Solid Earth Dynamics

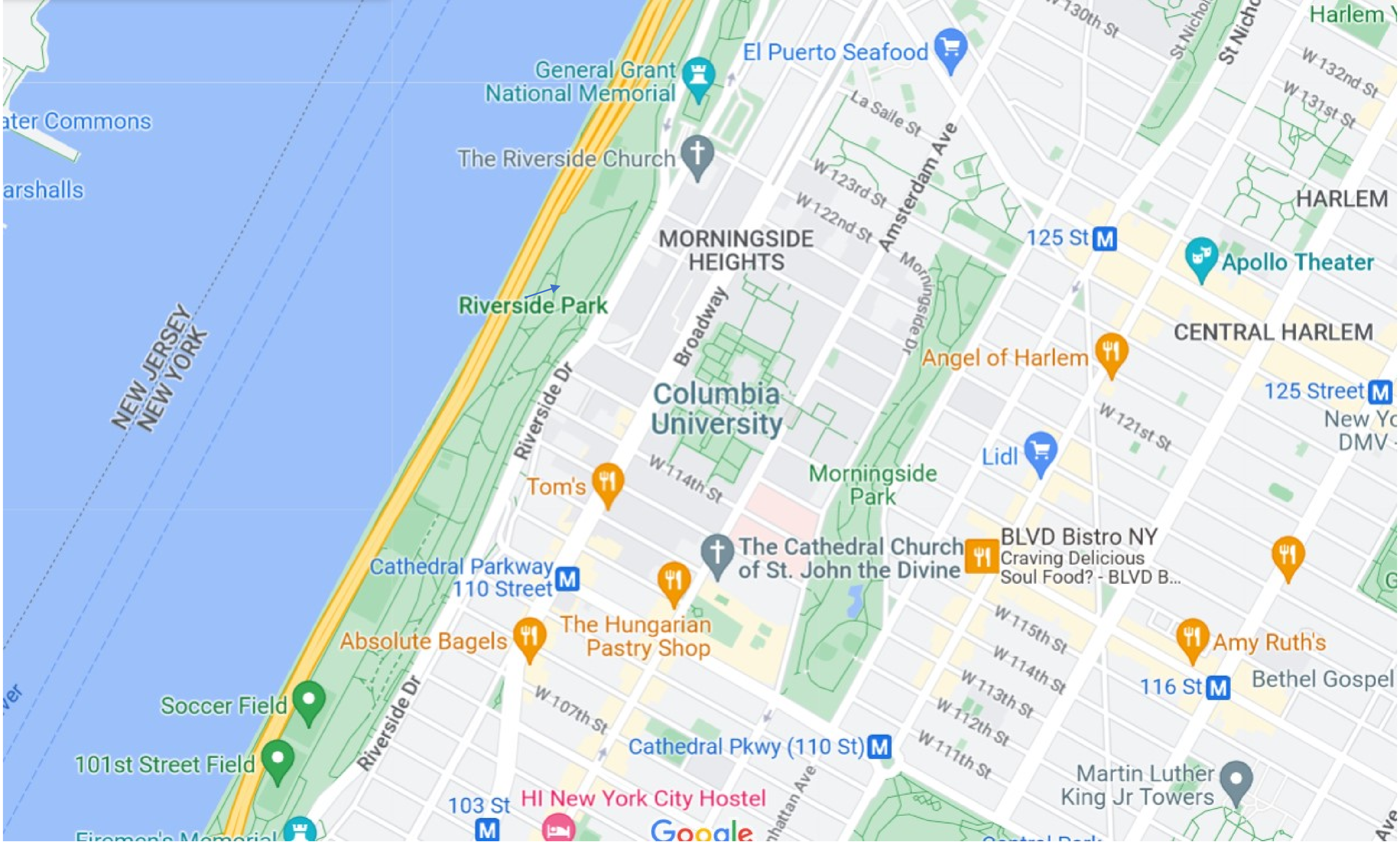
Bill Menke, Instructor

Lecture 21

Solid Earth Dynamics

Geomagnetism

cm
1:25000 Km
TAIWAN
N
E
S
W
NE
SW


El Puerto Seafood
General Grant National Memorial
The Riverside Church
Harlem
W 130th St
St Nicholas
W 132nd St
W 131st St
La Salle St
W 123rd St
W 122nd St
Amsterdam Ave
HARLEM
MORNINGSIDE HEIGHTS
125 St
Apollo Theater
Riverside Park
Broadway
Morningside Dr
CENTRAL HARLEM
Angel of Harlem
125 Street
Riverside Dr
Columbia University
W 121st St
Lidl
W 114th St
Morningside Park
Tom's
BLVD Bistro NY
Craving Delicious Soul Food? - BLVD B...
The Cathedral Church of St. John the Divine
Cathedral Parkway 110 Street
The Hungarian Pastry Shop
Absolute Bagels
W 115th St
Amy Ruth's
W 114th St
W 113th St
116 St
Bethel Gospel
W 112th St
W 111th St
W 107th St
Soccer Field
101st Street Field
Cathedral Pkwy (110 St)
Martin Luther King Jr Towers
103 St
HI New York City Hostel
NEW JERSEY
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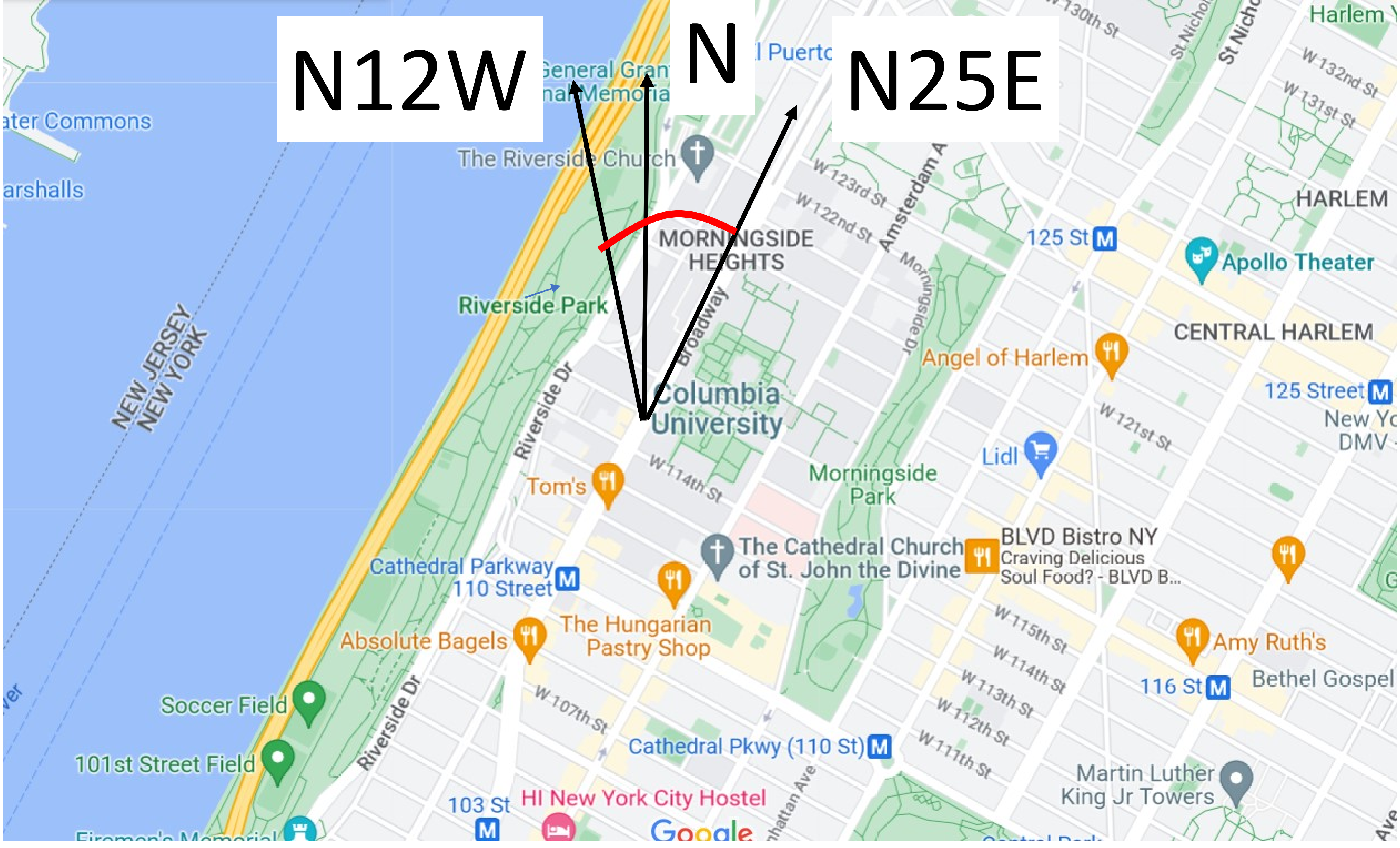
N12W
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General Grant National Memorial
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MORNINGSIDE HEIGHTS
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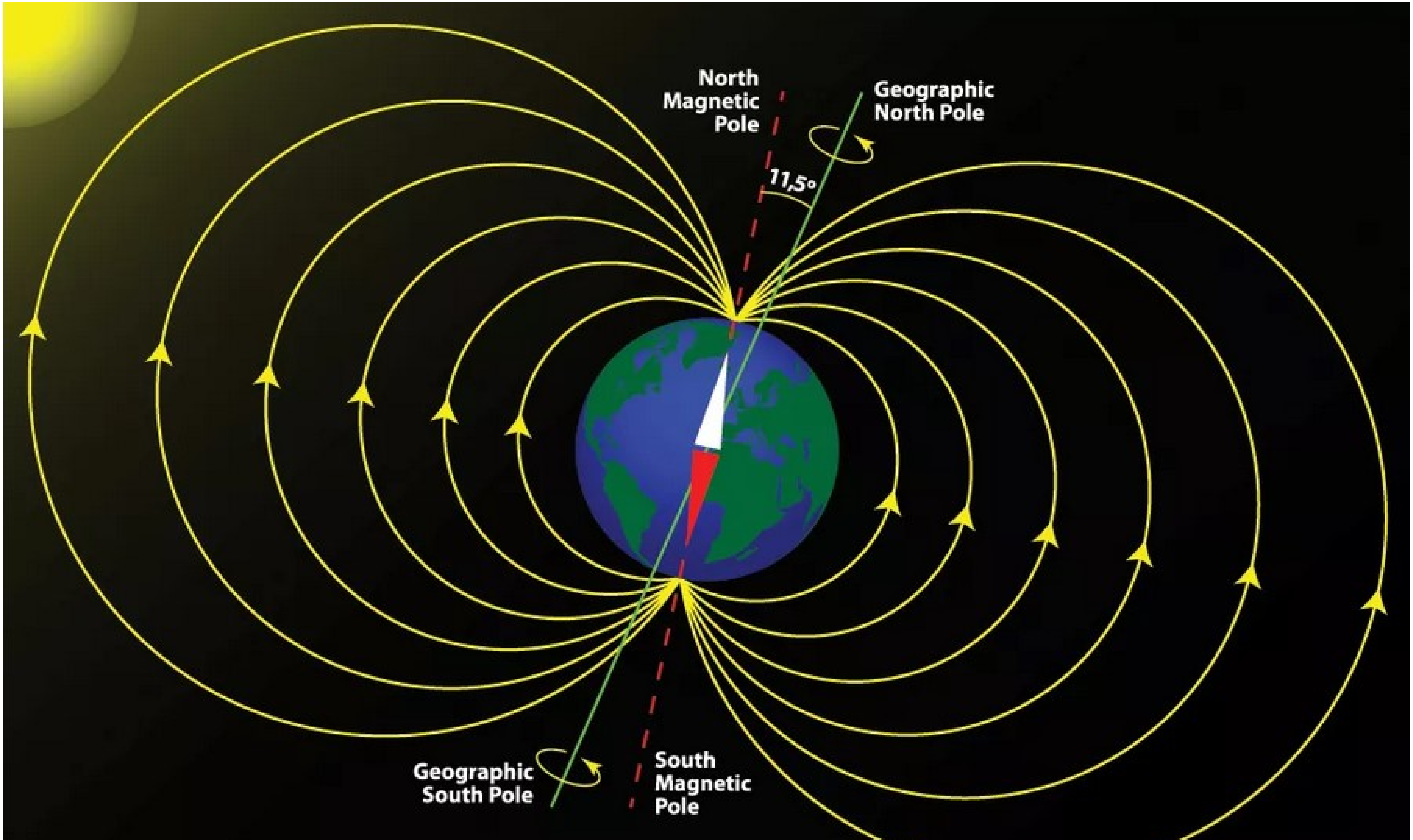
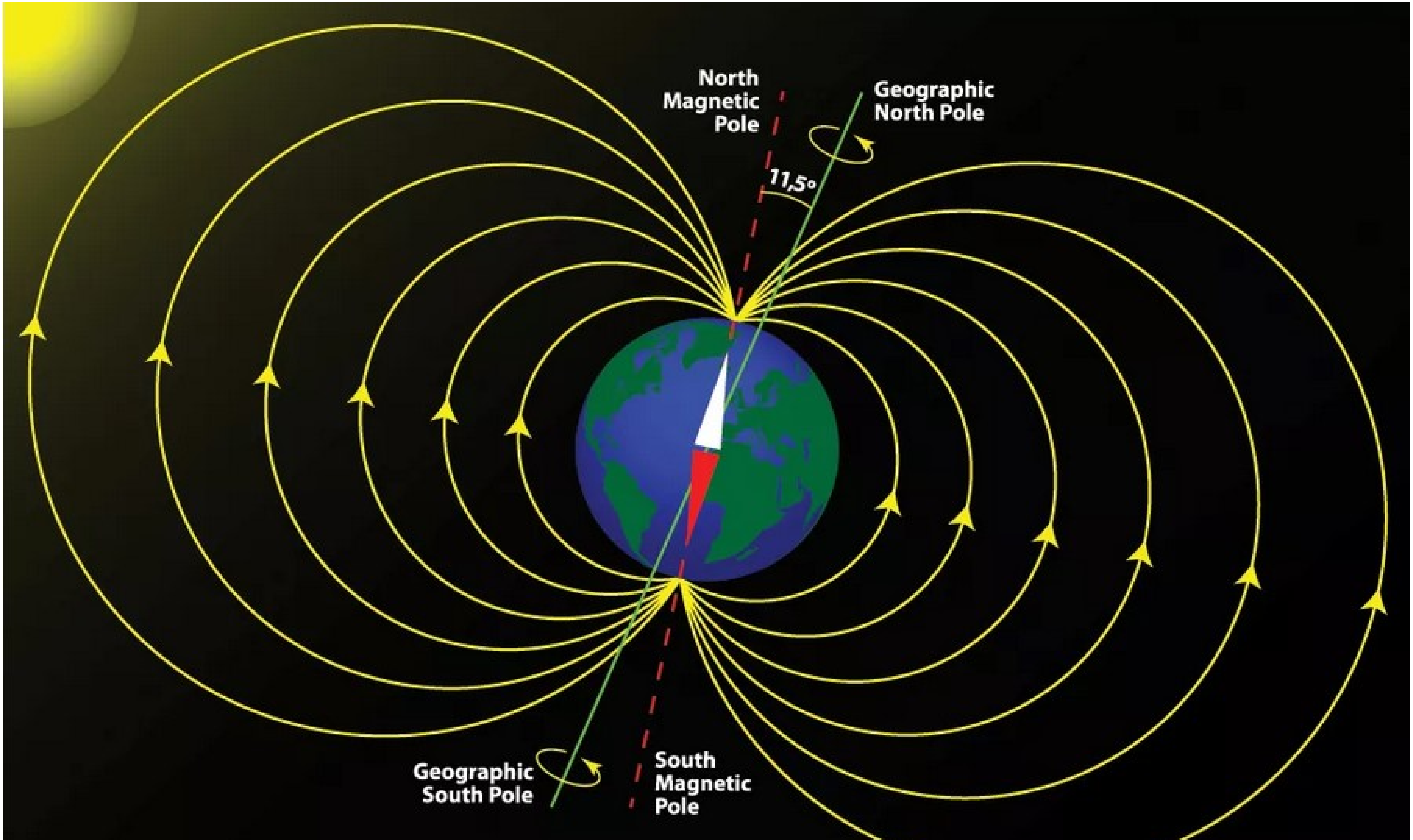
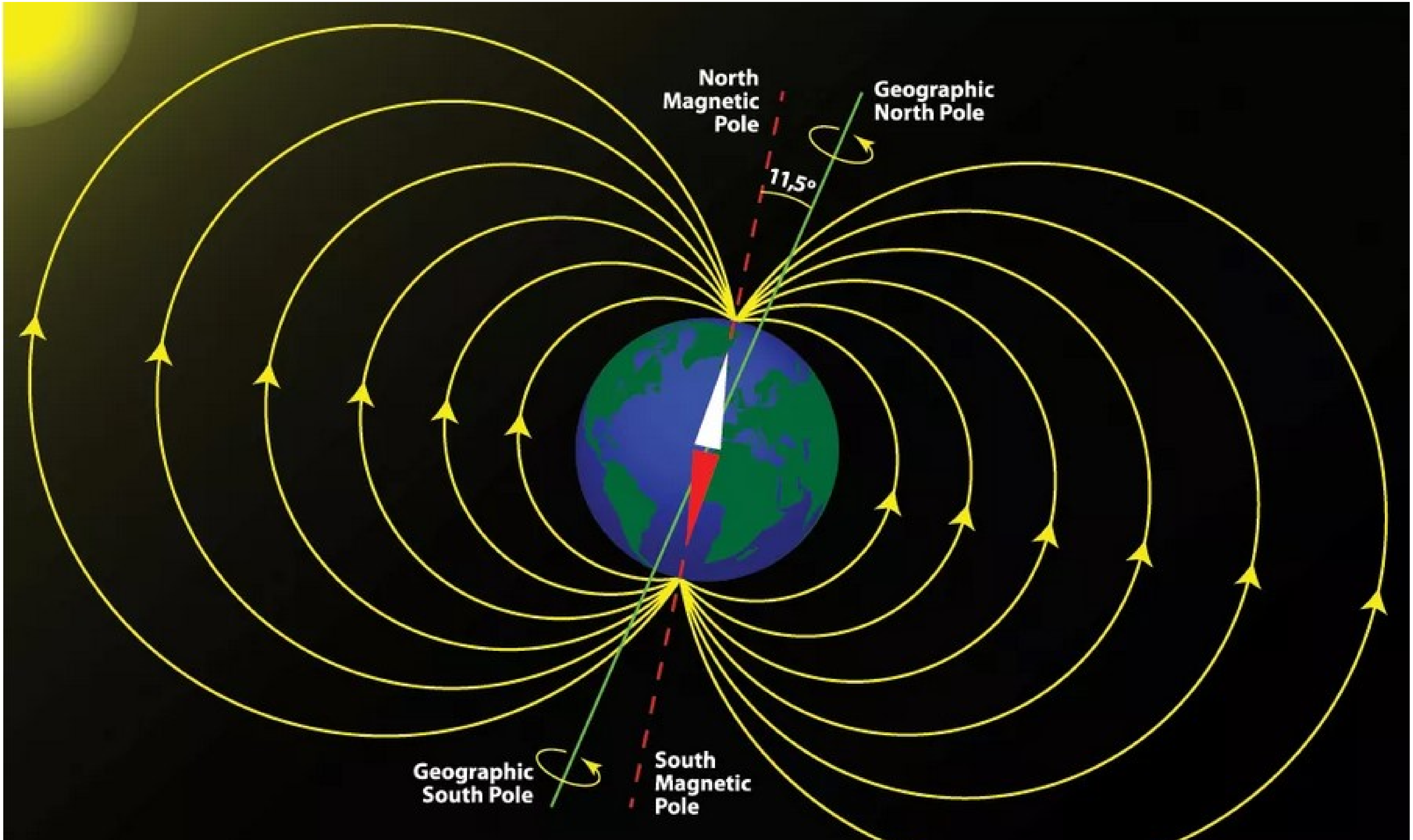


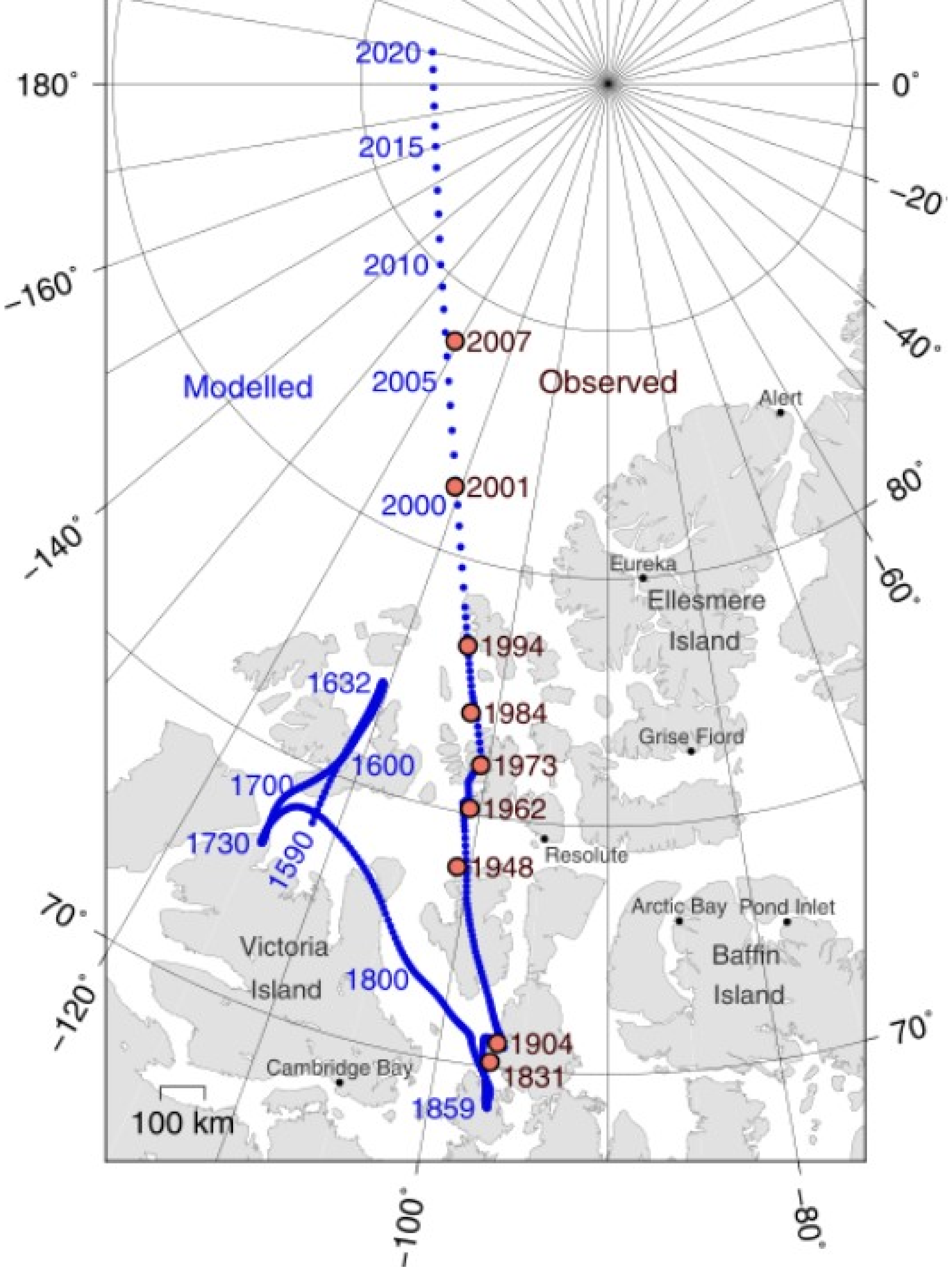
What controls its strength?



Why is shape dipolar?

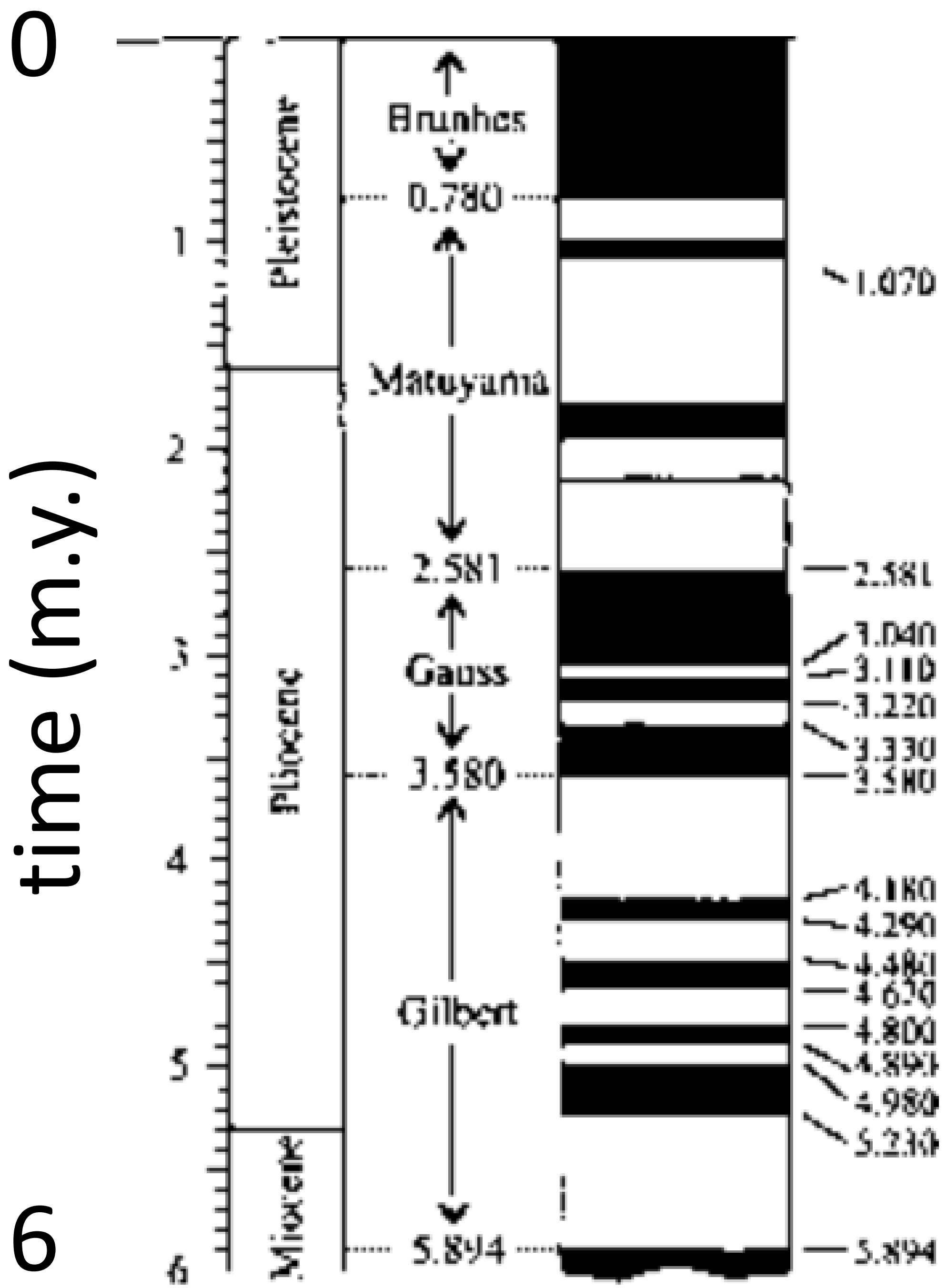


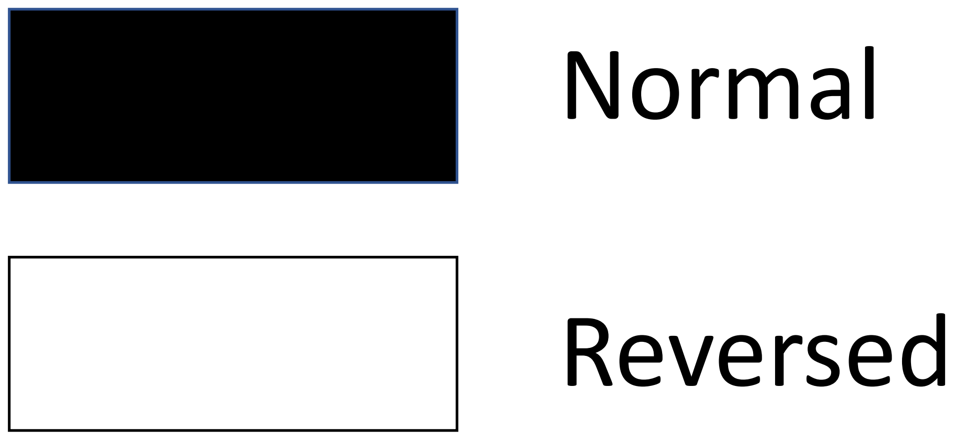
Why is axis tilted?



Why does pole position slowly move?

Why does polarity flip?

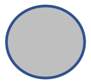




(I warn you that we don't have detailed answers to most of these questions)

Crash Course in Electromagnetism

Part 1
what electric and magnetic fields do

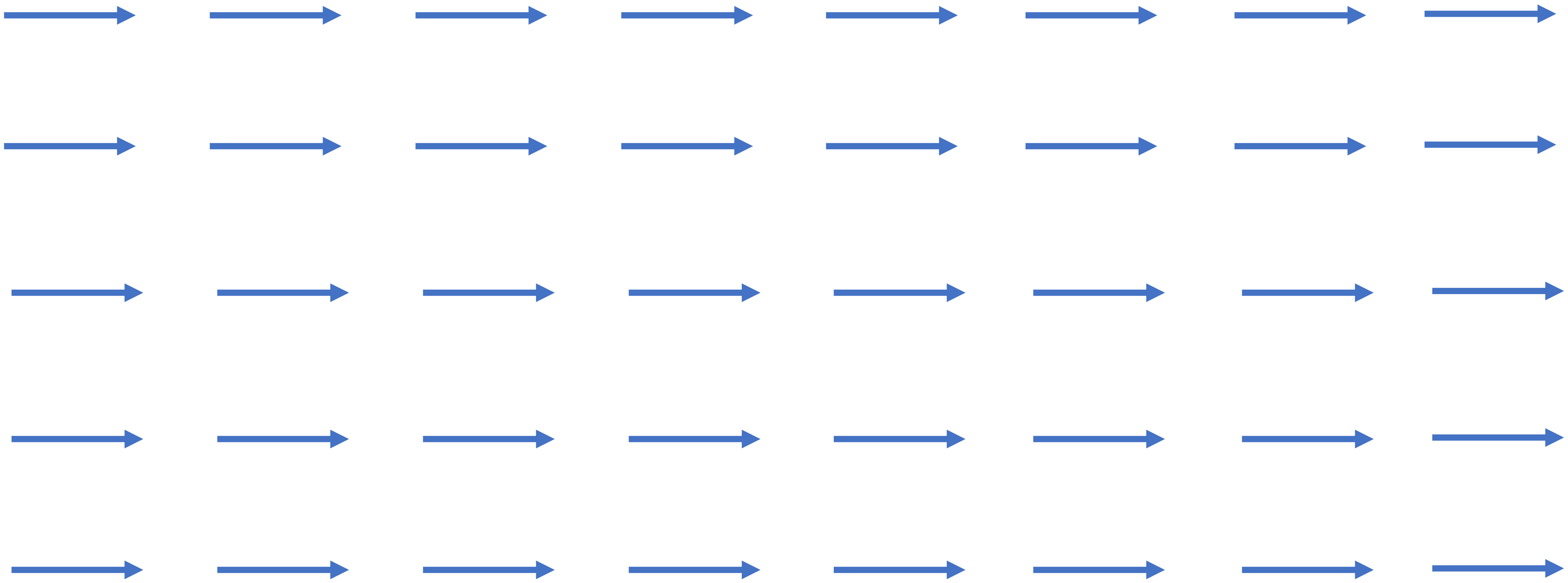


proton

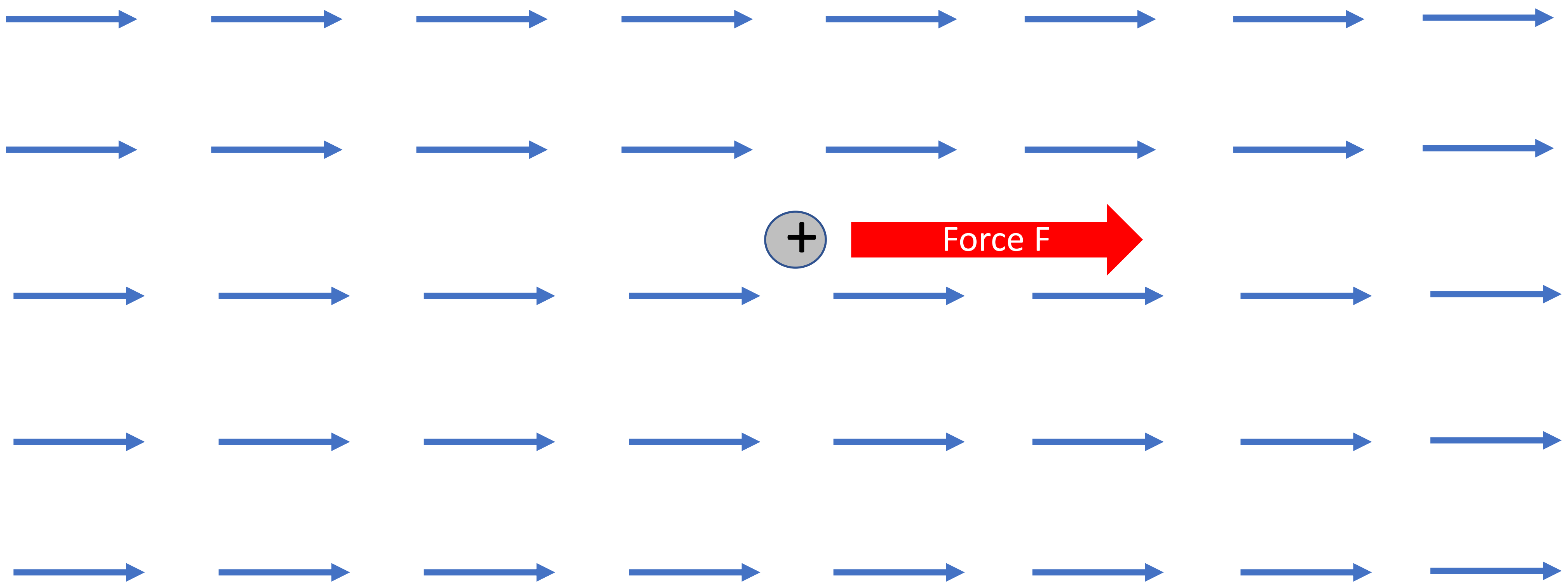
proton

electric charge q

Electric field $\mathbf{E}$

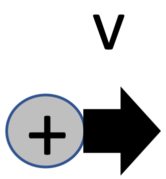


Electric field exerts force on a charged particle

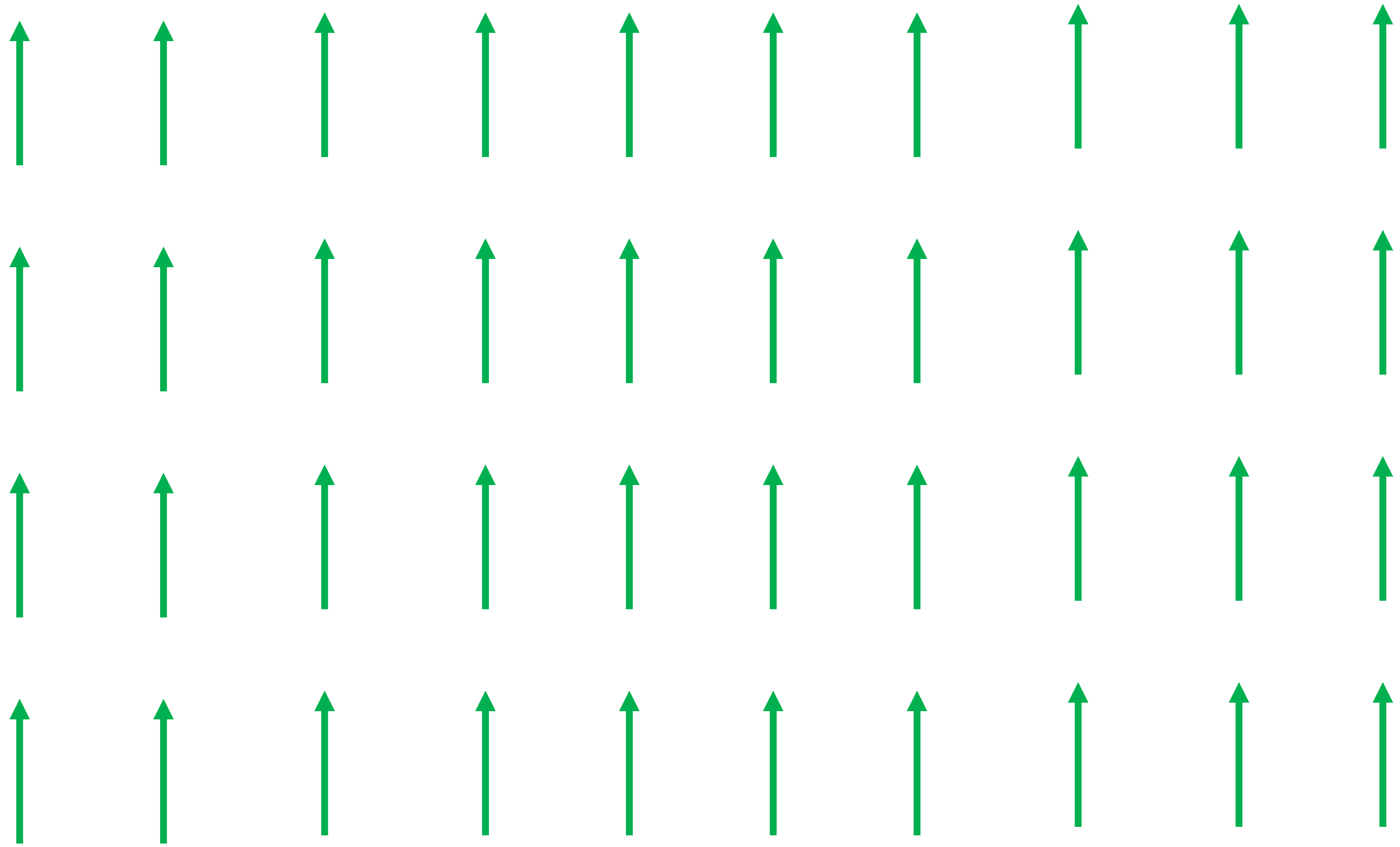


$$\mathbf{F} = q\mathbf{E}$$

proton moving with velocity v

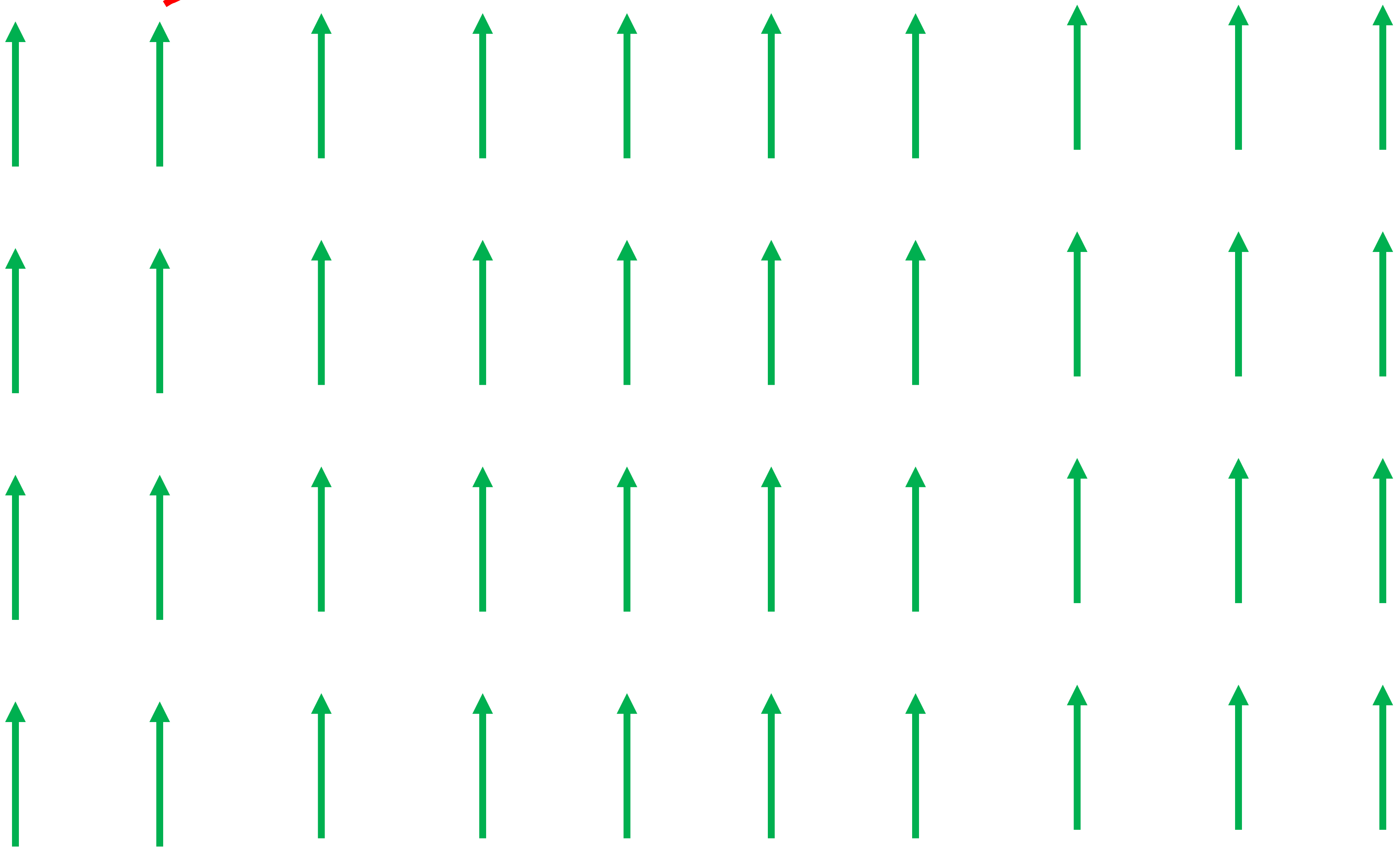


magnetic field, B

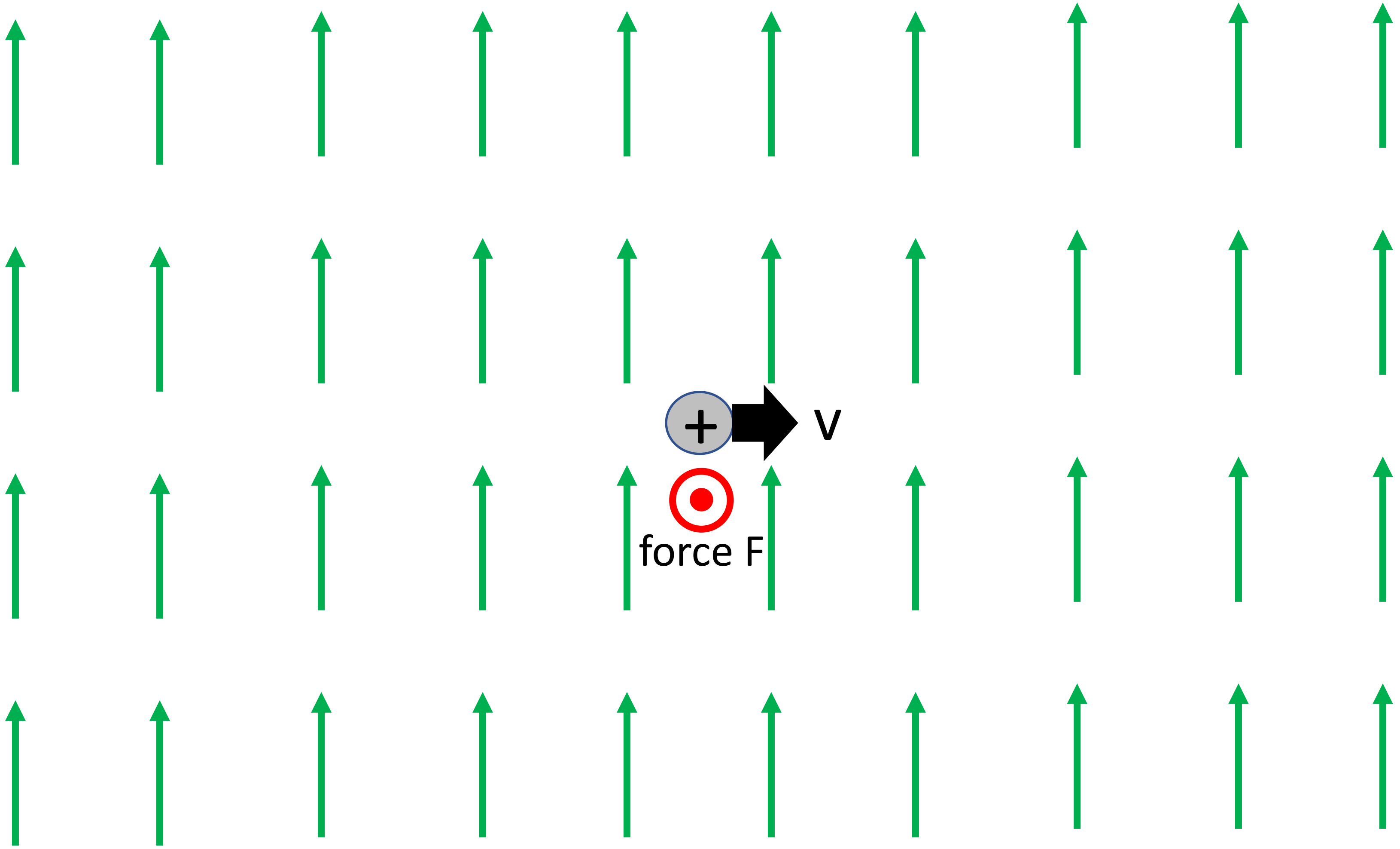


induction

magnetic ~~field~~, **B**

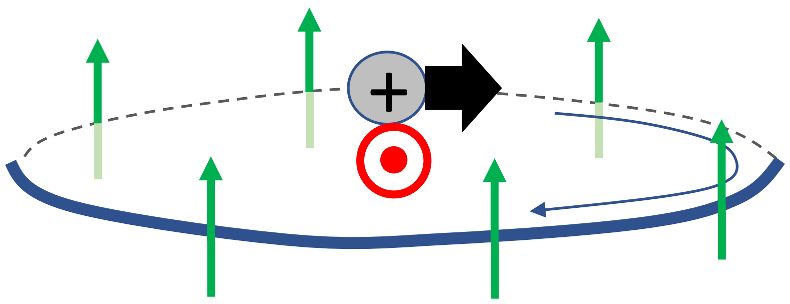


magnetic induction exerts force on a charged particle



$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

leads to curved trajectory



curved trajectory

magnetic induction exerts force on a charged particle

$$\mathbf{F} = q\mathbf{E} + q\mathbf{v} \times \mathbf{B}$$

Lorentz force law

How do you know there’s an electric field?

How do you know is there’s magnetic induction?

How do you know there’s an electric field?

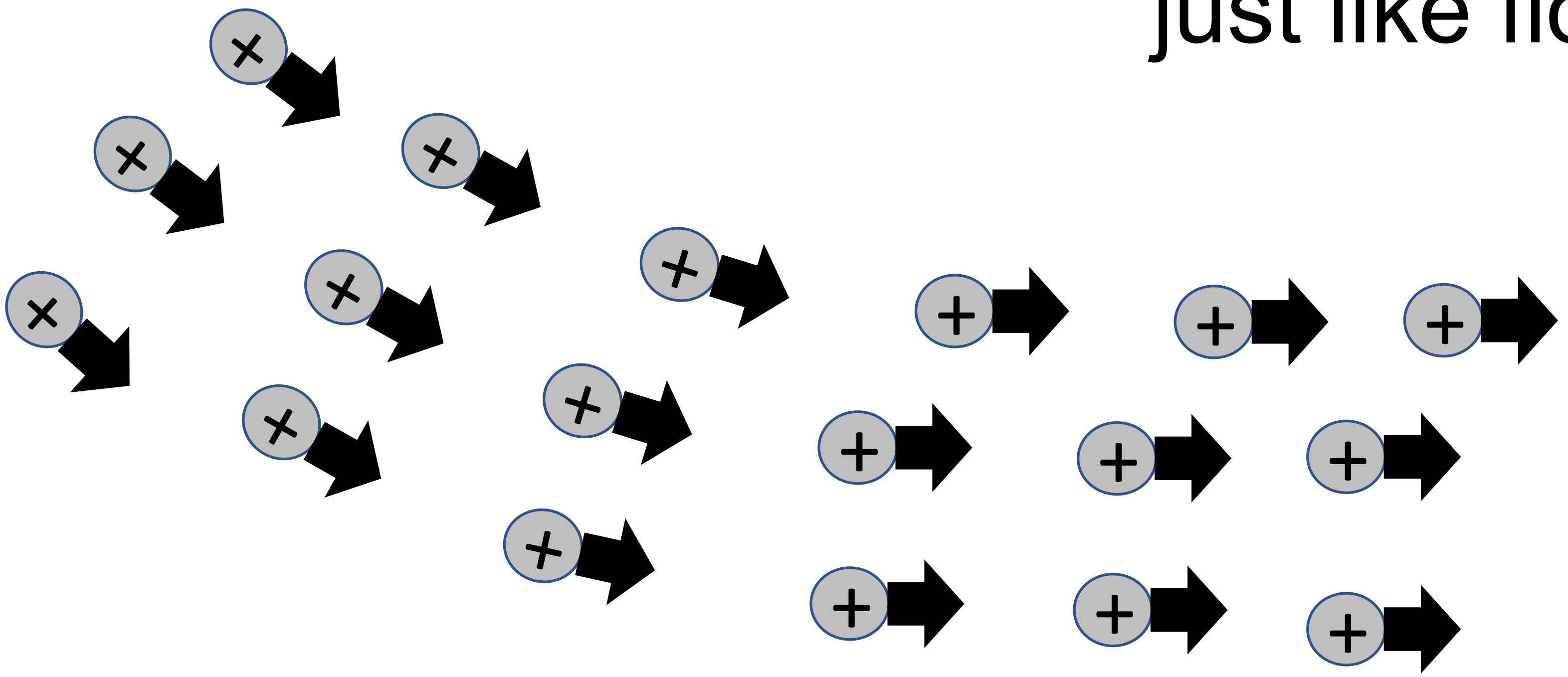
a stationary charged particle begins to move

How do you know is there’s magnetic induction?

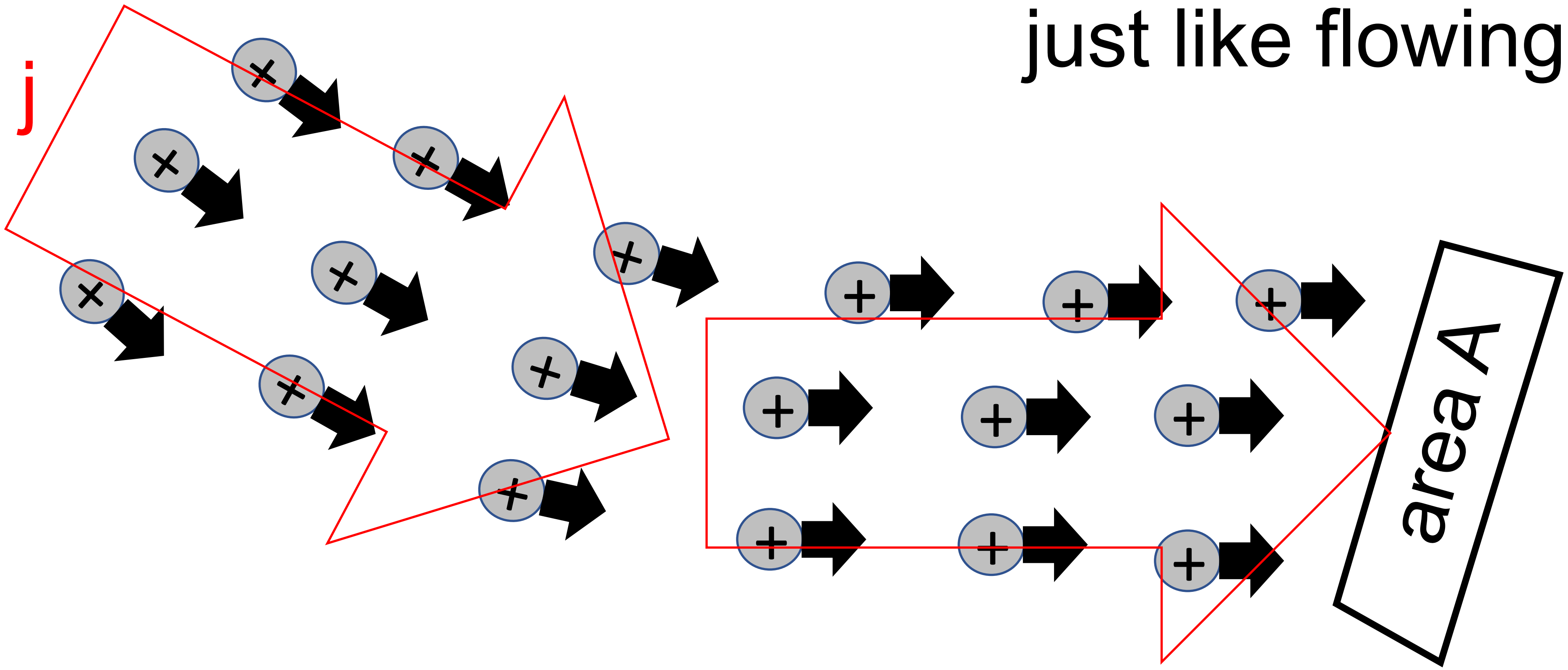
a moving charged particle follows a curved trajectory

Part 2
lots of charges
analogy to heat

moving charges
just like flowing heat



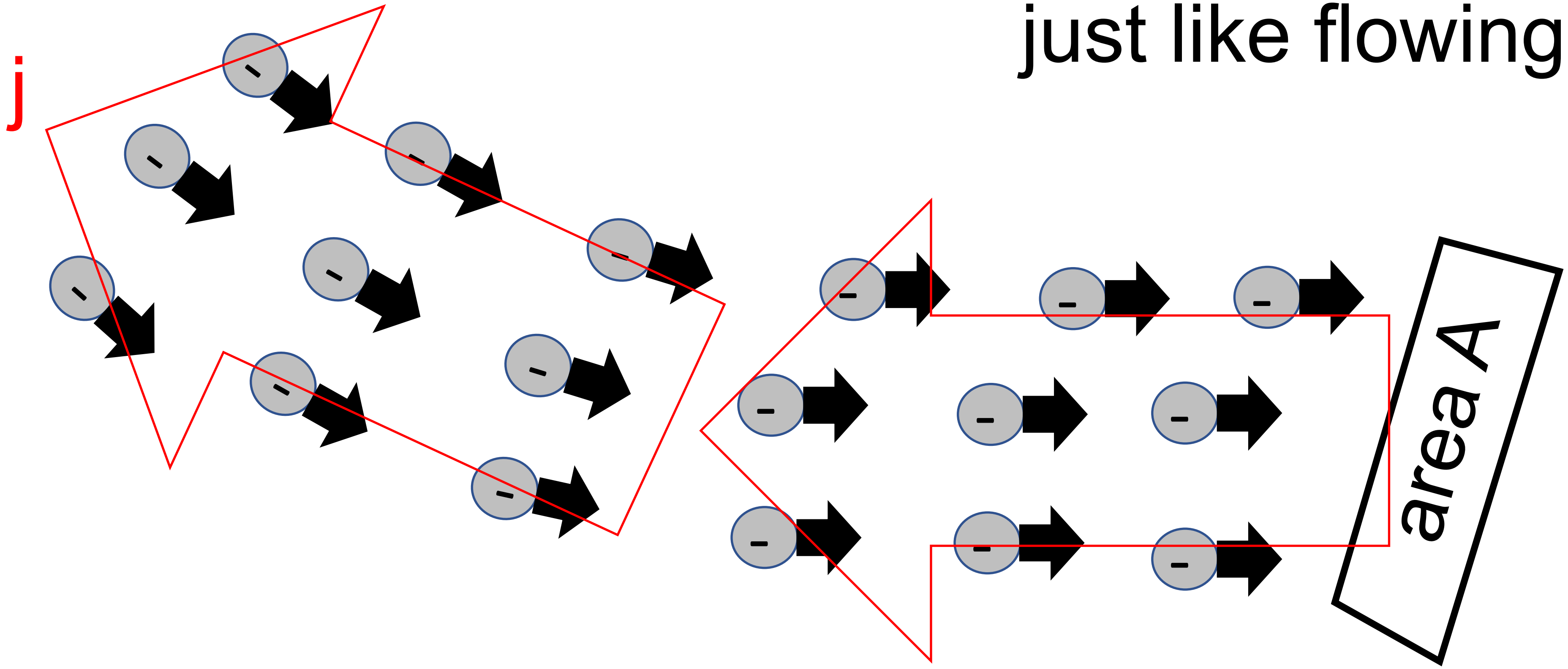
moving charges
just like flowing heat



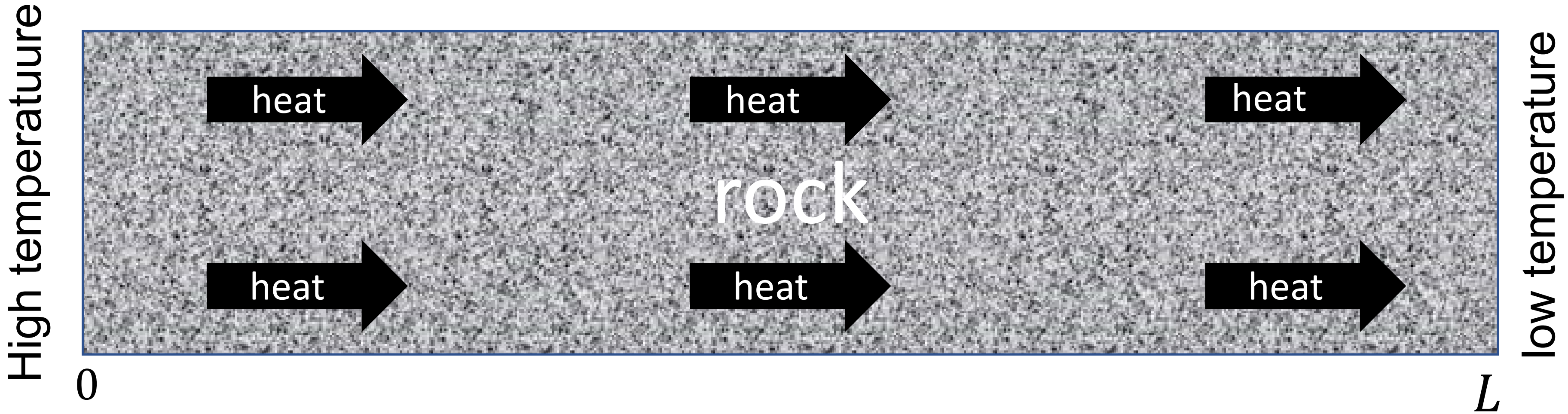
electric current j
charge flowing across a surface per unit time

whoop … really its electrons, not protons, that do most of the moving on Earth

moving charges
just like flowing heat



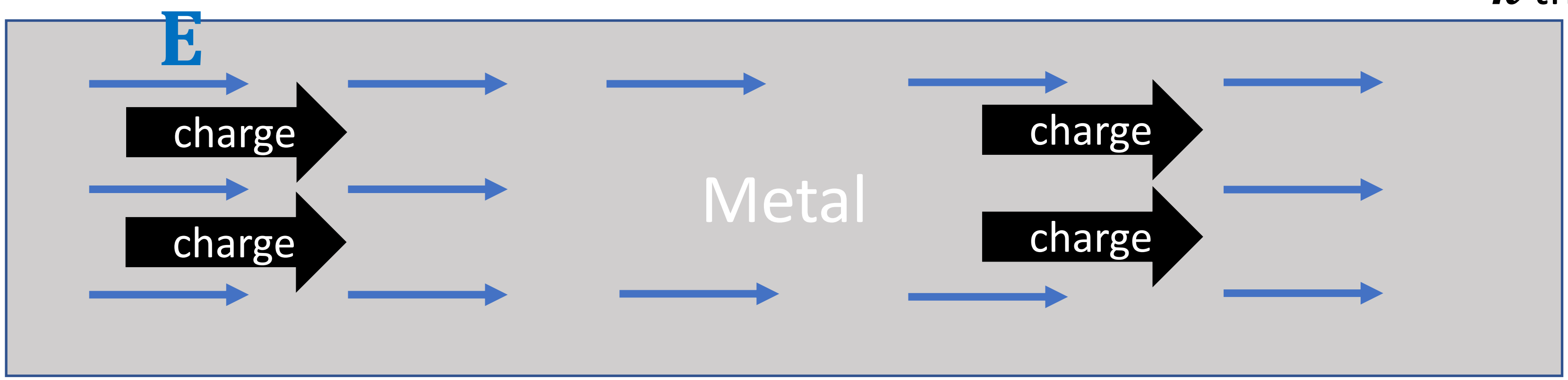
electric current j
charge flowing across a surface per unit time



heat flux proportional to temperature gradient

$$q = -k \frac{dT}{dx}$$

$\boldsymbol{k}$ thermal conductivity



current proportional to electric field

friction prevents indefinite acceleration

$$\mathbf{j} = \sigma \mathbf{E}$$

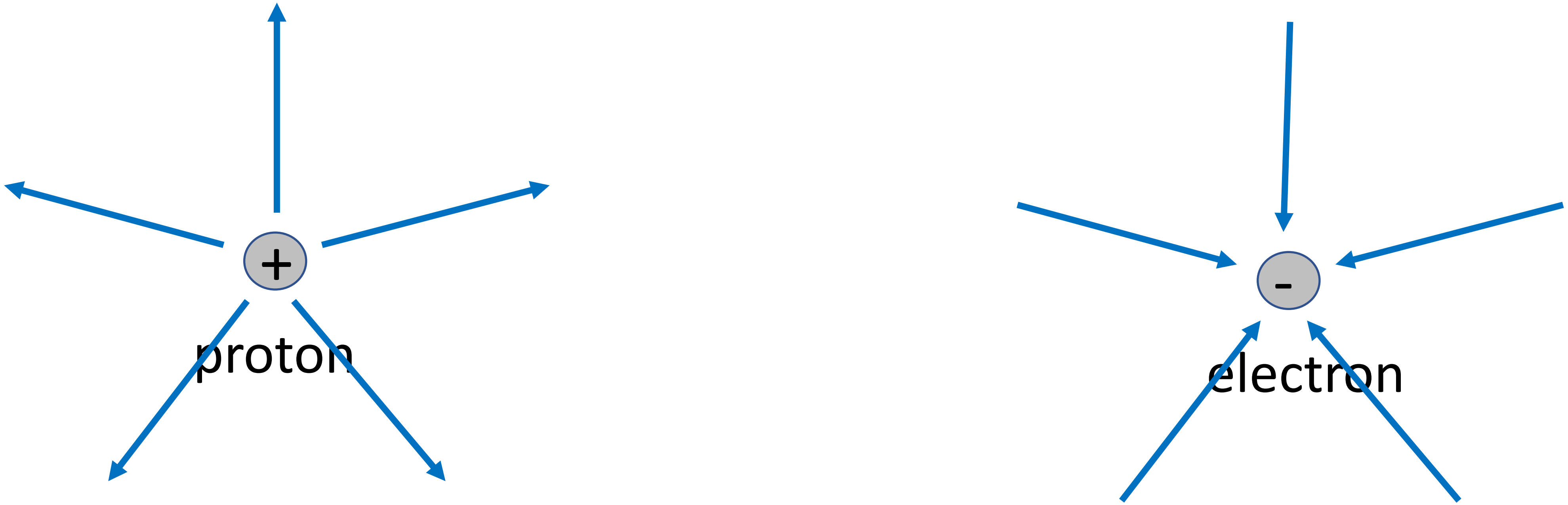
σ electrical conductivity

Part 3
where electric and magnetic fields come from

where electric fields come from


proton
electron

electrically charged particles emit electric fields

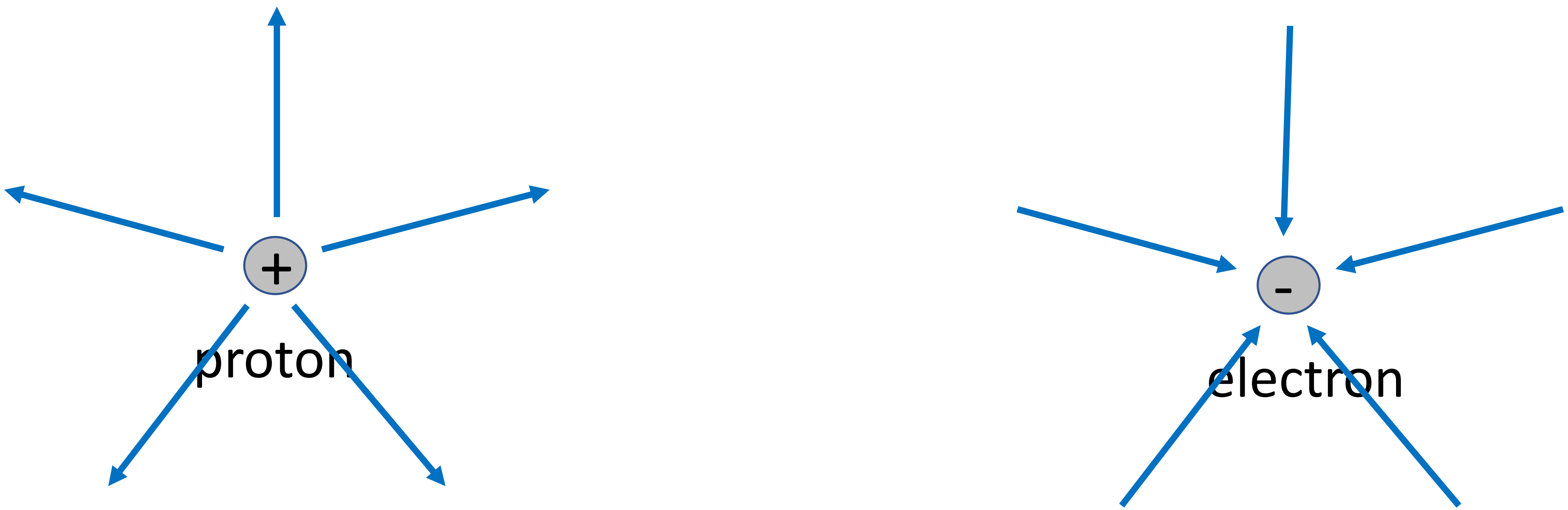


radial force with magnitude

$$|\mathbf{E}| = \frac{k_e q}{r^2}$$

k_e Coulumb constant

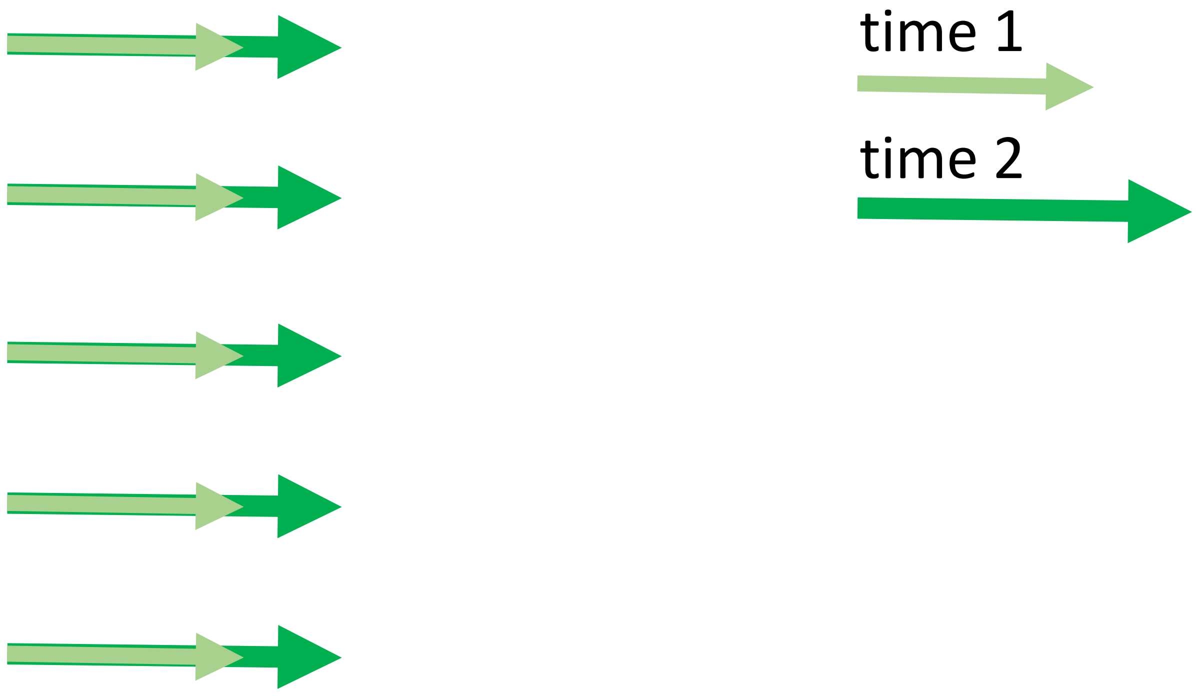
works just like gravity



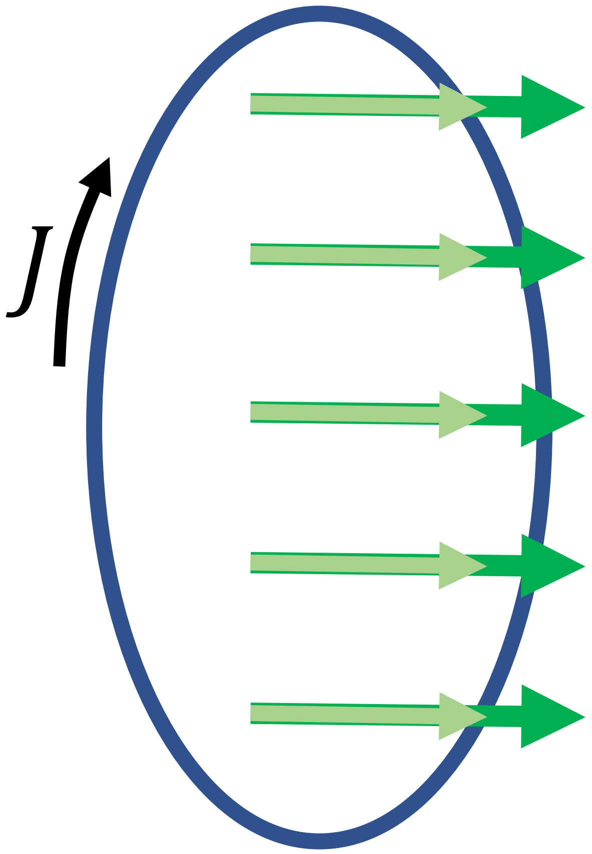
$$|\mathbf{E}| = \frac{k_e q}{r^2} \qquad |\mathbf{g}| = \frac{\gamma M}{r^2}$$

except …

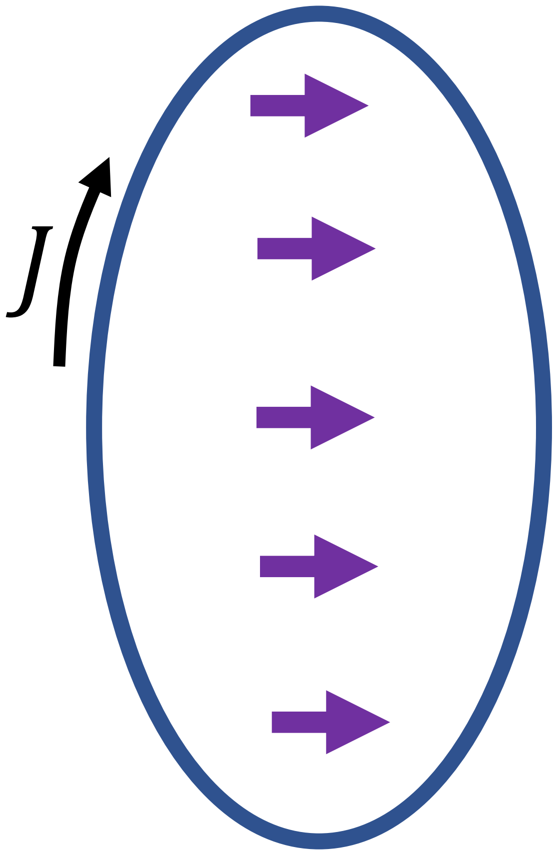
Time-varying B also makes an electric field

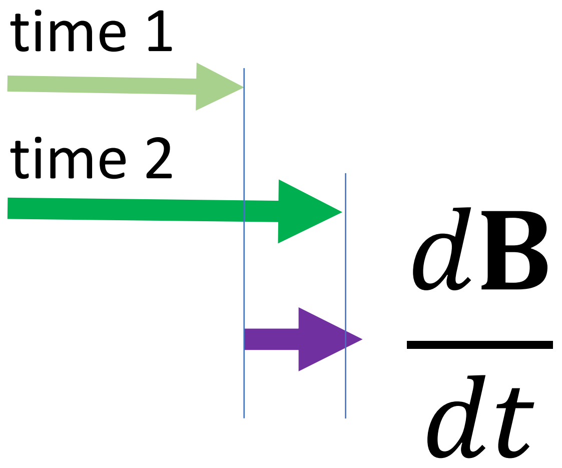


However, its easier to understand in terms of currents induced in a conductive loop of metal wire

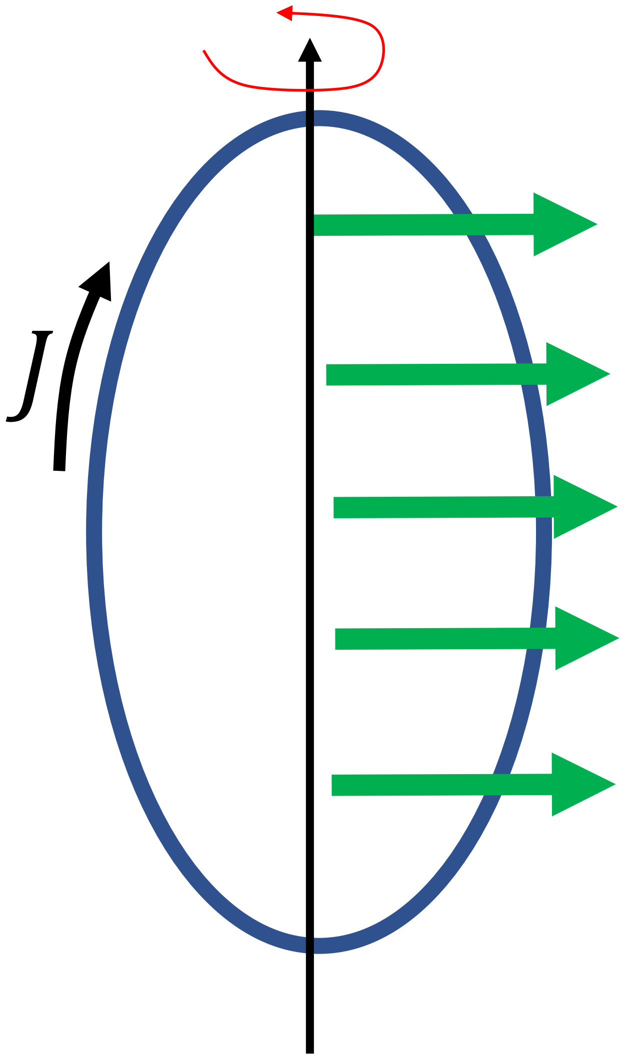


The more dB/dt crossing the plane of the loop, the bigger the current J

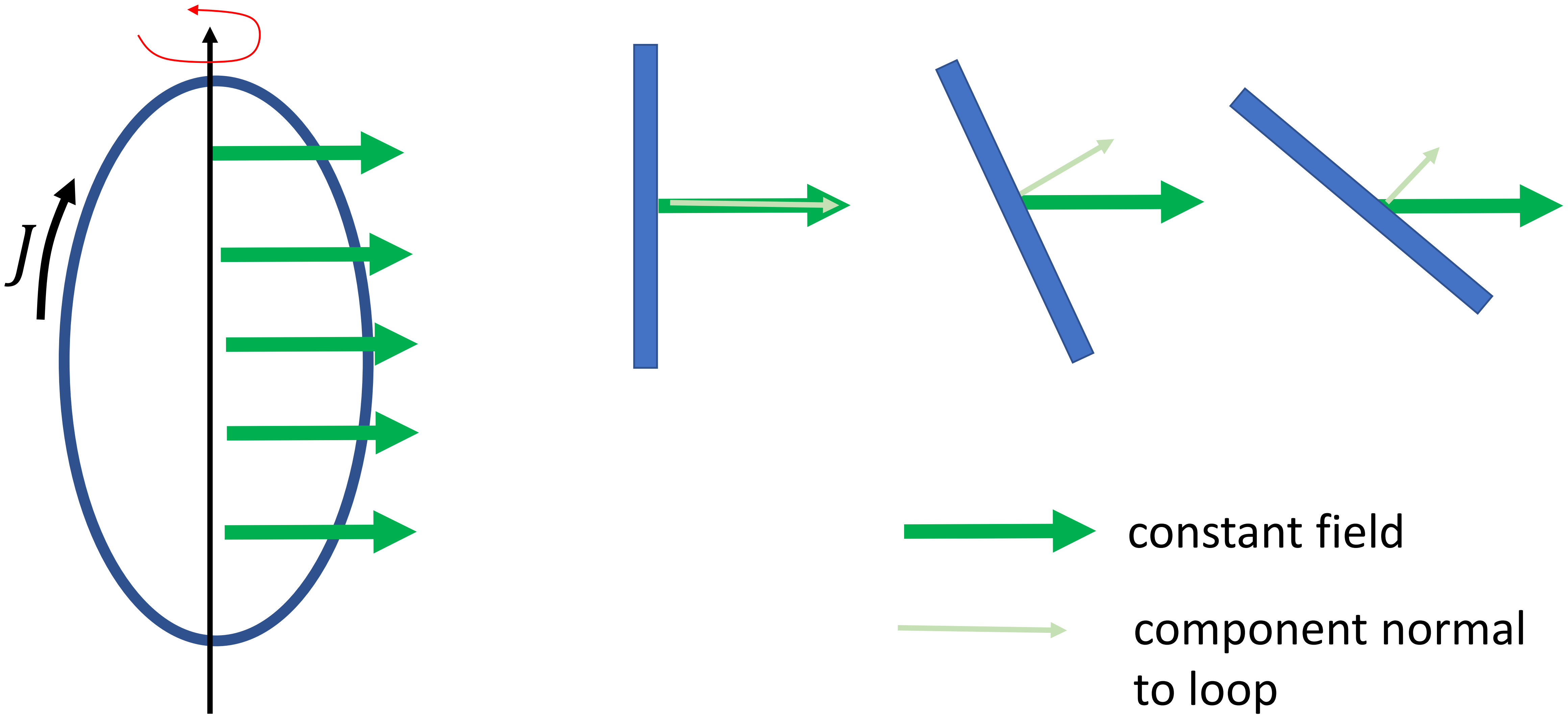




Works also to keep field constant and spin move the loop



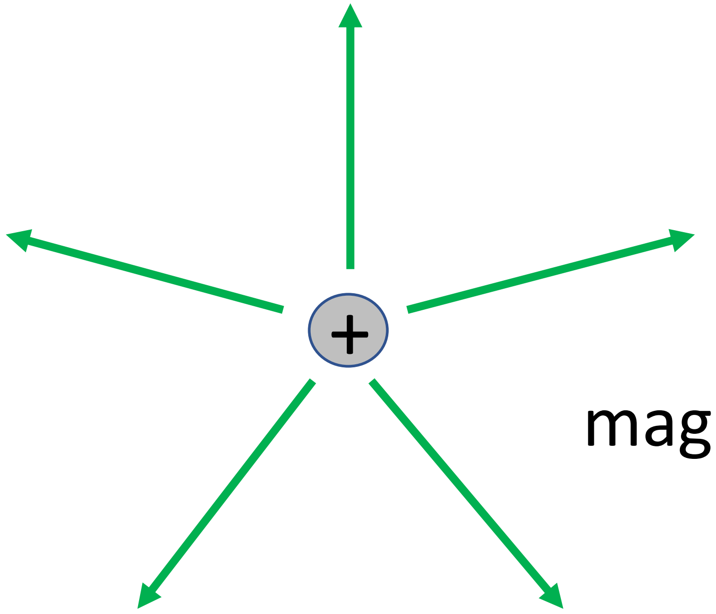
Works also to keep field constant and spin move the loop



Generator

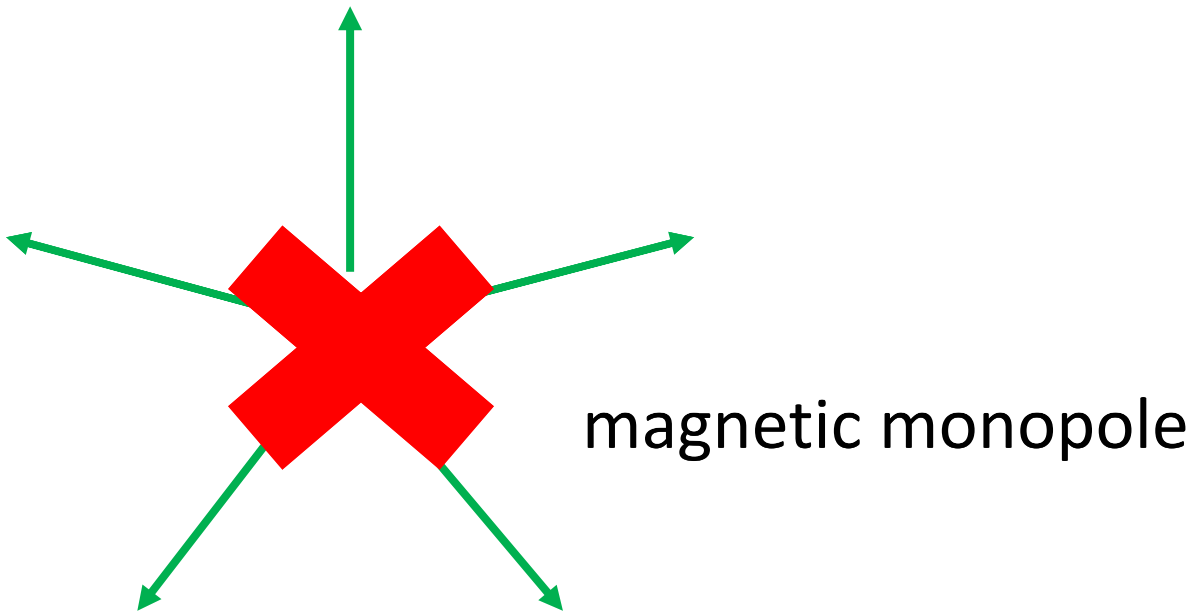
where magnetic fields come from

there are no magnetically-charged particles

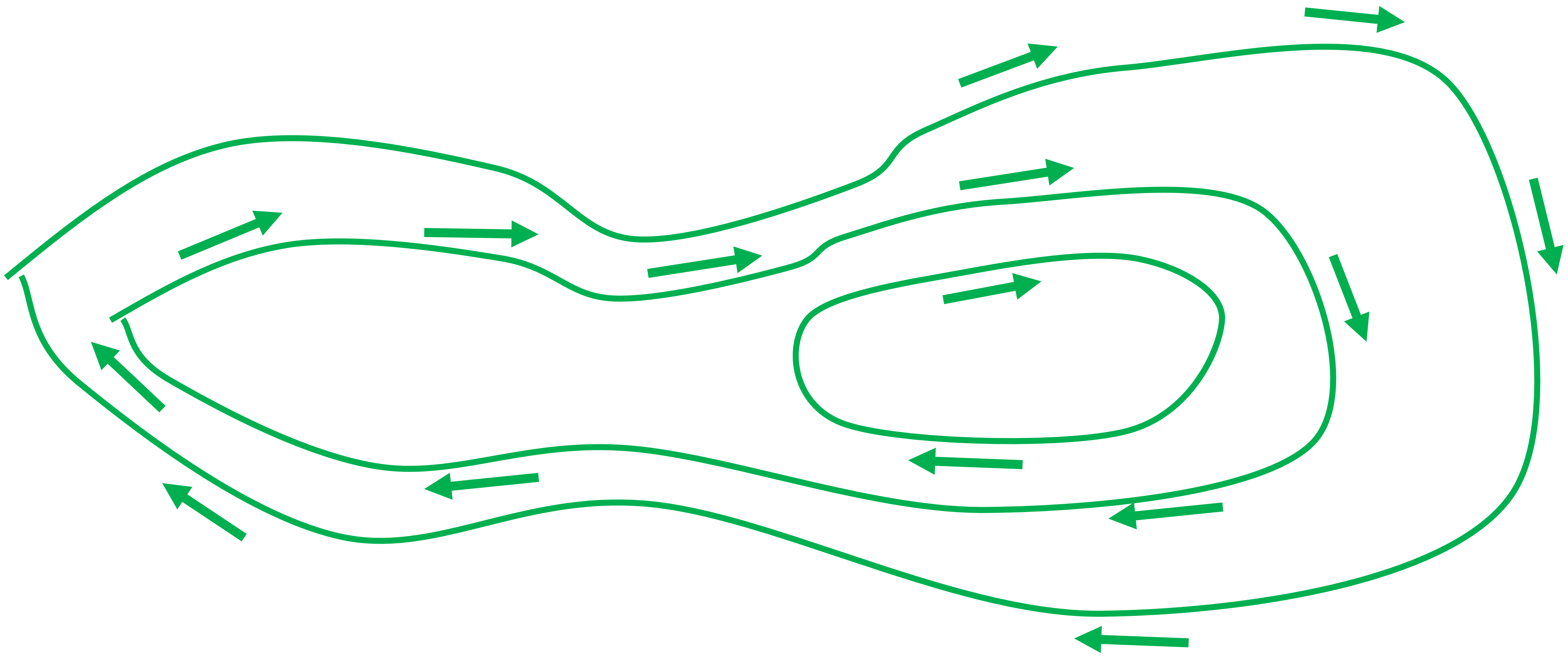


magnetic monopole

there are no magnetically-charged particles

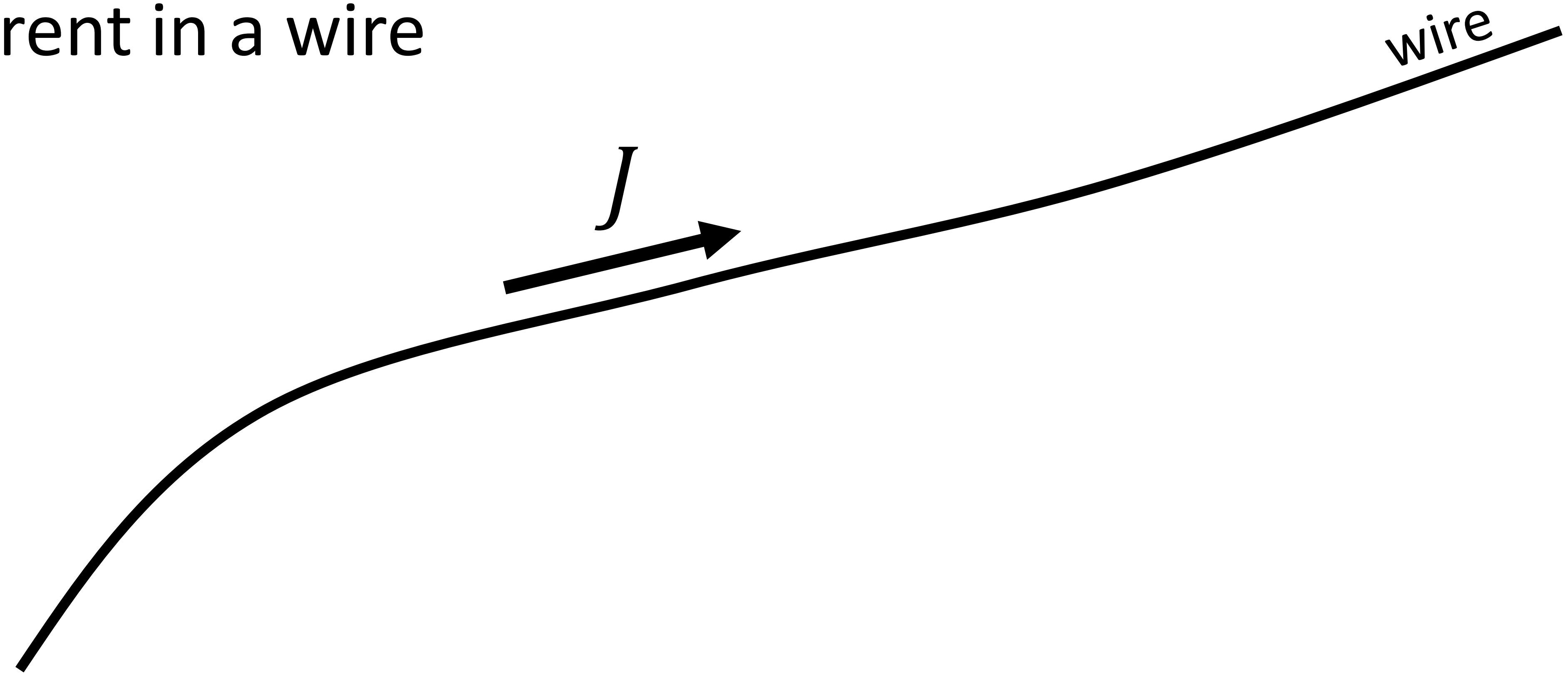


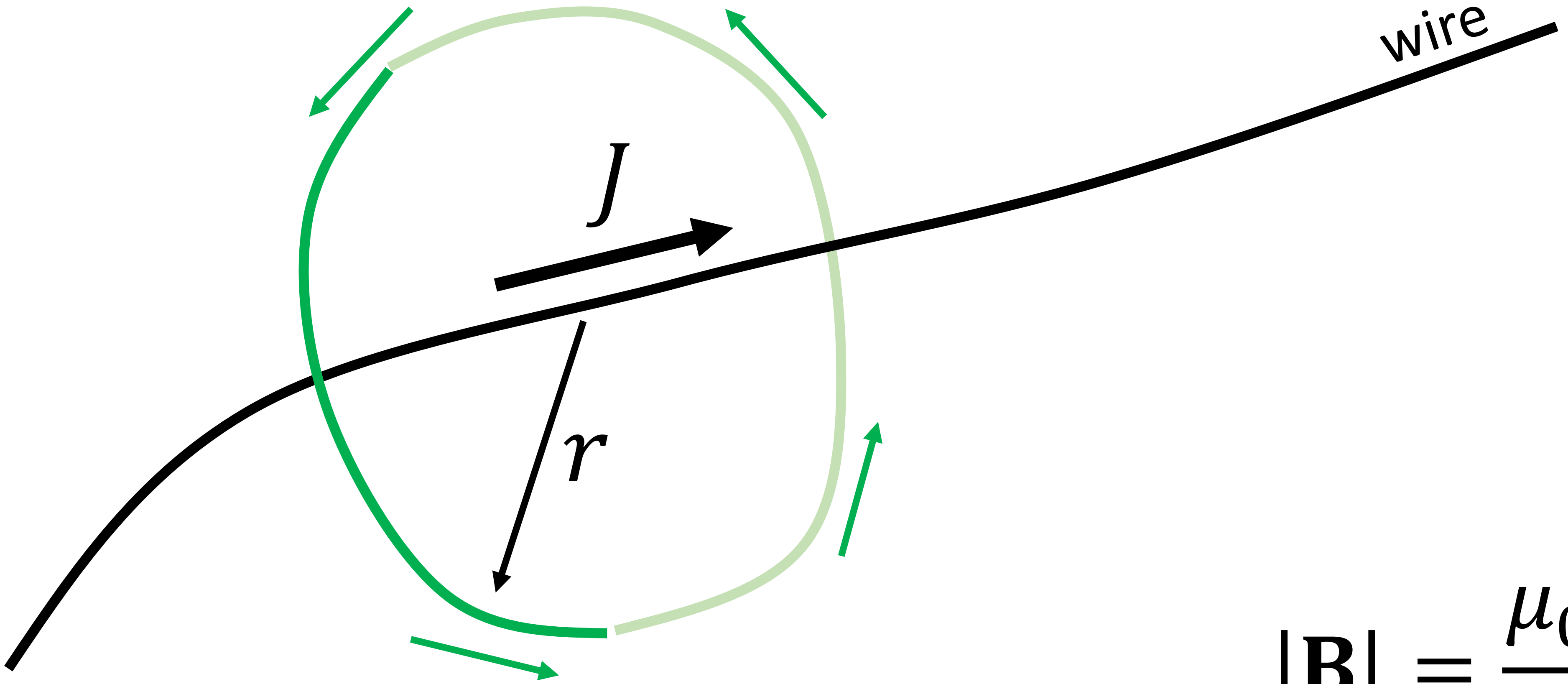
consequently, all magnetic fields trace out closed loops



Moving charge makes an electric field

but the concept is easier to understand with current in a wire

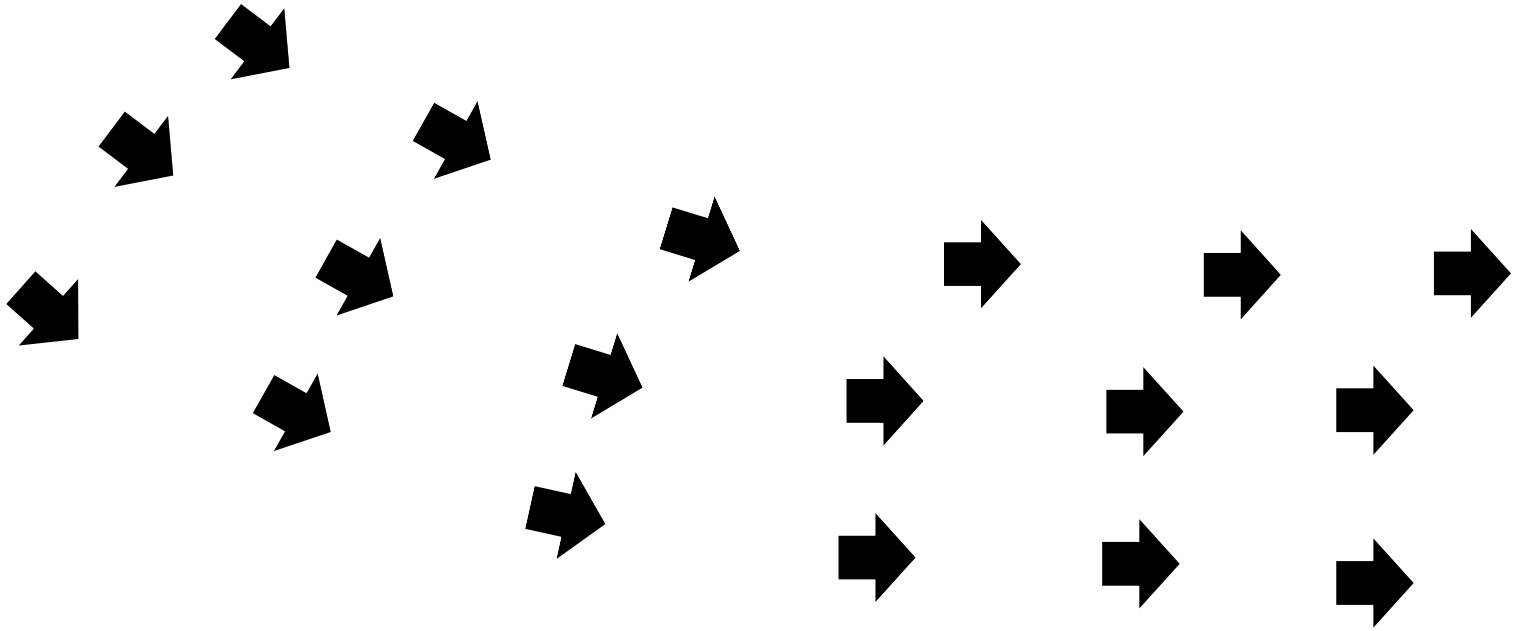




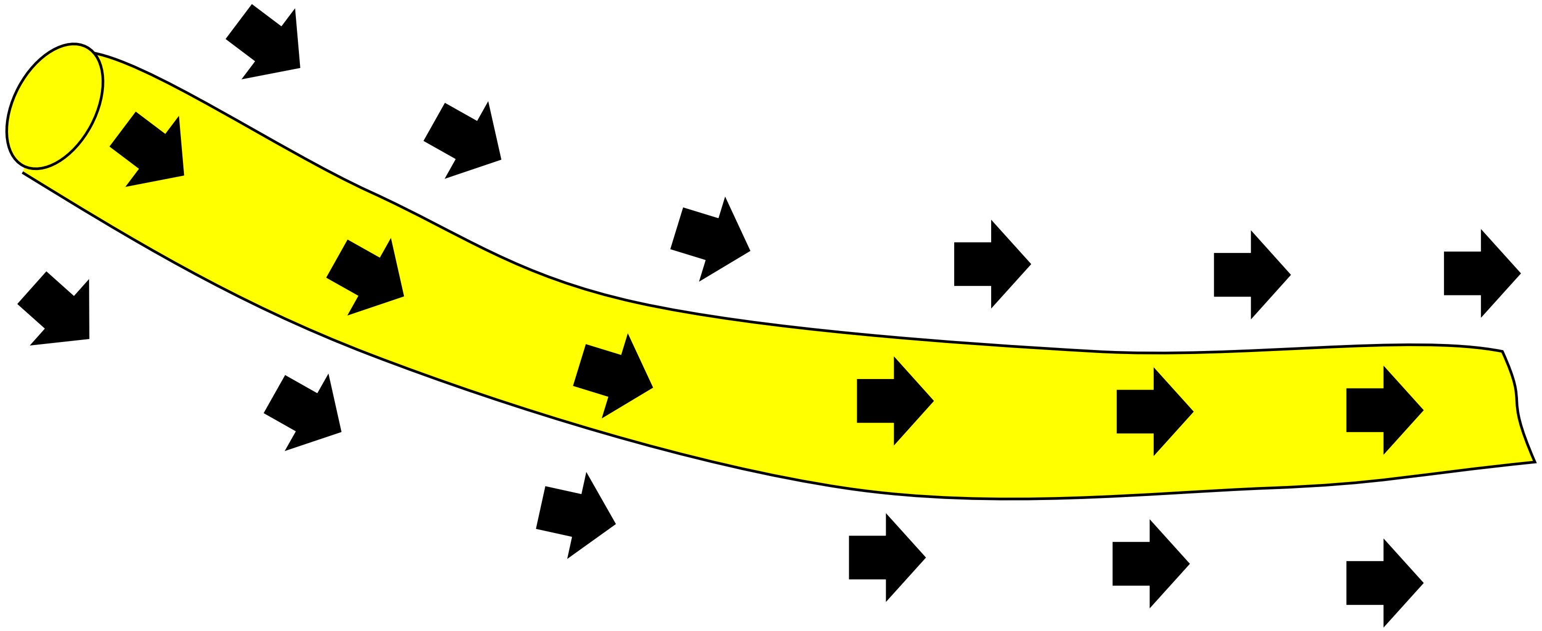
$$|\mathbf{B}| = \frac{\mu_0 J}{2\pi r}$$

μ_0 magnetic permeability

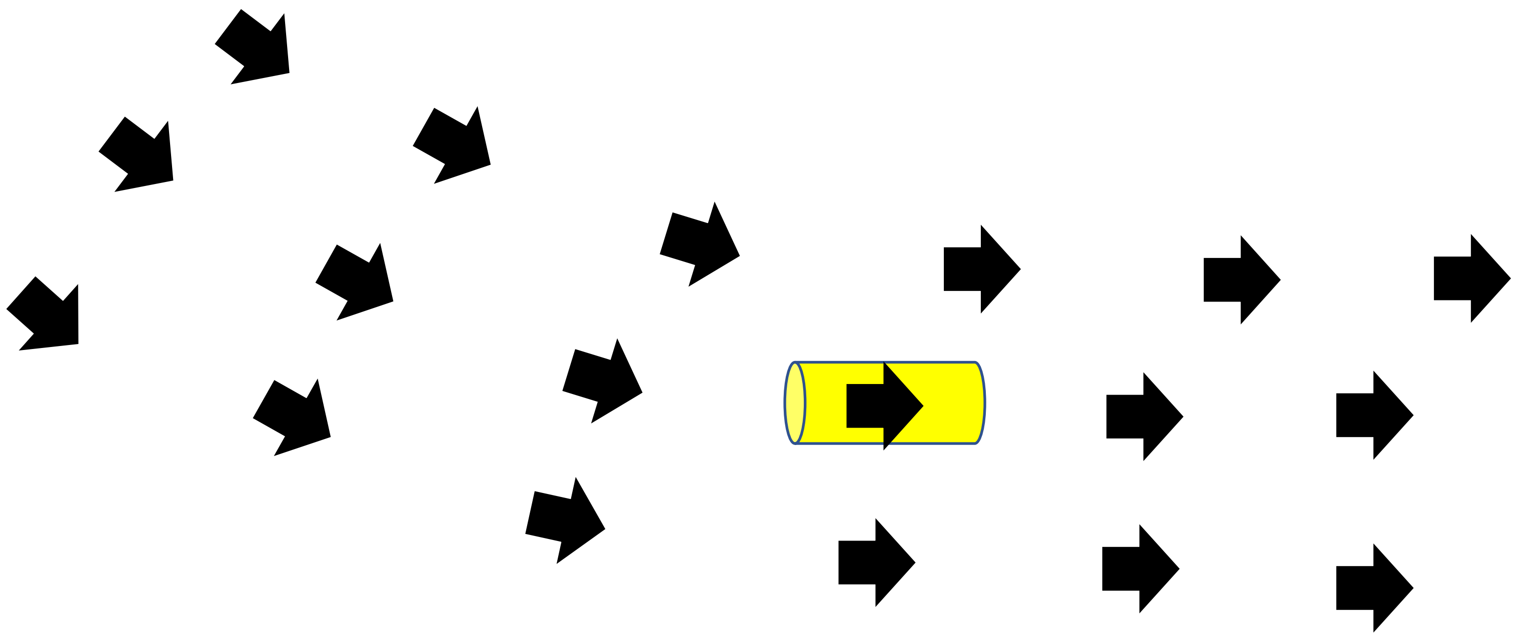
distribute electric current j



distribute electric current j

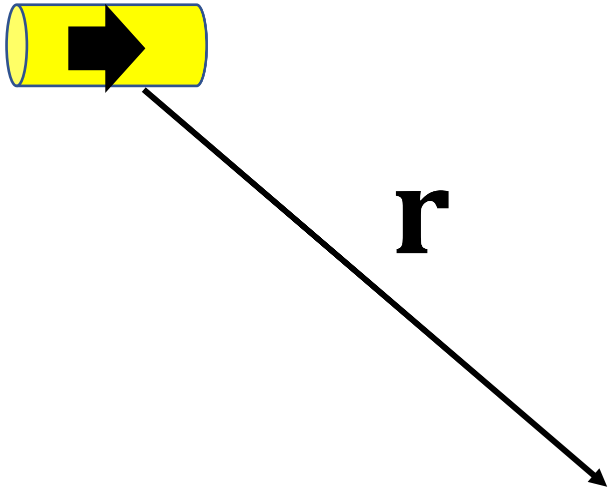


distribute electric current j



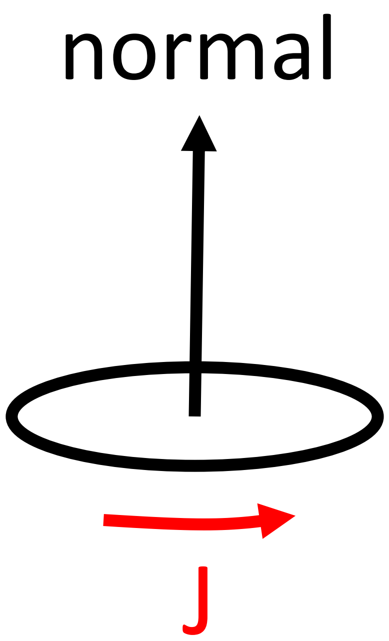
distributed electric current j

view as fragment of wire or length $\Delta\mathbf{L}$

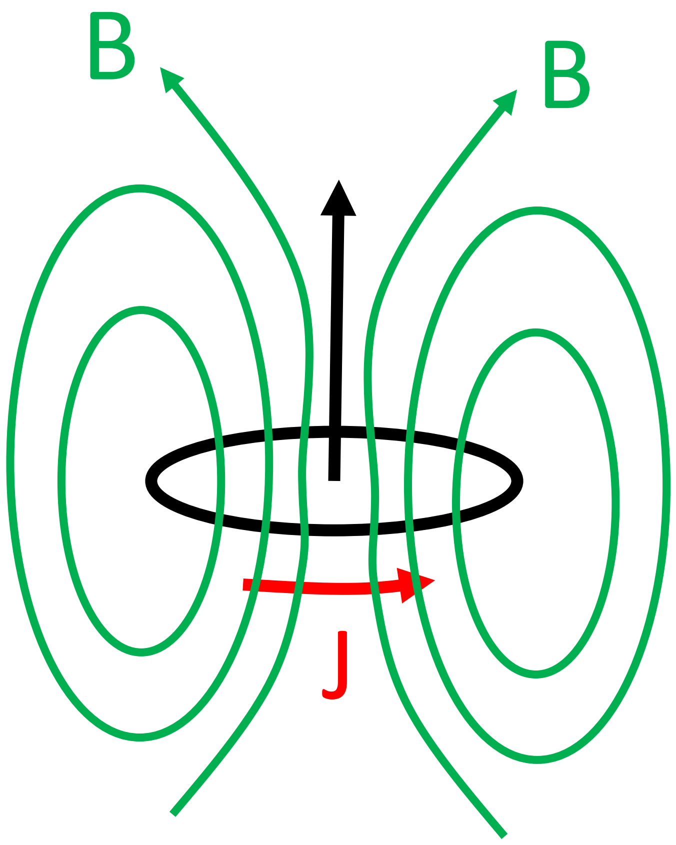


each fragment leads to $\mathbf{B} = \frac{\mu_0}{4\pi r^2} \mathrm{J}\Delta\mathbf{L} \times \mathbf{r}$

Solenoid: Loop of wire with current flowing in it



Solenoid: Dipolar magnetic field



Outer core of Earth

spherical in shape

iron metal

high electrical conductivity

fluid

low viscosity (similar to water)

hot

convecting

could support
electrical currents
flowing around equator
could act as a solenoid
and make a dipolar
magnetic field

Outer core of Earth

spherical in shape

iron metal

high electrical conductivity

fluid

low viscosity (similar to water)

hot

convecting

movement of conductive iron through a magnetic field could produce electrical currents

Geo-dynamo

feedback

- electrical currents create magnetic field
- convection moves magnetic field
- moving magnetic fields reinforce electrical currents