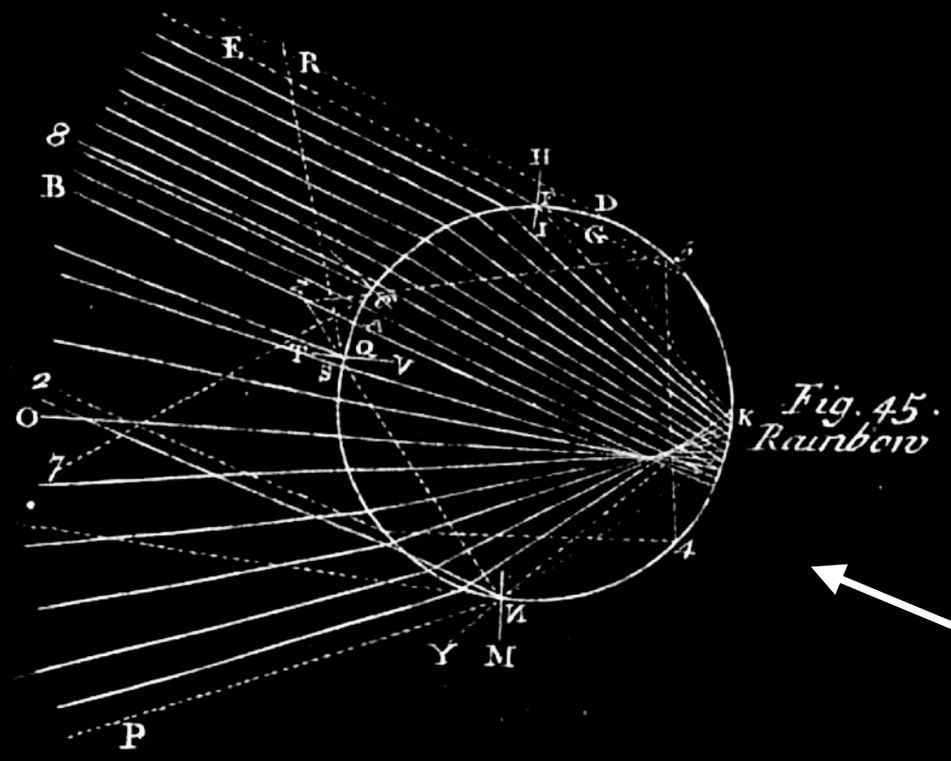
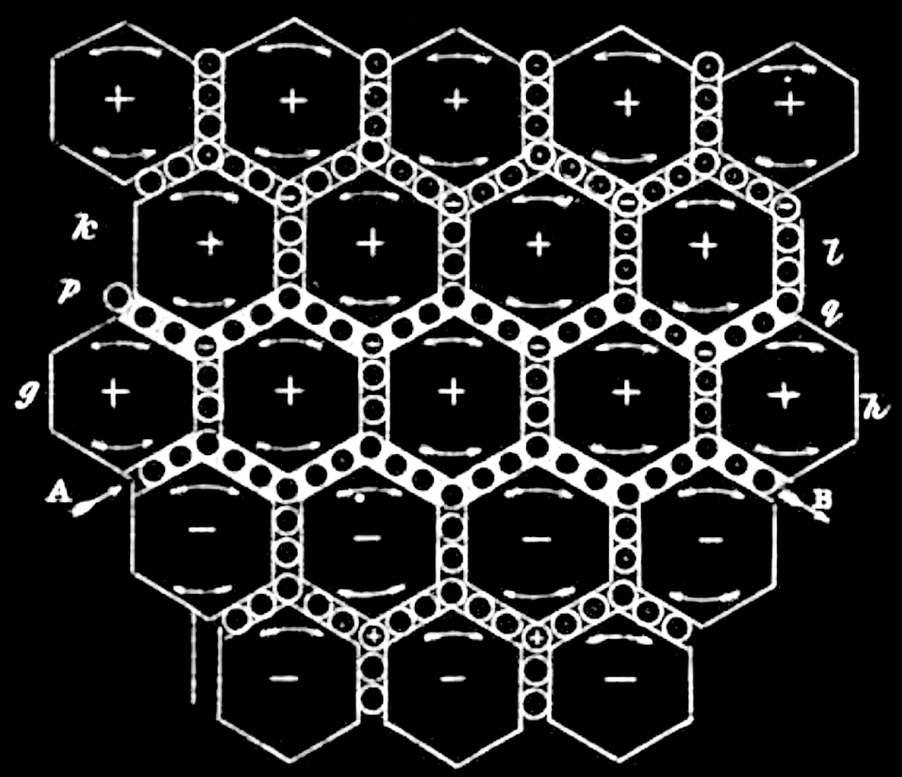


Fig. 45.
Raunbow

Vortices



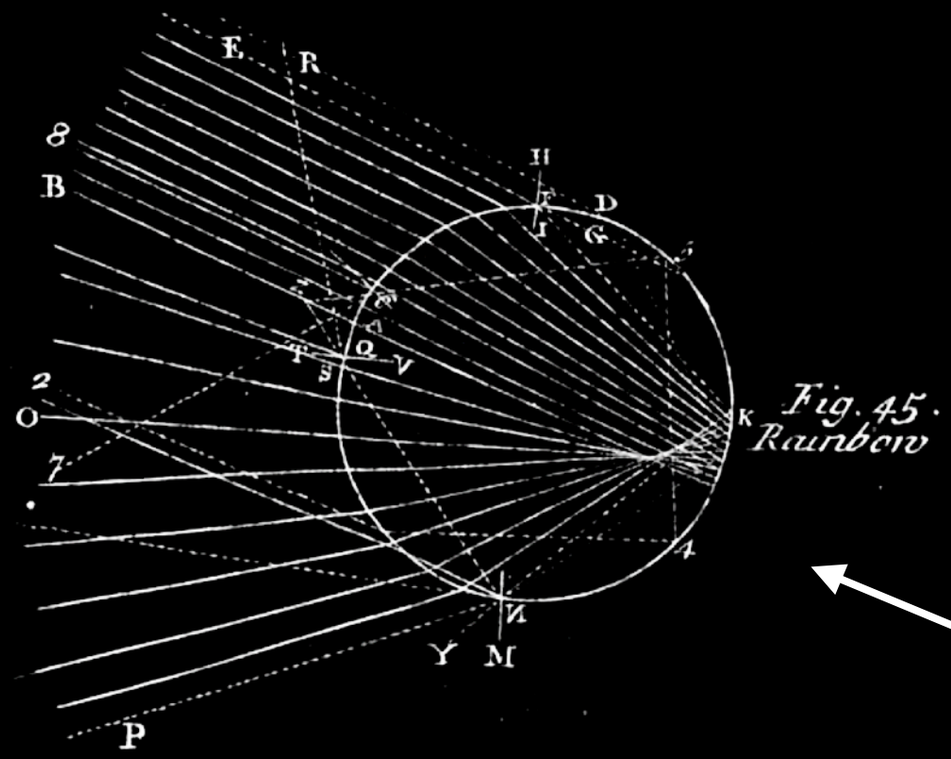
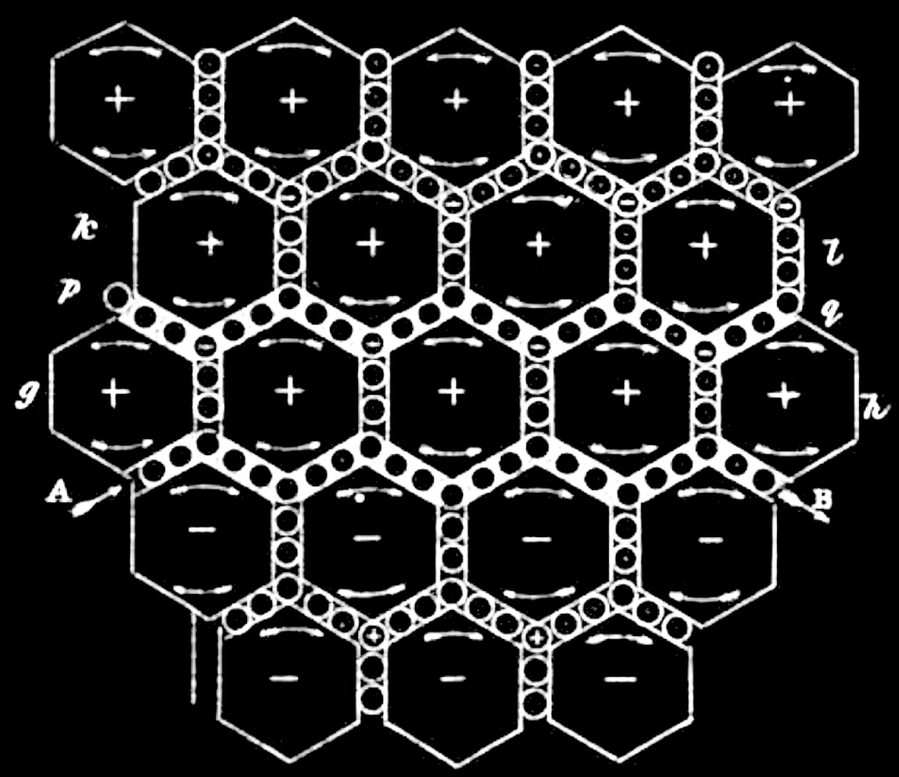


Fig. 45.
Raunbow

Vortices



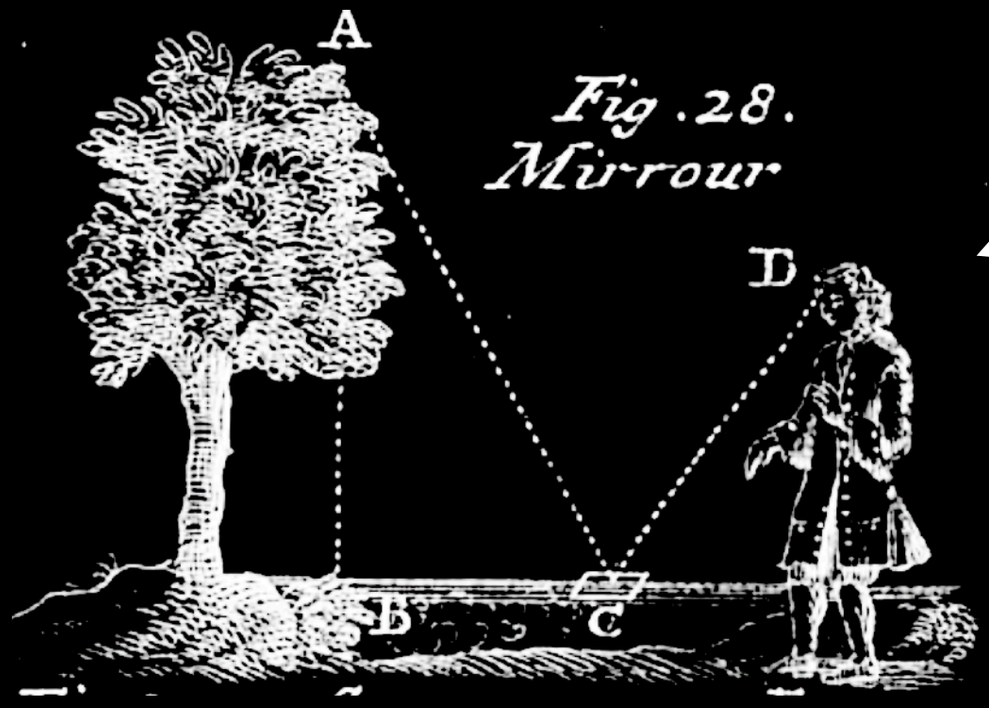


Fig. 28.
Mirrour

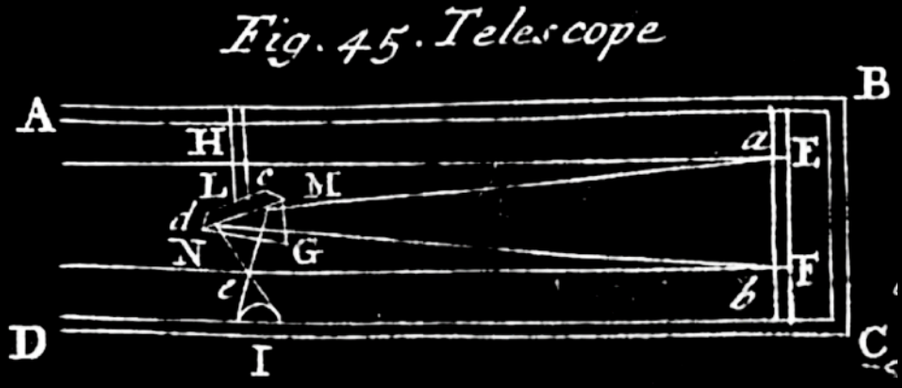


Fig. 45. Telescope

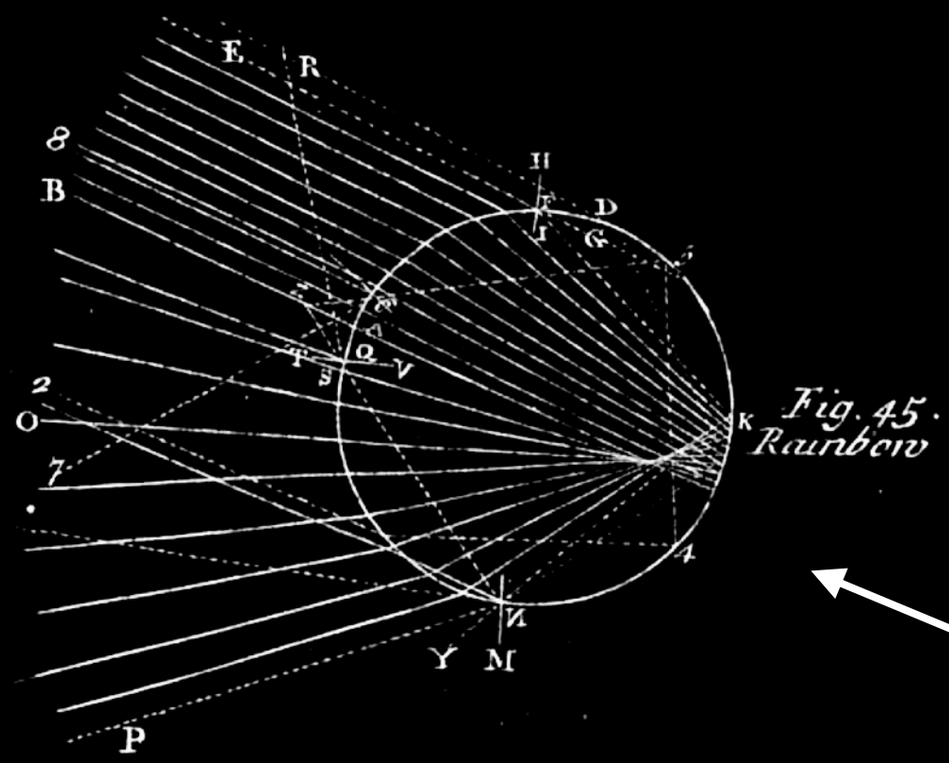


Fig. 45. Raunbow

Vortices

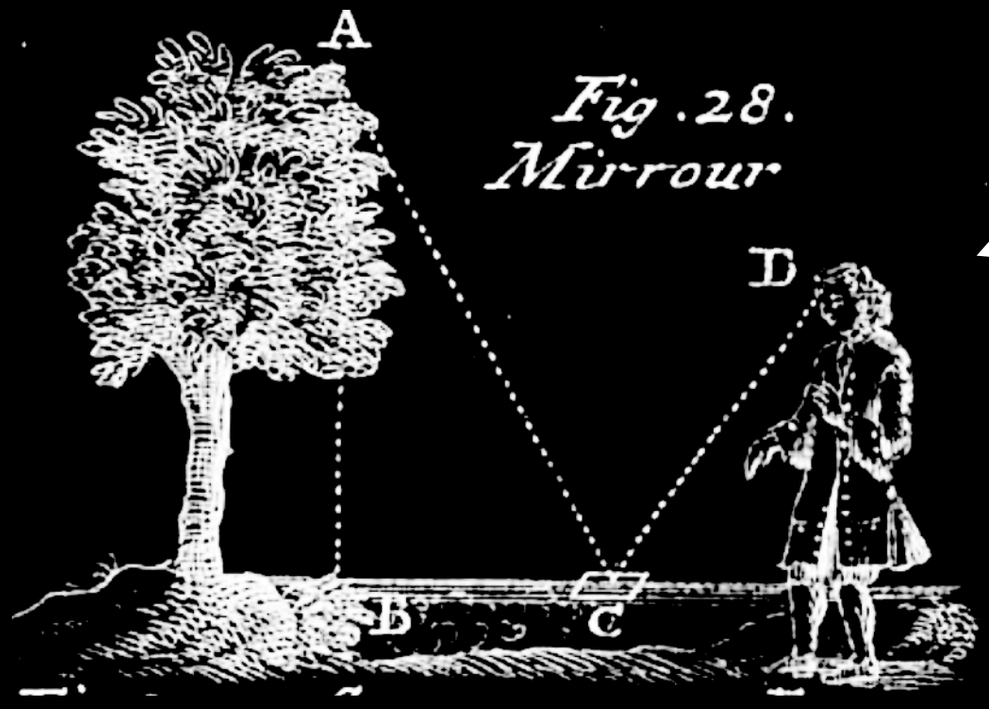
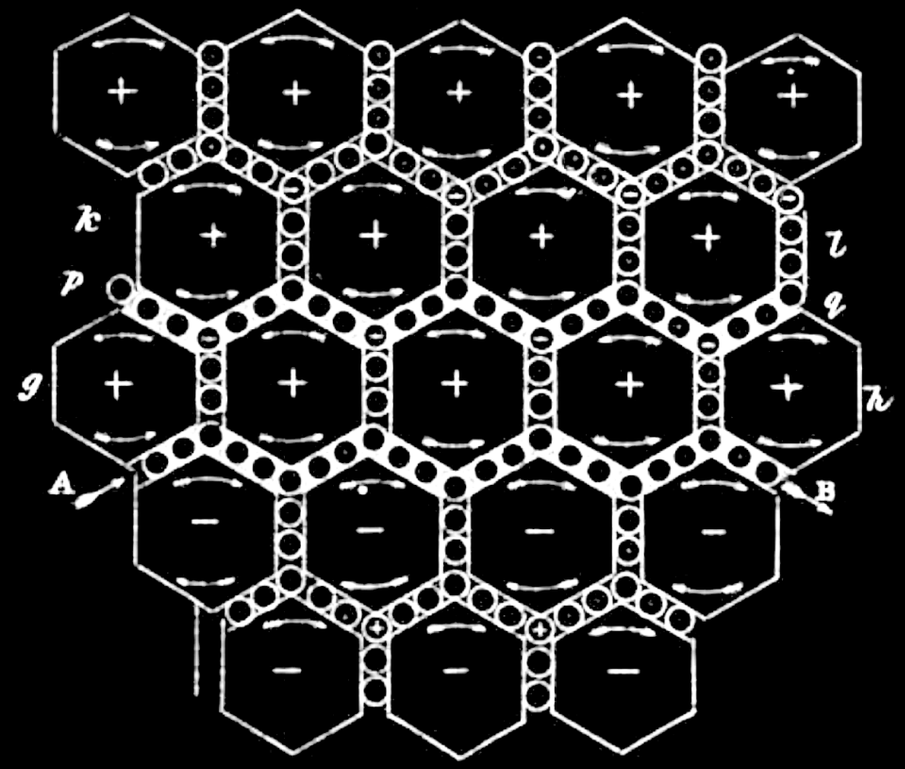
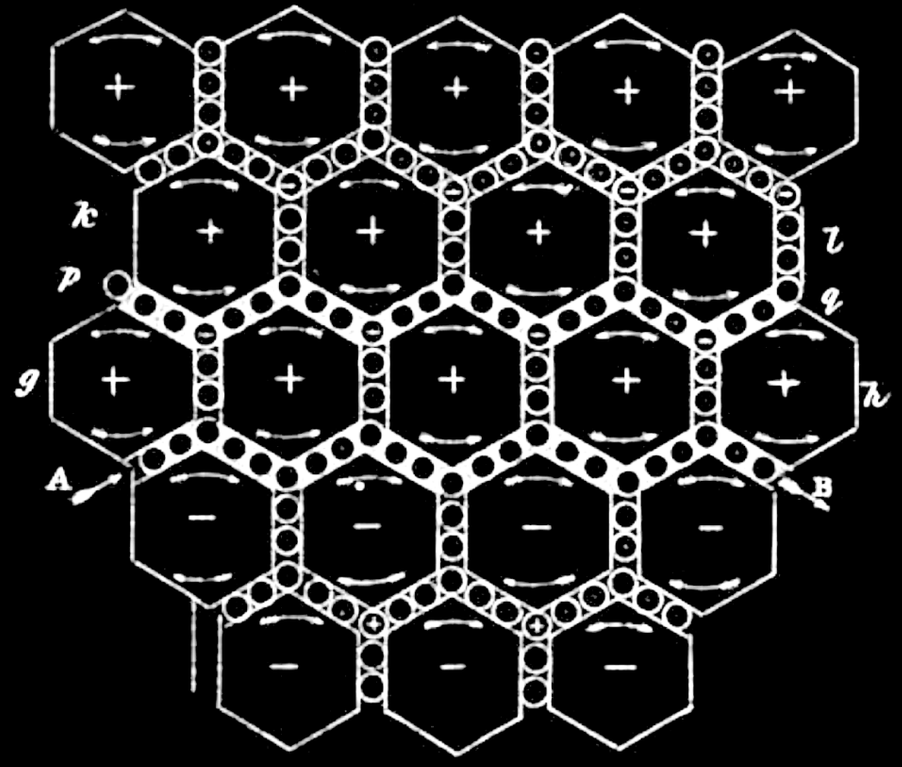


Fig. 28. Mirrour



Vortices



“Electric spiderwebs”

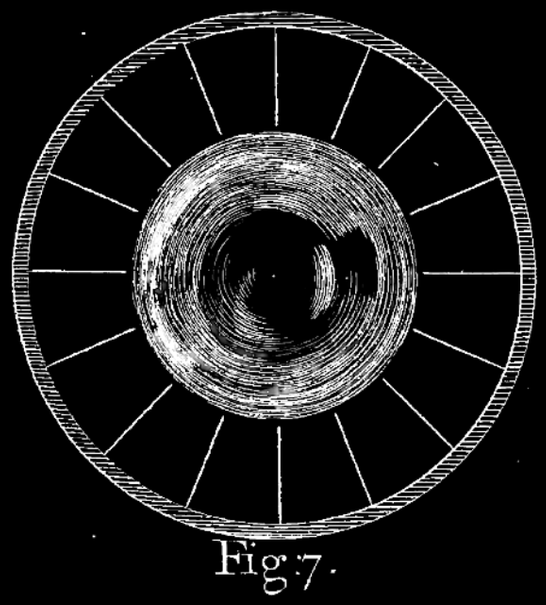
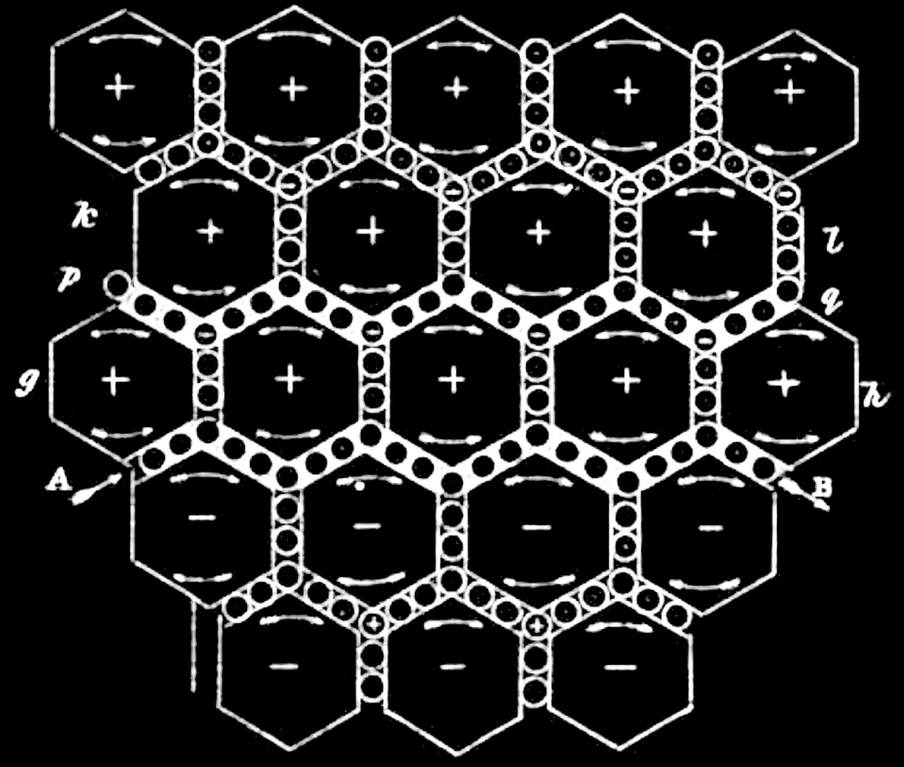
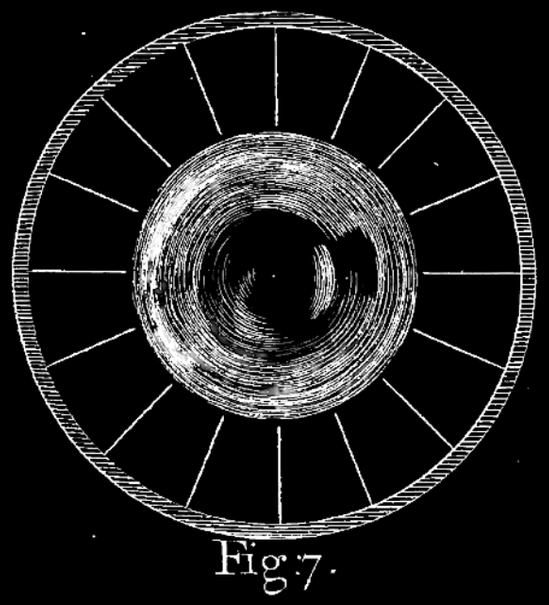


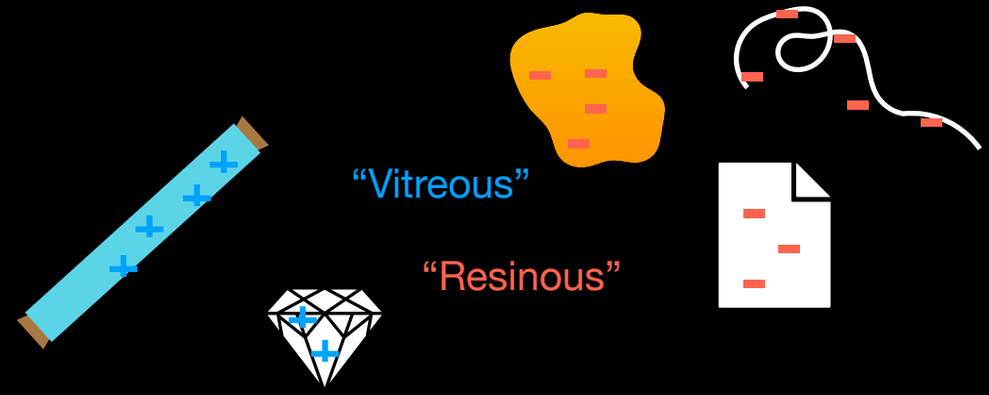
Fig. 7.

Vortices



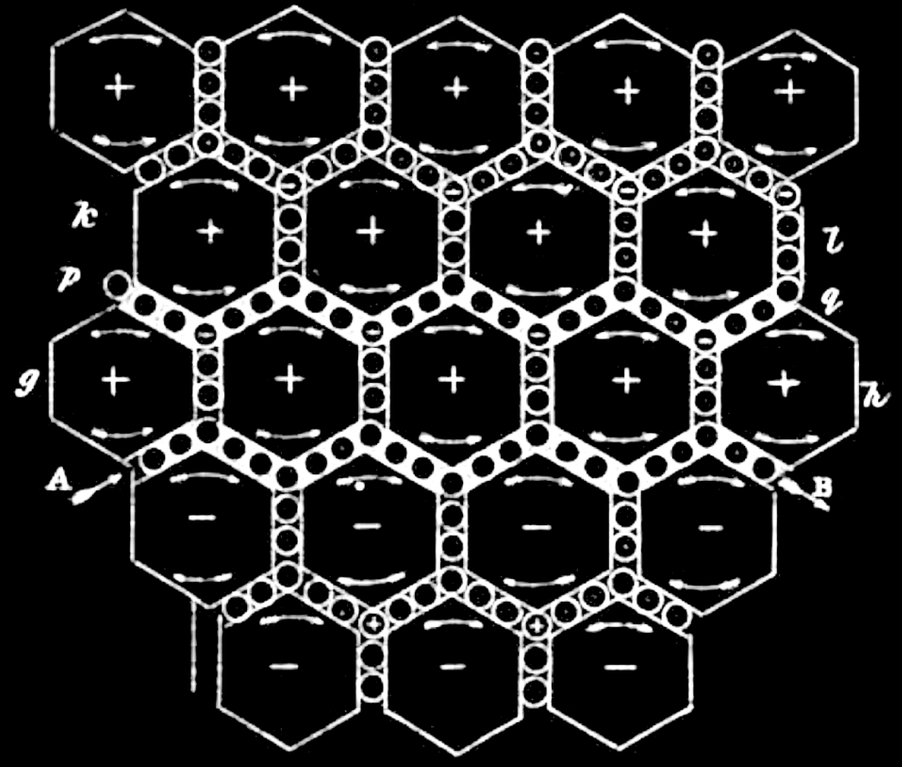
“Electric spiderwebs”



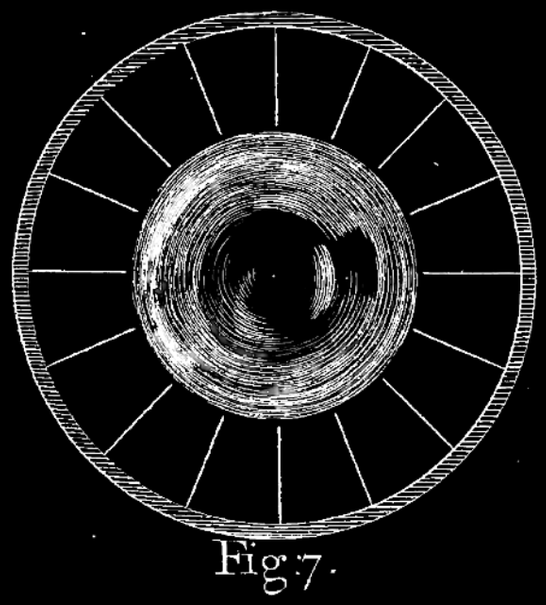


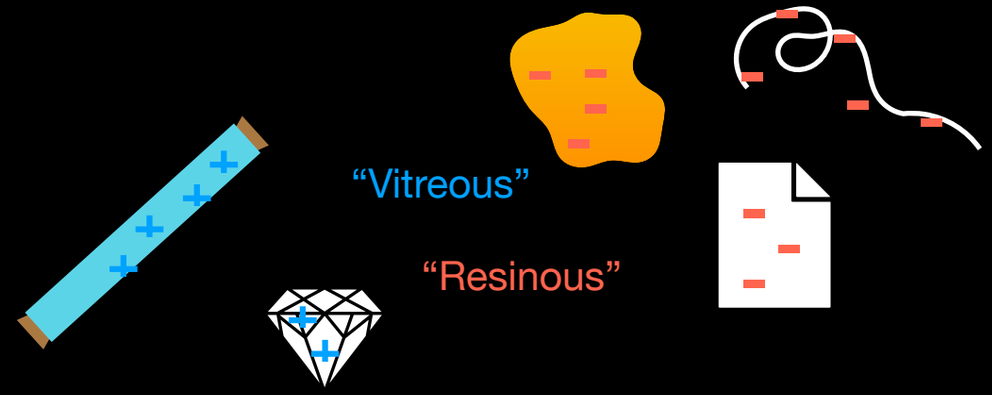
“Two kinds of electrick”

Vortices

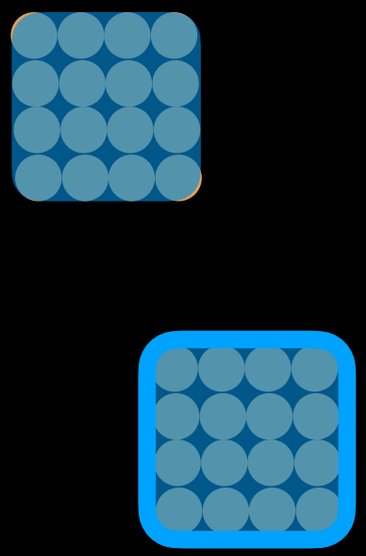


"Electric spiderwebs"



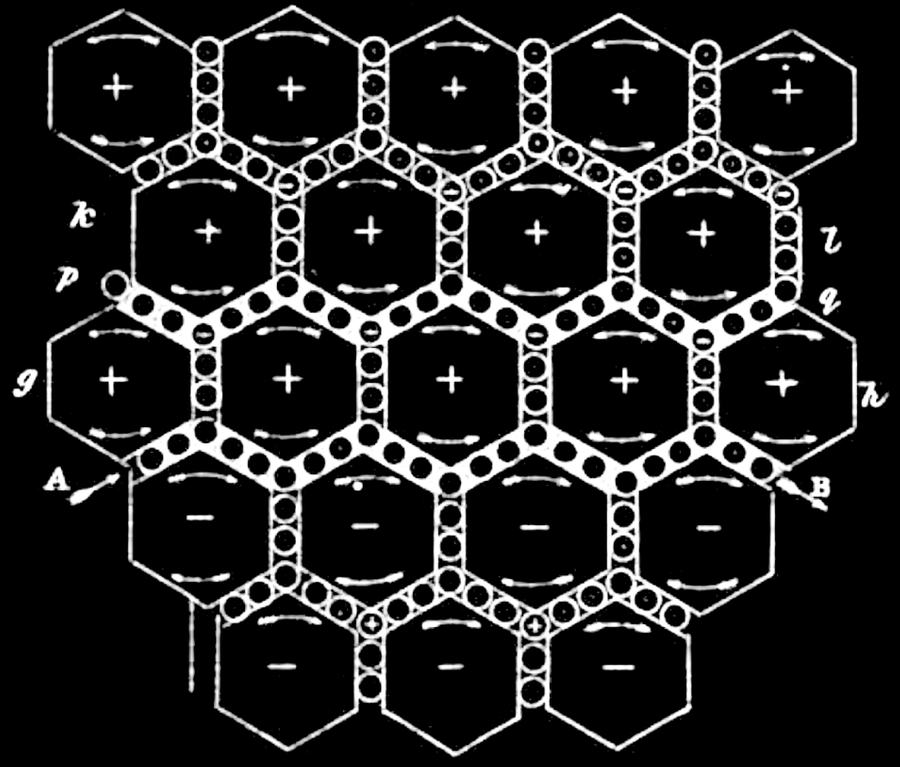


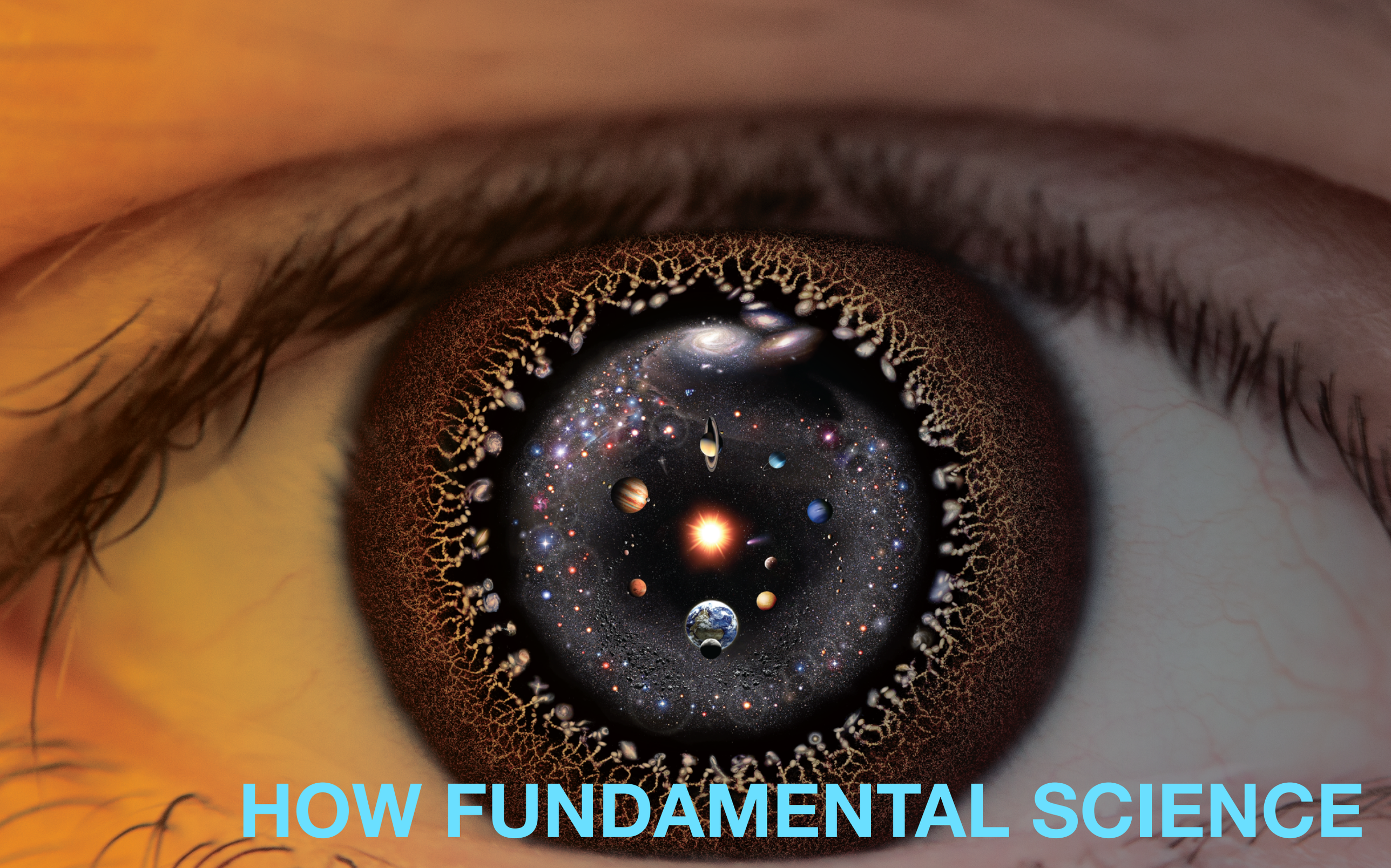
"Two kinds of electrick"



"Electrical atmospheres"

Vortices





HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD

A STORY OF INVENTION AND DISCOVERY

Important!

Next Saturday, November 4th

Room 120

(Enter by north entrance)