hi

Day 13, 20.02.2017

reprise Maxwell’s Equations — the high points

Particle Accelerators

housekeeping

Lectures forever now: Gotta come to class

Anyone have trouble with the videos inside Lesson 13?

I think MasteringAstronomy is screwed up. I'll fix it

question about *anything*? I'll make a movie for you:

Midterm…before Spring Break

see the blog post

February 2018

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	1	2	3

yadda yadda yadda

yadda yadda yadda

HW5

HW6

today

lesson 12

HW5 due

HW7

lecture

lecture

HW6 due

midterm

HW8

lecture

lecture

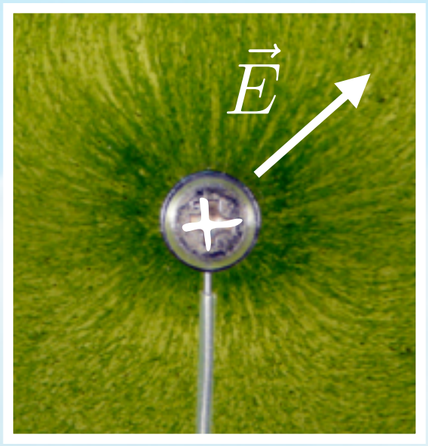
HW7 due

Eastern Time Time Zone

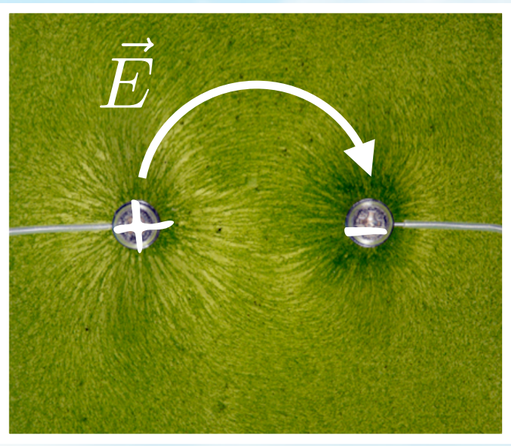
Page 1/1

HW8 due 3/16

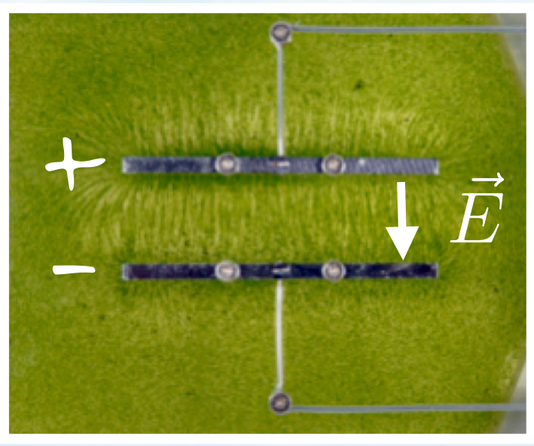
fields



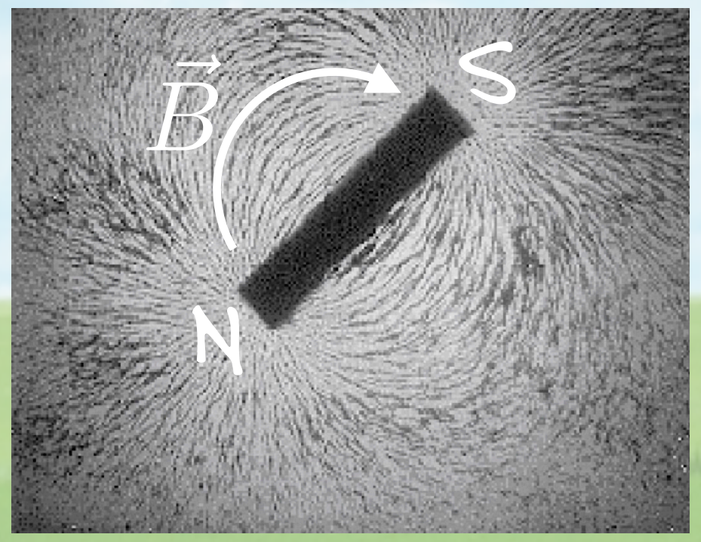
single electric charge



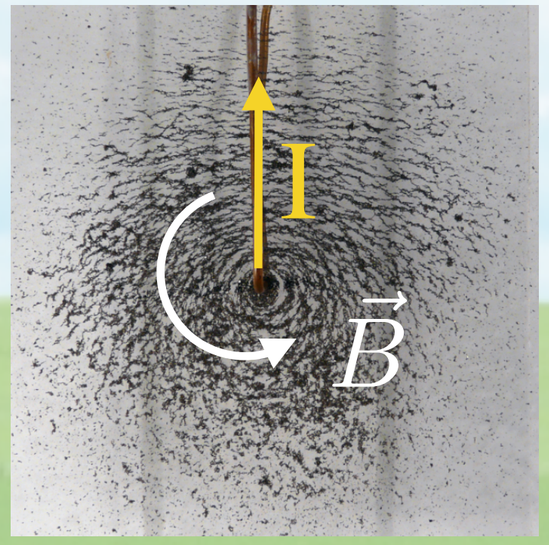
two opposite charges



parallel plates
oppositely charged

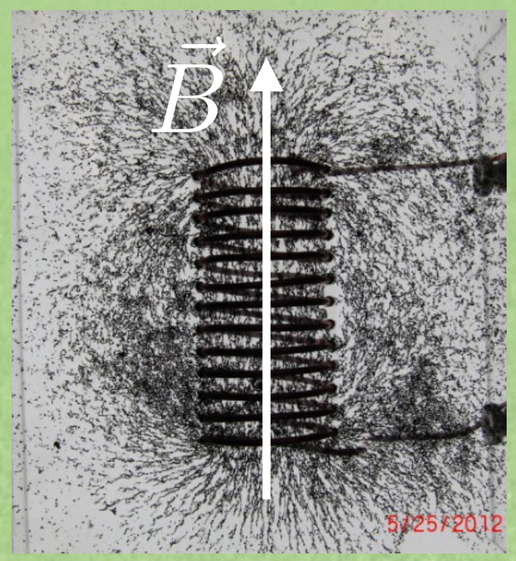


bar magnet

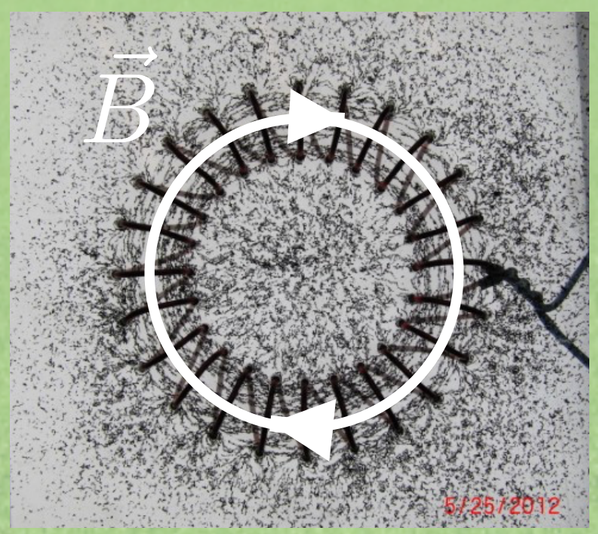


single current

current loop



solenoid

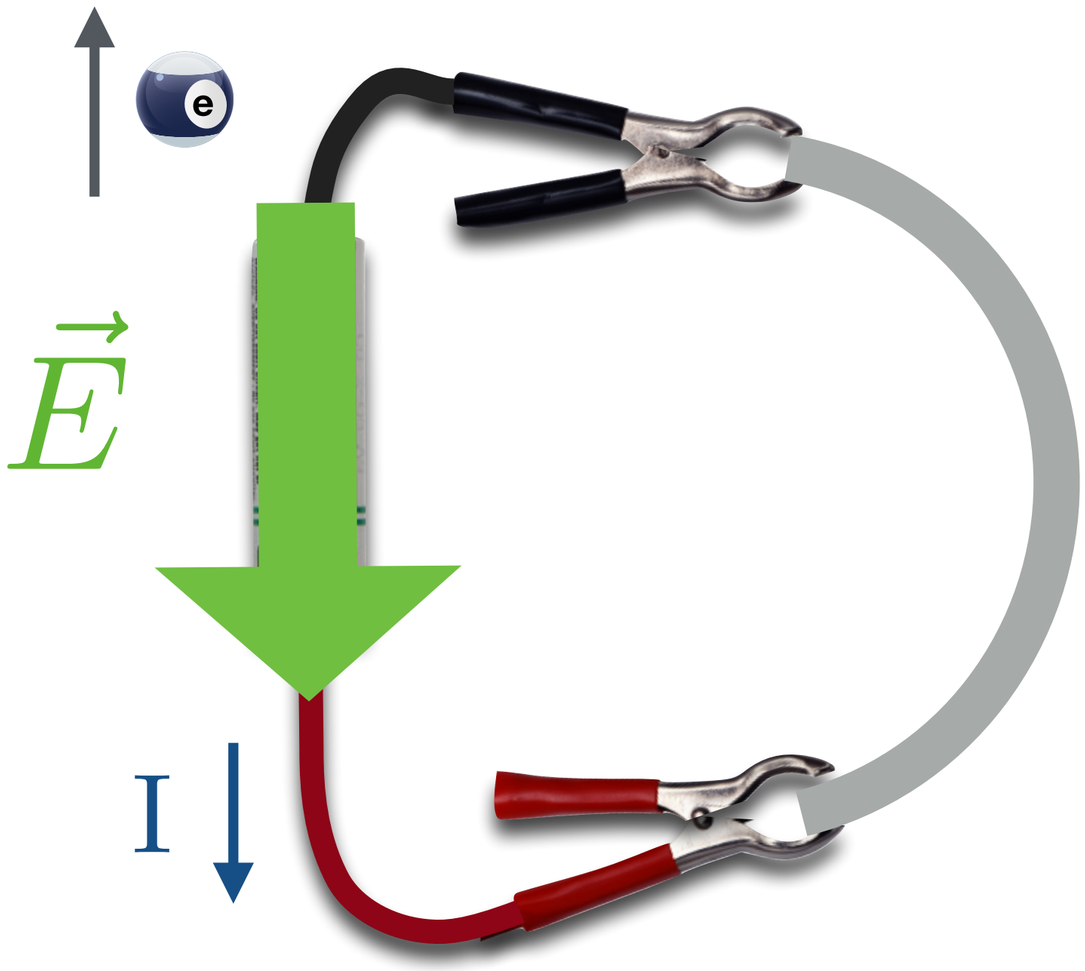


toroid

Faraday's Law

A changing B field creates a current in a loop of wire

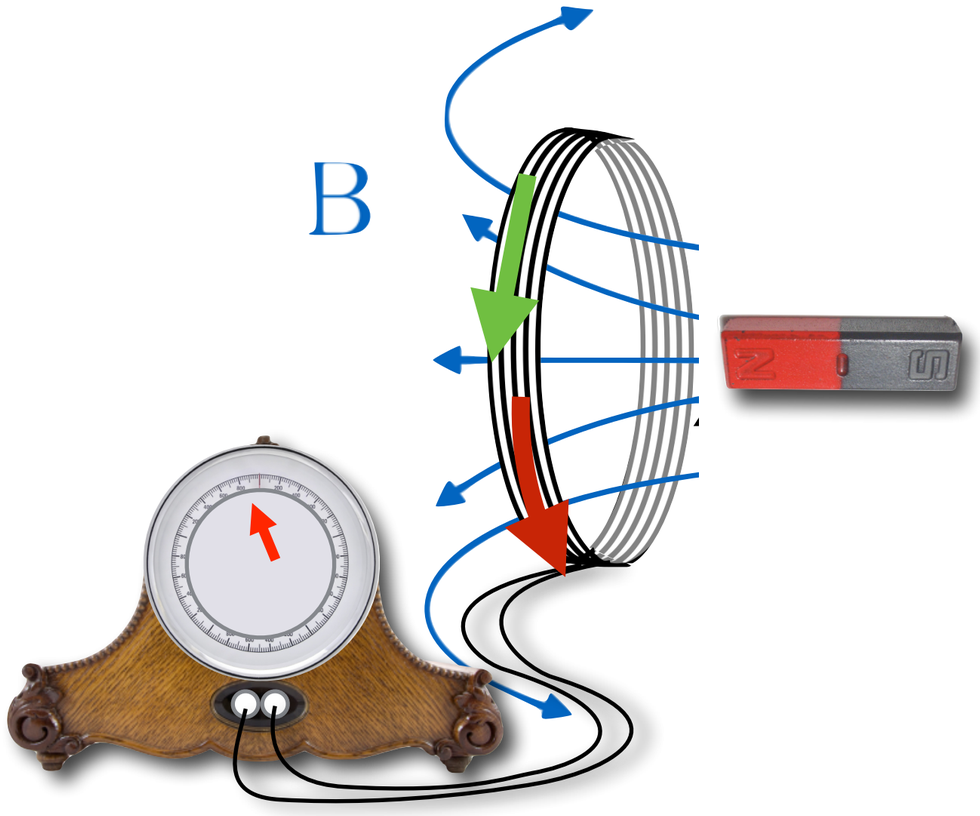
a current...



what makes electrons move in a wire?

an E field created by the battery

Faraday's Law



Remember…the changing magnetic field

created a current

What's really going on?*

a changing magnetic field

must create an changing electric field

the electrons in the wire feel the force of the electric field

and they move: a current

*

You might want to remember this:

a changing B field creates an E field

the famous, fabulous, four Maxwell's Equations

a schematic view of the mathematics

"Field equations" are like this:

(fancy calculus stuff) x (the **Field**) = (numbers) x (a "**source**")

of the

the "field equation" for electrical charges:

$$\text{stuff} \times \vec{E} = Q$$

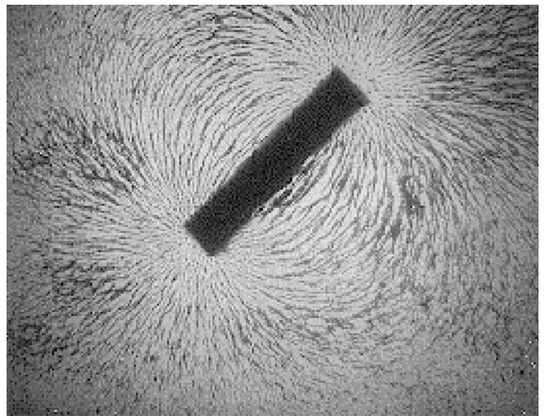
electric field

the source of

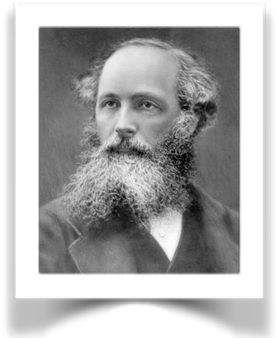
charge.

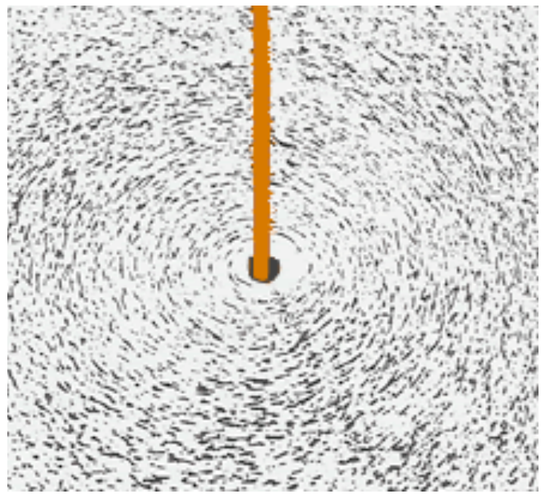
"Maxwell's Equations" in pictures?

$$\text{stuff} \times \overrightarrow{E} = Q$$



$$\text{stuff} \times \overrightarrow{B} = 0$$





$$\text{stuff} \times \overrightarrow{E} = \text{rate of change of } \overrightarrow{B}$$

a changing B field creates an E field

$$\text{stuff} \times \overrightarrow{B} = \qquad + I$$

a changing E field creates a B field

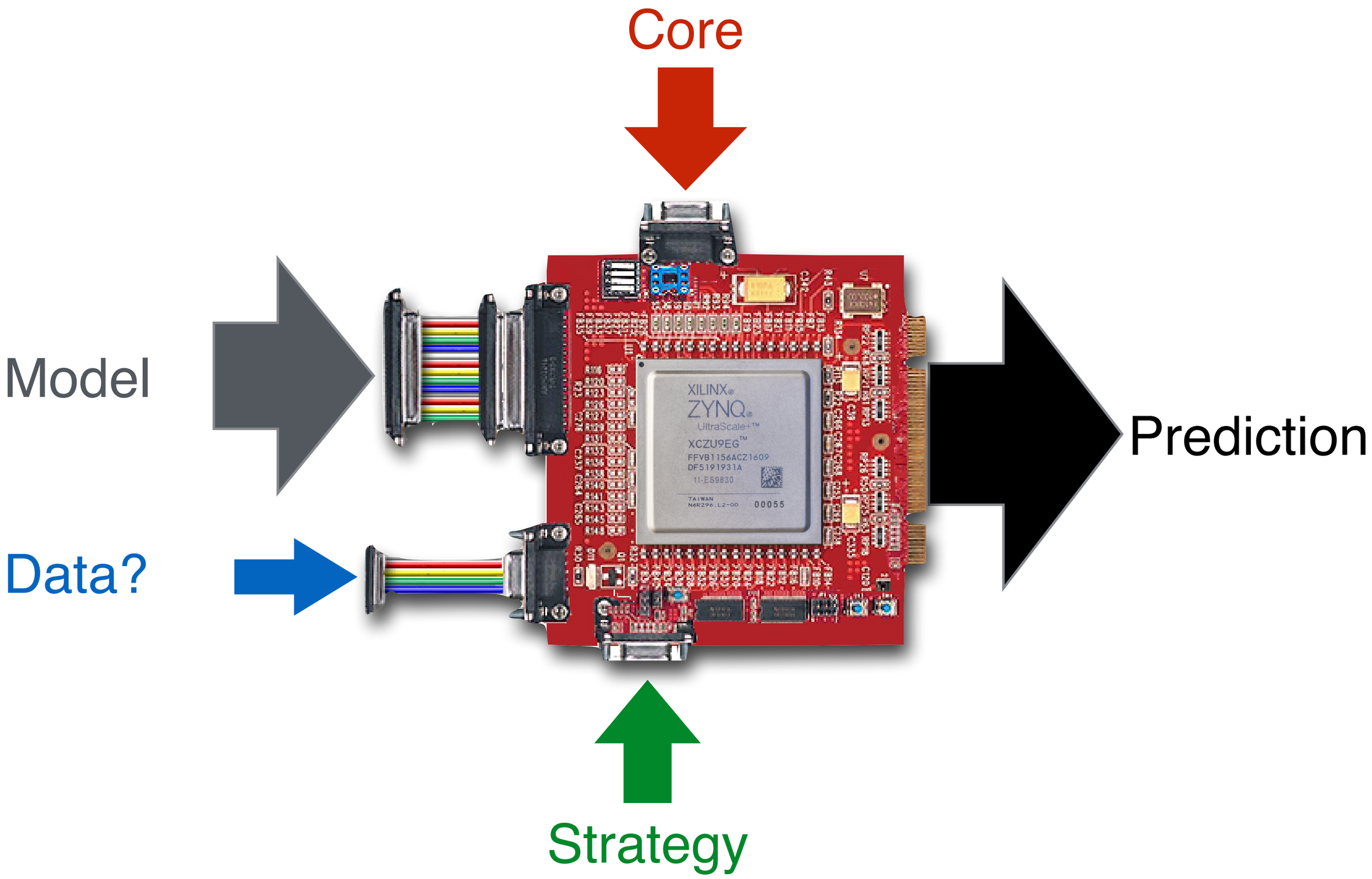
You might want to remember this:

a changing B field creates an E field

a changing E field creates a B field

remember my silly turning-the-crank image?

Lesson 3.1



Maxwells aha! moment

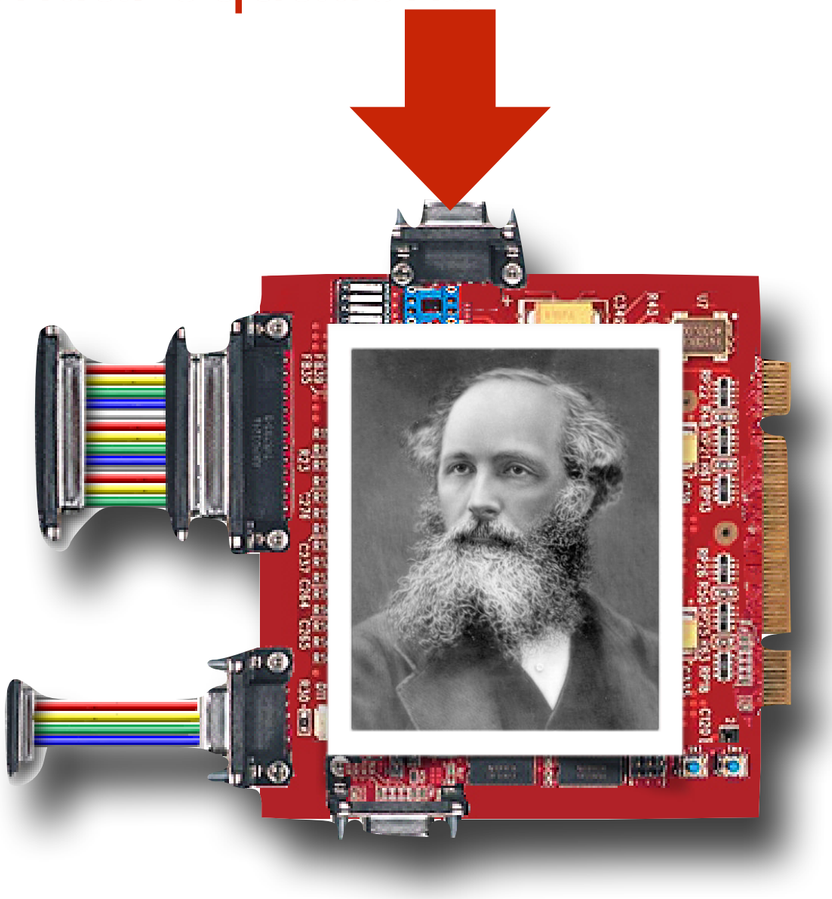
$$\text{stuff} \times \overrightarrow{E} = 0$$

$$\text{stuff} \times \overrightarrow{B} = 0$$

$$\text{stuff} \times \overrightarrow{B} = \text{rate of change of } \overrightarrow{E}$$

$$\text{stuff} \times \overrightarrow{E} = \text{rate of change of } \overrightarrow{B}$$

differential equations



remove the explicit sources, Q & I

Look how the equations are symmetric: E ↔ B

$$\frac{E}{B} = 3 \times 10^8 \text{ m/s}$$

c! the **speed of light!**

Which Maxwell knew.

$$\text{stuff} \times \overrightarrow{E} = 0$$

$$\text{stuff} \times \overrightarrow{B} = 0$$

$$\text{stuff} \times \overrightarrow{B} = \text{rate of change of } \overrightarrow{E}$$

$$\text{stuff} \times \overrightarrow{E} = \text{rate of change of } \overrightarrow{B}$$

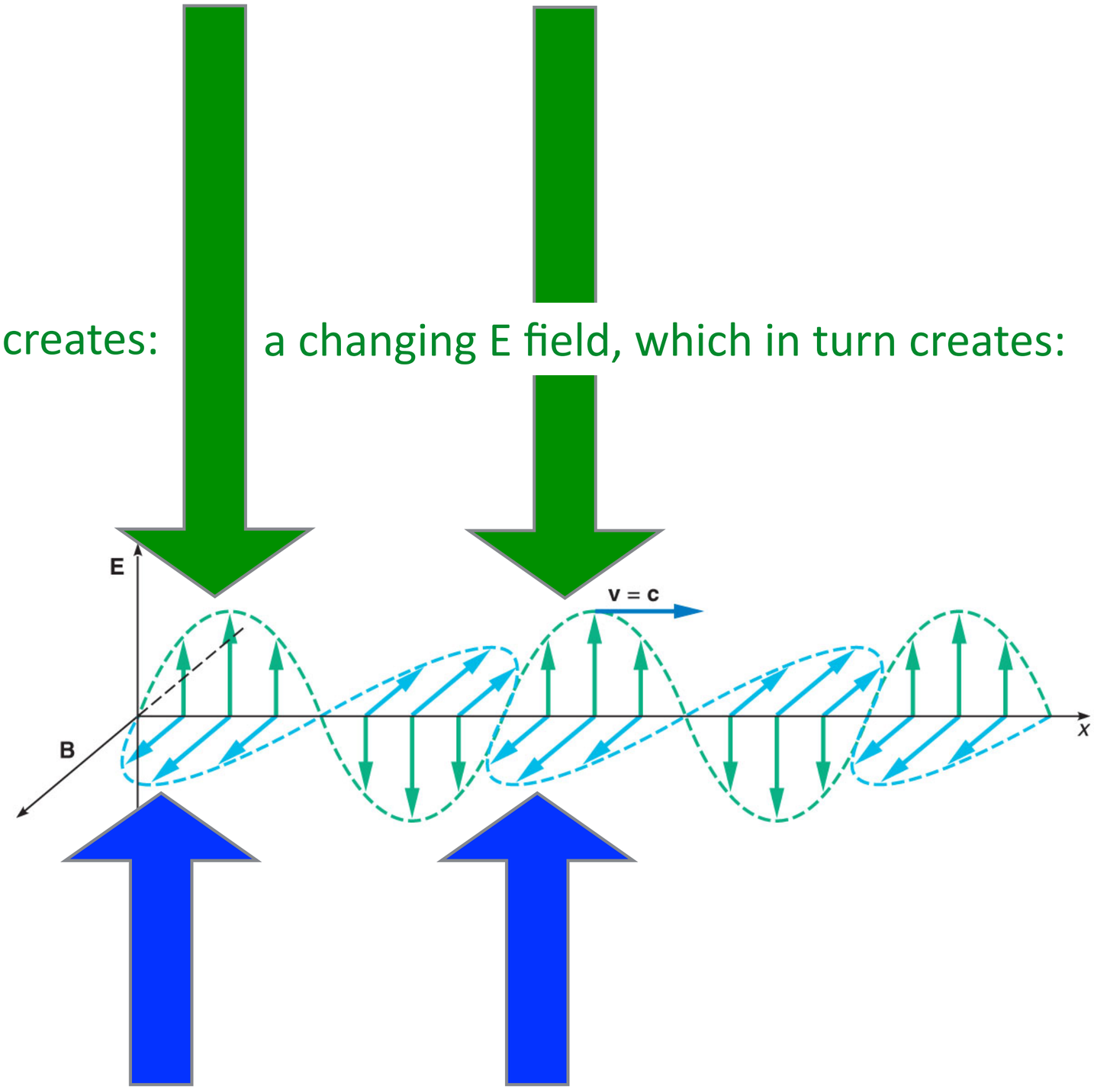
from his 4 equations

came coupled waves moving in time at the

speed of light

a changing E field creates:

a changing E field, which in turn creates:

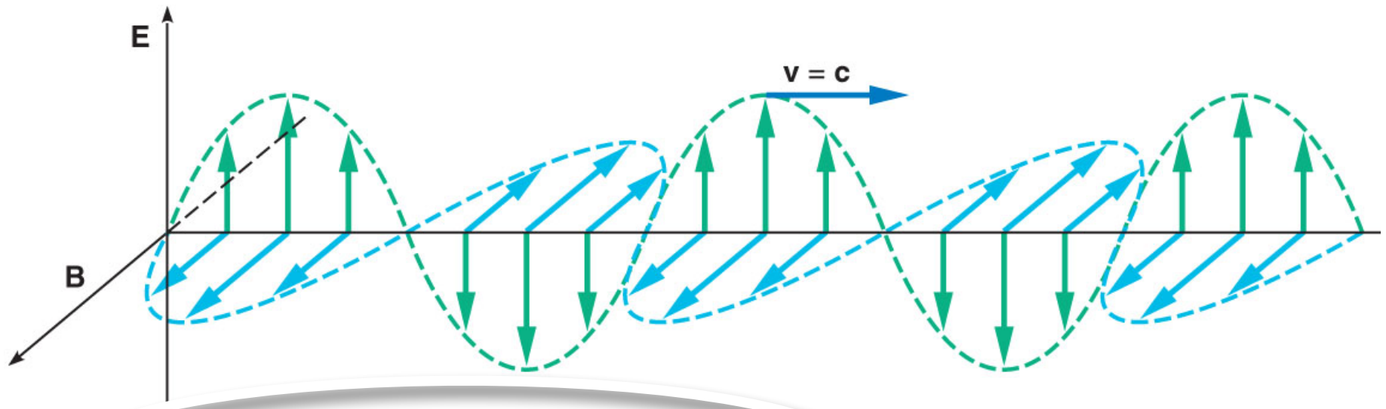


a changing B field, which in turn creates:

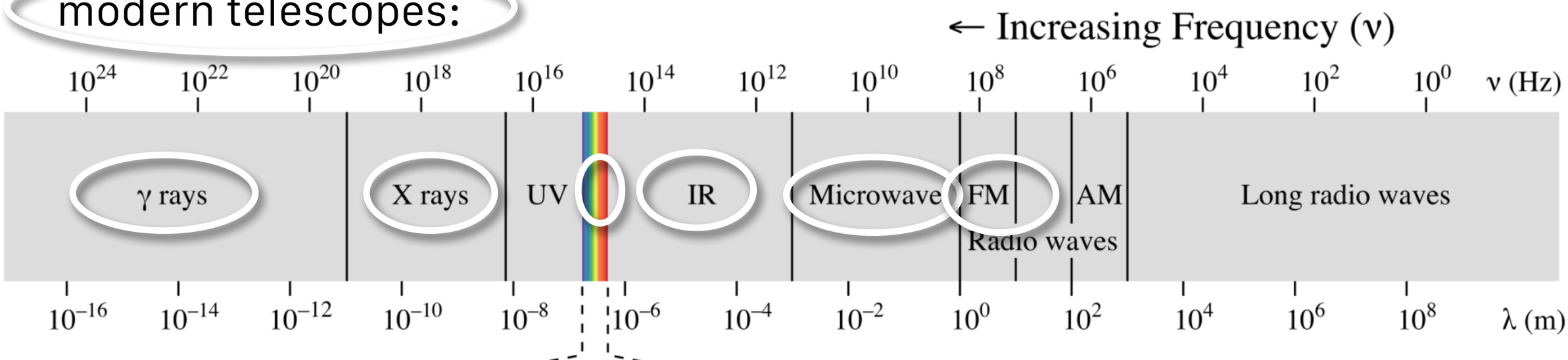
light, electricity, magnetism

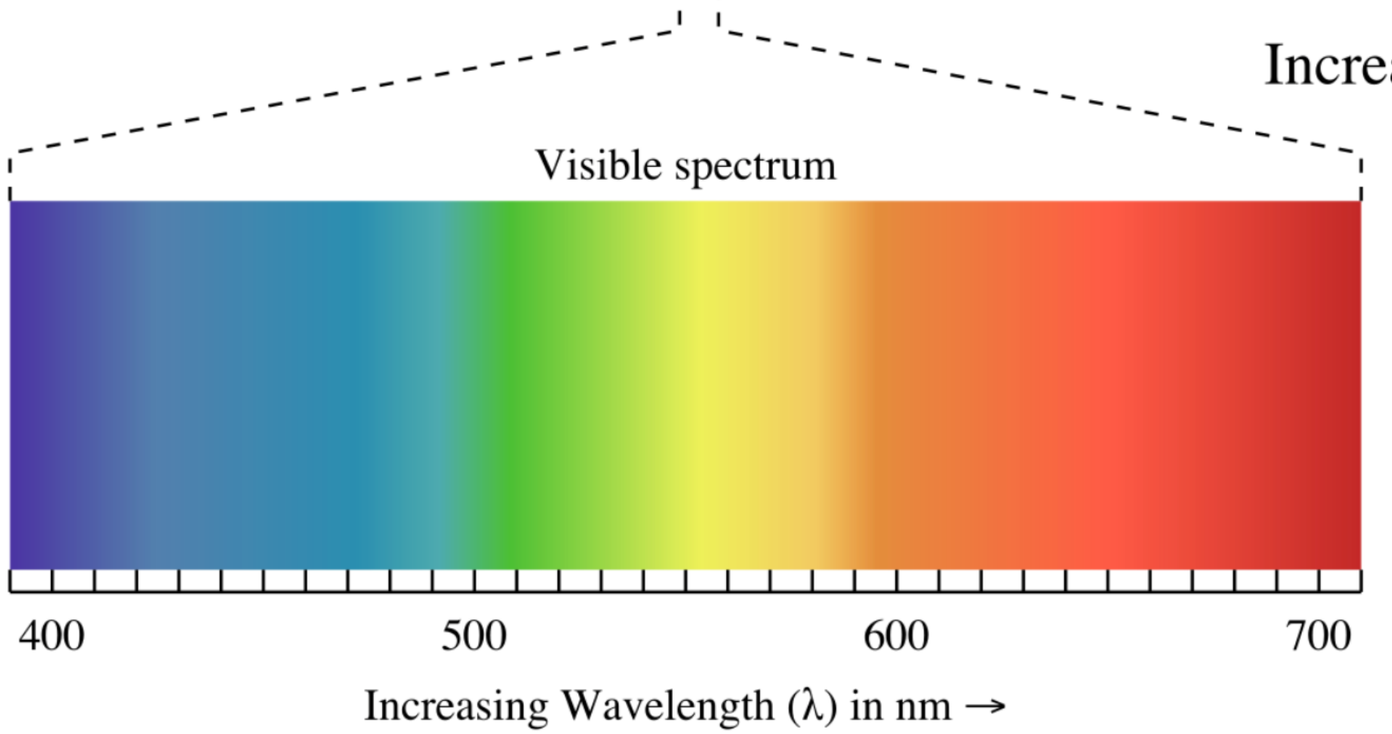
are all the same thing

Modern Electromagnetic Spectrum

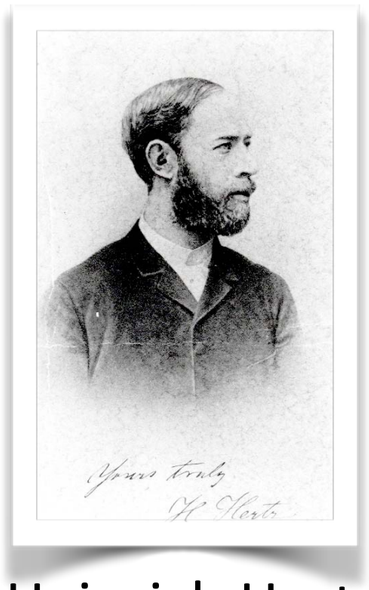


modern telescopes:





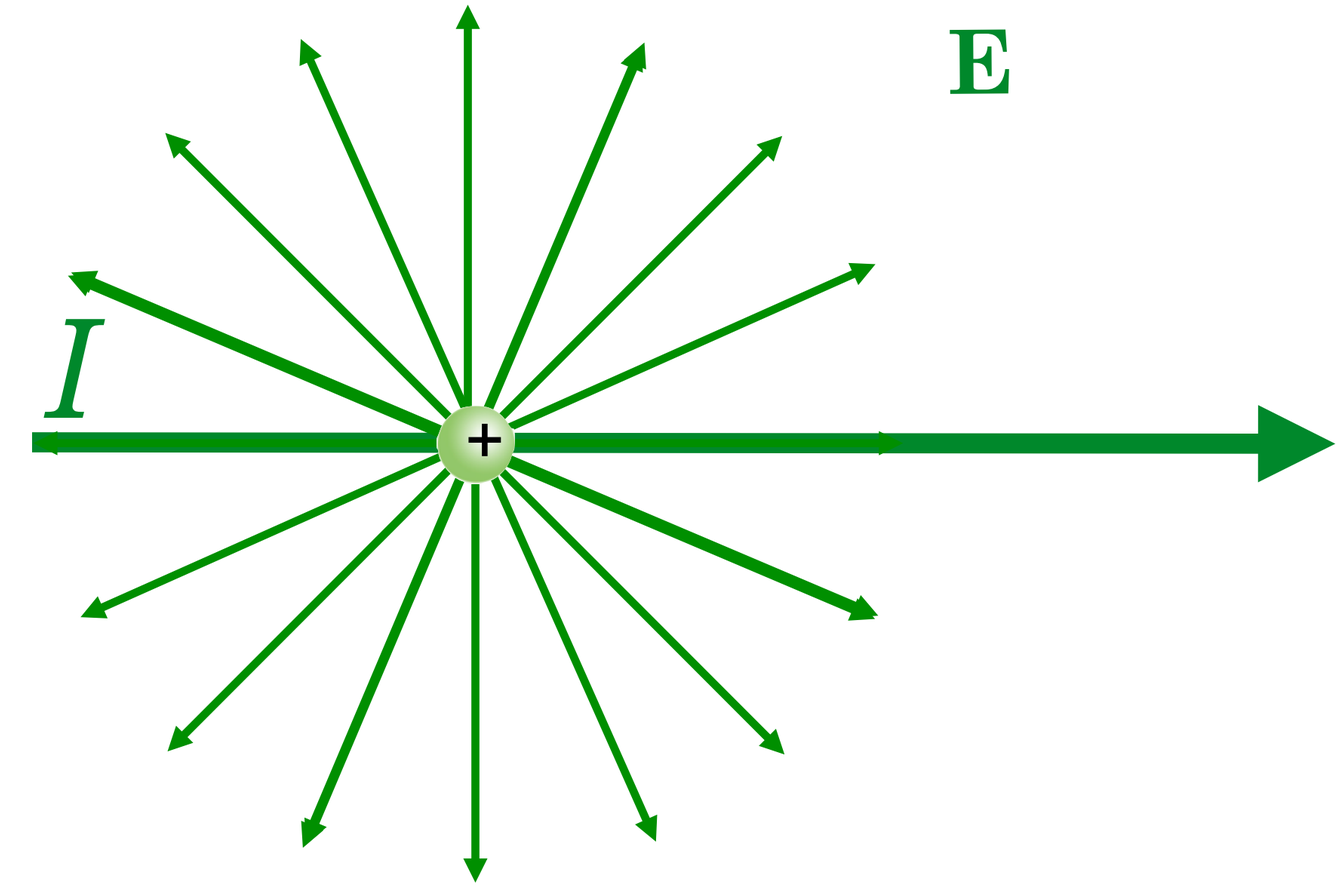
all travel at c = 3 x 10^8 m/s

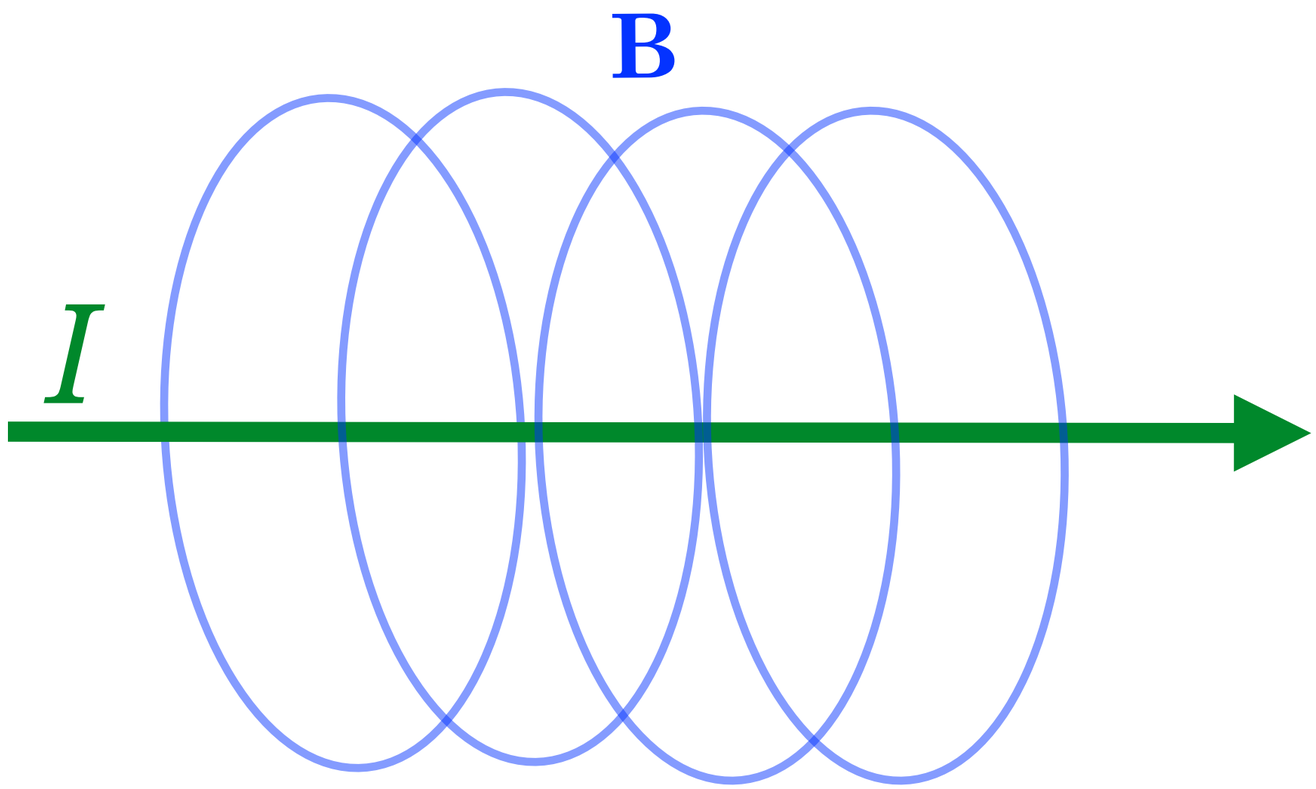


Heinrich Hertz

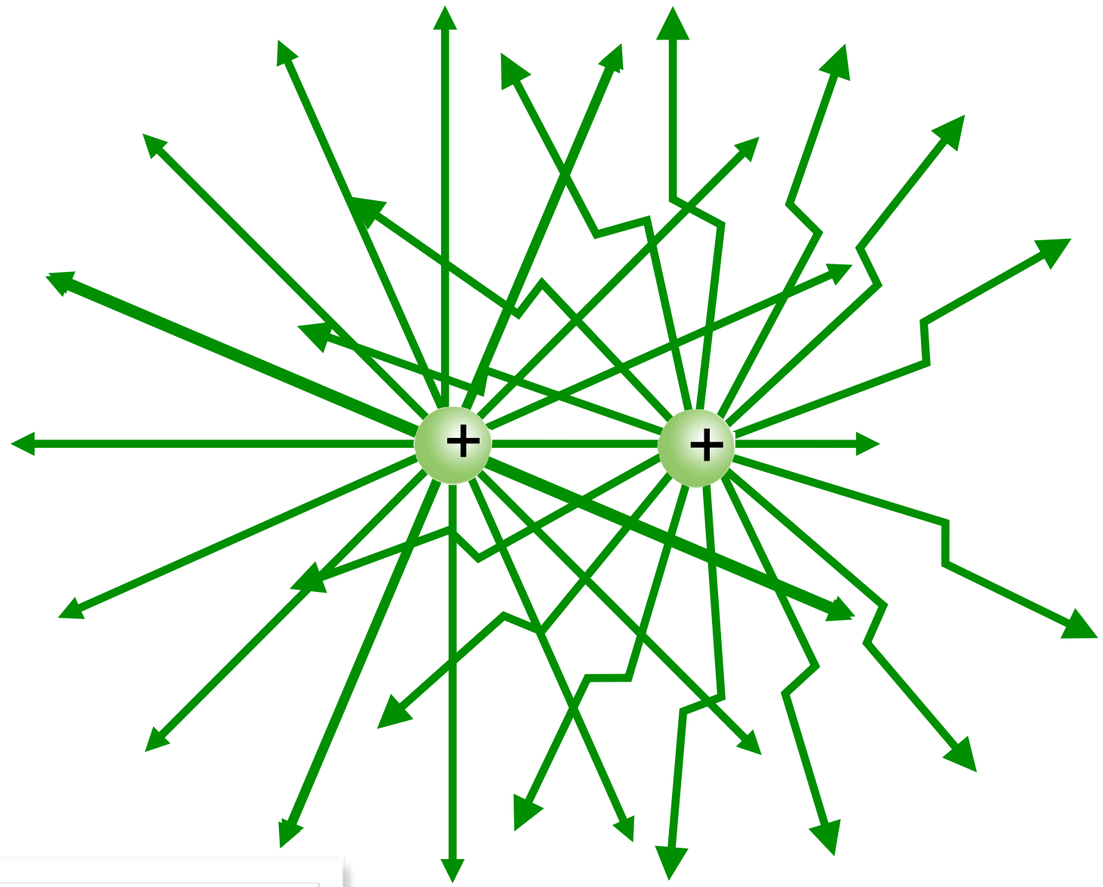
1857 – 1 January 1894

move a charge at a constant speed





now accelerate the charge

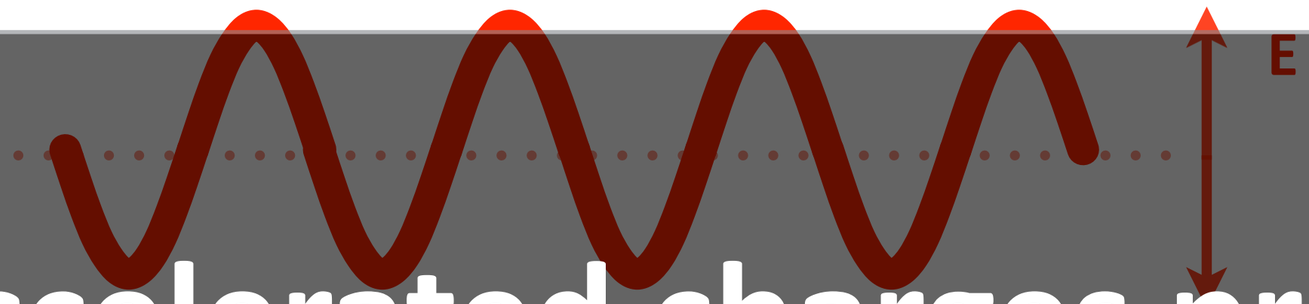


The kinks are the radiation of electromagnetic waves...

accelerated charges create electromagnetic radiation

E applies a force on any Q

E field for example:



the *value of the strength* of the field oscillates in time and **accelerates a charge**

accelerated charges produce

Electromagnetic radiation

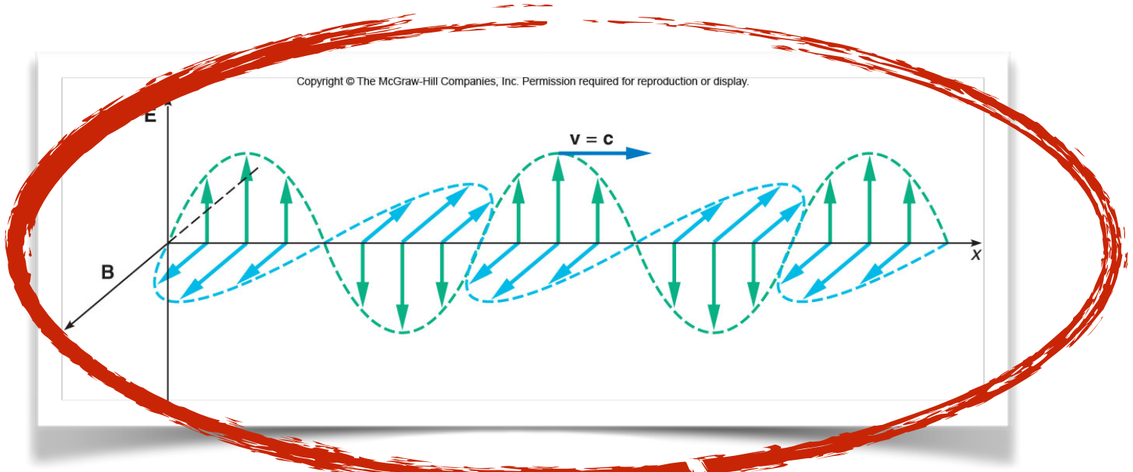
You might want to remember this:

a changing B field creates an E field

a changing E field creates a B field

accelerated charges produce electromagnetic radiation

think radio



energy is transmitted

energy is received

electrons accelerate over here

the transmitter ← Requires energy

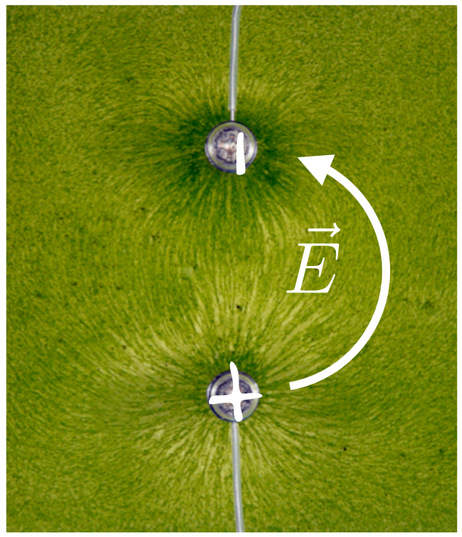
causing electrons to accelerate over there

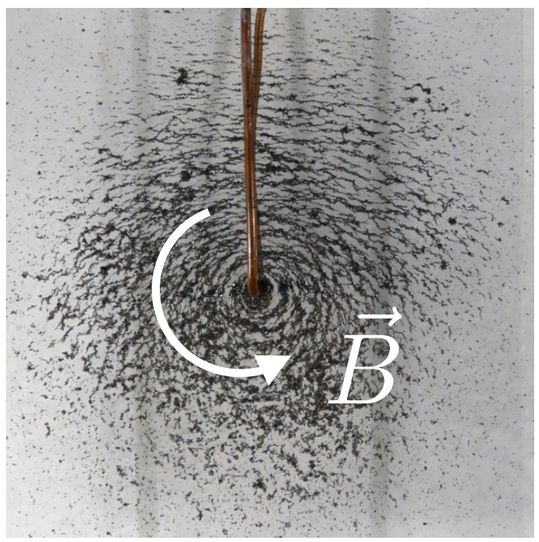
the receiver ← *Delivers* energy

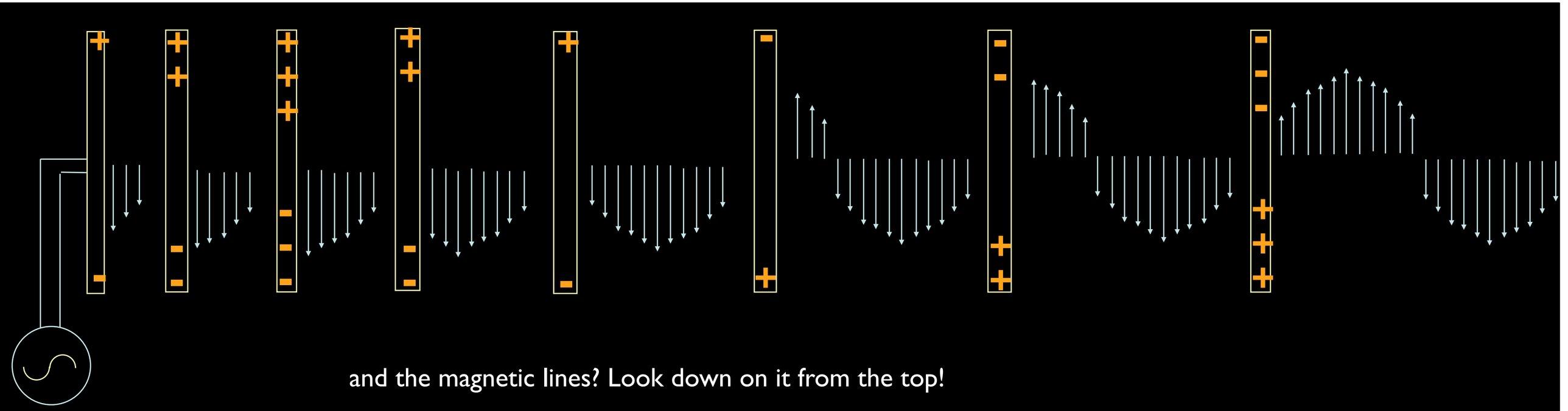
What's in between?

The fields…

propagating @ the finite speed, c





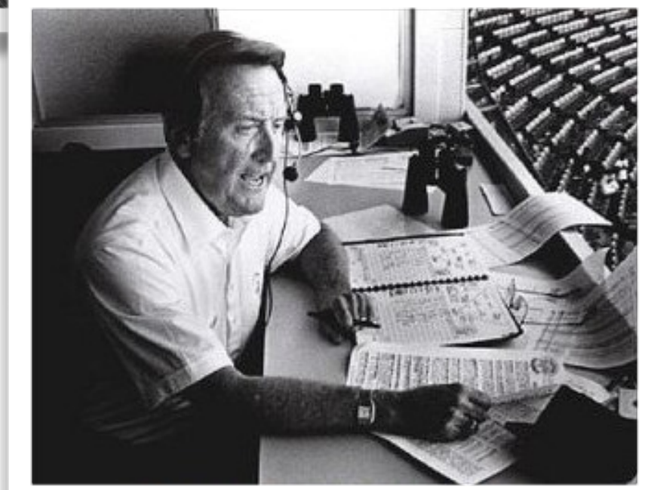


and the magnetic lines? Look down on it from the top!

et cetera...

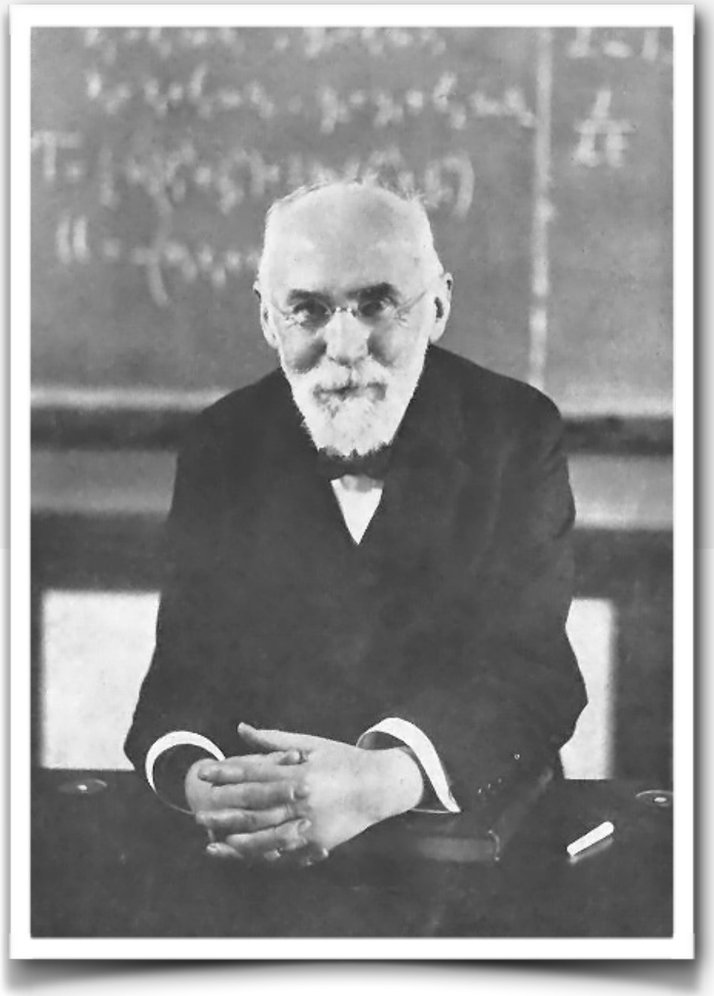
the good things in life

accelerating charges:



gave Ernie Harwell, Jack Brickhouse, Red Barber, Vin Scully, Mel Allen, Jesse Goldberg-Strassler, and Harry Caray each a job

now think “particles”



Maxwell concerned himself with macroscopic, charged objects

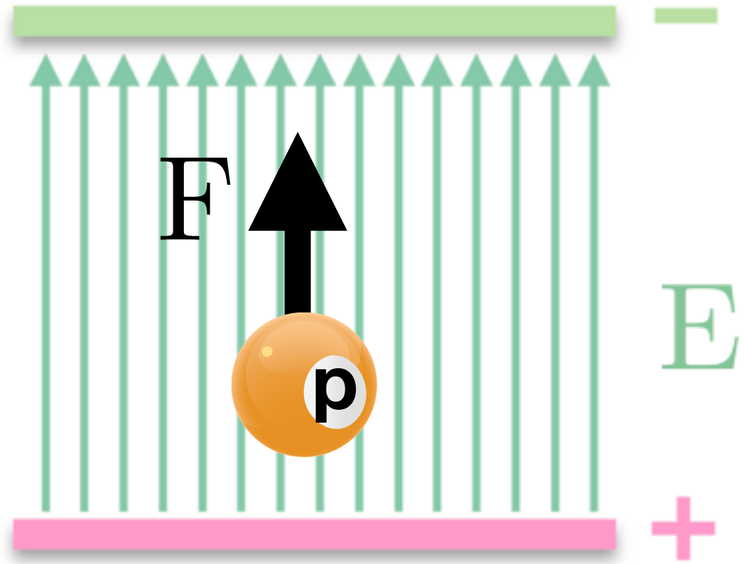
nobody believed in atoms, much less electrons

Our nearly-modern view is due to Hendrik Antoon Lorentz

Hendrik Antoon Lorentz
1853 – 1928

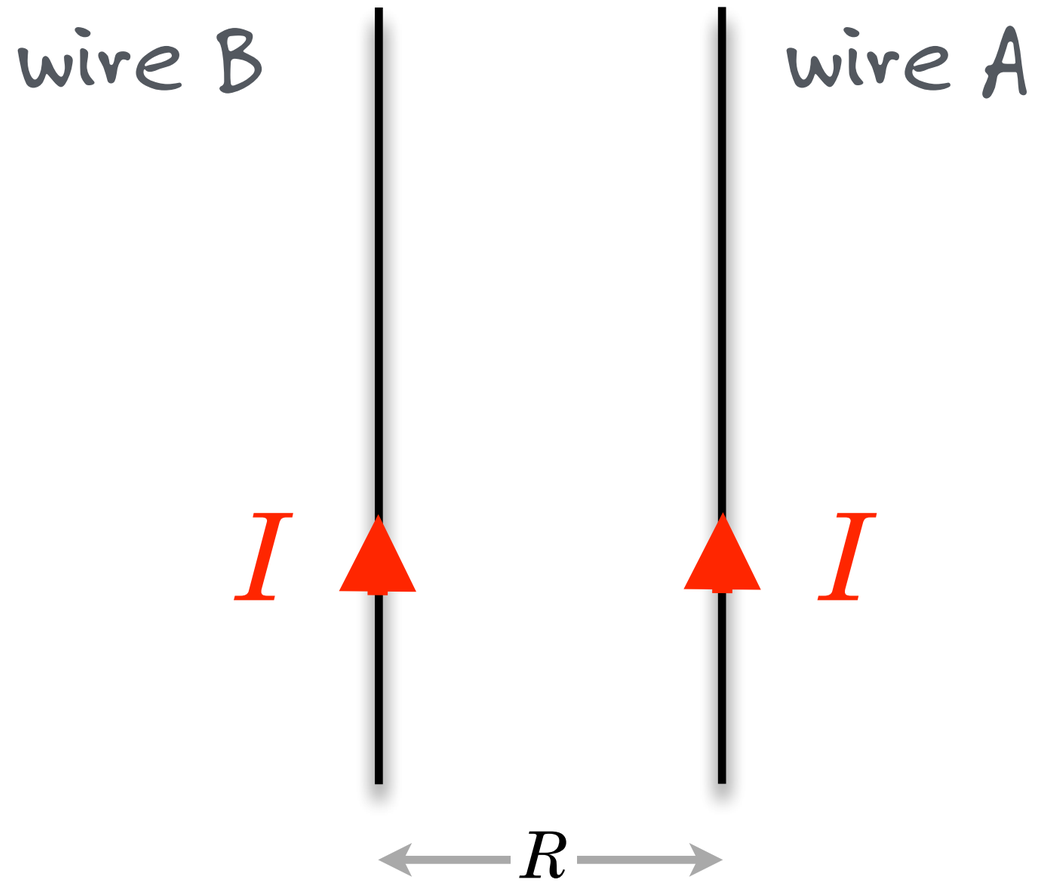
Electric Fields and particles

paradigm example of forces on particles: parallel plates: $F = EQ$



magnetic forces and particles

From a particle viewpoint



going to figure out force on a charged particle in the presence of a **B**

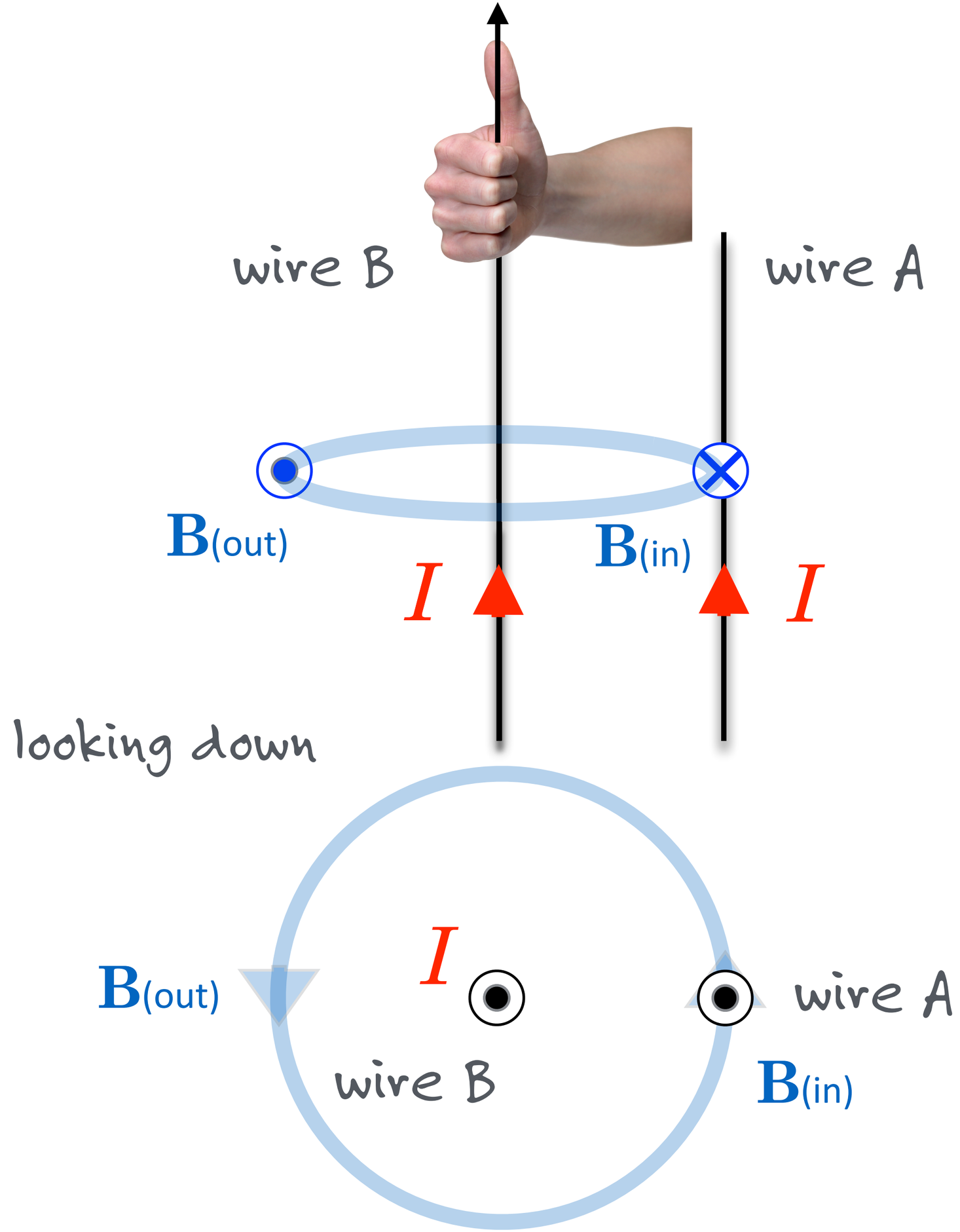
remember the *field* is the thing

Use the parallel currents...and remove the wire in B

step 1

remove wire B

replace with its field



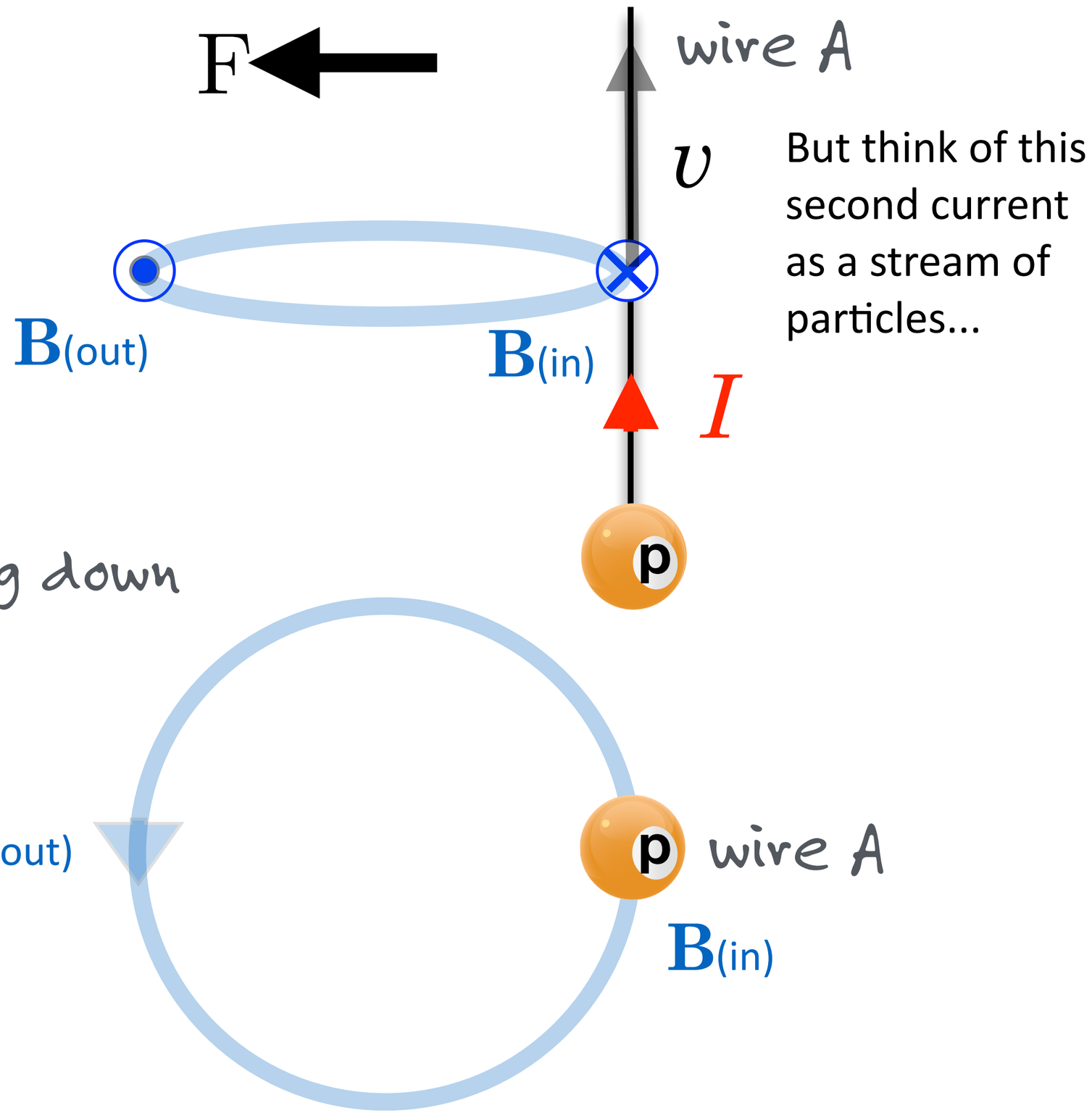
step 2

remove wire A

replace with moving **positive** charged particles

so **in the direction** of the current

But, Wire A moves towards Wire B



this is how magnetic fields deal with particles

they **bend** their paths.

perpendicular to the **field**

perpendicular to the particle's **velocity**

right hand, again

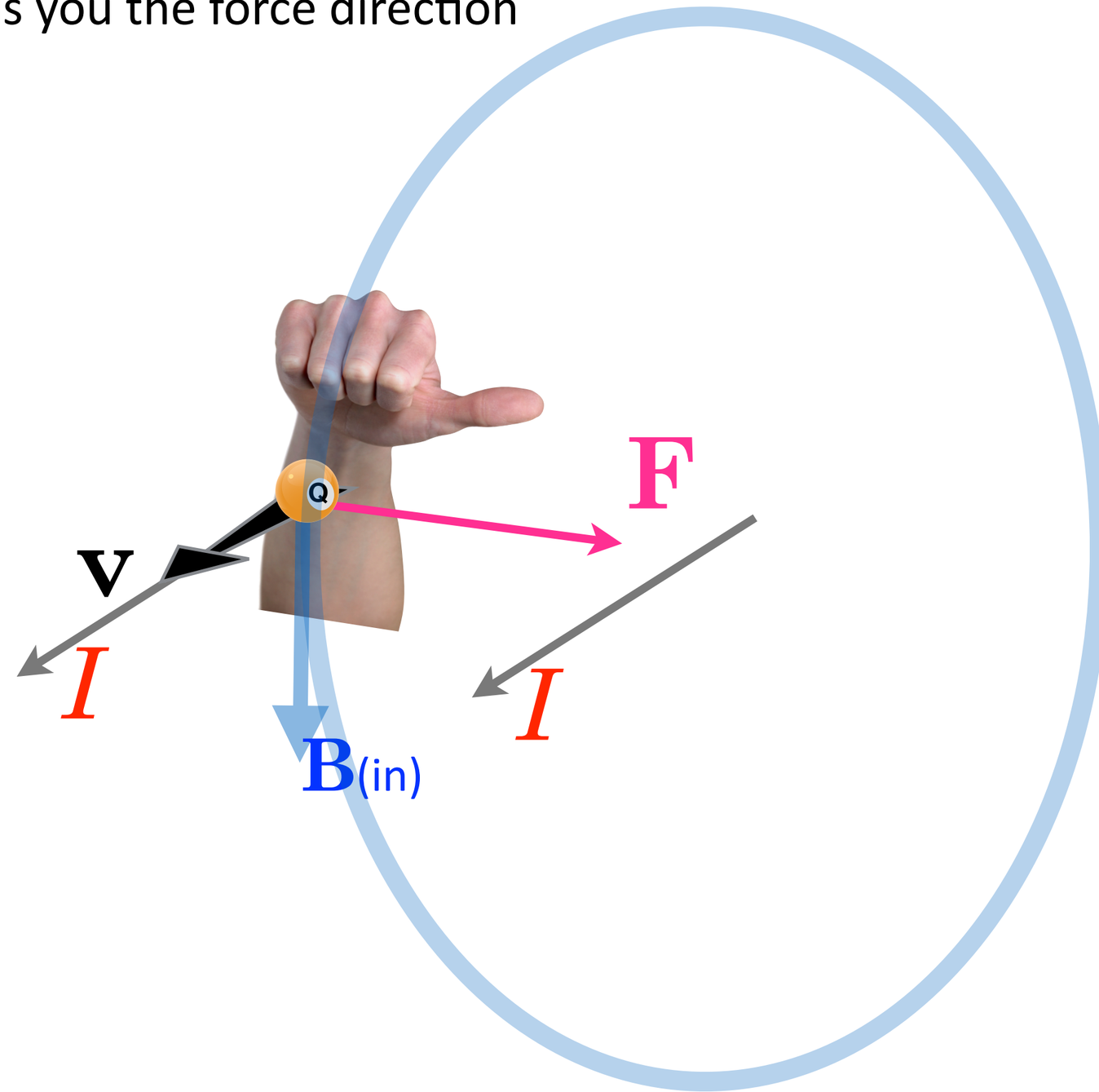
a **different right hand operation** tells you the force direction

this right hand is an operation:

1. take fingers and flow through the **v**

2. continue on and flow through the **B**

3. for +Q your thumb points in the direction of the **F**



Called the “cross product”

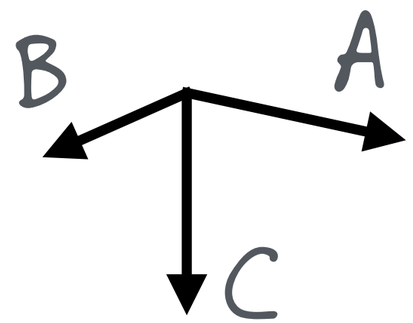
$$\overrightarrow{F} = Q\overrightarrow{v} \times \overrightarrow{B}$$

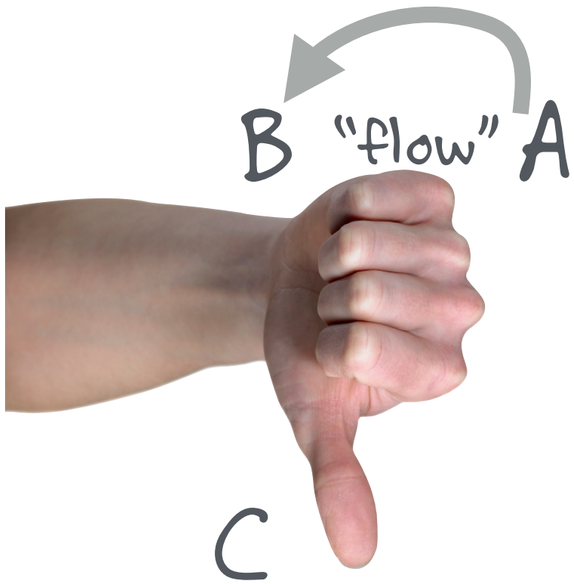
just care about the direction

multiplying vectors: "cross product"

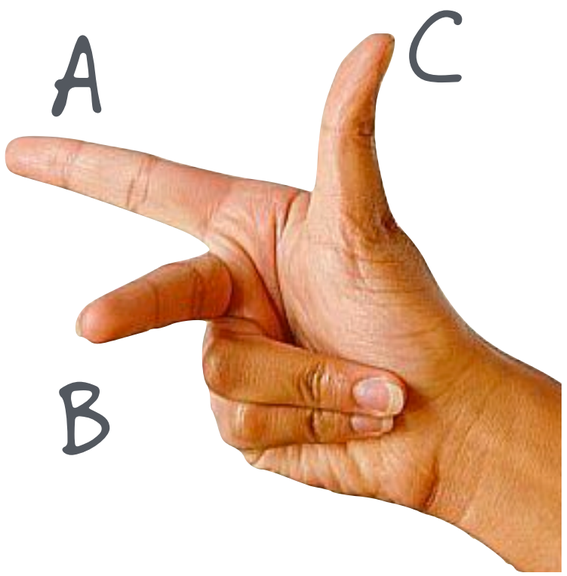
mathematics:

A "cross" B = C



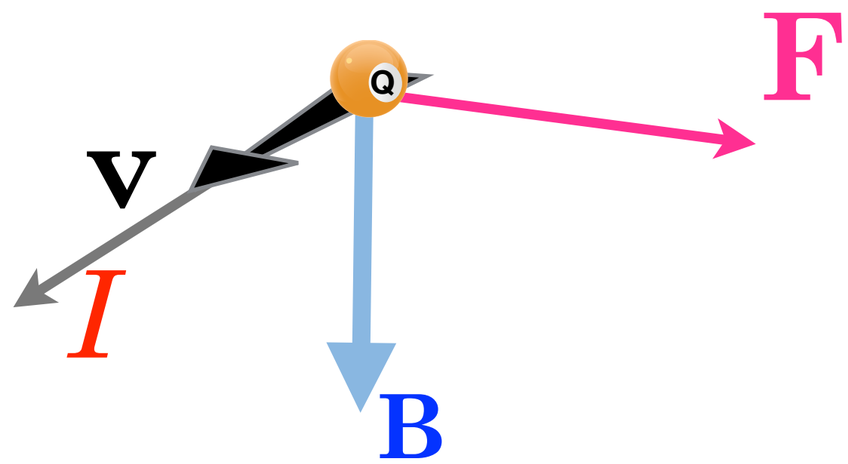


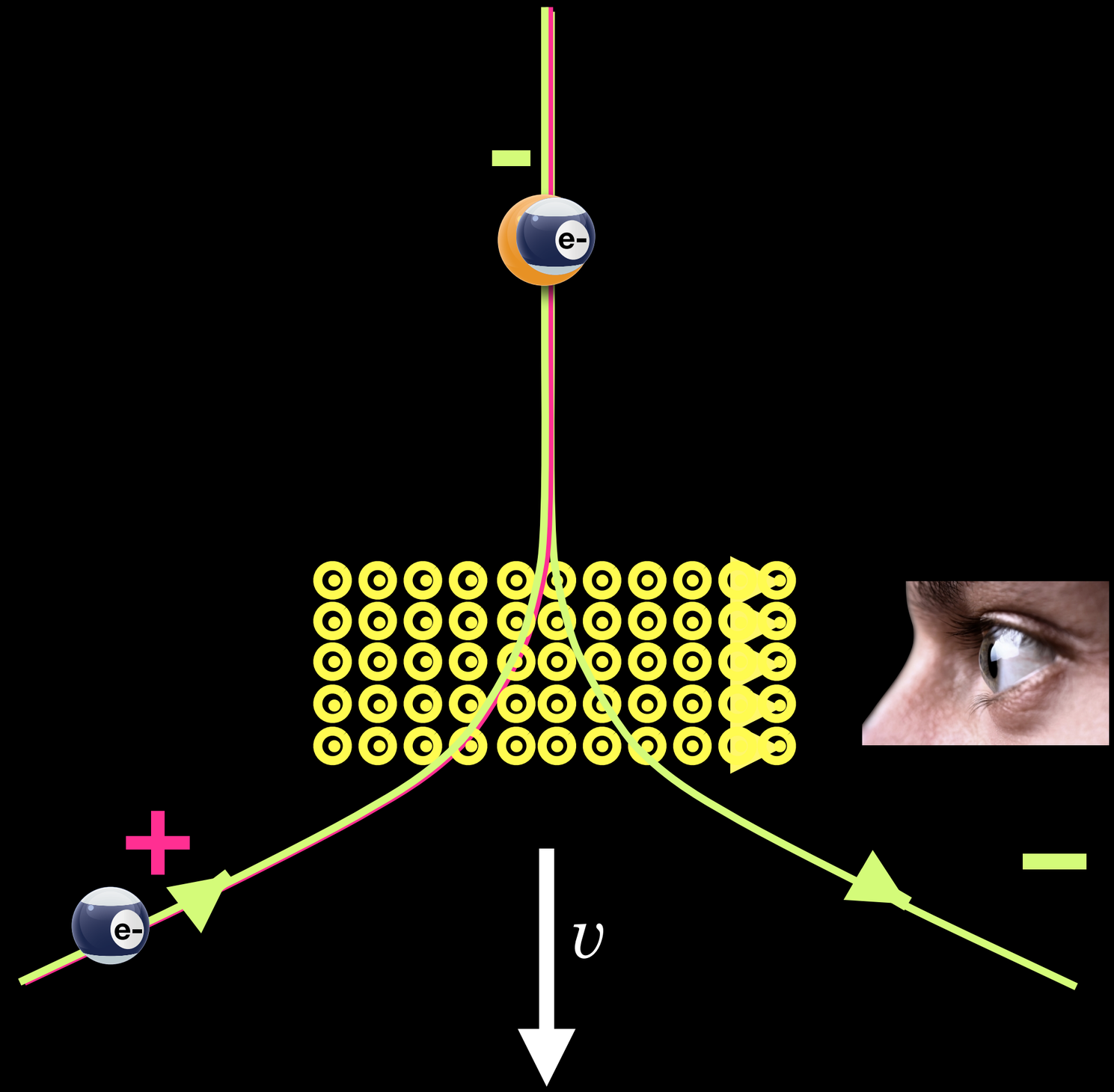
or:

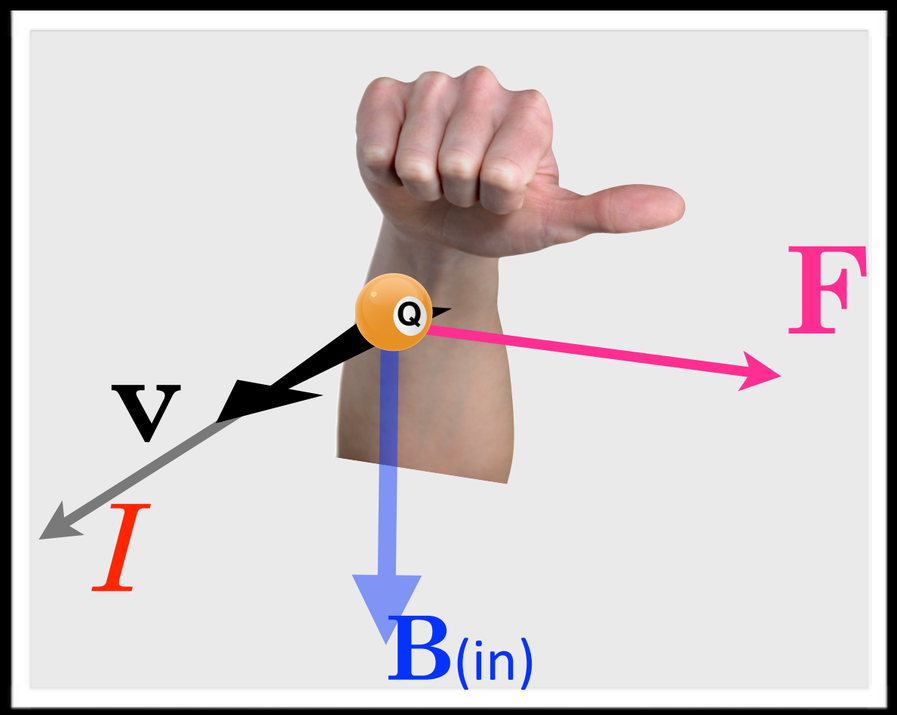


physics:

v "cross" B = F





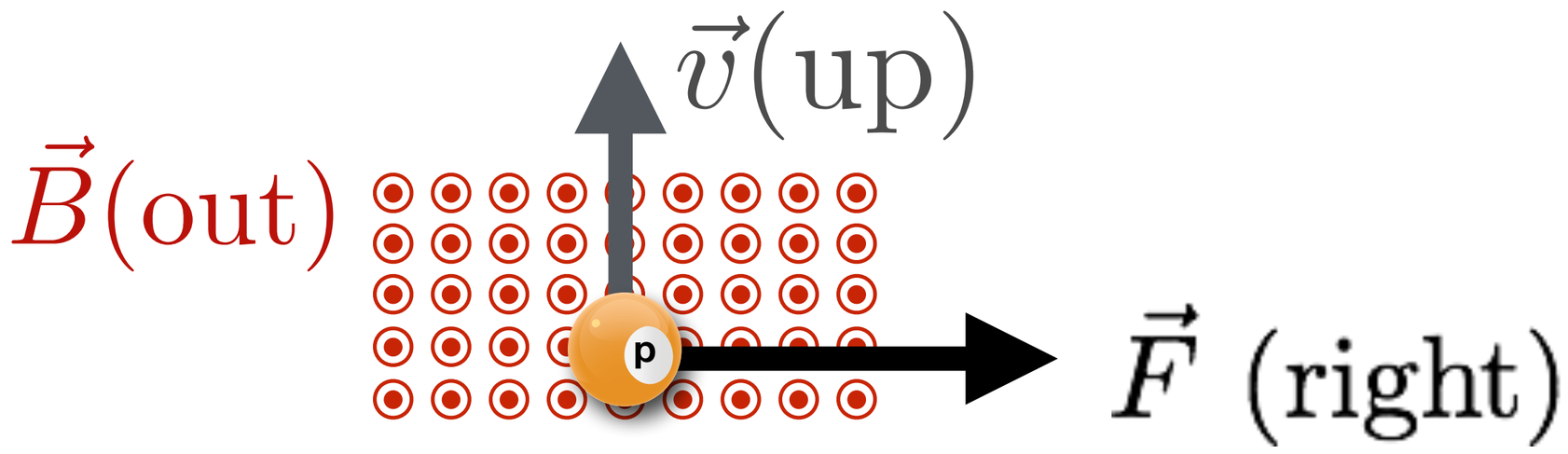


1. take fingers and flow through the **v**
2. continue on and flow through the **B**
3. for +Q your thumb points in the direction of the **F**

so Magnetic Fields bend

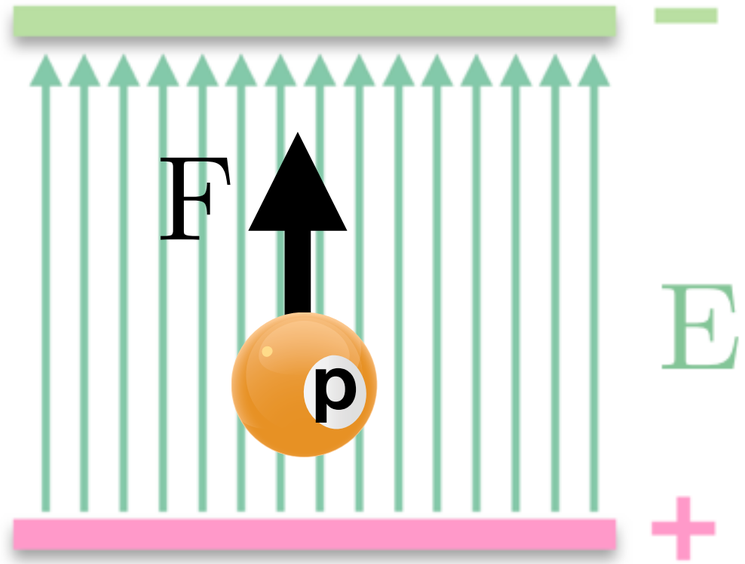
considered as forces on particles, F = qvB

perpendicular to v and B, right hand pointing in F (for +q)



and Electric Fields accelerate

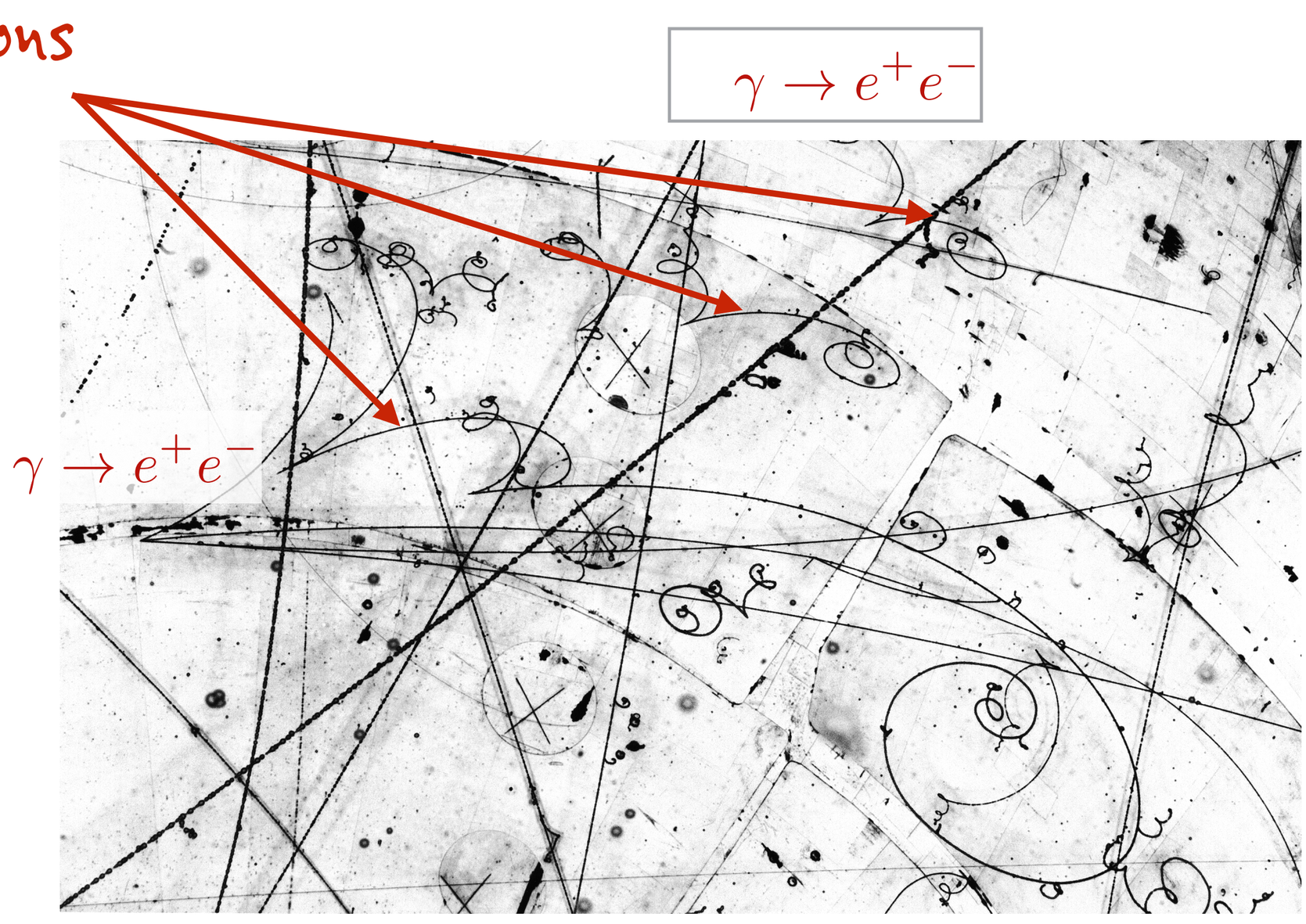
paradigm example of forces on particles: parallel plates: $F = EQ$



electrons

in a field…in a “bubble chamber”

what’s the direction of B?



recap

Electric charges create Electric Fields

Electric charges in motion (“current”) create Magnetic Fields

Accelerating electric charges create propagating electromagnetic fields

Electromagnetic fields propagate at the speed of light, “c” in a vacuum

$$c = 3 \times 10^8 \text{ m/s}$$

Charged particles are accelerated by Electric Fields

Charged particles are bent by Magnetic Fields

Electromagnetic fields possess energy and can do work

no pushing

think about “regular pushing”…

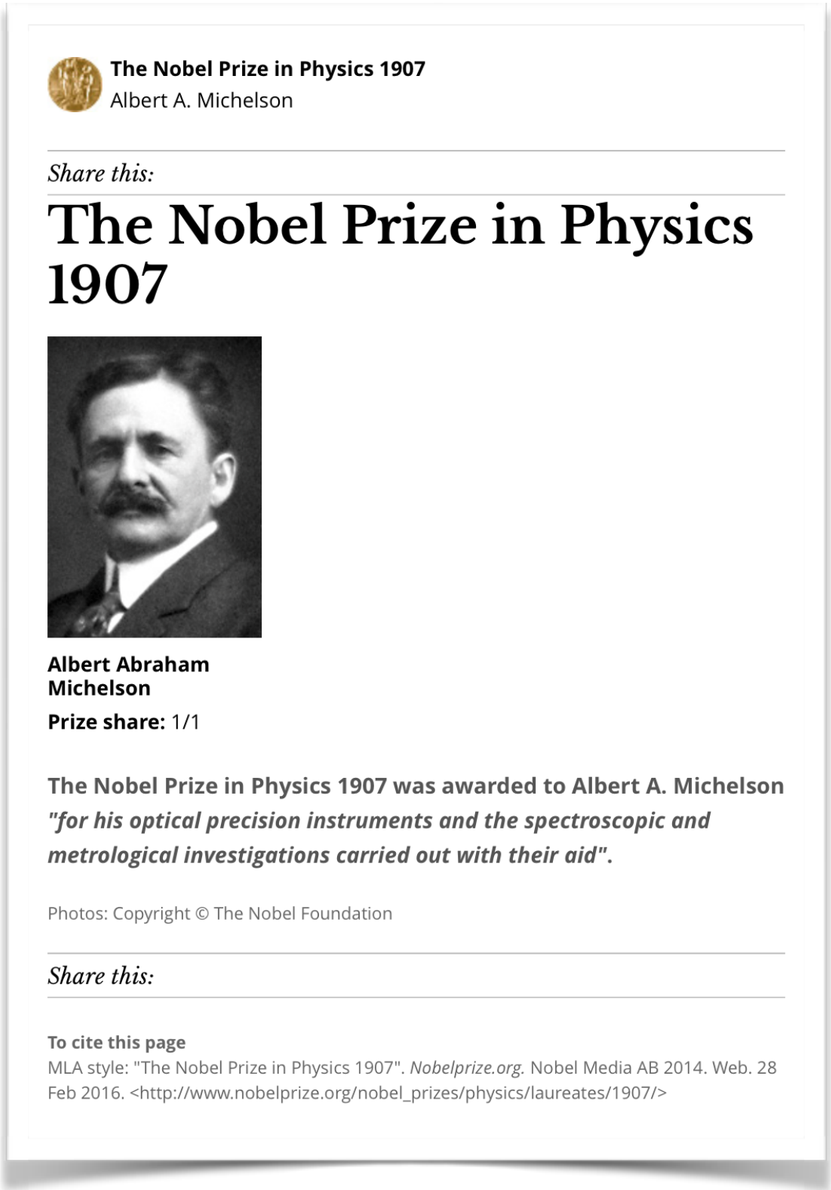
The field **is** everything.

the prevailing view

physics is done:

> "… it seems probable that most of the grand underlying principles [of physics] have been firmly established…"

Albert Michelson 1894



The Nobel Prize in Physics 1907
Albert A. Michelson

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The Nobel Prize in Physics 1907

Albert Abraham Michelson

Prize share: 1/1

The Nobel Prize in Physics 1907 was awarded to Albert A. Michelson *"for his optical precision instruments and the spectroscopic and metrological investigations carried out with their aid".*

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in 1895
the wheels came off

want a rollicking old time?

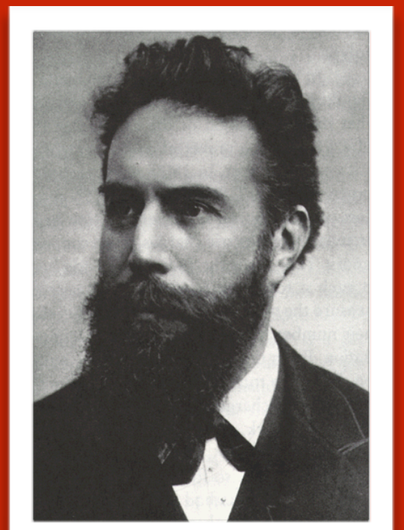
as much as physics can be rollicking...

1895, 1896, 1897, 1898, 1899

one weird, weird, weird, weird, weird thing after another

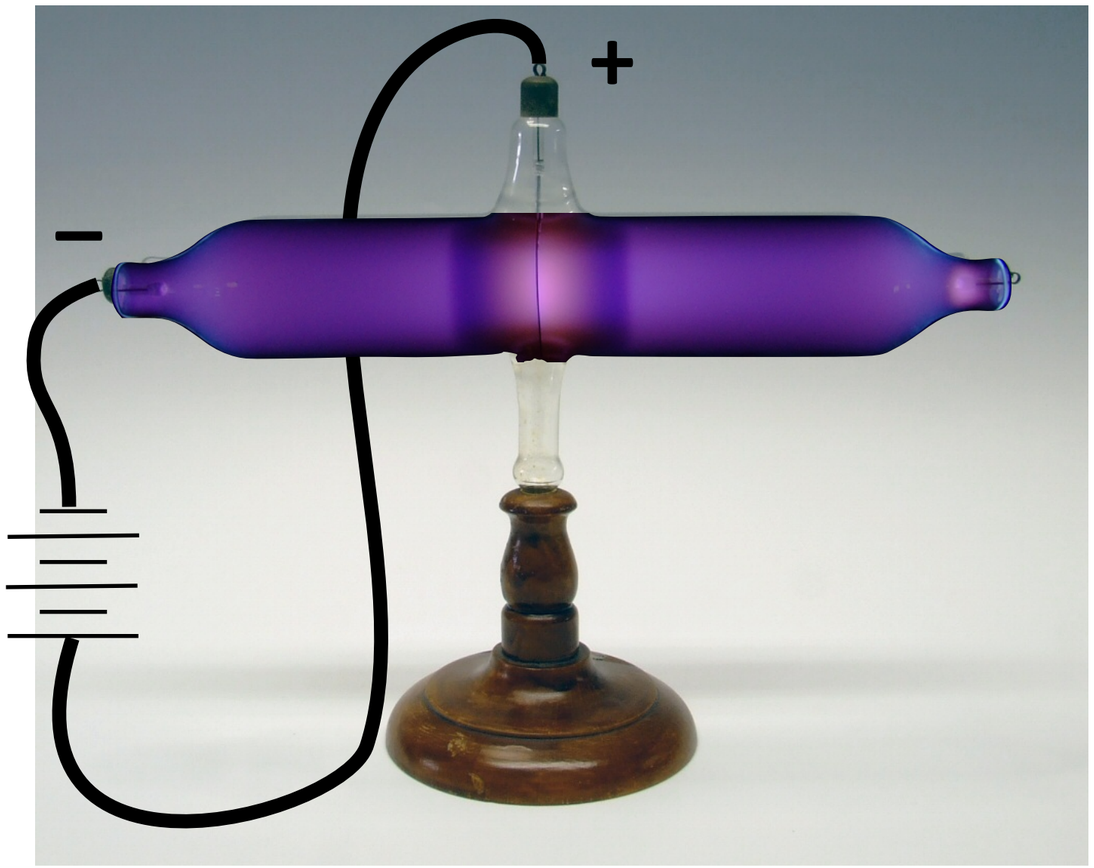
1895 Wilhelm Roentgen

1845-1923



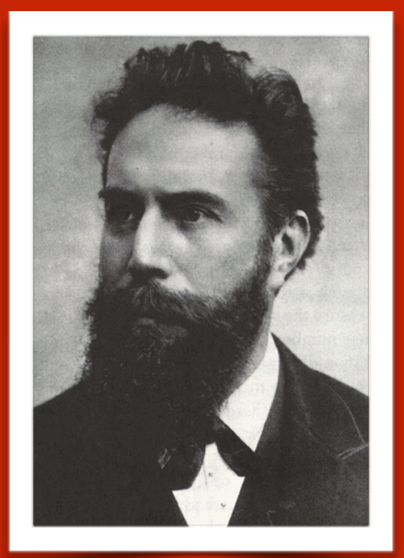
"Roentgen has really gone crazy." ...what Wilhelm Roentgen worried when at the age of 50 he found something unusual in his lab in Wurzburg, Germany.

Everyone studied "cathode ray tubes"–"Crookes Tubes"



1895 Wilhelm Roentgen

1845-1923



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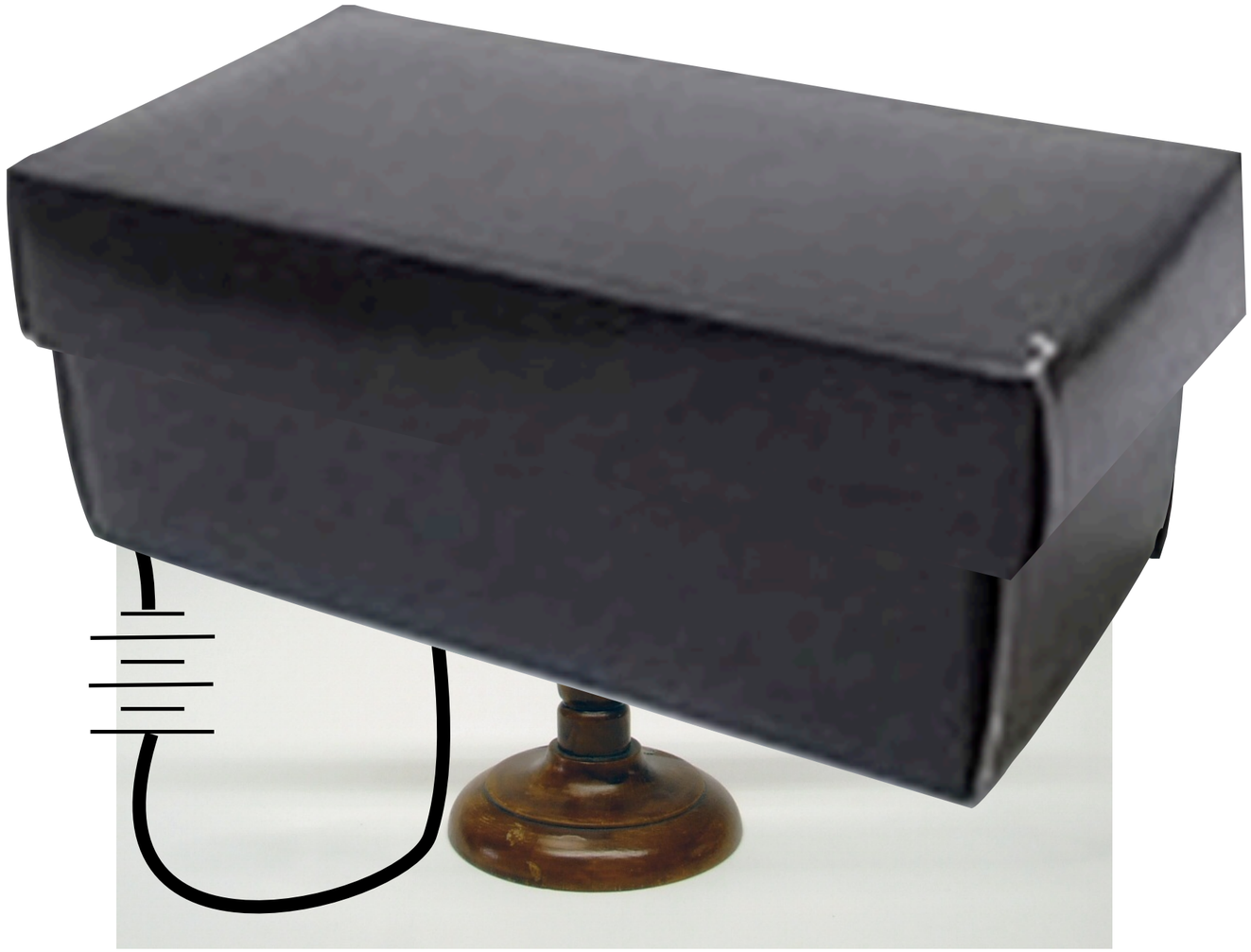

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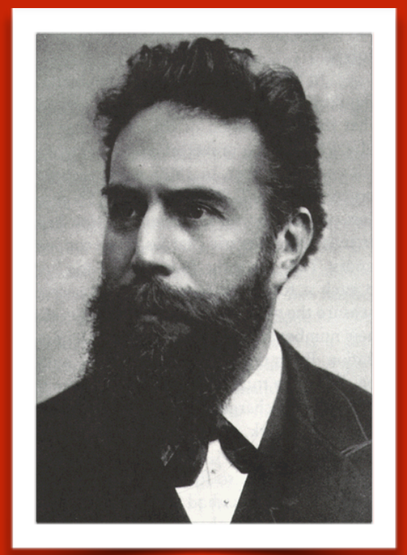
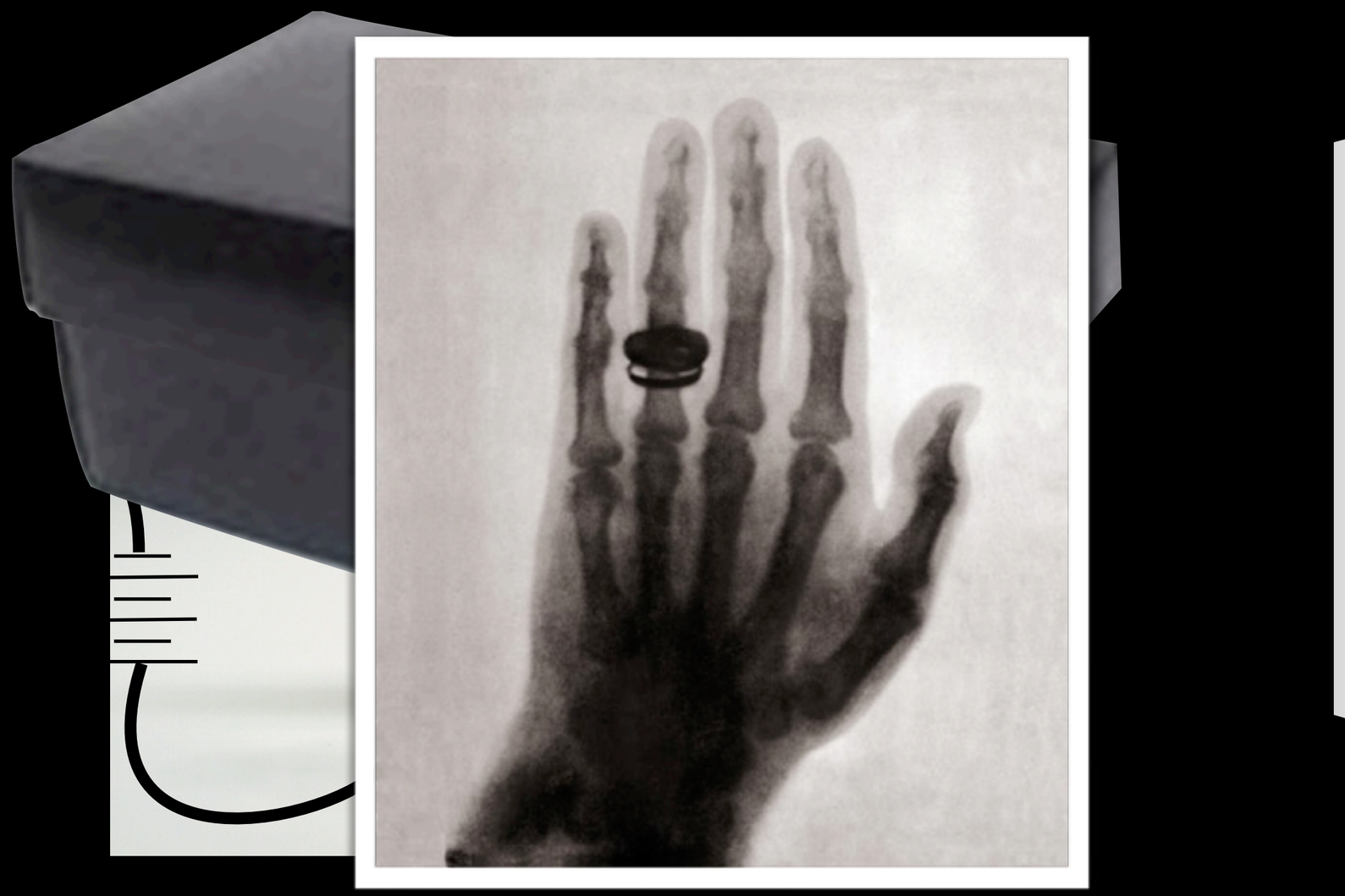




word got out

he spilled the beans

after 7 exhausting weeks

January 1, 1896 he circulated a picture of the bones of his hand and a description of his experiments: **called them "X."**

Within weeks, it was reprinted in *Science*, *Nature*, the *French Academie des Sciences* and other journals

Within a week of the Paris announcement, confirmation occurred in 4 labs

Within 5 weeks, X-Rays were used to set the broken arm of a boy in Dartmouth

Within a year, a thousand papers were published

within 4 months, Edison is manufacturing

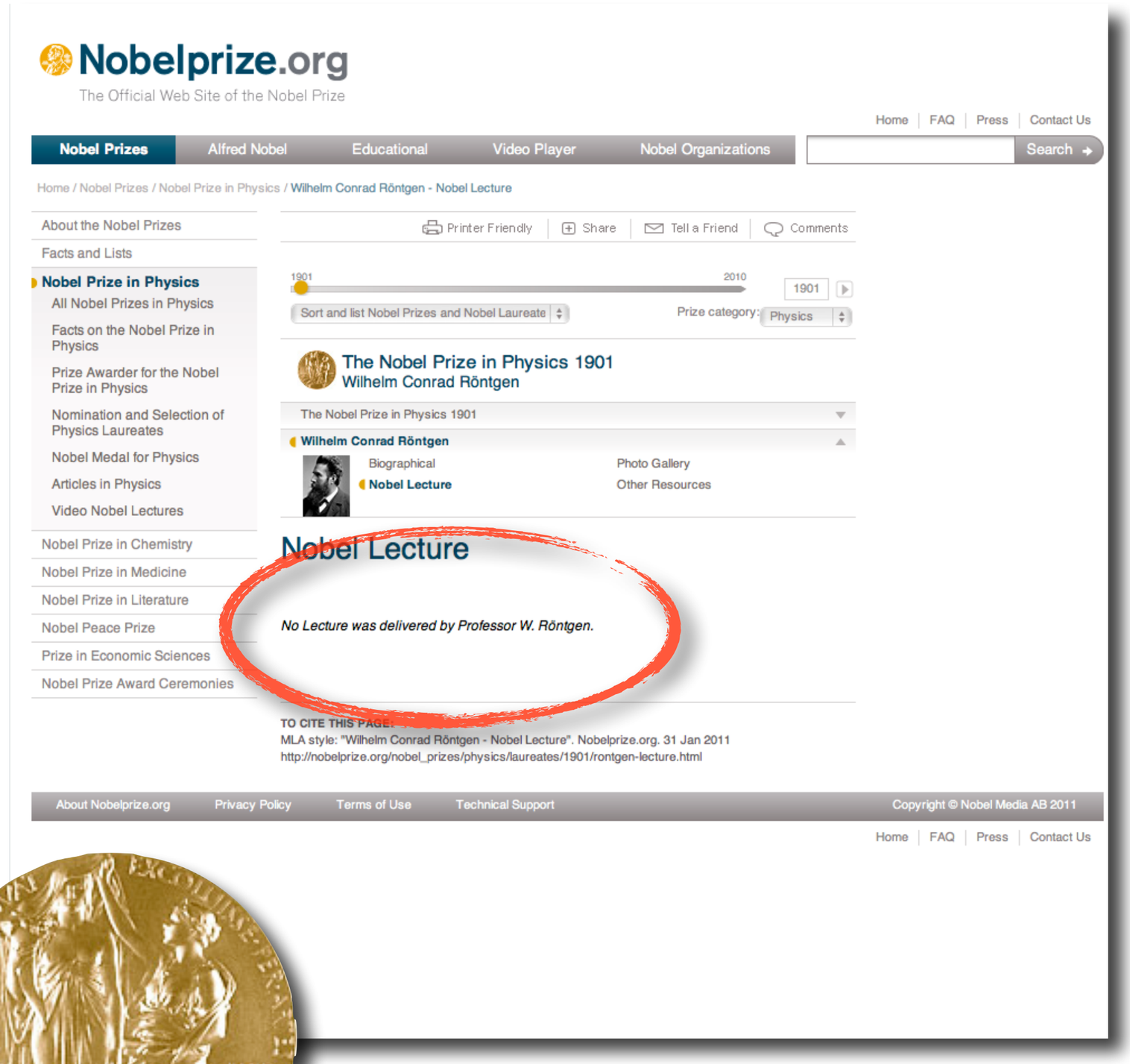
our first Nobel

1 talk

1 publication

no profit

suffered terribly during WWI



then

it got strange

what's a particle accelerator?

a device designed to:

accelerate elementary particles to interesting energies

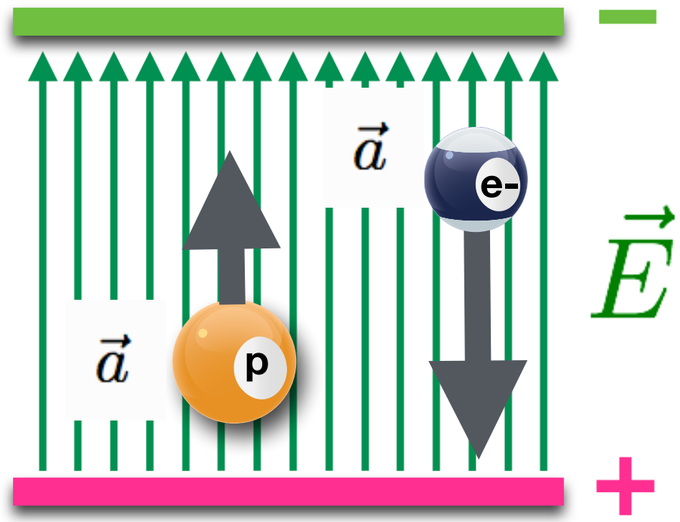
&

bend them where you want them to go

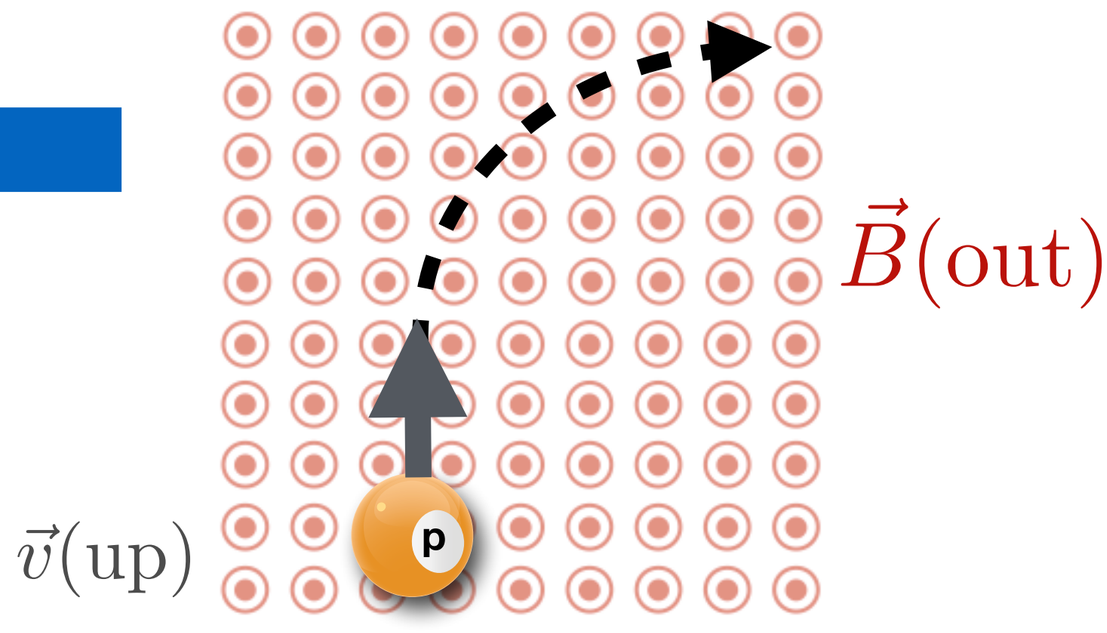
Accelerator ingredients: E and B

for two configurations of charges and currents

Electric Fields
accelerate



Magnetic Fields
bend



1897
J. J. Thomson

1856-1940

> Could anything at first sight seem more impractical than a body which is so small that its mass is an insignificant fraction of the mass of an atom of hydrogen?
>
> What are these particles? Are they atoms, or molecules, or matter in a still finer state of subdivision?

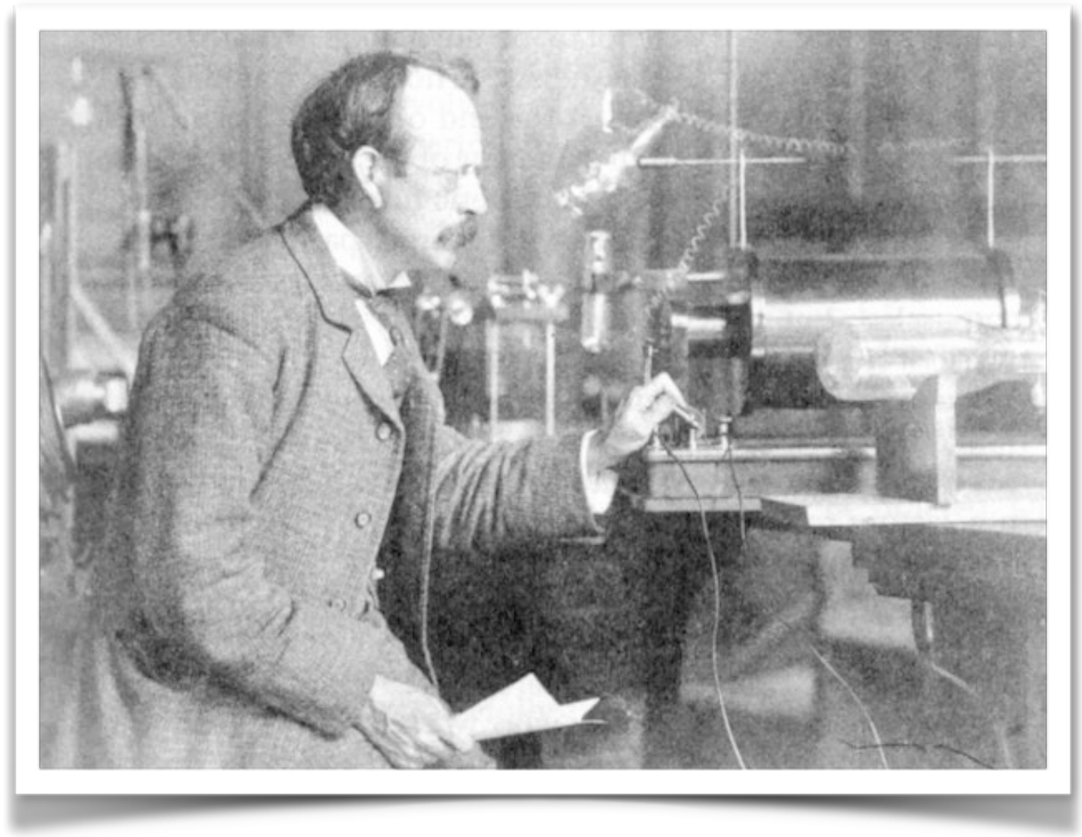
J.J.'s confusion was shared in 1897.

"J.J. was very awkward with his fingers, and I found it very necessary not to encourage him to handle the instruments! But he was very helpful in talking over the ways in which he thought things ought to go."

H. F. Newall, onetime assistant to the young Professor Thomson.

everyone studied cathode ray tubes

technologies enabled new experiments

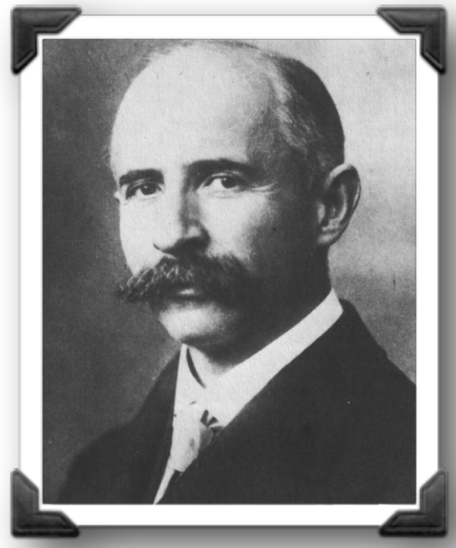


J.J. enjoyed:

1. better vacuum and better batteries

2. an un-prejudiced mind.
   German, Walter Kaufmann did everything better than JJ

except open his mind.



Walter Kaufmann (1871-1947)

laboratory: **Cavendish Laboratory**

location:	Cambridge University, U.K.
established:	1874
notable directors:	James Clerk Maxwell, Lord Rayleigh, J.J. Thompson, Ernest Rutherford, Neville Mott
type of lab:	general purpose physical sciences

laboratory: **Cavendish Laboratory**

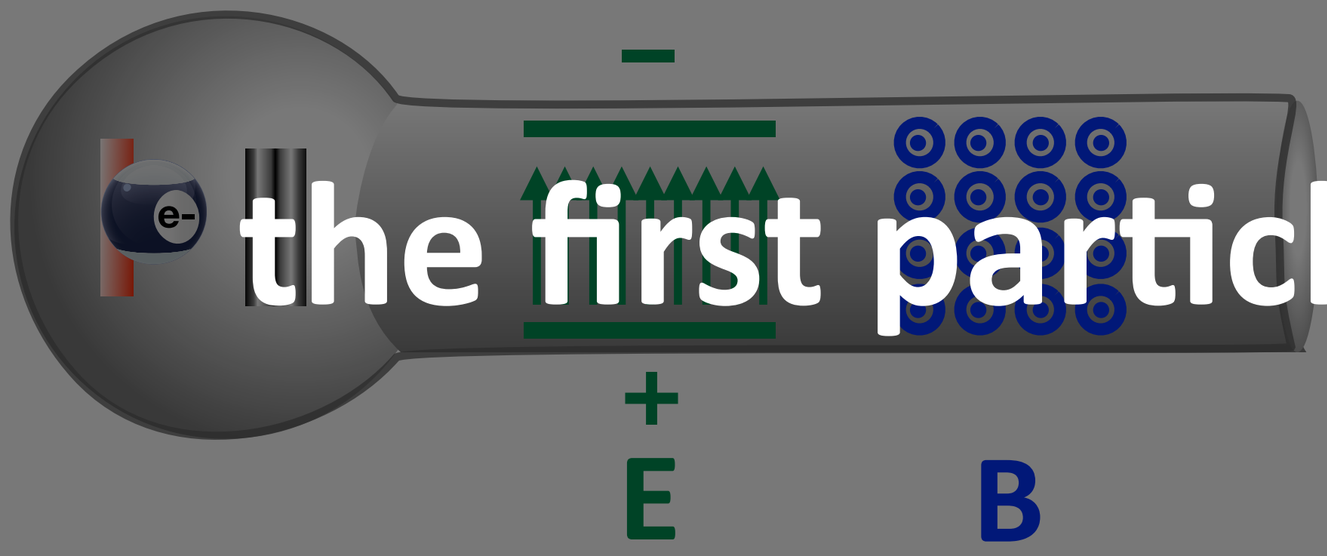
Nobel Prizes:

- Lord Rayleigh (Physics, 1904)
- Sir J.J. Thomson (Physics, 1906)
- Lord Ernest Rutherford (Chemistry, 1908)
- Sir Lawrence Bragg (Physics, 1915)
- Charles Barkla (Physics, 1917)
- Francis Aston (Chemistry, 1922)
- Charles Wilson (Physics, 1927)
- Arthur Compton (Physics, 1927)
- Sir Owen Richardson (Physics, 1928)
- Sir James Chadwick (Physics, 1935)
- Sir George Thomson (Physics, 1937)
- Sir Edward Appleton (Physics, 1947)
- Lord Patrick Blackett (Physics, 1948)
- Sir John Cockcroft (Physics, 1951)
- Ernest Walton (Physics, 1951)
- Francis Crick (Physiology or Medicine, 1962)
- James Watson (Physiology or Medicine, 1962)
- Max Perutz (Chemistry, 1962)
- Sir John Kendrew (Chemistry, 1962)
- Dorothy Hodgkin (Chemistry, 1964)
- Brian Josephson (Physics, 1973)
- Sir Martin Ryle (Physics, 1974)
- Anthony Hewish (Physics, 1974)
- Sir Nevill Mott (Physics, 1977)
- Philip Anderson (Physics, 1977)
- Pjotr Kapitsa (Physics, 1978)
- Allan Cormack (Physiology or Medicine, 1979)
- Sir Aaron Klug (Chemistry, 1982)
- Norman Ramsey (Physics, 1989)

JJ's experiment

presumed particles

presumption of particles

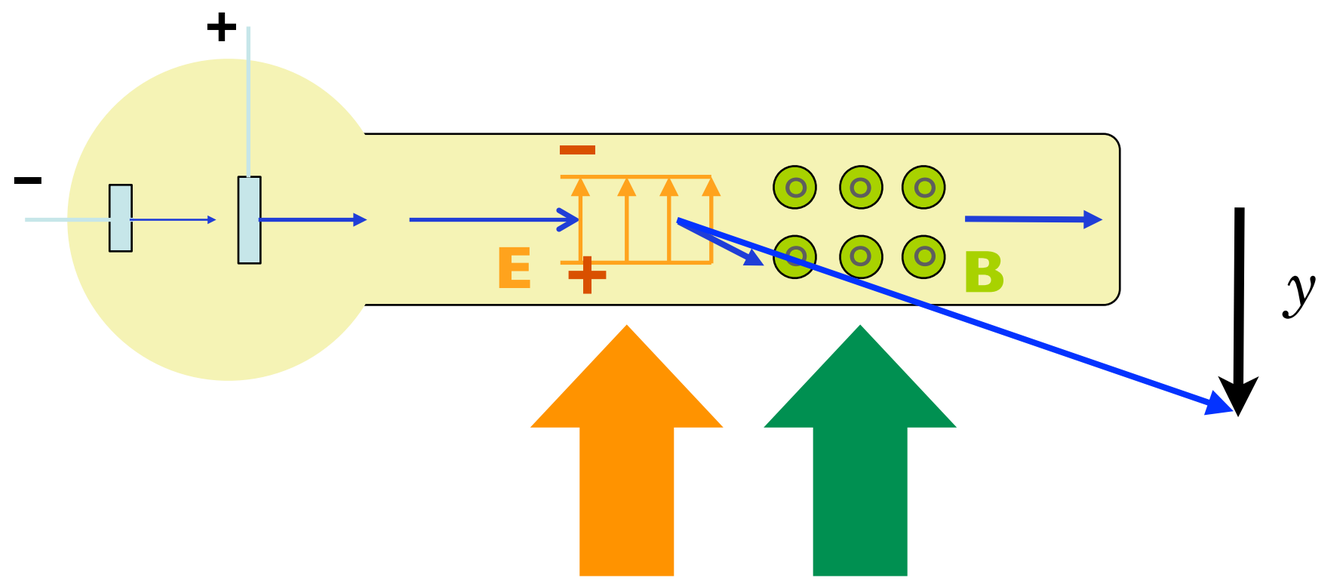


the first particle accelerator!

The measurement is the ratio of the charge to the mass:

if you assume that the beam is made of particles.

clever, actually



electric field bends electron DOWN

tuned the magnetic field to bend the electron UP

His assumption was that **there is a <u>something</u>** with an *m* & a *q*!

$$\frac{q}{m} = 1.76 \times 10^{11}\mathrm{C/kg}$$ 1000 times larger than Hydrogen.

Either: the “corpuscle” has huge charge or tiny mass.

Nobel 1906

The Nobel Prize in Physics 1906
J.J. Thomson

Share this:

The Nobel Prize in Physics 1906

Joseph John Thomson

Prize share: 1/1

The Nobel Prize in Physics 1906 was awarded to J.J. Thomson *"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".*

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"The Nobel Prize in Physics 1906". *Nobelprize.org.* Nobel Media AB 2014. Web. 10
http://www.nobelprize.org/nobel_prizes/physics/laureates/1906/>

“spin” is a defining quality of an electron..later

particle: **electron**

symbol: e

charge: $-1e$

mass: $m_e = 9.0 \times 10^{-31}$ kg ~ 0.0005 p

spin: 1/2

category: fermion, lepton

Tools of the trade

Particle Accelerators

Particle Detectors

Telescope Observatories

more convenient energy units

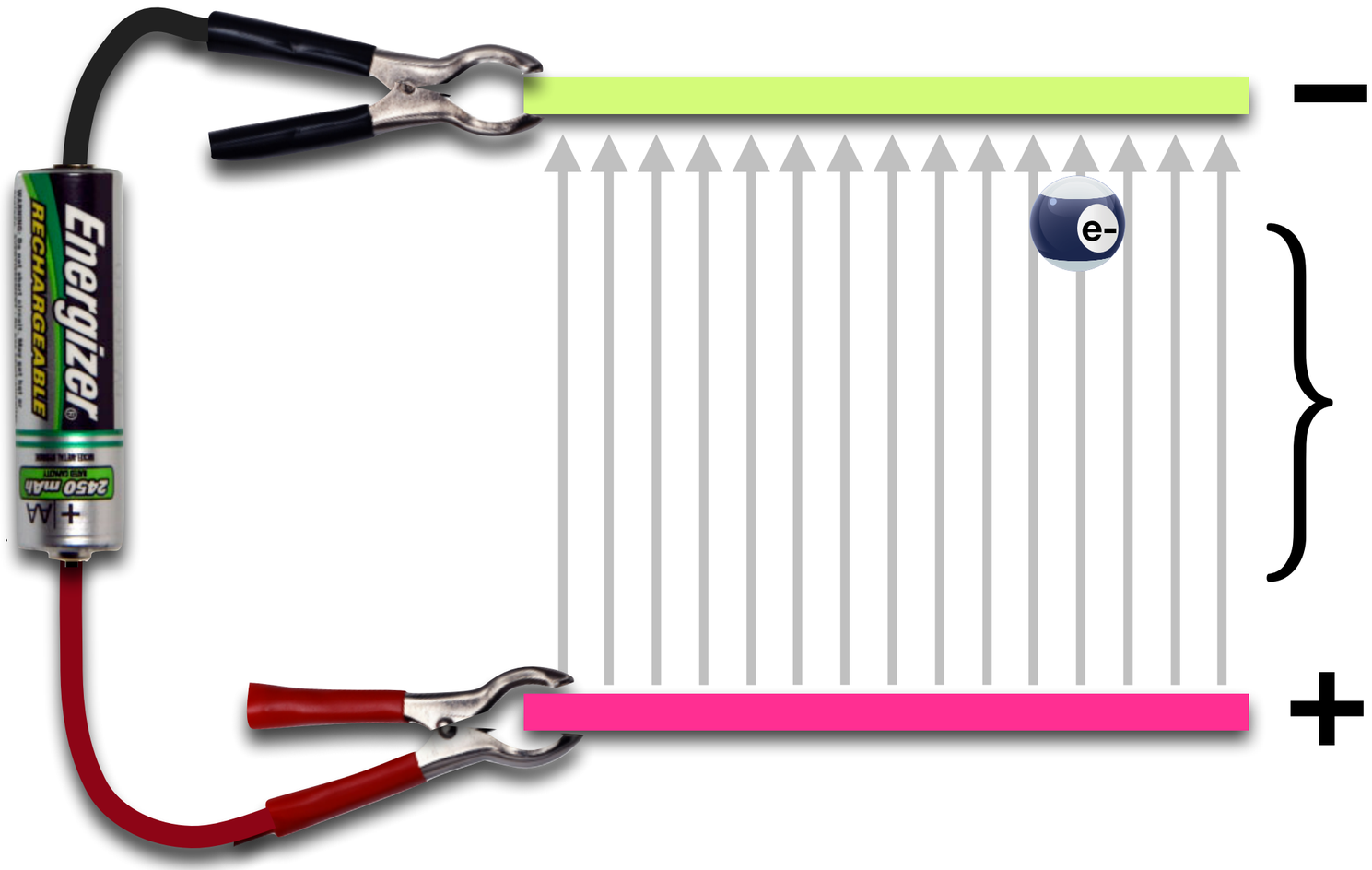
“electron volts”

remember that energy gained by particle of charge Q accelerated through a potential, V

$$U = QV$$

get rid of the 10^{-19}

If you're dealing with particles of the fundamental charge $e = 1.6 \times 10^{-19}$ C



$$U = QV$$

What's the energy gained by say, an electron - some thing possessing the fundamental charge of ***e***? accelerated through 1 Volt = 1 J/C?

$$U = QV$$

$$U = eV = 1.6 \times 10^{-19}\mathrm{C} \times 1\ \mathrm{J/C}$$

$$U = 1.6 \times 10^{-19}\ \mathrm{J} \equiv 1\ \text{electron volt}$$

the energy of accelerators

often quoted in terms of

keV, MeV, GeV, or TeV

10^3, 10^6, 10^9, 10^{12} electron volts

LHC proton beams: currently 13 TeV

a TV? keV's