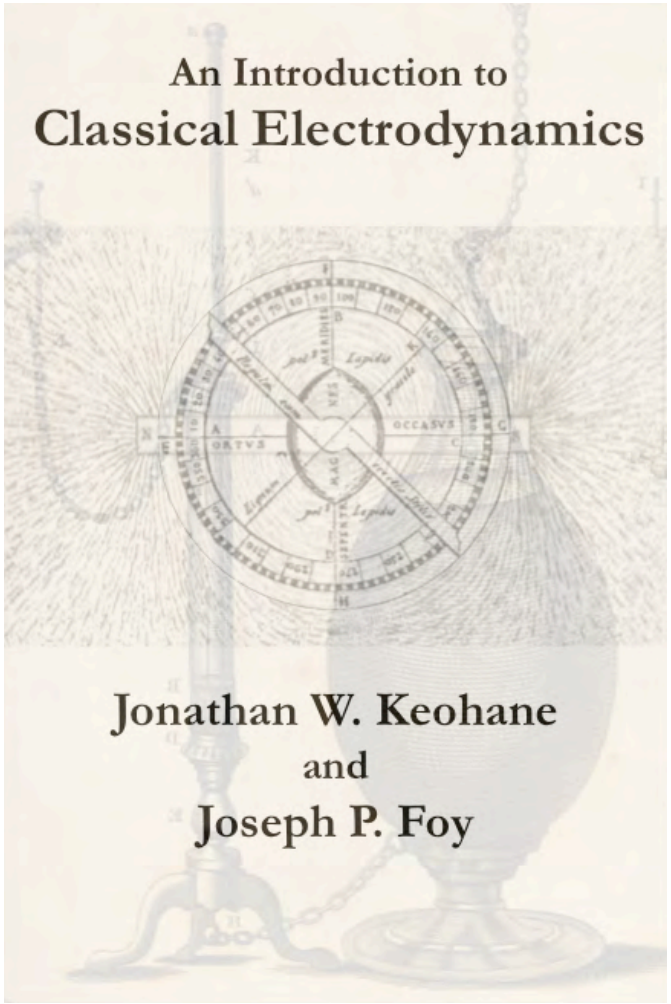
Peregrinus
vs.
The Pole Model



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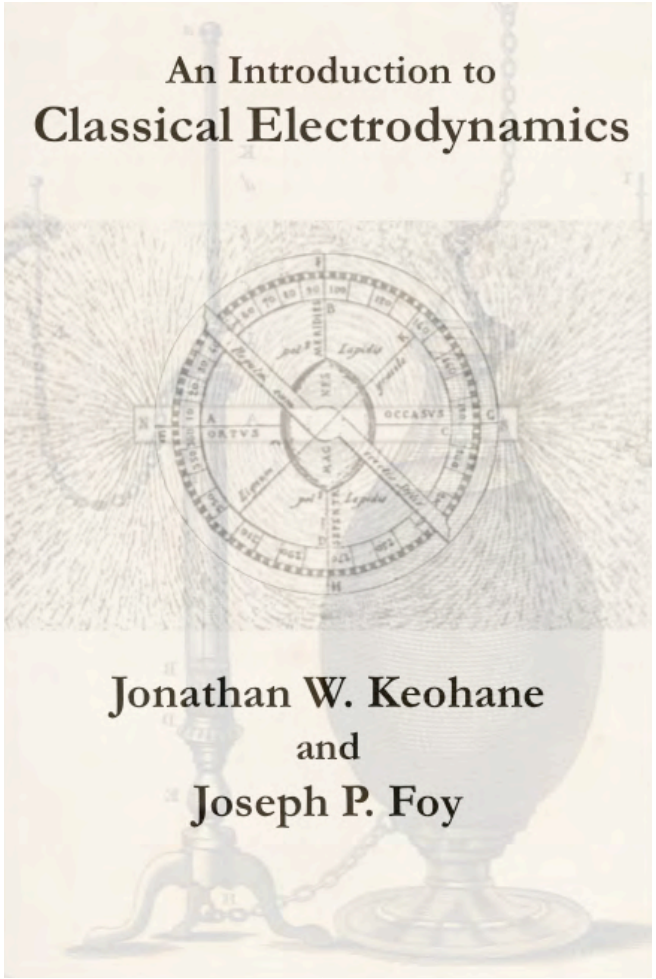


Did physics monotonically progress with time?

Consider a toy model of the history of physics:

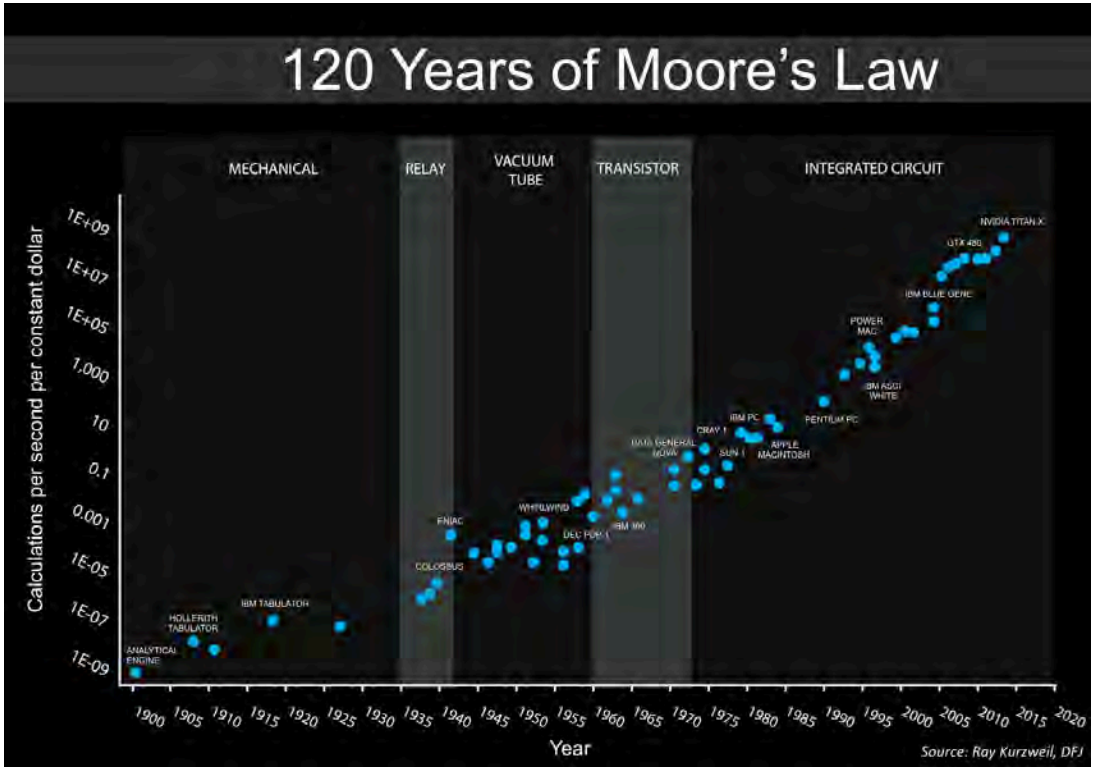
The more we know the faster we learn.

Is this true?

If so, in what fields and over how long?

If this were the case, then physical knowledge should increase exponentially over time.

Like Moore's law, as in this graph from the Wikipedia site. (Before that this graph was flat, in real dollars, as it depended on the cost of a clerk's wages.)



Our knowledge of electricity increased pretty much monotonically throughout history.

Why?

Because scientists pretty much got it right the first time.

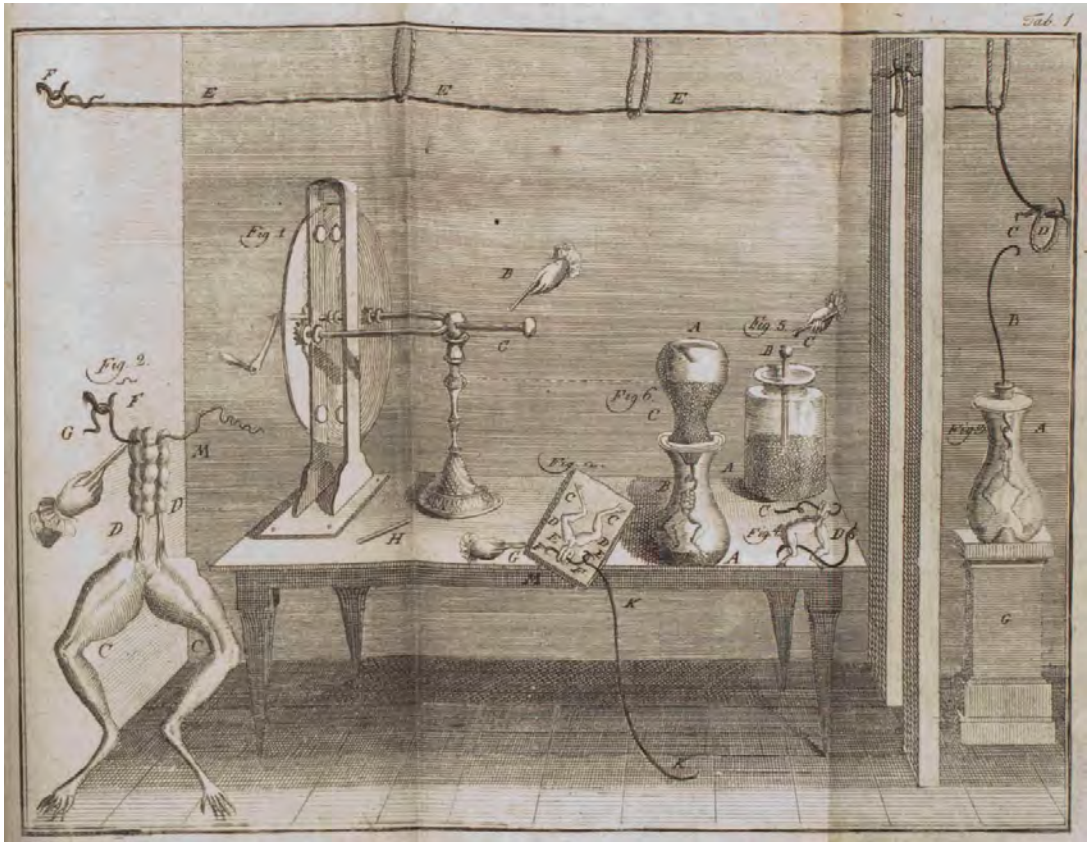
The exception that proves the rule:

Luigi Galvani discovered that electricity caused frog's legs to twitch.

He concluded that electricity was a property of animals.

Volta, on the other hand, followed up on the idea, discovered the Voltaic Pile.

So no generation of young physicists were taught the wrong theory as if it were fact!



Magnetism was Totally Different!

The right model came first,
and was superseded by the wrong model,
which was taught as fact to generations of
scientists and engineers.

Why?
Because the wrong theory was simple and
explained the observed phenomena
quantitatively.

Yes, it was quantitative science that led people astray!
We physicists are an odd lot:
The right theory has to be both right
quantitatively and qualitatively.

Here is the story …
Once upon a time there was a knight named Peter from
a town call Maricourt in France, and he …

The Battle of Benevento

In 1264, the French Pope Urban IV gave southwestern Italy to the French prince Charles of Anjou. There was a catch, however; Charles would have to take it by force. Despite the valiant efforts of a band of Muslim archers from the town of Lucera, he won the Battle of Benevento in 1266, killing the current king, Manfred, who was the son of the Holy Roman Emperor Frederick II of Hohenstaufen.

Battle of Tagliacozzo

Between 1264 and 1268 there were a number of revolts against the French, and in in 1268 the German Prince, Conradin (Conrad V), invaded Charles's nascent kingdom. Charles's army prevailed in putting down the rebellions and Conradin lost his head. These revolts made Charles sure up his power, and on all accounts he was a very good king, for the times.


Tagilacozzo
Lucera
Benevento
Charles of Anjou
1265
Peter III of Aragon
1282
MARG-
RAVATE
OF
TUSCANY
PATRIMONIUM
Perugia
Orvieto
Viterbo
Rome
Tagilacozzo
Termoli
Vieste
Manfredonia
Barletta
Trani
Bari
Florentino
Lucera
Foggia
Capua
Melfi
Castel
del Monte
Benevento
Gioia del Colle
Salerno
Gravina
di Puglia
Altamura
Taranto
Ora
APULIA
CALABRIA
Cosenza
Nicastro
Vibo Valentia
Messina
Palermo
Trapani
Reggio
SICILY
Taormina
Enna
Catania
Augusta
Residence of Frederick II
Castles
Staufen castles

Lucera

Lucera was a thriving Islamic community under German (Holy Roman) Rule in the 13th century. They were very productive farmers, and the city became quite wealthy.

They also had some of the best archers in the whole kingdom, who fought long and hard against Charles's army at Benevento.

All in all, Lucera was a model of multiculturalism under the Holy Roman Empire.

But, after the Battle of Tagliacozzo, the German Mayor lead the city in revolt against Charles's rule.

So, Charles's knights had to lay siege to the city.

Lucera

This, of course, meant surrounding the walls and waiting it out.

And what should a knight do to to pass the time …

Conducting Magnetism Experiments of Course ... what else silly?

THE LETTER OF
PETRUS
PEREGRINUS
ON THE MAGNET, A.D. 1269

TRANSLATED BY

BROTHER ARNOLD, M.Sc.
PRINCIPAL OF LA SALLE INSTITUTE, TROY

WITH

INTRODUCTORY NOTICE

BY

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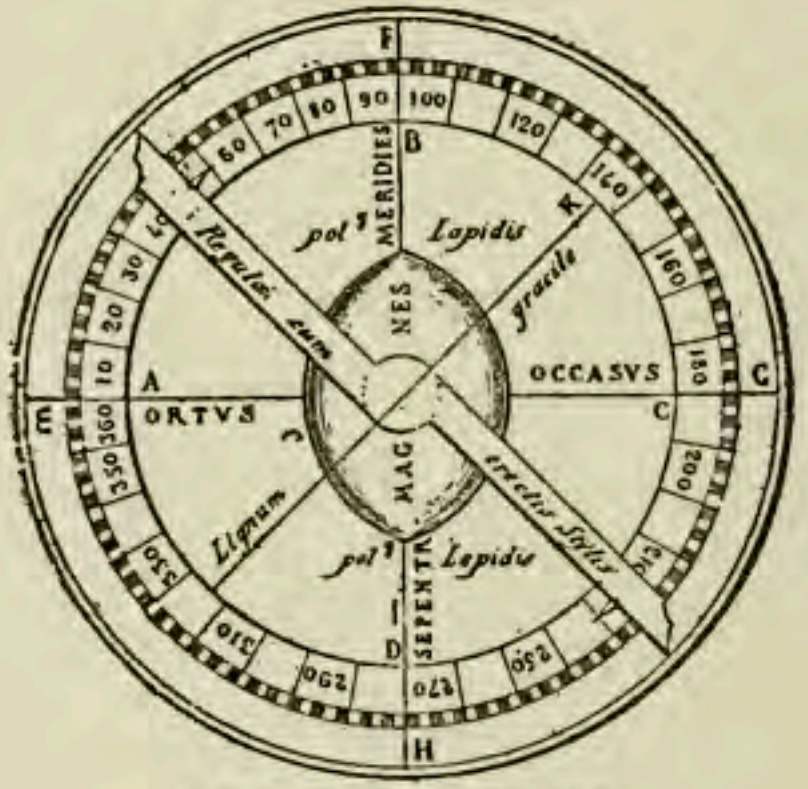
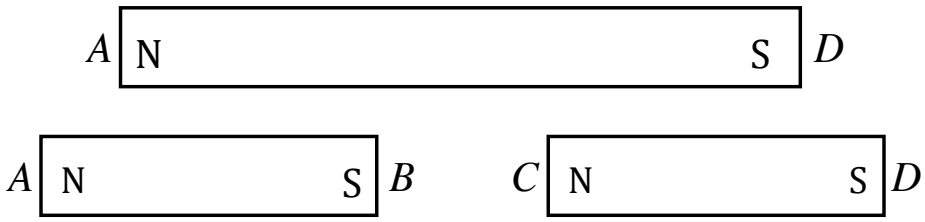


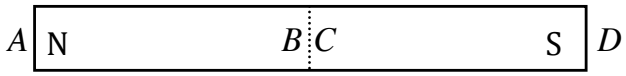
FIG. I.—AZIMUTH COMPASS

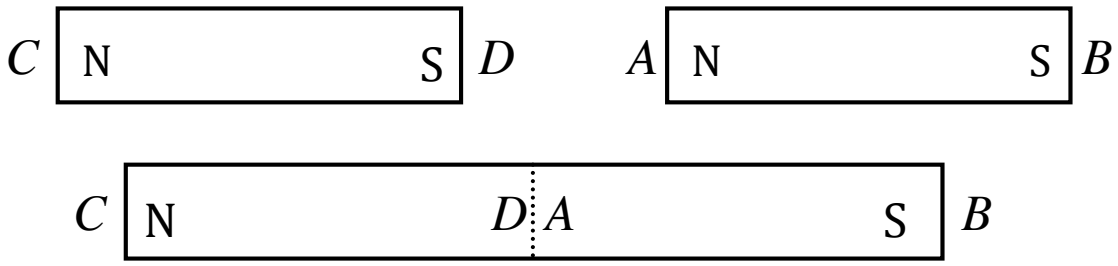
Peregrinus's Argument

Take a lodestone which you may call AD, in which A is the north pole and D the south; cut this stone into two parts, so that you may have two distinct stones; place the stone having the pole A so that it may float on water and you will observe that A turns towards the north as before; the breaking did not destroy the properties of the parts of the stone, since it is homogeneous; hence it follows that the part of the stone at the point of fracture, which may be marked B, must be a south pole; this broken part of which we are now speaking may be called AB. The other, which contains D, should then be placed so as to float on water, when you will see D point towards the south because it is a south pole; but the other end at the point of fracture, lettered C, will be a north pole; this stone may now be named CD.



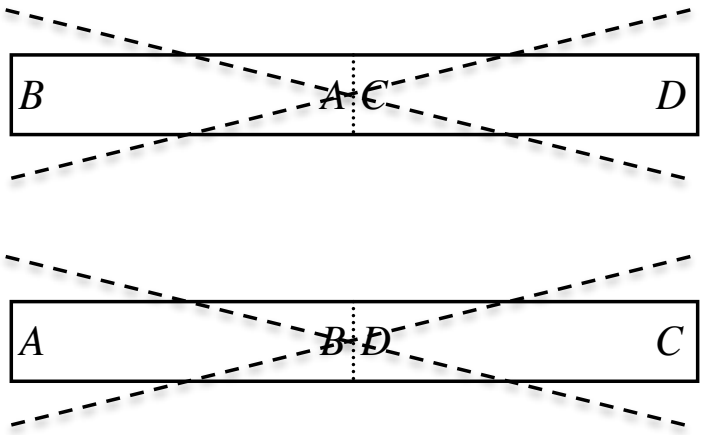
If we consider the first stone as the active agent, then the second, or CD, will be the passive subject. You will also notice that the ends of the two stones, which before their separation were together, after breaking will become one a north pole and the other a south pole. If now these same broken portions are brought near each other, one will attract the other, so that they will again be joined at the points B and C, where the fracture occurred. Thus, by natural instinct, one single stone will be formed as before. This may be demonstrated fully by cementing the parts together, when the same effects will be produced as before the stone was broken. As you will perceive from this experiment, the active agent desires to become one with the passive subject because of the similarity that exists between them. Hence C, being a north pole, must be brought close to B, so that the agent and its subject may form one and the same straight line in the order AB, CD and B and C being at the same point. In this union the identity of the extreme parts is retained and preserved just as they were at first; for A is the north pole in the entire line as it was in the divided one; so also D is the south pole as it was in the divided passive subject, but B and C have been made effectually into one.





In the same way it happens that if A be joined to D so as to make the two lines one, in virtue of this union due to attraction in the order CD AB, then A and D will constitute but one point, the identity of the extreme parts will remain unchanged just as they were before being brought together, for C is a north pole and B a south, as during their separation. If you proceed in a different fashion, this identity or similarity of parts will not be preserved; for you will perceive that if C, a north pole, be joined to A, a north pole, contrary to the demonstrated truth, and from these two lines a single one, BACD, is formed, as D was a south pole before the parts were united, it is then necessary that the other extremity should be a north pole, and as B is a south pole, the identity of the parts of the former similarity is destroyed.

If you make B the south pole as it was before they united, then D must become north, though it was south in the original stone; in this way neither the identity nor similarity of parts is preserved. It is becoming that when the two are united into one, they should bear the same likeness as the agent, otherwise nature would be called upon to do what is impossible. The same incongruity would occur if you were to join B with D so as to make the line ABDC, as is plain to any person who reflects a moment. Nature, therefore, aims at being and also at acting in the best manner possible; it selects the former motion and order rather than the second because the identity is better preserved. From all this it is evident why the north pole attracts the south and conversely, and also why the south pole does not attract the south pole and the north pole does not attract the north.



There is no such thing as *northness* nor *southness*?

Whatever Happened to Lucera

Charles was, relatively, kind to the inhabitants of the city. He taxed them heavily for their belligerence, but otherwise treated them well allowing them to keep living peacefully and practice their own religion.

All in all, he was a very good king …

His son, Charles II, on the other hand ethnically cleansed the region, selling all the Muslims into slavery by the end of the century.

The Hospital for Wounded Knights

We do not know what happened to Sir Peter of Maricourt after his letter of 1269.

Presumably he would have completed more scientific works had he returned to Picardy, but one never knows. He may have fallen in battle, quietly joined a monastery, or settled down somewhere in Italy.

What we do know, however, is that in 1270 the king granted a number of the knights funds to build a church and hospital in Naples (St. Eligio) to tend to the wounded.

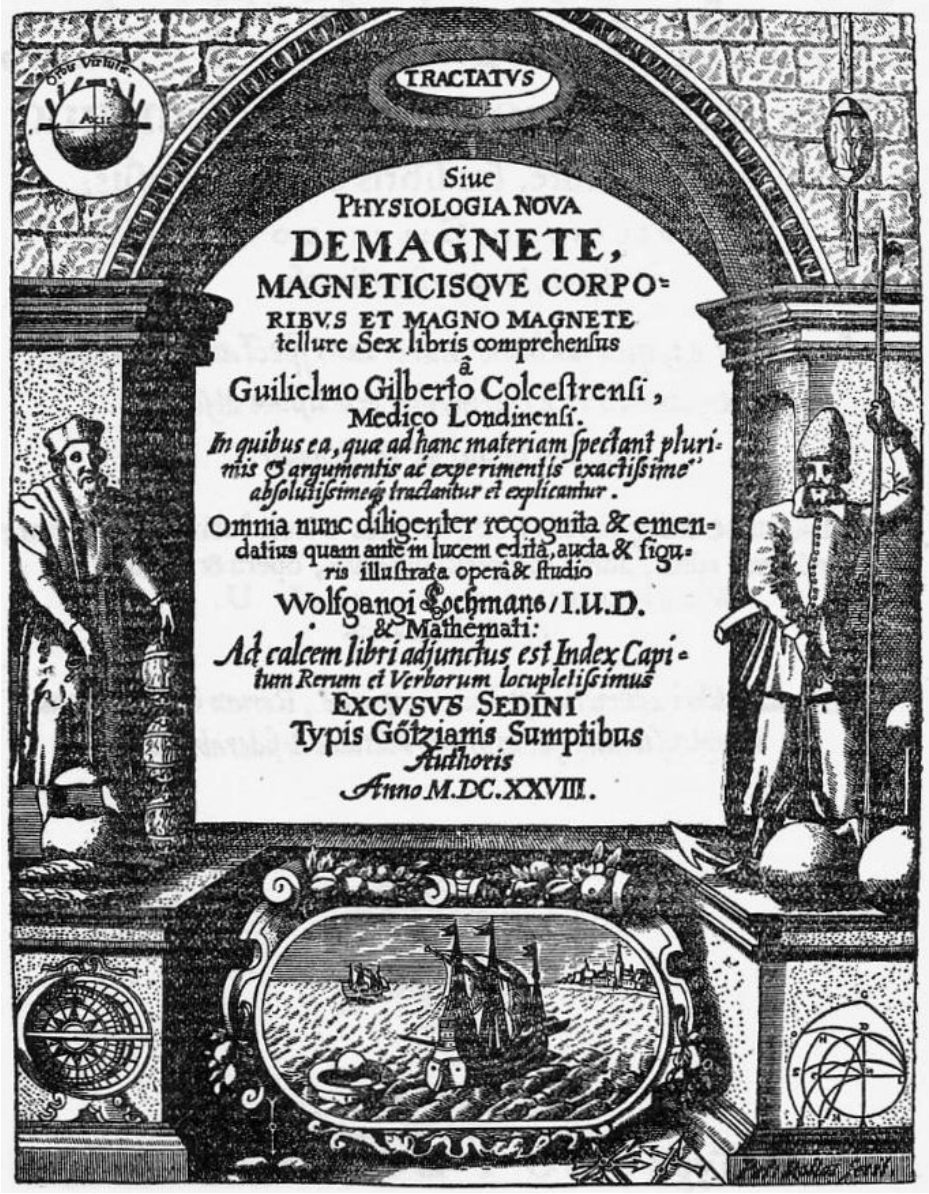
We also know that the king brought as much French culture as possible to southwestern Italy, and personally oversaw the building of two Cistercian monasteries in the French Gothic style.

Caroline A. Bruzelius, "'ad modum francia': Charles of Anjou and Gothic Architecture in the Kingdom of Sicily," Journal of the Society of Architectural Historians Vol. 50, No. 4 (1991), 402-420.

How did Peregrinus's ideas affect later work?

William Gilbert (1544-1603) reproduced, and expanded upon, the experiments, and in turn published his own treatse. Gilbert's work influenced other scientists, whose work influenced others, and so on.

This is, of course, what libraries are for.


TRACTATVS

Siue
PHYSIOLOGIA NOVA
DEMAGNETE,
MAGNETICISQVE CORPO-
RIBVS ET MAGNO MAGNETE
tellure Sex libris comprehensus
à
Guilielmo Gilberto Colcestrensi,
Medico Londinensi.
In quibus ea, quæ ad hanc materiam spectant plurimis & argumentis ac experimentis exactissime absolutissimeq; tractantur et explicantur.
Omnia nunc diligenter recognita & emendatius quam antè in lucem edita, aucta & figuris illustrata operâ & studio
Wolfgangi Lochmanni I.U.D.
& Mathematis:
Ad calcem libri adjunctus est Index Capitum Rerum et Verborum locupletissimus
EXCVSVS SEDINI
Typis Gõtzianis Sumptibus
Authoris
Anno M.DC.XXVIII.

Coulomb's Pole Model

$$\vec{F}_g = \frac{-G m_1 m_2}{r^2}\hat{r}$$

N's Law of Gravity (1687)

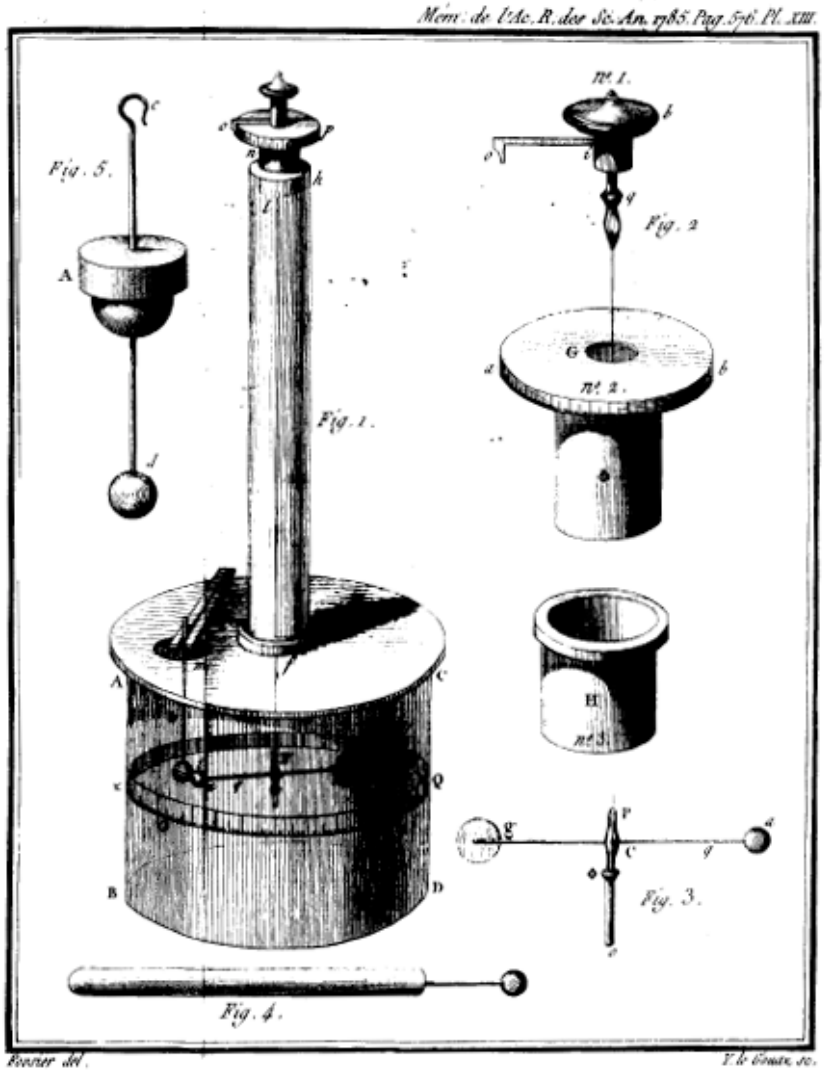
$$\vec{F}_E = \frac{q_1 q_2}{r^2}\hat{r}$$

Coulomb's Law (1784)

Reasoning by analogy, shouldn't magnets follow a similar law? Why not?

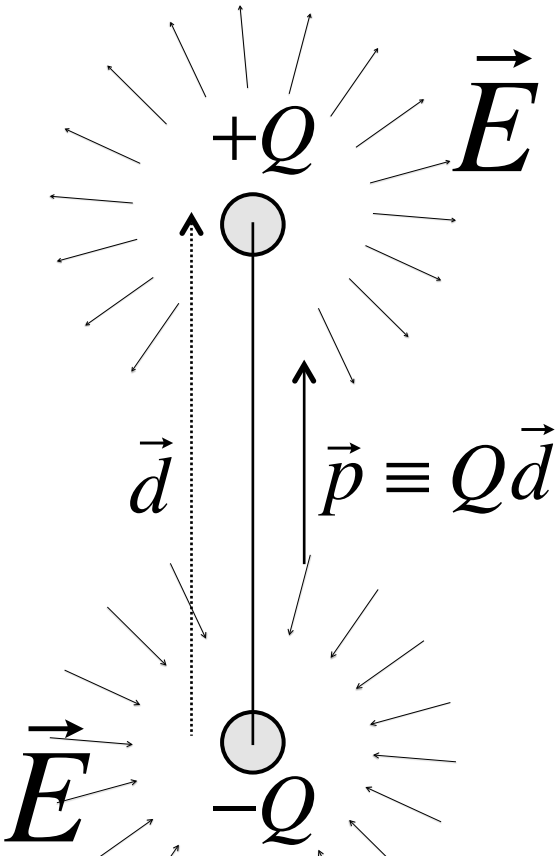
Basic idea: North poles repel, as do south poles. But a north attracts a south. But iron is attracted to everything. Why?

This is exactly the way electrostatics works. So it makes sense … right?



What is a “pole” anyway?

Electric Dipoles

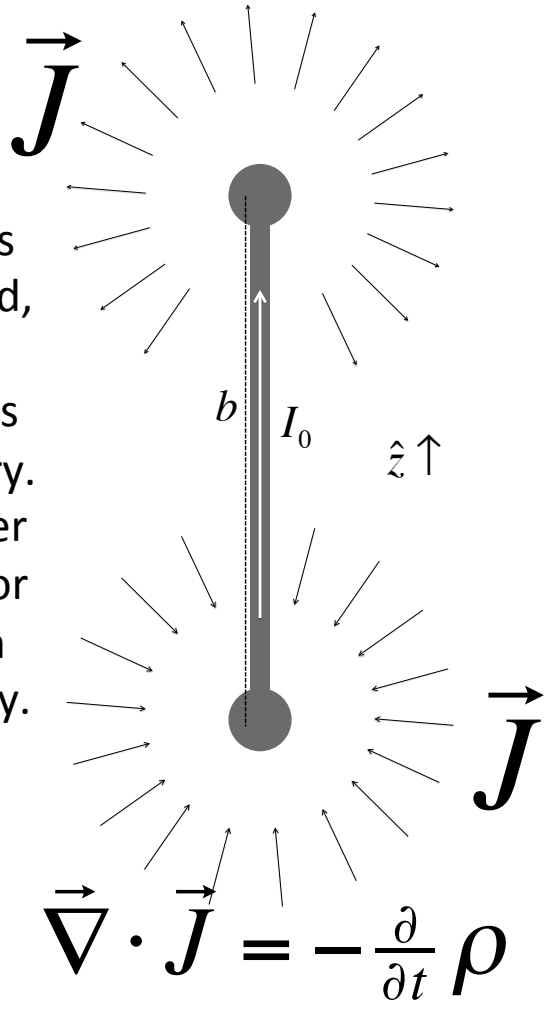


$$\vec{\nabla} \cdot \vec{E} = 4\pi\rho$$

The force follows an inverse square law, so the electric field points radially toward, or from, charges.

A Dipole Circuit

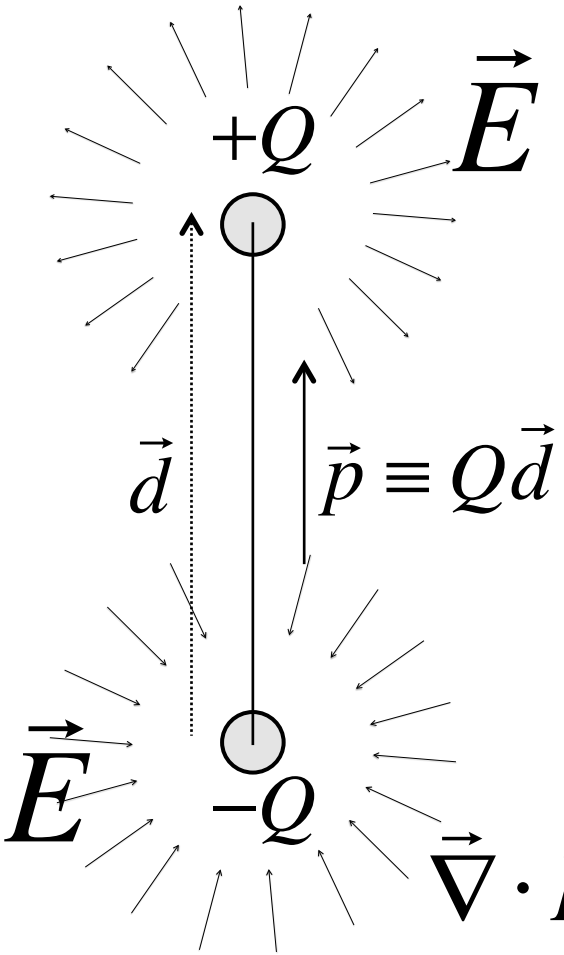
Charge is conserved, so the current is circulatory. Like water in pipes or blood in your body.



$$\vec{\nabla} \cdot \vec{J} = -\frac{\partial}{\partial t}\rho$$

What is a “pole” anyway?

Electric Dipoles

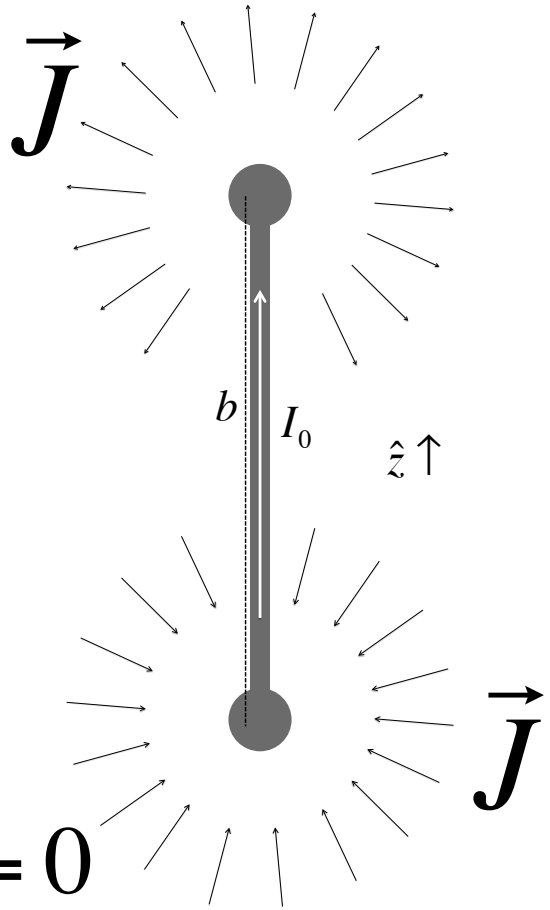


$$\vec{\nabla} \cdot \vec{E} = 0$$

Microscopically, however, charge is a fluid!

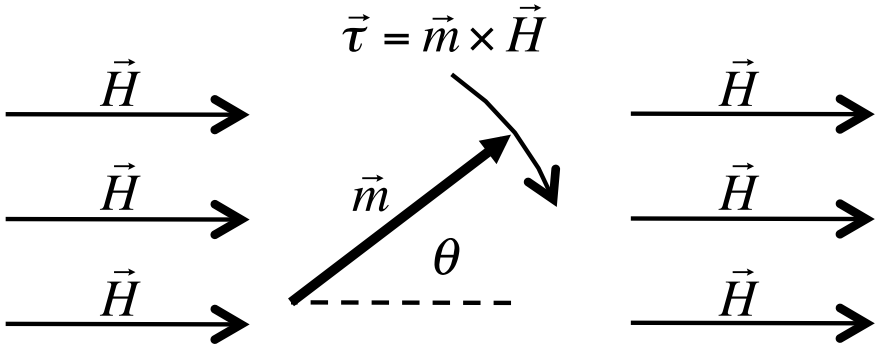
The electron was not discovered until 1897!

A Dipole Circuit



$$\vec{\nabla} \cdot \vec{J} = 0$$

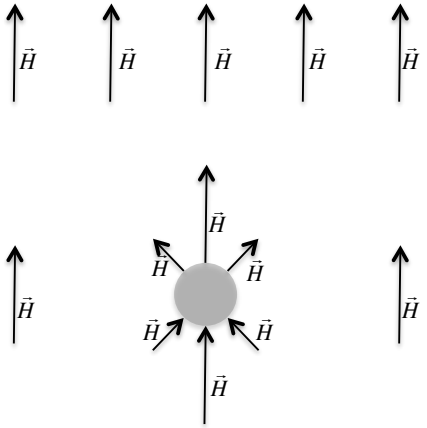
Consider a Magnet



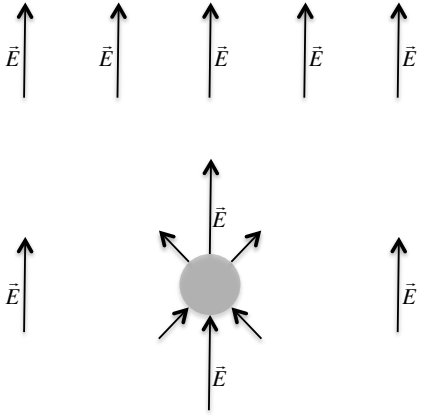
A similar relationship is true for electric dipoles, but not circulatory dipoles.

$$\vec{\tau} = \vec{p} \times \vec{E}$$

Consider a Piece of Iron



A similar relationship is true for conductors in electric fields.



$\vec{M} \propto \vec{H}$ $\quad$ $\vec{P} \propto \vec{E}$

Gauss's Laws

$$\vec{\nabla} \cdot \vec{g} = -4\pi \rho_{\text{mass}}$$

$$\vec{\nabla} \cdot \vec{E} = 4\pi \rho_{\text{charge}}$$

$$\vec{\nabla} \cdot \vec{H} = 4\pi \rho_{\text{poles}}$$

Gauss's Laws:
Inverse Square Laws can be written as a divergence.

In analogy to conservation laws, such as mass and charge.

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Gauss's Laws:
Inverse Square Laws can be written as a divergence.

In analogy to conservation laws, such as mass and charge.

NOTE: Peregrinus's Principle is the Opposing Theory to Gauss's Law of Magnetism!

Geology and Surface Gravity

Consider surveying the Earth with a gravimeter.

We would then model the interior density.

$$\vec{\nabla} \cdot \vec{g} = -4\pi\rho_{\text{mass}} \qquad \vec{g} = -\vec{\nabla}\mathbb{V}_g$$

$$\vec{\nabla} \cdot \left(-\vec{\nabla}\mathbb{V}_g\right) = -4\pi\rho_{\text{mass}}$$

$$\nabla^2\mathbb{V}_g = 4\pi\rho_{\text{mass}}$$

Geology and Magnetic Field

Consider surveying the Earth with a magnetometer.

We would then model the interior pole density.

$$\vec{\nabla} \cdot \vec{H} = 4\pi \rho_{\text{pole}} \qquad \vec{H} = -\vec{\nabla}\mathbb{V}_{\text{magnetism}}$$

$$\vec{\nabla} \cdot \left(-\vec{\nabla}\mathbb{V}_{\text{magnetism}} \right) = 4\pi \rho_{\text{pole}}$$

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$$\nabla^2 \mathbb{V}_{\text{magnetism}} = -4\pi \rho_{\text{pole}}$$

Because of Gauss's great work, this is the way geologists still do it.
Even though it is totally wrong conceptually!

The Discovery of Electromagnetism

On July 21 of 1820, Hans Christian Ørsted published a short Latin paper summarizing his discovery that a current carrying wire deflects a compass needle. But it was not until late summer that, while visiting Geneva, Arago learned of the discovery. As the news was received with disbelief when Arago reported it on the first Monday in September, he experimentally demonstrated it the following Monday. This sparked a race for an explanation, primarily between Biot and Ampère.

The Pole vs Loop Model

The Early 19th Century was a busy time for Electrodynamics

On July 21 of 1820, Hans Christian Ørsted published a short Latin paper summarizing his discovery that a current carrying wire deflects a compass needle.

But it was not until late summer that, while visiting Geneva, Francois Arago learned of the discovery.

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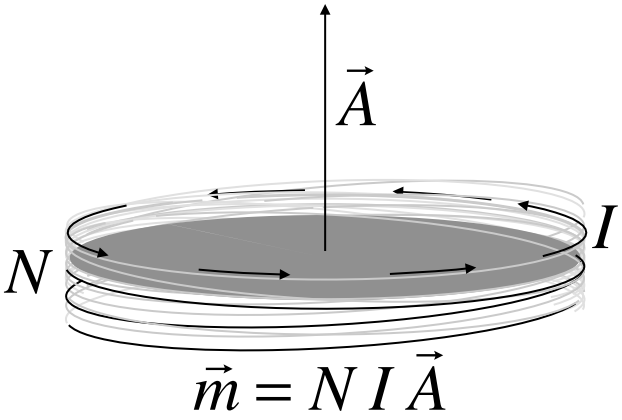
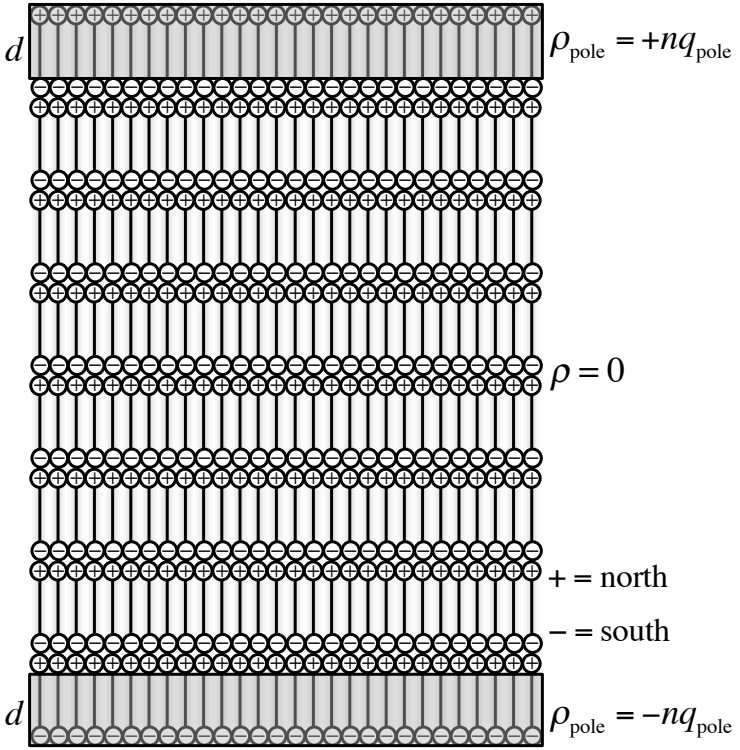
The Loop vs. Pole Model

What causes a magnetic moment?



Ampere argued that rather than poles, it was current loops that caused magnetization.



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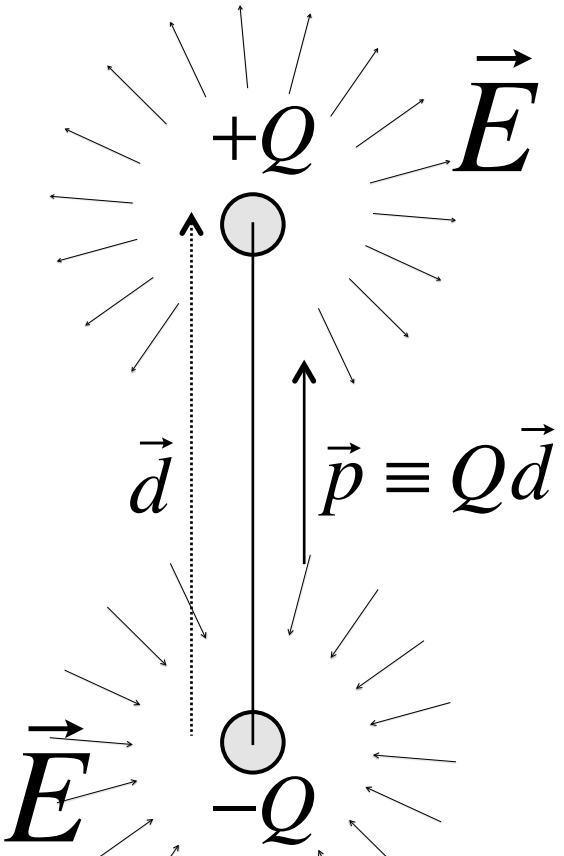
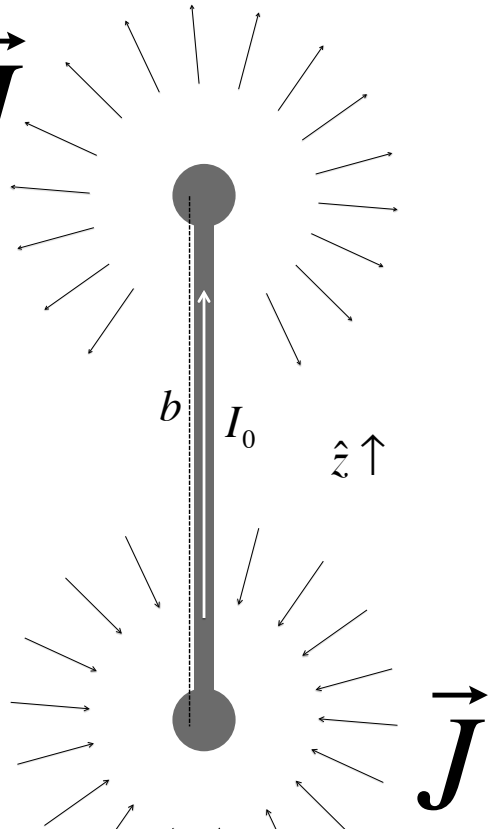


$$\vec{\nabla} \cdot \vec{E} = 4\pi\rho$$

Coulomb’s Pole Model Imagined poles like separate static charges.

A Dipole Circuit

Faraday Imagined the Magnetic Field like a Circular Fluid.



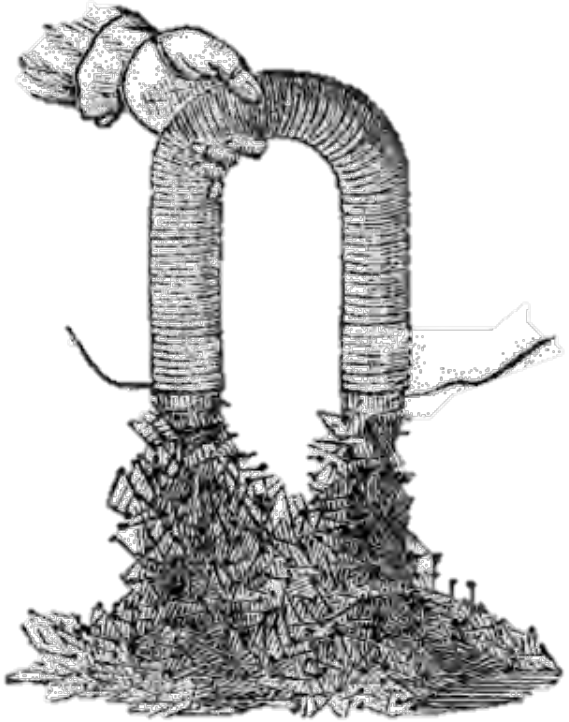
$$\vec{\nabla} \cdot \vec{J} = -\frac{\partial}{\partial t}\rho$$

Problems with the Loop Model

Magnets Should Repel Your Fridge Door?

Lenz, in 1833, pointed out that eddy currents would make magnets repel.

According to the loop model, all induced magnetic moments would be opposite the external field. This is not what is observed!

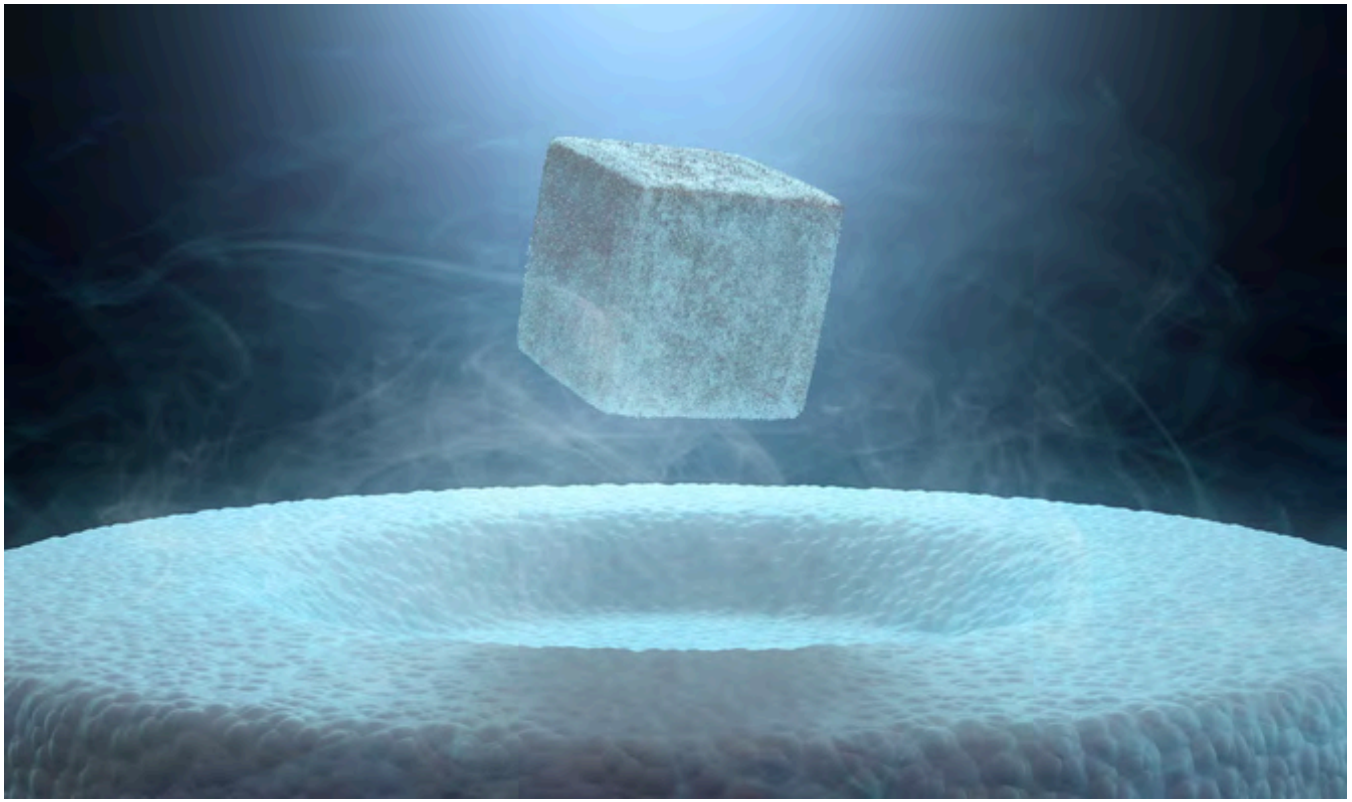


Problems with the Loop Model

Magnets Should Repel Your Fridge Door?

Lenz, in 1833, pointed out that eddy currents would make magnets repel.

According to the loop model, all induced magnetic moments would be opposite the external field. Until the 20th Century!



Michael Faraday
Agreed with Peregrinus, not Gauss!

The Principle as Faraday put it

In the magnet such a division does develop new external lines of force; which being equal in amount to those dependent on the original poles, shows that the lines of force are continuous through the body of the magnet, and with that continuity gives the necessary reason why no absolute charge of northness and southness is found in the two halves.

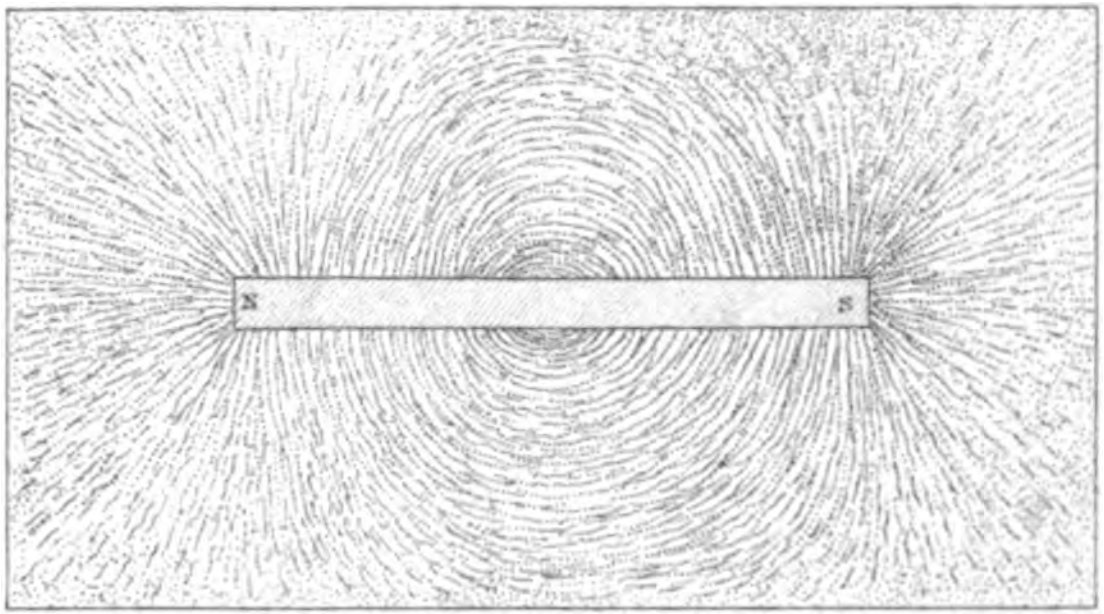
No magnetic monopoles have ever been reproducibly observed.

Faraday's Representation

The term *line of magnetic force* is intended to express simply the direction of the force in any given place, and not any physical direction or notion of the manner in which the force may be exerted; as by actions at a distance, or pulsations, or waves, or a current, or what not. A line of magnetic force may be defined to be that line which is described by a very small magnetic needle, when it is so moved in either direction correspondent to its length, that the needle is constantly a tangent to the line of motion; or, it is that line along which, if a transverse wire be moved in either direction, there is no tendency to the formation of an electric current in the wire, whilst if moved in any other direction there is such a tendency. The direction of these lines is easily represented in a general manner by the well-known use of iron filings.

Magnetic field lines appear continuous at the surface of magnets.

Faraday Continues

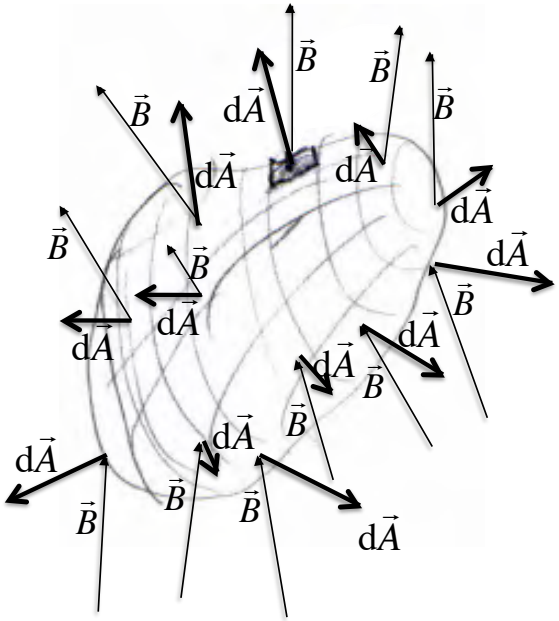


The lines of force already described will, if observed by iron filings or a magnetic needle or otherwise, be found to start off from one end of a bar-magnet, and after describing curves of different magnitudes through the surrounding space, to return to and set on at the other end of the magnet; and these forces being regular, it is evident that if a ring, a little larger than the magnet, be carried from a distance toward the magnet and over one end until it has arrived at the equatorial part, it will have intersected *once* all the external lines of force of that magnet.

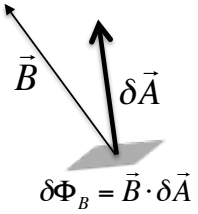
Modern Representation

In the magnet such a division does develop new external lines of force; which being equal in amount to those dependent on the original poles, shows that the lines of force are continuous through the body of the magnet, and with that continuity gives the necessary reason why no absolute charge of *northness* and *southness* is found in the two halves.

(Faraday again)



$$\vec{\nabla}\cdot\vec{B} \equiv \lim_{V\to 0} \frac{\oint_{\text{surface}} \vec{B}\cdot \mathrm{d}\vec{A}}{V} = 0$$



This is exactly Peregrinus's Argument!

Maxwell's Equations are Agnostic

Maxwell's Equations work under either interpretation.

Maxwell's Equations have 4 force fields.

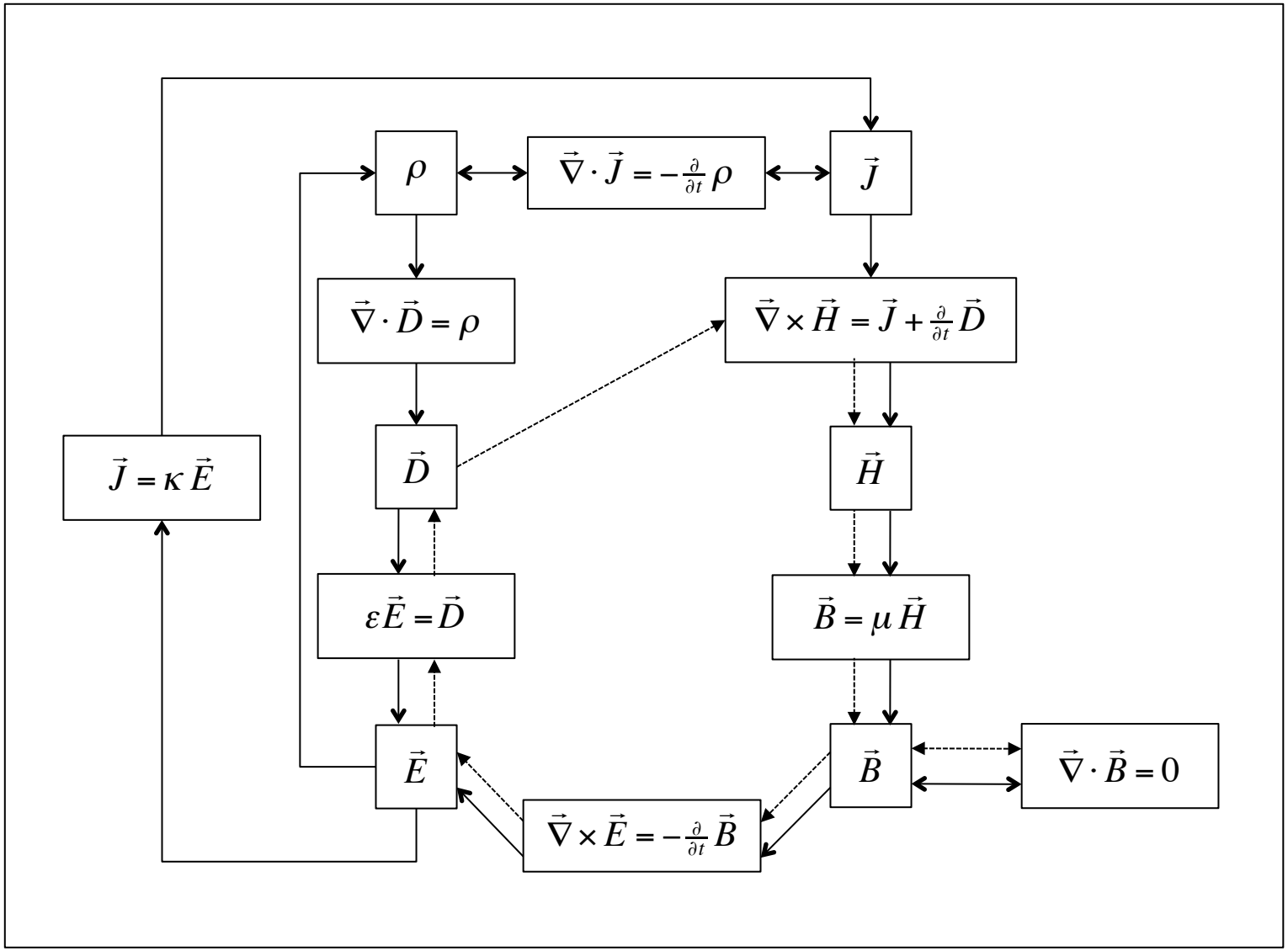
He had bigger fish to fry than whether magnetic monopoles exist.

His dragon was spooky action at a distance!

OK, "spooky" was added by Paul Ehrenfest and Albert Einstein later.

James Clerk Maxwell's primary point was that there must be an aether to mediate the fields.

Maxwell's 4 Field Approach from Cause to Effect



Maxwell's Equations are Agnostic

But what we call them does not!

Maxwell's Equations have 4 force fields.

Maxwell's Equations have to do with what you think is real, and it all has to do with names.

Field	Name
$\vec{E}$	The Electric Field
$\vec{H}$	The Magnetic Field
$\vec{D}$	The Electric Displacement
$\vec{B}$	The Magnetic Induction

Maxwell's Equations are Agnostic

THESE NAMES MAKE PERFECT SENSE USING THE POLE MODEL, AS THEY IMPLY THAT H IS THE FIELD THAT AFFECTS MATTER.

Field	Name
$\vec{E}$	The Electric Field
$\vec{H}$	The Magnetic Field
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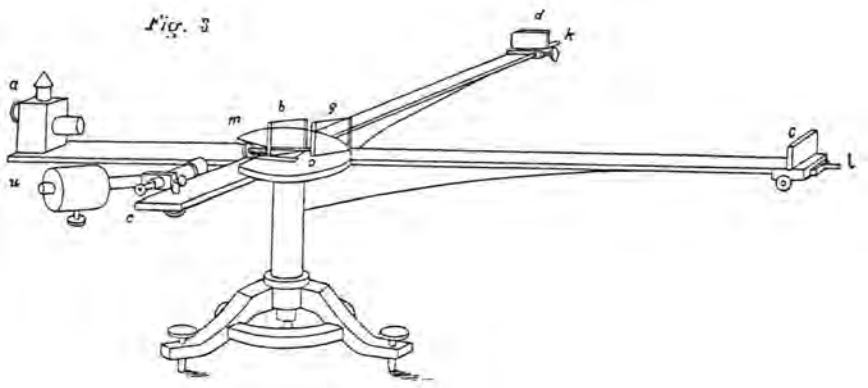
Maxwell's Equations are Agnostic

Maxwell's Equations, as they are now taught in physics, but not engineering, do not need 4 fields, but only two:

Field	Name
$\vec{E}$	The Electric Field
$\vec{B}$	The Magnetic Field
$\vec{D}$	The Electric Displacement OR The Auxiliary Electric Field
$\vec{H}$	The Magnetizing Field OR The Auxiliary Magnetic Field

Albert Michelson

In 1881, the American naval officer Albert Michelson made an account of a failed attempt to measure differences in the speed of light because of the relative motion of the earth through the aether, using a tabletop interferometer (his figure shown). Michelson published the following bold conclusion:



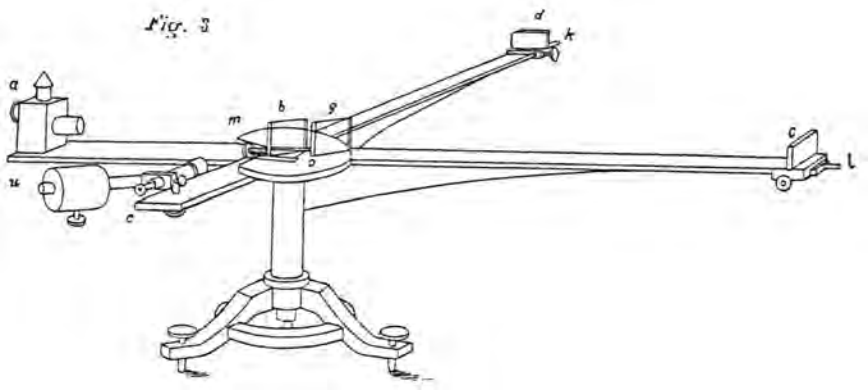
"The result of the hypothesis of a stationary ether is thus shown to be incorrect, and the necessary conclusion follows that the hypothesis is erroneous."

Albert A. Michelson, "The Relative Motion of the Earth and the Luminiferous Ether", American Journal of Science, **22** (1881), 120-129.

Albert Michelson

The weight of evidence for an extraordinary claim must be proportional to its strangeness.

Laplace 1812



Nobody believed him. The work was criticized and largely ignored.

"The result of the hypothesis of a stationary ether is thus shown to be incorrect, and the necessary conclusion follows that the hypothesis is erroneous."

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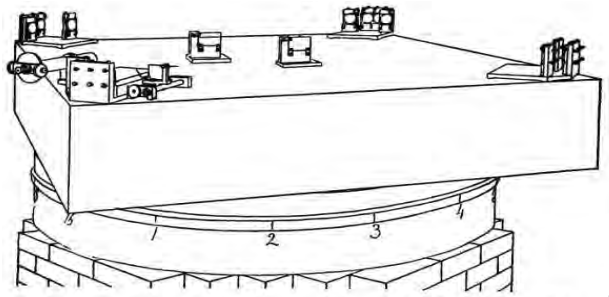
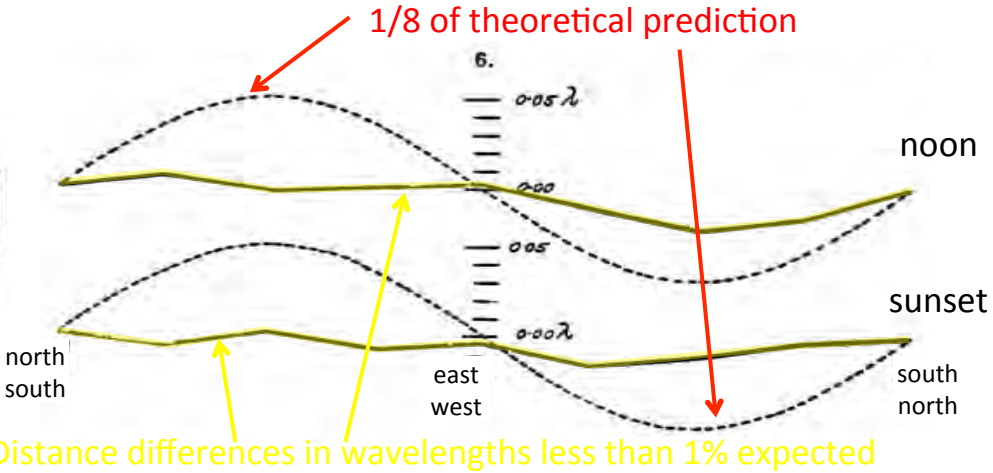
Michelson & Morley





Michelson soon left the Naval Academy and moved on to a larger university, where he and Edward Morley built the most accurate optical interferometer to date. Alas, he failed again, and after this heroic feat he concluded:

"the relative velocity of the earth and the ether is probably less than one sixth the earth's orbital velocity, and certainly less than one-fourth. "

Albert A. Michelson & Edward W. Morley, "On the Relative Motion of the Earth and the Luminiferous Ether", American Journal of Science **34** (1887), 333–345.

Is the Aether Dead?

What is it that electromagnetic waves propagate through?

Are we not already measuring fields inside of a medium?

But what about the pole model?

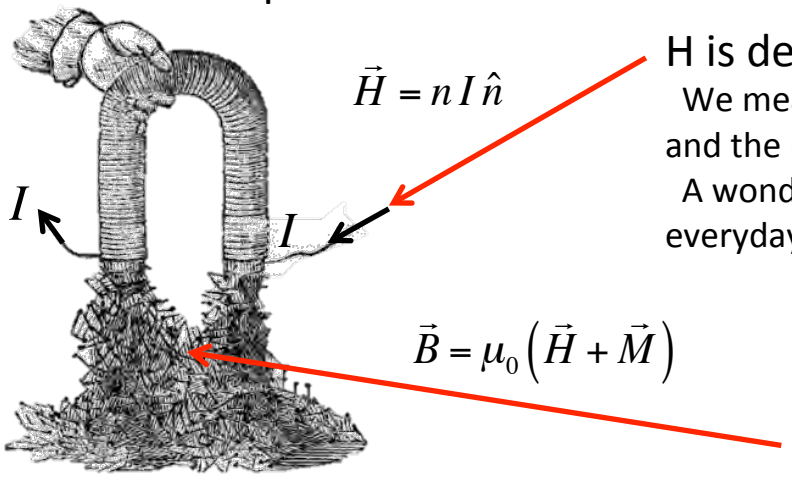
Does this mean that the permittivity and permeability of free space are not properties of the aether?

Without a viable alternative theory, even extraordinary evidence will not convince the scientific community?

What about the Pole Model?

OK, this wrecks havoc for Maxwell's theory of light, but how does it affect Peregrinus and the Pole model?

Consider a chunk of iron with wire wrapped around it.
Let's compare H and B.



H is defined by what causes it.
We measure it by knowing the current and the number of turns per length.
A wonderful independent variable in everyday laboratory experiments.

B is defined by what it does.
We measure it by how it affects things, like compass needles, tacks, and circuits.
A wonderful dependent variable in everyday laboratory experiments.

Now that we do not necessarily have a medium, the one that can be measured *in situ* must be the real one. This is a fundamental idea in the philosophy of science.
If it cannot be measured, is it real?
(Similar arguments about the vector potential actually apply much better to H.)

What is H?

With no poles, H has no purpose. That said, what is it really? M means something physically and B mean something physically, what about H?

Consider the conservation of (free) charge:

$$\vec{\nabla}\cdot\vec{J} = -\frac{\partial}{\partial t}\rho$$

Let some vector field, **D**, exist such that:

Gauss's Law $\vec{\nabla}\cdot\vec{D} = \rho$

$$0 = \vec{\nabla}\cdot\vec{J} - \frac{\partial}{\partial t}\rho = \vec{\nabla}\cdot\vec{J} - \frac{\partial}{\partial t}\vec{\nabla}\cdot\vec{D} = \vec{\nabla}\cdot\left(\vec{J} - \frac{\partial}{\partial t}\vec{D}\right).$$

Since: $\vec{\nabla}\cdot\vec{\nabla}\times(\text{Any Vector Field}) = 0$

We can let some vector field, **H**, exist such that:

$$\vec{\nabla}\times\vec{H} = \vec{J} + \frac{\partial}{\partial t}\vec{D}$$ Maxwell-Ampere Law

And the vector identity ensures that charge is conserved.

$$\vec{\nabla}\cdot\vec{\nabla}\times\vec{H} = \vec{\nabla}\cdot\left(\vec{J} + \frac{\partial}{\partial t}\vec{D}\right) = \vec{\nabla}\cdot\vec{J} + \vec{\nabla}\cdot\frac{\partial}{\partial t}\vec{D} = \vec{\nabla}\cdot\vec{J} + \frac{\partial}{\partial t}\vec{\nabla}\cdot\vec{D} = \vec{\nabla}\cdot\vec{J} + \frac{\partial}{\partial t}\rho!$$

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Gauss's law and the Maxwell-Ampere law are based on real physics!
This reduces them to mere change in notation. Where is the physics?

What is H?

Gauss's law and the Maxwell-Ampere law are based on real physics!
This reduces them to mere change in notation. Where is the physics?

Hidden away in these three equations!

1. The Conservation of (free) charge:

$$\vec{\nabla} \cdot \vec{J} = -\frac{\partial}{\partial t}\rho$$

Maxwell stressed the medium!
The next great thing was figuring out the aether.

2. The Constitutive Relations

$$\varepsilon_0 \vec{E} = \vec{D} - \vec{P}$$

$$\vec{B} = \mu_0 \left(\vec{H} + \vec{M} \right)$$

Constitutive is old fashioned for *restorative*.

The problem with being right so often
is that people believe you even when you are wrong.

As Heinrich Hertz put it:

To the question, "What is Maxwell's theory?"
I know of no shorter or more definite answer than the following:
Maxwell's theory is Maxwell's system of equations.

H. Hertz, Electric Waves, trans. D. Jones (London: MacMillan and Co., 1893), 21.

Einstein Killed the Aether in 1905!

The speed of light is NOT a characteristic speed in a medium, like the speed of sound.
Rather it is fundamental to the kinematics of the universe.

It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighborhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighborhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Examples of this sort, together with unsuccessful attempts to discover any motion of the earth relative to the 'light medium', suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest.

From "On the Electrodynamics of Moving Bodies," by Albert Einstein (1905), translated by Anna Beck, ©1989 by the Hebrew University of Jerusalem.

What About Action at a Distance?

What is it that electromagnetic waves propagate through?

How can we have waves without a medium?
This is spooky!

Einstein's Solution was the same and Newton's.

Make light a particle rather than a wave. Then it does not need an aether!

Rookie Mistake!

He published the particle paper before he publishes his paper on relativity, so the dynamics of light particles made no sense to anyone else.

He is not dead yet?

It was in 1905 that Einstein made the first coupling of photo effects and with any form of quantum theory by bringing forward the bold, not to say the reckless, hypothesis of an electro-magnetic light corpuscle of energy *hv*, which energy was transferred upon absorption to an electron. This hypothesis may well be called reckless first because an electromagnetic disturbance which remains localized in space seems a violation of the very conception of an electromagnetic disturbance, and second because it flies in the face of the thoroughly established facts of interference. The hypothesis was apparently made solely because it furnished a ready explanation of one of the most remarkable facts brought to light by recent investigations, viz., that the energy with which an electron is thrown out of a metal by ultra-violet light or X-rays is independent of the intensity of the light while it depends on its frequency.

R.A. Millikan, "A Direct Photoelectric Determination of Planck's 'h'," Physical Review **7** (1916), 355-388.

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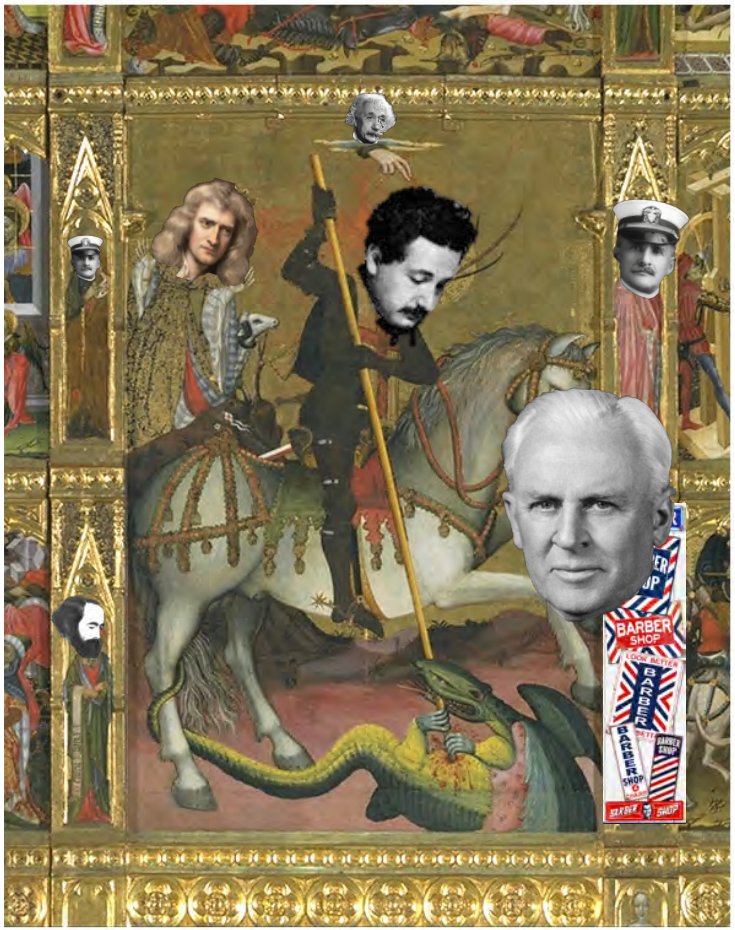


What About Action at a Distance?

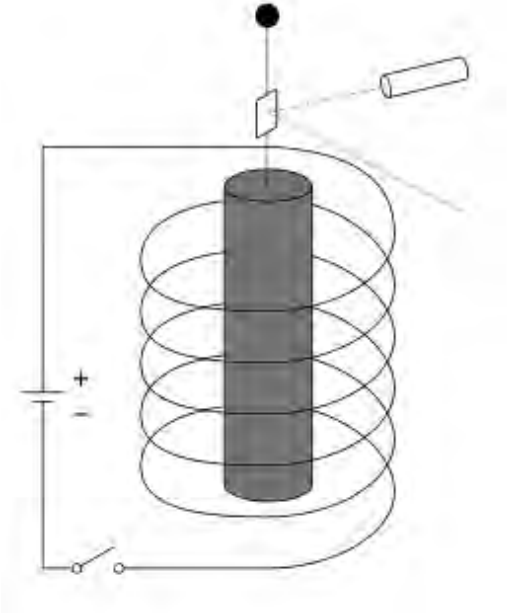
What is it that electromagnetic waves propagate through?

How can we have waves without a medium?
Is it the waves themselves that are spooky?

Einstein's Solution was the same and Newton's.

Make light a particle rather than a wave. Then it does not need an aether!

The Pole Model Died with Angular Momentum?



Albert Einstein and Wander deHaas published a 1915 paper confirming that magnetizing a permanent magnet causes a torque of about what would be expected by a spinning electron.

Meanwhile, the American physicist Samuel Barnett published the converse effect, where spinning ferromagnetic materials become magnetized.

Note: All three of these men were married to fellow physicists. In the case of both deHaas and Barnett, I really do not know how much they worked together. But, if I had my guess, and they had good marriages, they probably did everything together. We just do not know one way or the other. In Einstein's case, he had a poor first marriage, and did not work with his wife. Perhaps if he did, he would have had a better first marriage.

S.J. Barnett, "Magnetization by Rotation," Phys. Rev., **6**:4, (1915), 239-270.

The Pole Model Died with Angular Momentum?

But the fight was still going on well into the 20th century!

By then systems of units had become well-established and many fields had already been using the pole model for decades.

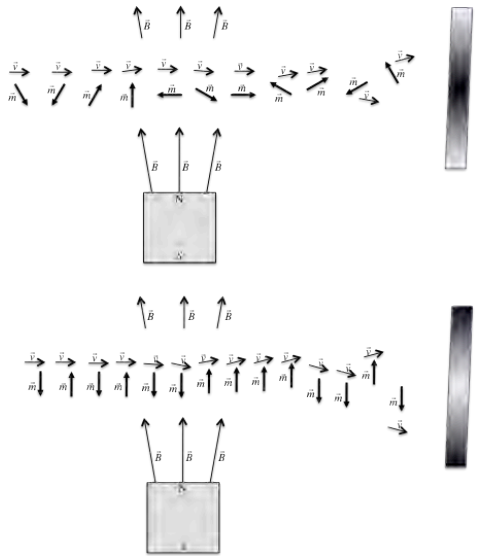
Especially Electrical Engineering, Astronomy, and Geology.

Look at any work on magnetism now, and you will see a totally confusing jumble of formulas. Many of which were derived by physicists who believed avidly in the pole model, and now they are founded upon false premises but still work because the math works out that way.

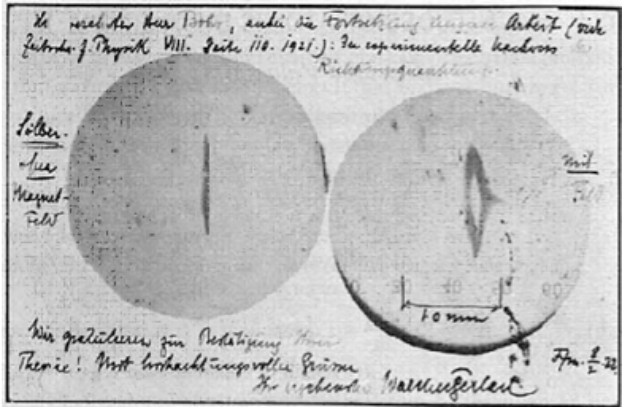
S.J. Barnett, "Magnetization by Rotation," Phys. Rev., **6**:4, (1915), 239-270.

The Stern-Gerlach Experiment

In a famous 1922 experiment, Otto Stern and Walther Gerlach injected silver atoms into a non-uniform magnetic field so as to measure the distribution of their magnetic moments. Classically, since one would expect that atoms would have randomly oriented magnetic moment vectors, a deflection of neutral atoms by a non-uniform magnetic field should be uniformly distributed. However, this was not observed.



Instead, the magnetic moments appeared to be always aligned with the detector, regardless of the detector direction, with 50% pointing along in one direction called “up” and 50% of the magnetic moments in the “down” direction. The postcard below was sent by Gerlach to Niels Bohr with the message: “Attached the experimental proof of directional quantization.”



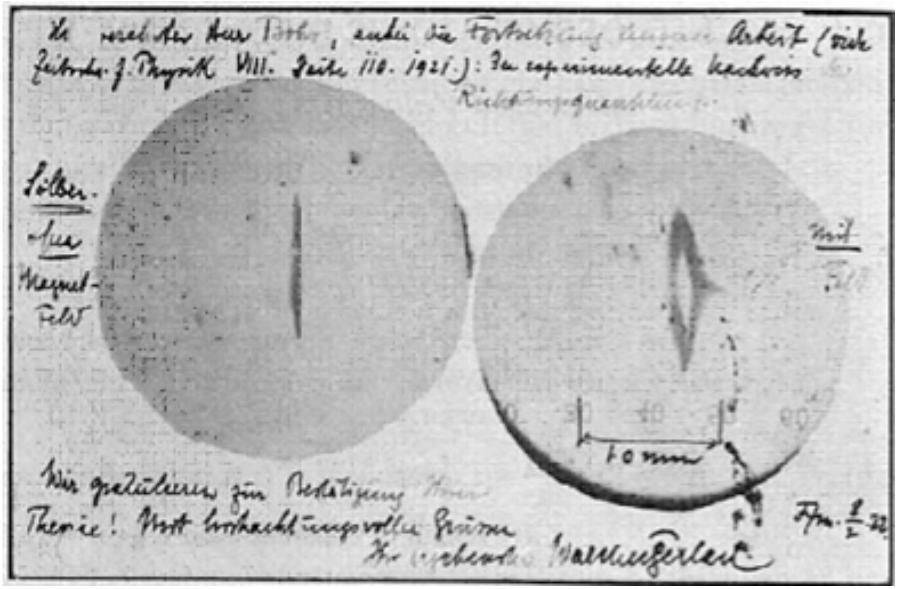
What about magnetic matter?

Fundamental particles have intrinsic magnetic moments, especially electrons.

Magnetic matter, primarily, has unpaired electrons. Iron and Nickel.

Due to symmetry, and the Pauli Exclusion Principle, sometimes it is energetically advantageous for these magnetic moments to line in the same direction. That is ferromagnetic material.

It is impossible to model atoms classically, so you should not even bother trying.



We Should Represent Maxwell's Equations as:

Peregrinus's Principle: $\vec{\nabla} \cdot \vec{B} = 0$

Gauss's Law $\vec{\nabla} \cdot \vec{E} = \frac{1}{\varepsilon_0}\rho - \frac{1}{\varepsilon_0}\vec{\nabla} \cdot \vec{P}$

Faraday's Law $\vec{\nabla} \times \vec{E} = -\frac{\partial}{\partial t}\vec{B}$

The Maxwell-Ampere Law

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial}{\partial t}\vec{E} + \mu_0 \varepsilon_0 \frac{\partial}{\partial t}\vec{P} + \mu_0 \vec{\nabla} \times \vec{M}$$

No short cuts! No hidden physics! No major misconceptions.

And, of course, the conservation of charge is even more fundamental.

$$\vec{\nabla} \cdot \vec{J} = -\frac{\partial}{\partial t}\rho$$

What about Units?

1. Use the SI because it is the accepted standard. If you are not using SI units, it better be for a very good reason.
2. Gaussian unit systems, like CGS units, were predicated on the pole model. They are completely inappropriate for expressing modern magnetism – even if they "work."
3. The SI uses constants were predicated on there being an aether. This is much less of a misconception than the pole model.
4. Maxwell's equations can also be written in terms of the speed of light, but without the confusing issues of competing unit systems.

Or Maxwell's Equations can be Written

Peregrinus's Principle: $\vec{\nabla} \cdot \vec{B} = 0$

Gauss's Law $\vec{\nabla} \cdot \vec{E} = Z_0 c \rho - Z_0 c \vec{\nabla} \cdot \vec{P}$

Faraday's Law $\vec{\nabla} \times \vec{E} = -\frac{\partial}{\partial t} \vec{B}$

The Maxwell-Ampere Law

$$\vec{\nabla} \times \vec{B} = \frac{1}{c} Z_0 \vec{J} + \frac{1}{c^2} \frac{\partial}{\partial t} \vec{E} + \frac{1}{c^2} \frac{\partial}{\partial t} \vec{P} + \frac{1}{c} Z_0 \vec{\nabla} \times \vec{M}$$

$c \approx 300 \frac{\mathrm{m}}{\mu \mathrm{s}}$ $Z_0 \approx 377 \Omega$

Coulomb's constant $K = \frac{1}{4 \pi \varepsilon_0} = \frac{Z_0 c}{4 \pi}$

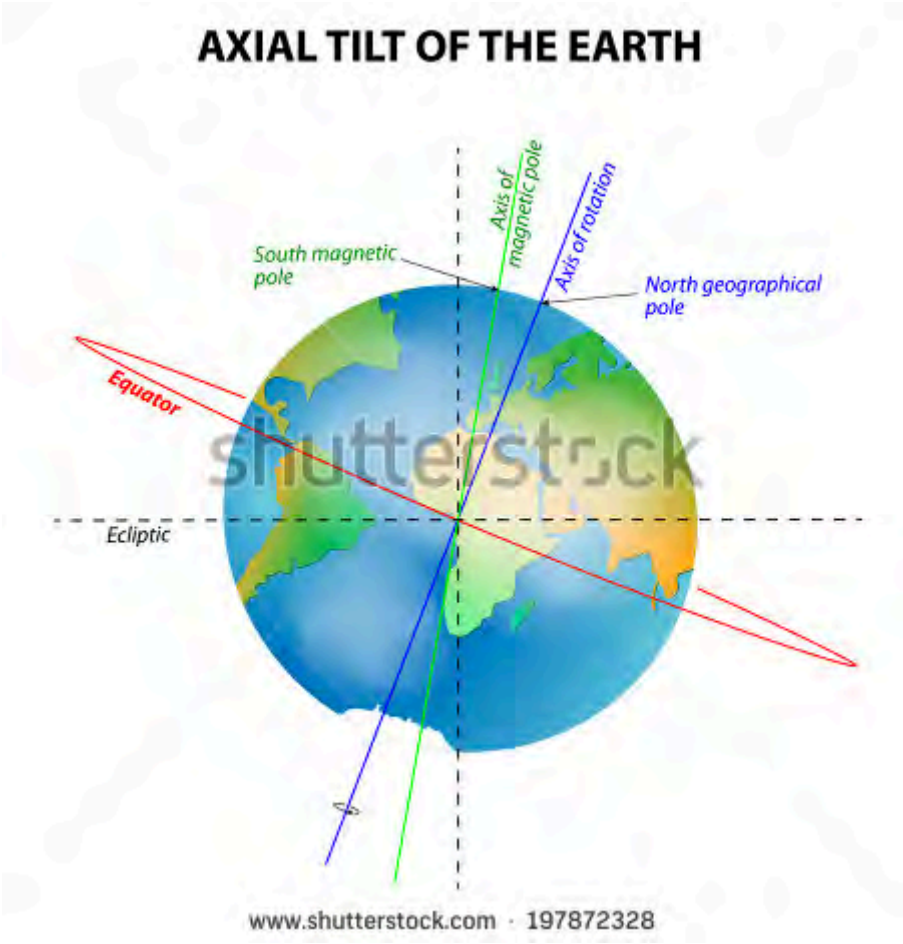
How Should we Explain Magnetic Poles?

Why is it a pole in the first place?

Because Peregrinus made a magnetic globe.

A pole is simply an axis of symmetry.

It is also the point of a surface where the axis of symmetry breaks the surface.



Summary

1. Almost 750 years ago, Petrus Peregrinus was right!
2. The pole model thrived because the mathematics happened to work out.
3. The pole model is still used today, despite having been thoroughly debunked.
4. Maxwell's 4 field approach was also based on a false premise, but it is still used by engineers.
5. Ampere's current loop model also fails, except in the case of superconductors where it works perfectly.
6. Magnetic moments and angular momentum are directly related.

7. Whenever anyone uses H, except as simply the external magnetic field, they are implying that poles move, which they do not!
8. Whenever anyone used the magnetic scalar potential, they should be using the magnetic vector potential. The only reason not to is if they are using theory from before 1915.