HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD
A STORY OF INVENTION AND DISCOVERY

Philipp Windischhofer
October 28, 2023
~300 BC

ηλεκτρων (elektron)
"Ordinary" electricity
~1700

~300 BC

ηλεκτρον (elektron)
~300 BC

“Ordinary” electricity
~1700

Transportation of the “electrick vertue”

1729

ʔλεκτρον (elektron)
~300 BC

`هةكتروم (elektron)

~1700

“Ordinary”

electricity

Transportation of the

“electrick vertue”

1729

Leyden
Jar: storage

(“amplification”)

1745

“Vitreous electricity”

(Positive)

1745

“Resinous electricity”

(Negative)
~300 BC

**ℏλεκτρον (elektron)**

~1700

“Ordinary” electricity

~1700

Transportation of the “electrick vertue”

1729

“Voltaic electricity”

Leyden Jar: storage (“amplification”)

1800

“Vitreous electricity” (Positive)

1745

“Resinous electricity” (Negative)
Stephen Gray:
Stephen Gray:

*Electrical conductivity: a chance discovery*
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Charles du Fay:

Two kinds of electric charge: a product of methodical investigation
Stephen Gray:

*Electrical conductivity: a chance discovery*

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“Vitreous”
Stephen Gray:

Electrical conductivity: a chance discovery

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Two kinds of electric charge: a product of methodical investigation

"Vitreous"

"Resinous"
~300 BC

"Ordinary" electricity  
~1700

Transportation of the "electrick vertue"  

Leyden Jar: storage ("amplification")

"Voltaic electricity"  
1729

"Vitreous electricity" (Positive)  
1800

"Resinous electricity" (Negative)  
1745
~300 BC

-haspopup (elektron)

~1700

“Ordinary” electricity

Transportation of the “electrick vertue”

1729

Leyden Jar: storage (“amplification”)

1745

No precision instruments!

“Vitreous electricity” (Positive)

“Resinous electricity” (Negative)

1800

“Voltaic electricity”
~300 BC

ἤλεκτρον (elektron)

“Ordinary” electricity

~1700

The elephant in the room

“Voltaic electricity”

1745

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

Leyden Jar: storage (“amplification”)

“Vitreous electricity” (Positive)

“Resinous electricity” (Negative)

1729

Leyden Jar: storage (“amplification”)

No precision instruments!

1800

“Ordinary” electricity

~1700

“The elephant in the room
Hans Christian Ørsted
Physicist, chemist
Hans Christian Ørsted

Physicist, chemist

Thesis at Copenhagen: “The Architectonics of Natural Metaphysics”
Hans Christian Ørsted

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3-year travel scholarship:
Scientific tour around Europe

J. Ritter
Hans Christian Ørsted
Physicist, chemist

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Extracting “argillium” for the first time
Today: aluminum
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THE
SOUL IN NATURE.

BY
HANS CHRISTIAN ØRSTED.

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BY
LEONORA AND JOSEPH H. HOOPER.

LONDON:
HENRY G. Bohn, YORK STREET, COVENT GARDEN.
1843.
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.”
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“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

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“If we imagine a Voltaic pile, it would have the most perfect analogy with a magnet.”
Electricity and magnetism around 1820

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

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From Ørsted's notebook
“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.”

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“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

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“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.”

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What is the magnetic effect of an electric current?

Along the direction of the current?
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What is the magnetic effect of an electric current?

Along the direction of the current?

Wire in east-west orientation:

Nothing!
“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.”

July 1820:

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

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What is the magnetic effect of an electric current?

Outwards from the wire?

This is not what happened!
Finding the law

July 1820:

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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?
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!
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”

Utter confusion!

“Voltaic electricity”
Electricity in 1800

1820

“Animal electricity”

“Ordinary electricity”

Utter confusion!

“Voltaic electricity”
Electricity in 1800

1820

“Animal electricity”

“Ordinary electricity”

Utter confusion!

“Voltaic electricity”

“Electro-magnetism”
Electricity in 1800

1820

“Animal electricity”

“Ordinary electricity”

Utter confusion!

It will get worse before it gets better …

“Voltaic electricity”

“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
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
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
Ørsted’s discovery
Ørsted’s discovery

Current-carrying wire

Force
Ørsted’s discovery

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

Current-carrying wire

Force
Faraday takes over

Current-carrying wire

Force

Wire
cross-section
Faraday takes over

Current-carrying wire

Force

Wire cross-section
Faraday takes over

Current-carrying wire

Force

Wire

cross-section
Faraday takes over

Current-carrying wire

Force

Wire

cross-section
Faraday takes over
Faraday takes over

Current-carrying wire

Force

Wire
cross-section
Faraday takes over

Current-carrying wire

Force

“Poles” of the magnet

Wire

cross-section
Faraday takes over

Current-carrying wire

Force

“Poles” of the magnet

Wire

cross-section
Faraday takes over

Current-carrying wire

Force

“Poles” of the magnet

Wire
cross-section
“It was evident, also, that the pole of the magnet had a tendency to revolve round the wire …”
Faraday takes over

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

“\textit{... 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

Fig. 1.

To Voltaic pile
The first electric “motor” (1821)

“Rotation of a pole around a wire”

“Rotation of a wire around a pole”

Mercury

To Voltaic pile

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“Rotation of a wire around a pole”

---

To Voltaic pile

Mercury

Magnet

---

To Voltaic pile
The first electric “motor” (1821)

“Rotation of a pole around a wire”

“Rotation of a wire around a pole”

[Diagram showing a device with two Mercury vessels connected to a Voltaic pile, with a Magnet inside each vessel, demonstrating the concept of a motor.]
The first electric “motor” (1821)

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To Voltaic pile
The first electric “motor” (1821)

“Rotation of a pole around a wire”

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Fig. 1.
The first electric “motor” (1821)

“Rotation of a pole around a wire”

To Voltaic pile

“Rotation of a wire around a pole”

Mercury

Magnet

Fig. 1.

Mercury

To Voltaic pile
Other wire arrangements
Other wire arrangements

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

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


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 …”
"... 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

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

Butoir

Aig. indicatrice

Multiplicateur

Routon de rappel

Indicating needle
Faraday’s Galvanometer

- Butoir
- Bouton de rappel
- Fine silk thread
- Indicating needle
- Aig indicatrice
- Multiplicateur
Faraday’s Galvanometer

- **Butoir**
- **Aig. indicatrice**
- **Multiplicateur**
- **Coil** ("Multiplicator")
- **Indicating needle**
- **Fine silk thread**
- **Bouton de rappel**
Faraday’s Galvanometer

- **Butoir**
- **Routon de rappel**
- **Indicating needle**
- **Sensing needle**
- **Coil** ("Multiplicator")
- **Fine silk thread**
- **Aig. indicatrice**
- **Multiplicateur**
Faraday’s Galvanometer

- Fine silk thread
- Indicating needle
- Sensing needle
- Coil ("Multiplicator")
Faraday’s Galvanometer

Two magnetic needles in opposite orientation:

Compensation of Earth’s magnetic field
The first experiment

Voltaic pile

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

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

“"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.”

“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.”
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“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.”
William Sturgeon
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“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 […]”
The first electromagnet (1826)
The first electromagnet (1826)

“On making the galvanic connexion through the copper wire, the iron wire becomes a strong horseshoe 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 horseshoe 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!)

"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

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“The galvanometer was immediately affected, and to a degree far beyond what has been described.”
Back to Faraday: increasing the strength

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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

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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 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”

“Voltaic electricity”

“Ordinary electricity”

“Electro-magnetism”
Electricity in 1800

1820

1830

“Animal electricity”

“Ordinary electricity”

“Voltaic electricity”

“Electro-magnetism”
Electricity in 1800

1800

1820

1830

“Animal electricity”

“Ordinary electricity”

“Voltaic electricity”

“Electro-magnetism”

“Magneto-electricity”
Electricity in 1800

1820

1830

“Animal electricity”

“Voltaic electricity”

“Electro-magnetism”

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.”

“Magneto-electricity”
Effects of electricity

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

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

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“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.”

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“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

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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?

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“Relay” stations

Single-wire telegraph key

Electromagnet
Battery
Electricity connects the world

Samuel Morse: How to efficiently cover larger distances?

Single-wire telegraph key

“Relay” stations

Electromagnet

Battery

Weak Permanent Magnet.

Receiver / printer

Electro-magnet Strong.
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

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**One kind of electricity**
# Electromagnetism

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One kind of electricity

“Magnetic lines of force”
# Electromagnetism

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**One kind of electricity**

Electricity $\rightarrow$ magnetism

"Magnetic lines of force"
# Electromagnetism

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One kind of electricity

Electricity $\rightarrow$ magnetism

Magnetism $\rightarrow$ electricity

“Magnetic lines of force”
Electromagnetism

“Magnetic lines of force”

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One kind of electricity

Electricity \rightarrow magnetism

Magnetism \rightarrow 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

Saturn’s rings are made of many small particles

Color photography
James Clerk Maxwell
Scottish master physicist

Saturn’s rings are made of many small particles.

Drawing ovals with thread and pins.

Saturn’s rings are made of many small particles.

Kinetic theory of heat
Relation between temperature and speed of gas molecules.

Number of gas molecules
Cold
Warm
Velocity
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.”

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“Action at a distance” again!
A “magnetic medium” (1861)
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.”
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.”
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 […]”
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

Lines of magnetic force
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
“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 […]”

Faraday’s observation

Maxwell’s model

Lines of magnetic force

Direction of line of force

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

Current

Lines of magnetic force
“We know that when electricity circulates in a conductor, it produces lines of magnetic force passing through the circuit […]”
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
“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.”
Maxwell: under the right conditions, vortices *themselves* create vortices
Vortices create vortices

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Maxwell: under the right conditions, vortices themselves create vortices.
Vortices create vortices

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Vortices create 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

\[
V = E,
\]

\[
= 310,740,000,000 \text{ millimetres per second},
\]

\[
= 193,088 \text{ miles per second}.
\]

(186)
Electromagnetic “waves”

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

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V = E, \\
= 310,740,000,000 \text{ millimetres per second}, \\
= 193,088 \text{ miles per second.}
\] . (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

\[
V = 314,858,000,000 \text{ millimetres} \\
= 195,647 \text{ miles per second.} \quad \ldots \ldots \quad (137)
\]
Electromagnetic “waves”

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“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
Vortices
Vortices
Vortices
“Electric spiderwebs”

Vortices
“Electric spiderwebs”

Fig. 7.

“Vitreous”

“Resinous”

“Two kinds of electrick”

Vortices
“Electric spiderwebs”

“Electrical atmospheres”

“Vitreous”

“Resinous”

“Two kinds of electrick”

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)