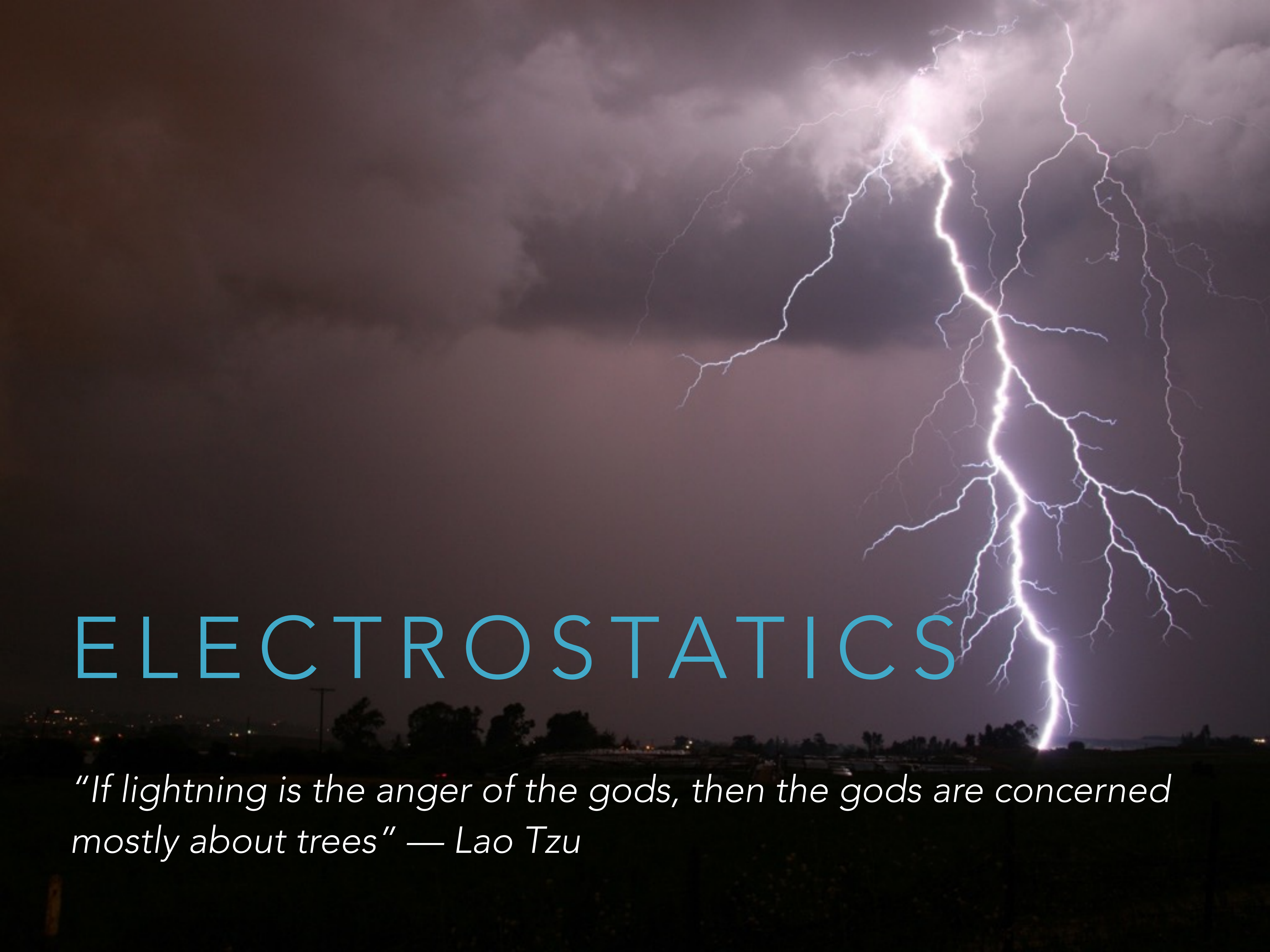


ELECTROSTATICS

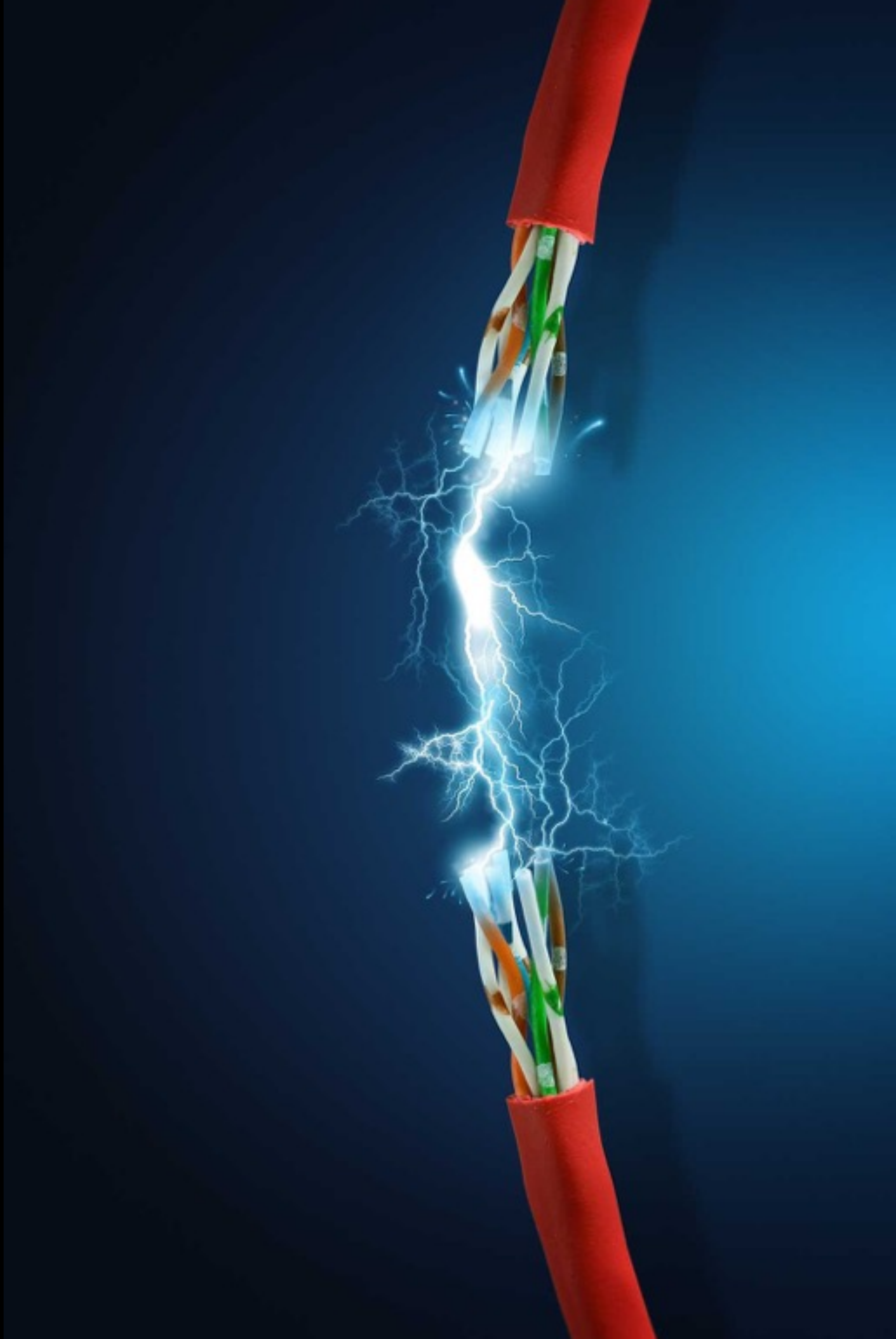
"If lightning is the anger of the gods, then the gods are concerned mostly about trees" — Lao Tzu

LIGHTNING

- They say lightning strikes the tallest things around…
- So how *does* lightning pick its targets?

ELECTRICITY

- Electric forces include:
  - the forces between atoms and molecules holding them together
  - the forces involved in metabolic processes in our bodies
  - elastic forces
  - normal forces
  - other contact forces



Four Fundamental Forces of Fysics

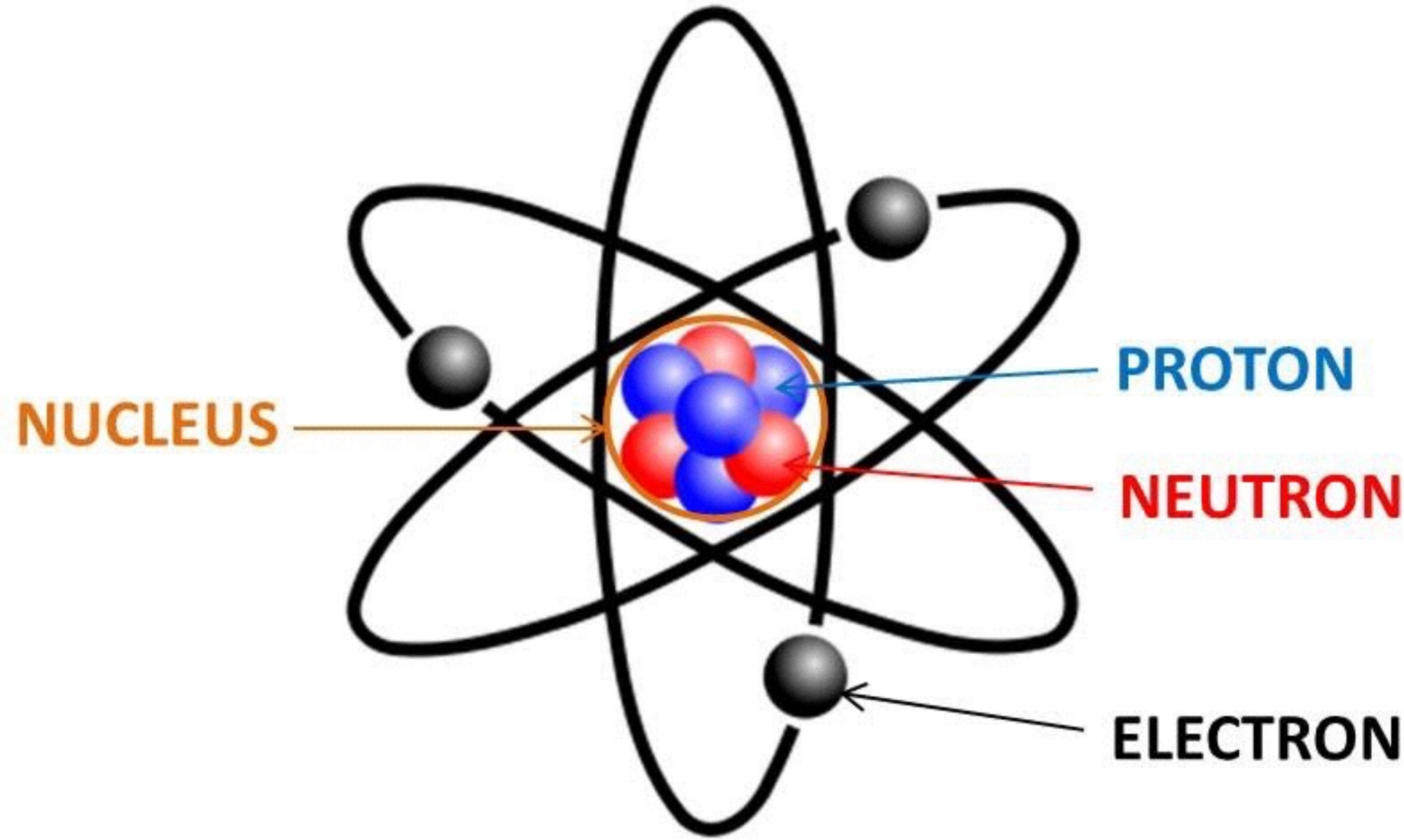
Force	Particles Experiencing	Force Carrier Particle	Range	Relative Strength*
Gravity acts between objects with mass	all particles with mass	graviton (not yet observed)	infinity	much weaker
Weak Force governs particle decay	quarks and leptons	W^+, W^-, Z^0 (W and Z)	short range	
Electromagnetism acts between electrically charged particles	electrically charged	γ (photon)	infinity	
Strong Force** binds quarks together	quarks and gluons	*g* (gluon)	short range	much stronger

STATIC ELECTRICITY

- The word *electricity* comes from the Greek word *elektron*, meaning "amber"
- The ancients discovered that if you rub an amber rod with a piece of cloth, the amber attracts small pieces of leaves or dust
  - Today, we called this "amber effect" ***static electricity***


Zap!

THE STRUCTURE OF AN ATOM

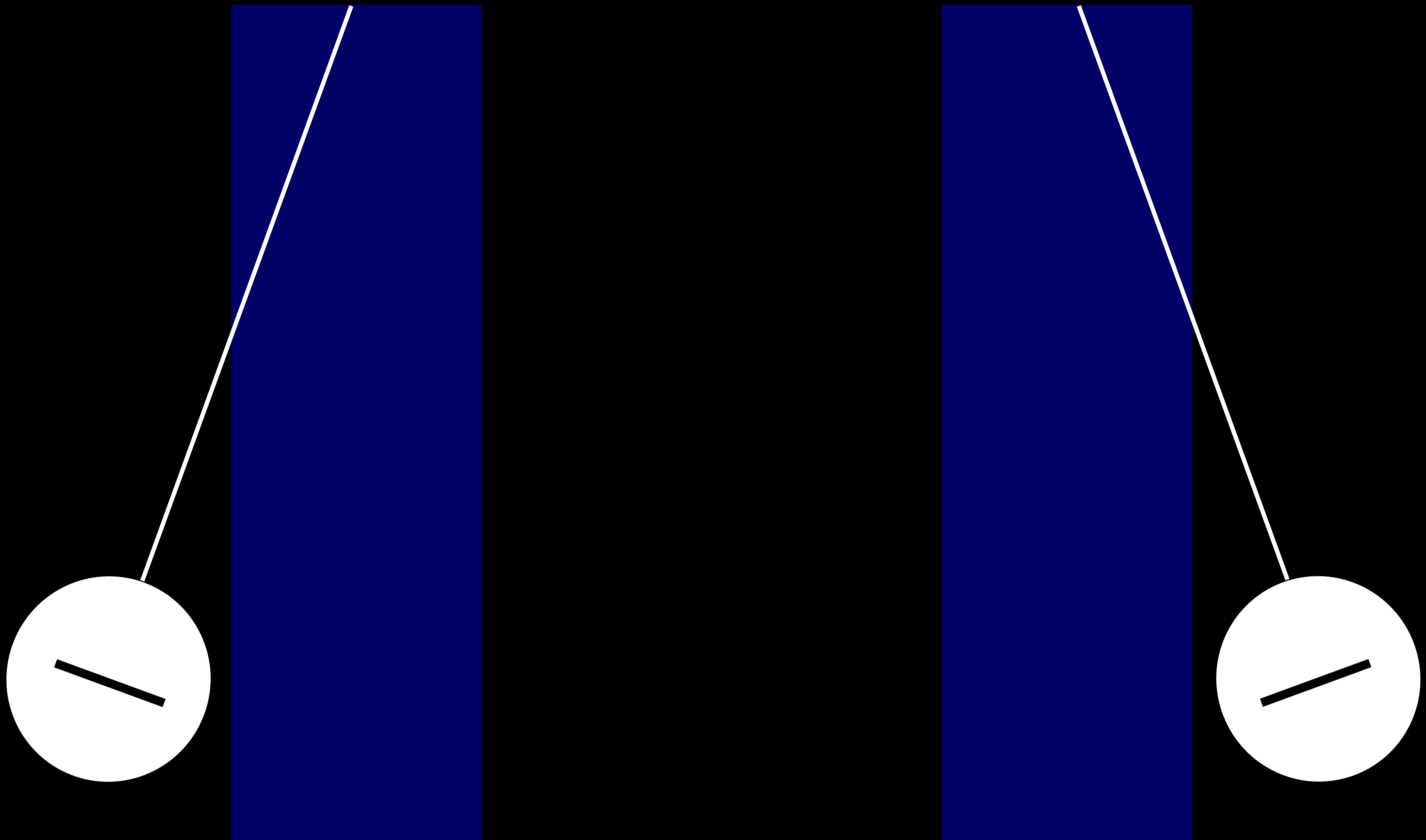


CHARGE

- Protons and electrons have an attribute called ***charge***
  - Protons have *positive* charge
  - Electrons have *negative* charge
  - Neutrons have *no* charge
- Charge is measured in ***Coulombs*** (**C**)

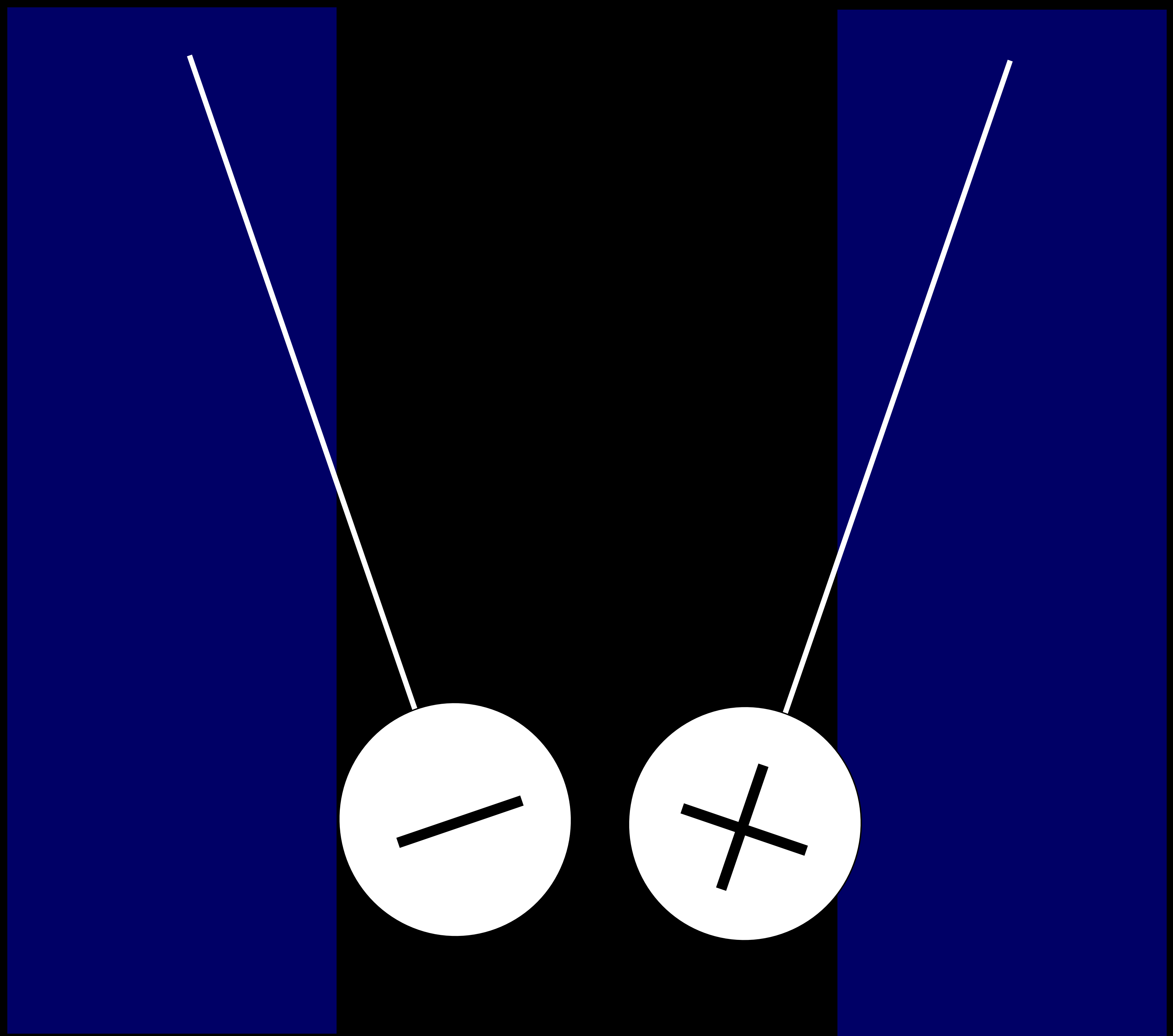
CHARGE

LIKE CHARGES REPEL



CHARGE

OPPOSITE CHARGES ATTRACT

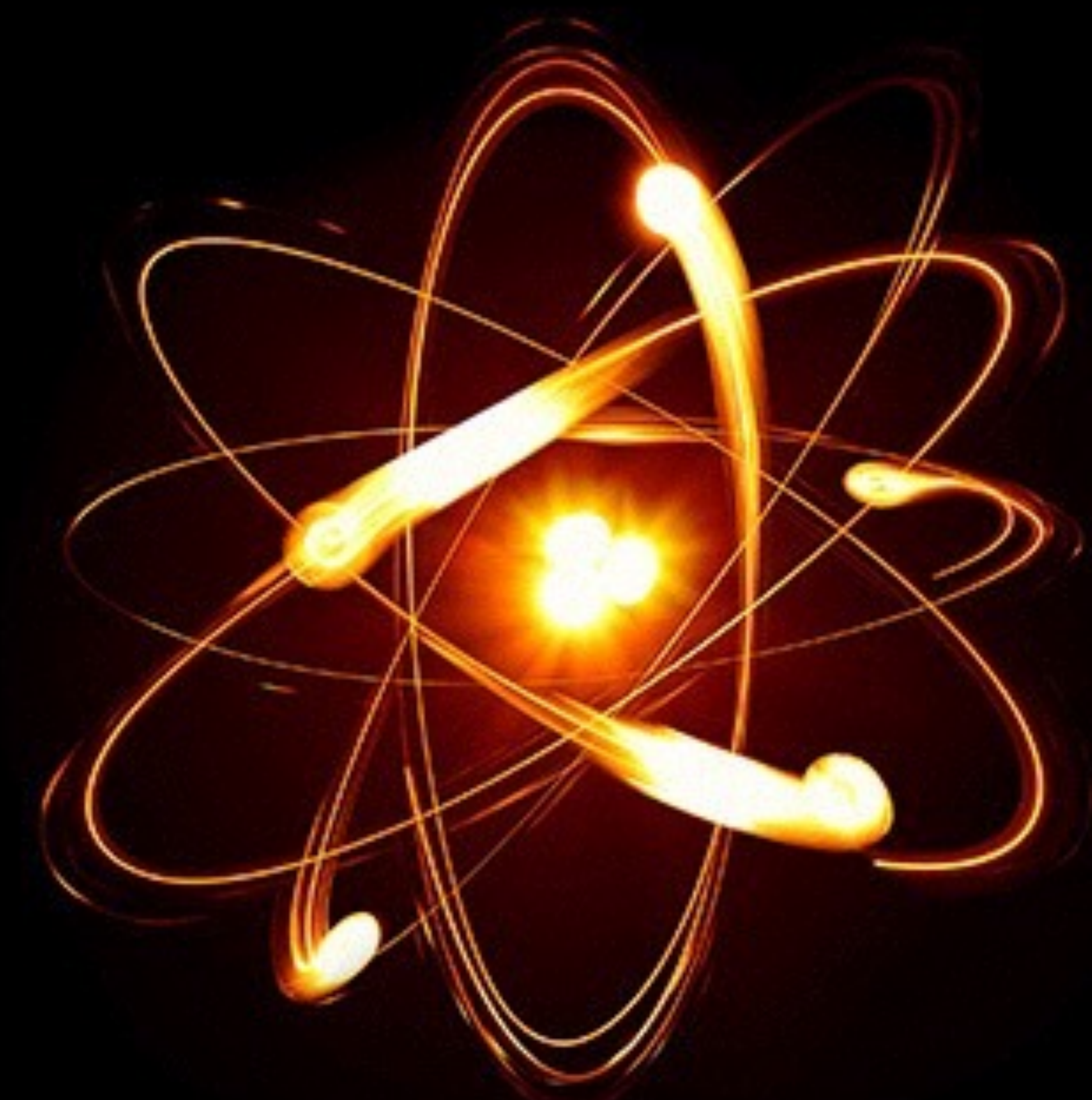


QUANTIZATION OF CHARGE

- $e^- = -1.6\times10^{-19}$ C (charge on an electron)
- $p^+ = +1.6\times10^{-19}$ C (charge on a proton)
- ***Quantization of Charge*** means that how much charge you can have is restricted to discrete quantities
  - A charged object will *always* have a charge that is an integer multiple of the charge on an electron (or proton)

QUANTIZATION OF CHARGE

- $Q = ne$
- Q = total charge
- n = (number protons) - (number of electrons)
- $e = 1.6\times10^{-19}$ C
- e is called the ***elementary charge***
  - Indivisible — you will never find a smaller charge in nature



PARTICLE	RELATIVE MASS	RELATIVE CHARGE	CHARGE (C)	MASS (KG)
PROTONS	1	+1	$+1.6 \times 10^{-19}$	1.67×10^{-27}
NEUTRONS	1	0	0	1.67×10^{-27}
ELECTRONS	0.0005	-1	-1.6×10^{-19}	9.11×10^{-31}

MILLIKAN OIL DROP EXPERIMENT

https://www.youtube.com/watch?v=XMfYHag7Liw

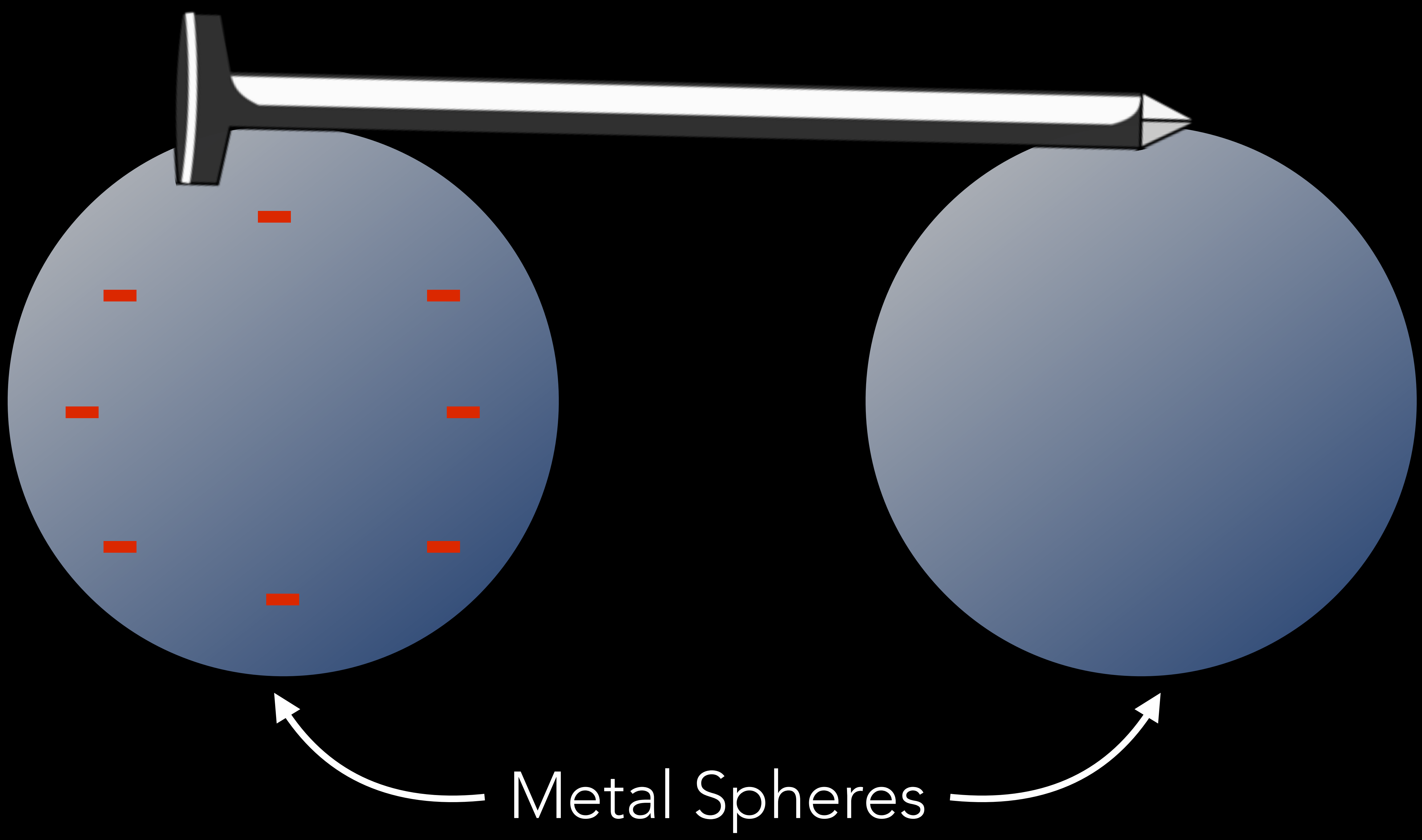
CHARGE AND EVERYDAY OBJECTS

	AMOUNT OF CHARGE
Charges in static electricity from rubbing materials together	~ microcoulombs
Charges traveling through a lightning bolt	15 - 350 C
Charge that travels through a typical alkaline AA battery from being fully charged to discharged	about 5000 C

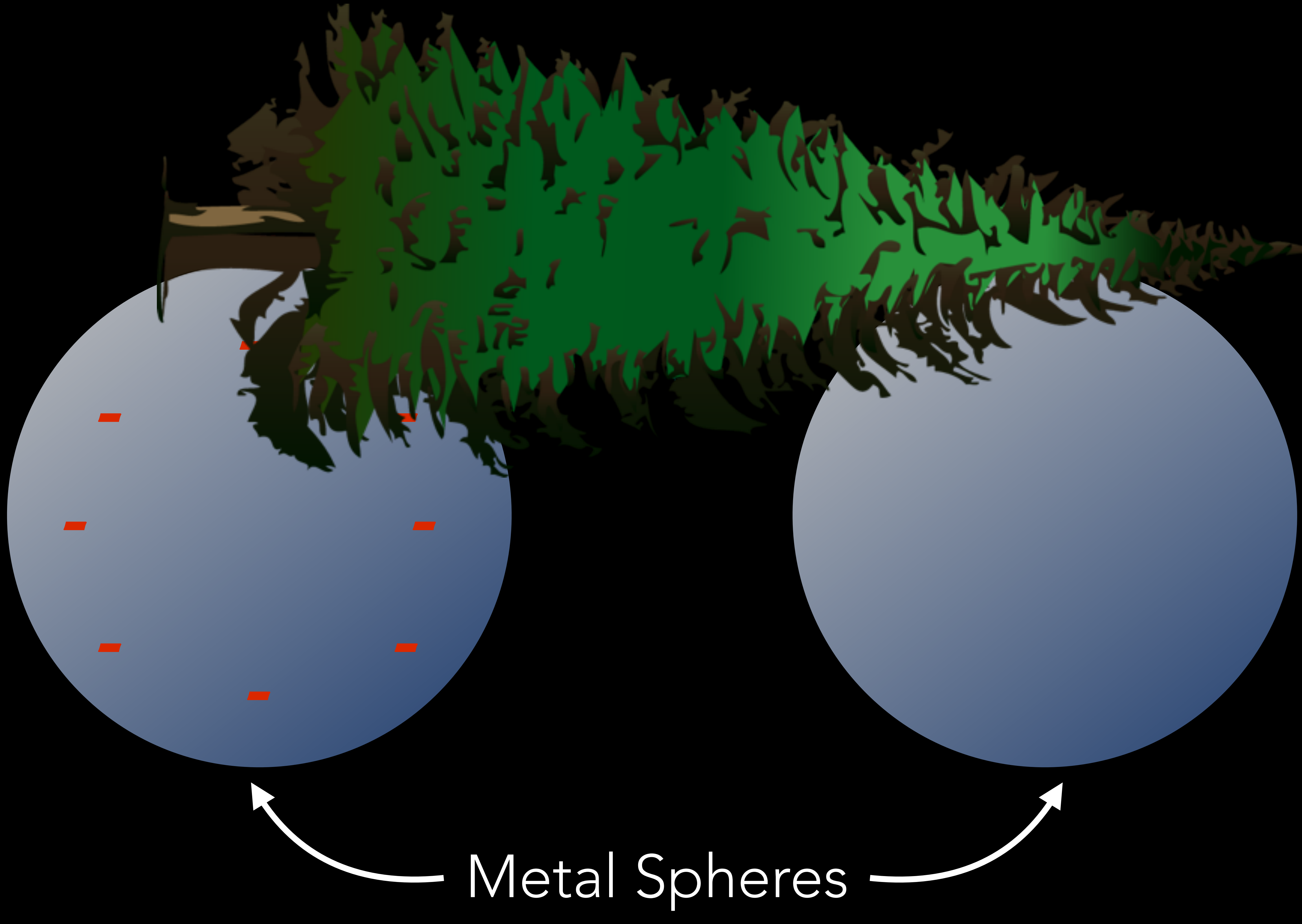
THE LAW OF CONSERVATION OF ELECTRIC CHARGE

- **Electric charge cannot be created or destroyed. The net amount of electric charged produced in any process is *always* zero.**
  - If one object or region of space acquires a positive charge, then an equal amount of negative charge will be found in neighboring areas or objects.

INSULATORS & CONDUCTORS



INSULATORS & CONDUCTORS



INSULATORS & CONDUCTORS

- Materials like the iron nail are said to be ***conductors*** of electricity (typically metals)
- Materials like wood or rubber are *nonconductors* or ***insulators***
- Nearly all natural materials fall into one or the other of these two distinct categories
  - A few (like silicon, germanium, and carbon) fall into an intermediate (but distinct) category known as ***semiconductors***

HOW TO MOVE CHARGES

- There are three basic ways to move charges between and/or within objects

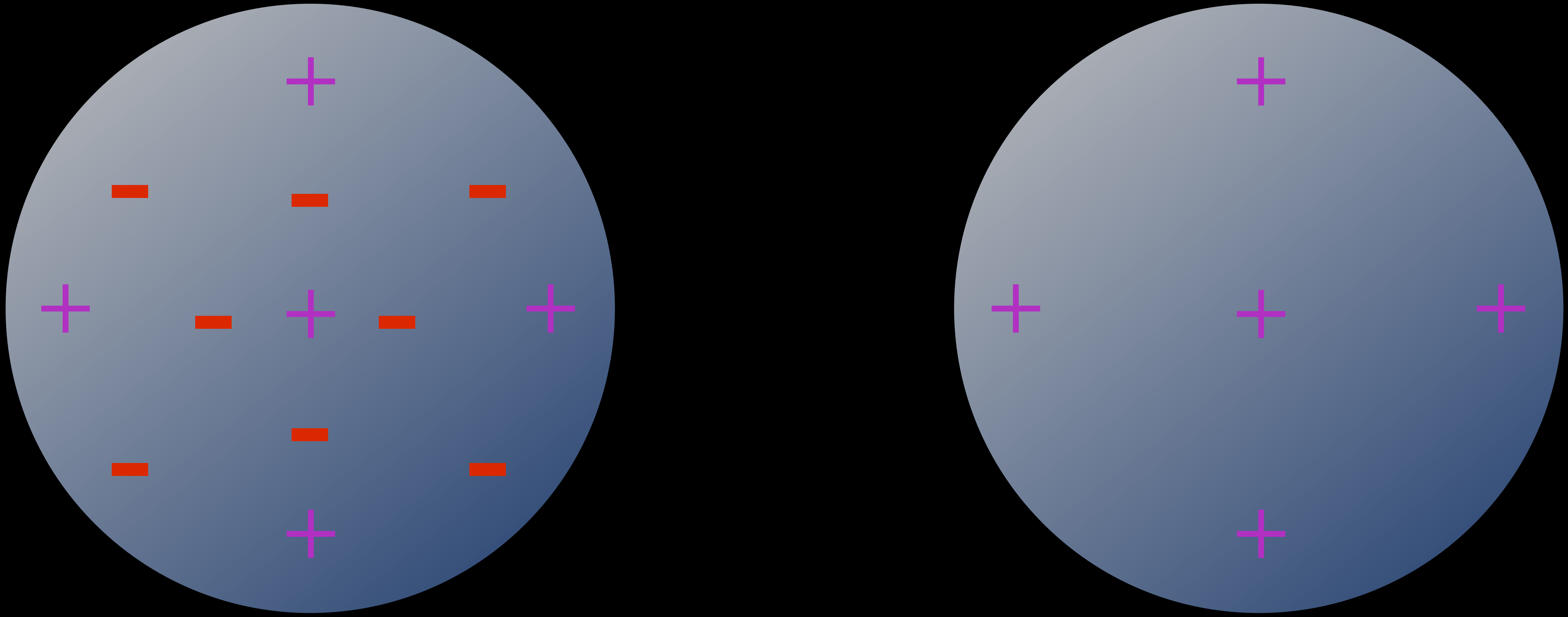
  1. Conduction

  2. Induction

  3. Friction

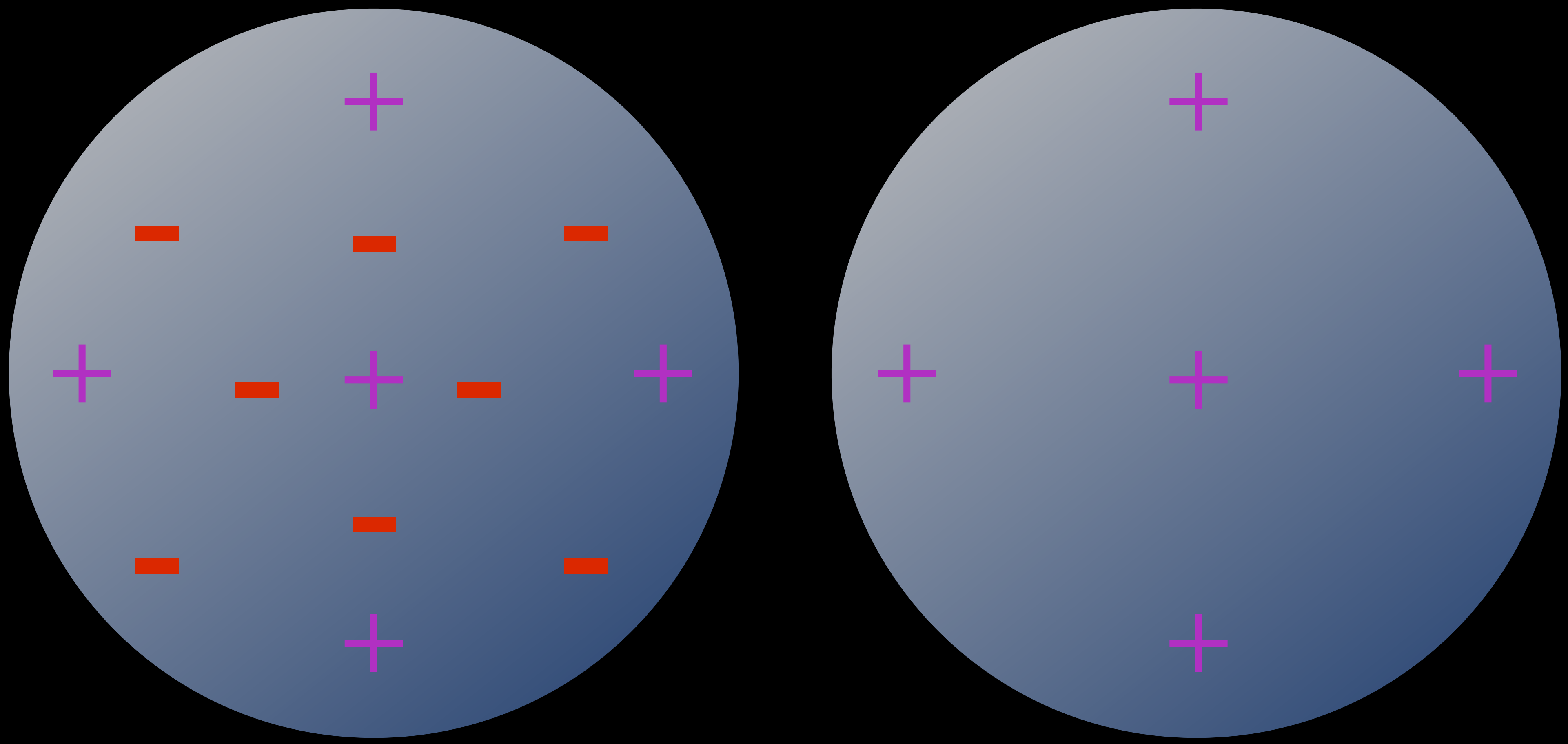
HOW TO MOVE CHARGES

- ***Conduction*** is where charges move between objects when they *touch*



HOW TO MOVE CHARGES

- ***Induction*** is *separation of charge* within an object because of the close approach of another charged object but *without touching*

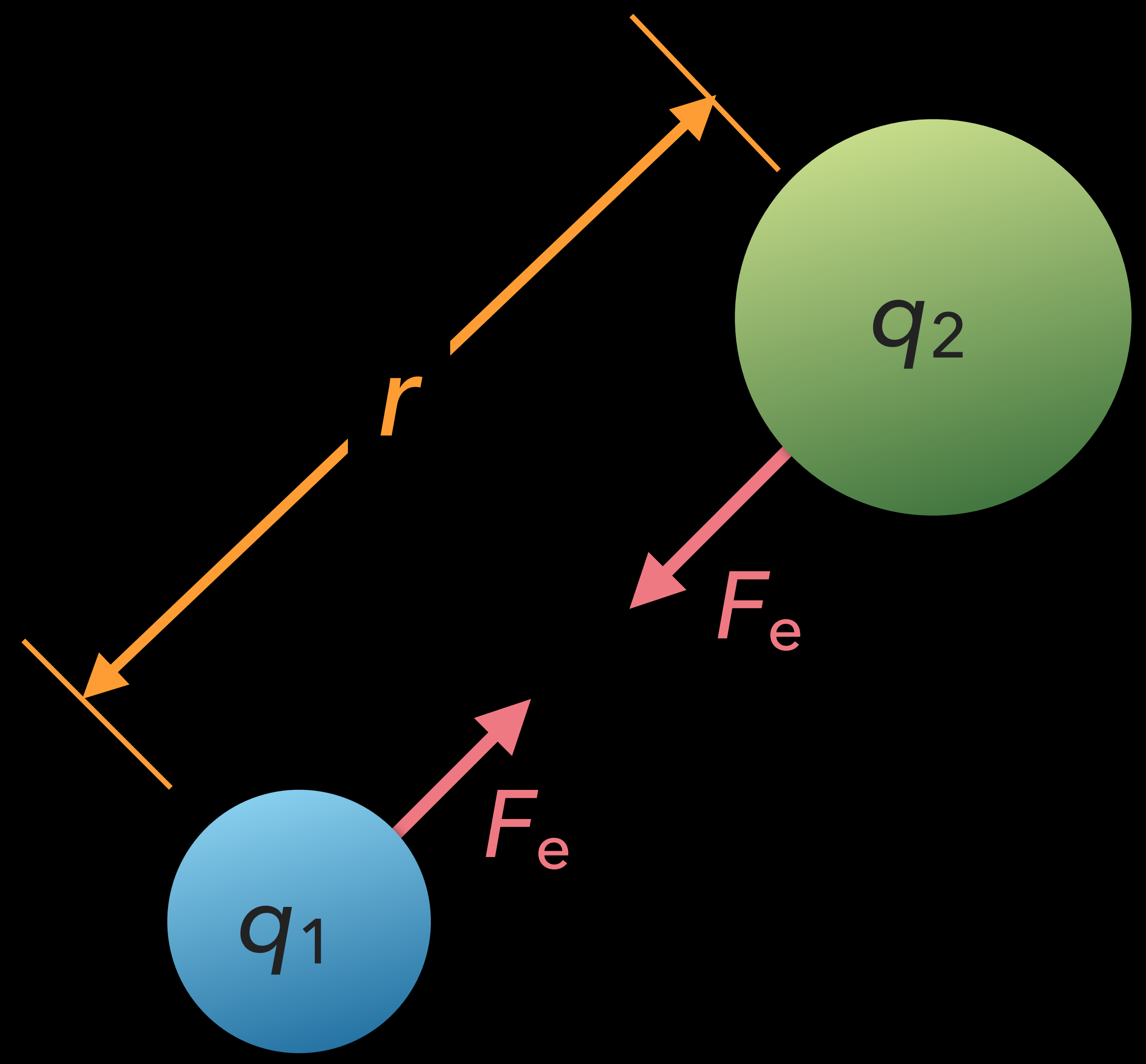


HOW TO MOVE CHARGE

- Charging by ***friction*** is where electrons are physically stripped from one material and transferred to another

FORMALIZING ELECTRIC FORCE

- The electric force between two objects depends on 3 quantities
  - How big is the first charge: q_1
  - How big is the second charge: q_2
  - How far apart are they: r



COULOMB'S LAW

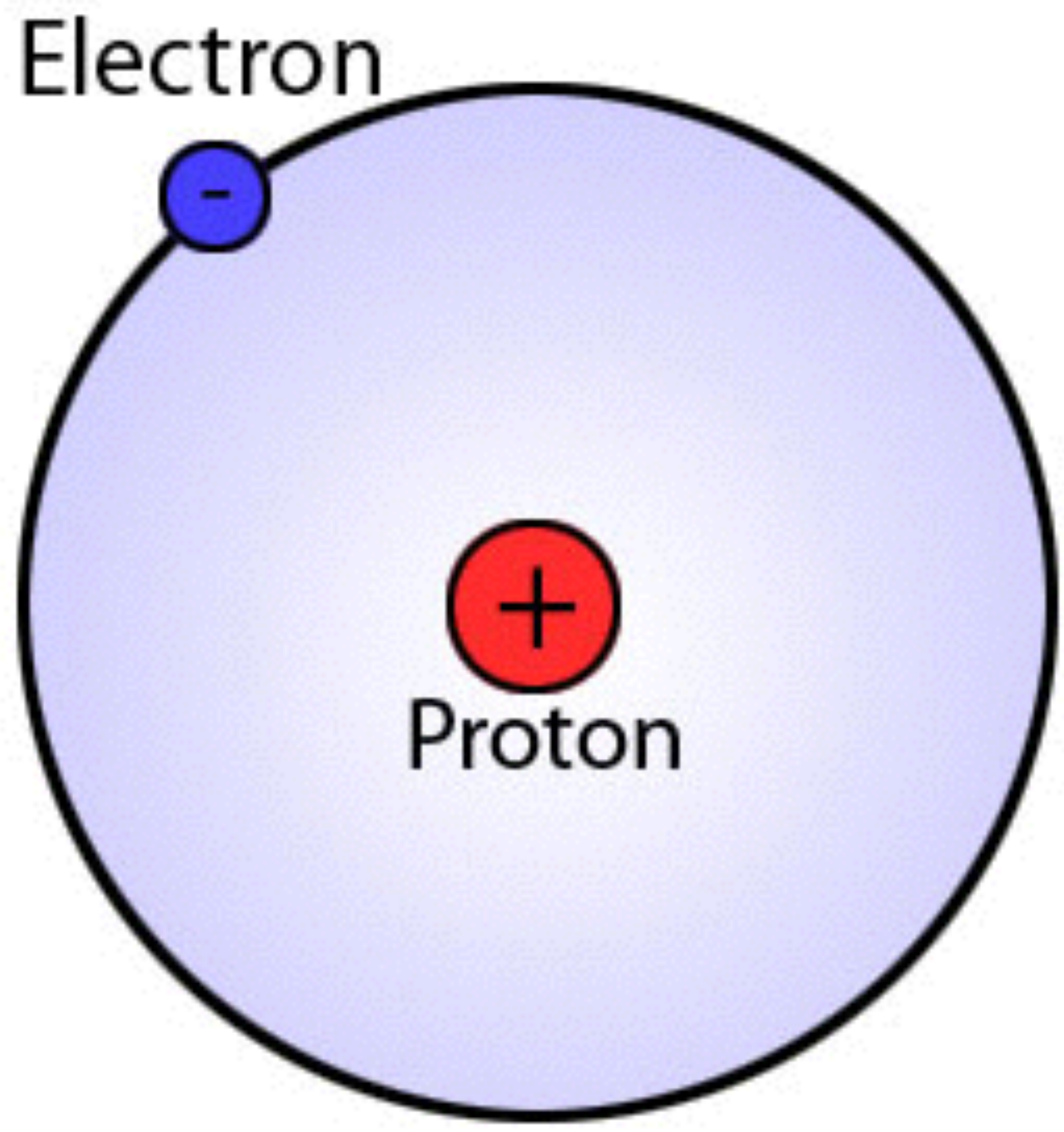
- $F_e = \dfrac{kq_1q_2}{r^2}$ Inverse square law!
  - $k = 9.0 \times 10^9$ Nm^2/C^2
- If F_e is positive, the force is *repulsive*
- If F_e is negative, the force is *attractive*

COULOMB'S LAW

- *k* is often written in terms of another constant
  - $k = 1/4\pi\varepsilon_0$
  - $\varepsilon_0 = 8.85\times10^{-12}\ C^2/Nm^2$
    - Called the ***permittivity of free space***
    - It's a measure of how accepting a vacuum is of an electric field
  - Other fundamental equations we'll see later are simpler in terms of ε_0 rather than *k*, but for the coulomb force, go ahead and use *k*

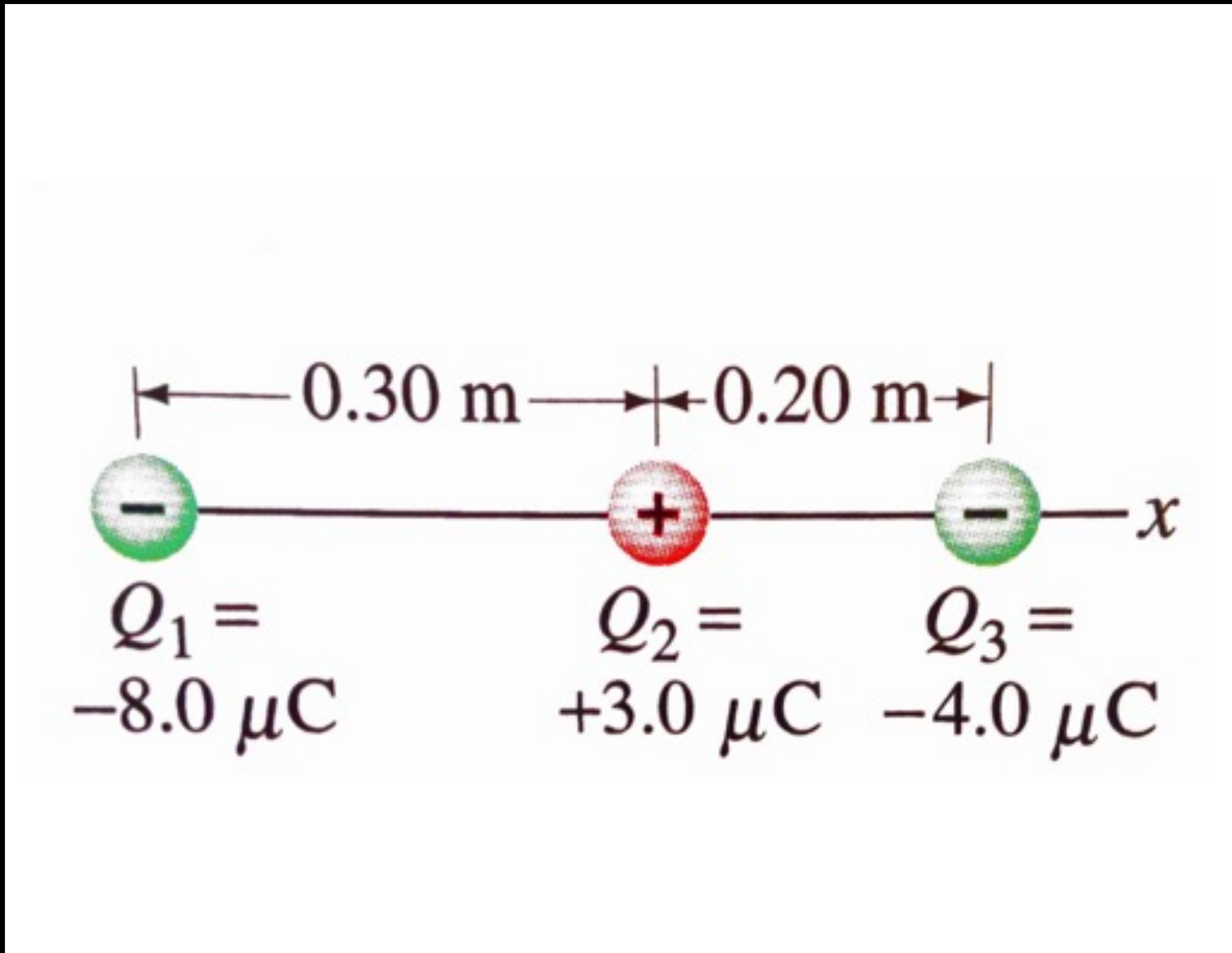
EXAMPLE 1

- Determine the electric force on an electron in a hydrogen atom from the proton if they are separated by an average distance of $r = 0.53\times10^{-10}$ m
  - *Ans.* $F_e = -8.2\times10^{-8}$ *N*



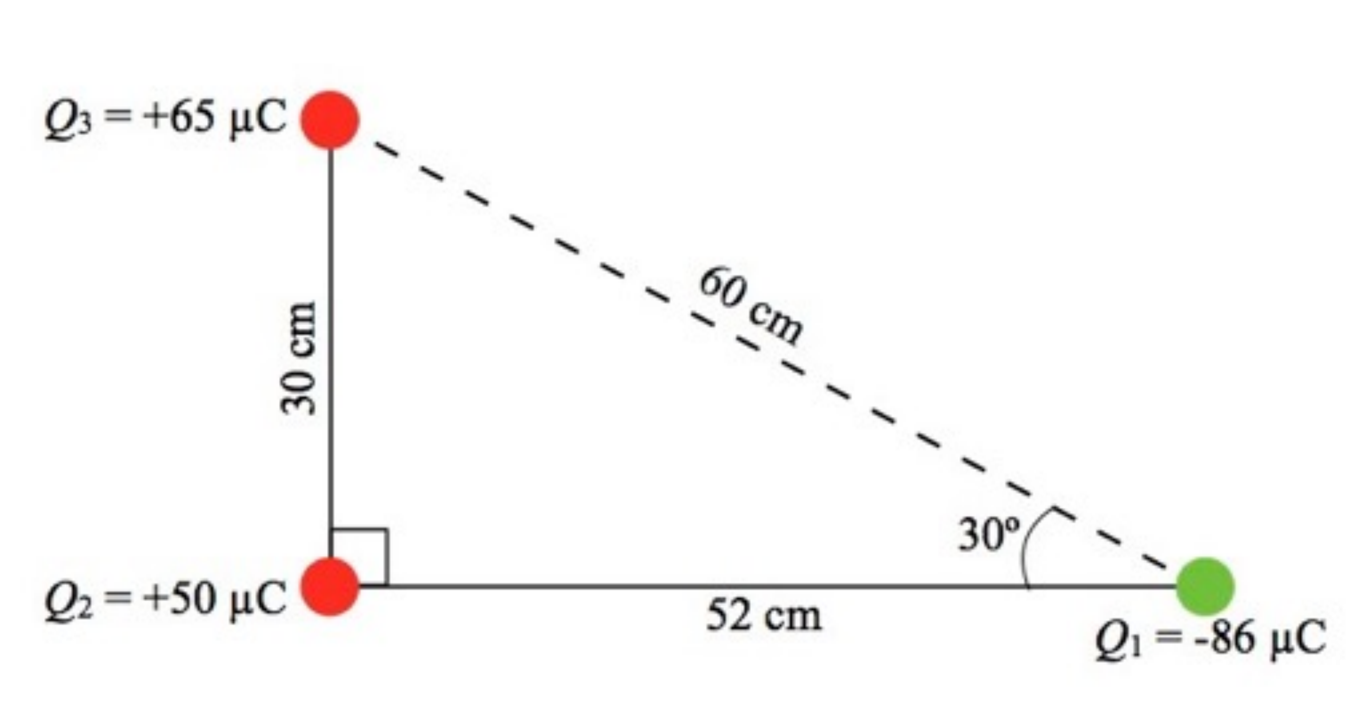
EXAMPLE 2

- Three charged particles are arranged in a line (as shown). Calculate the net electrostatic force on particle 3 (on the right) due to the other three charges.
  - *Ans.* ***F*** *= 1.5 N to the left*



EXAMPLE 3

- Calculate the net electrostatic force on charge 3 due to charges 1 & 2.
  - *Ans.* ***F*** *= 282 N @ 65°*



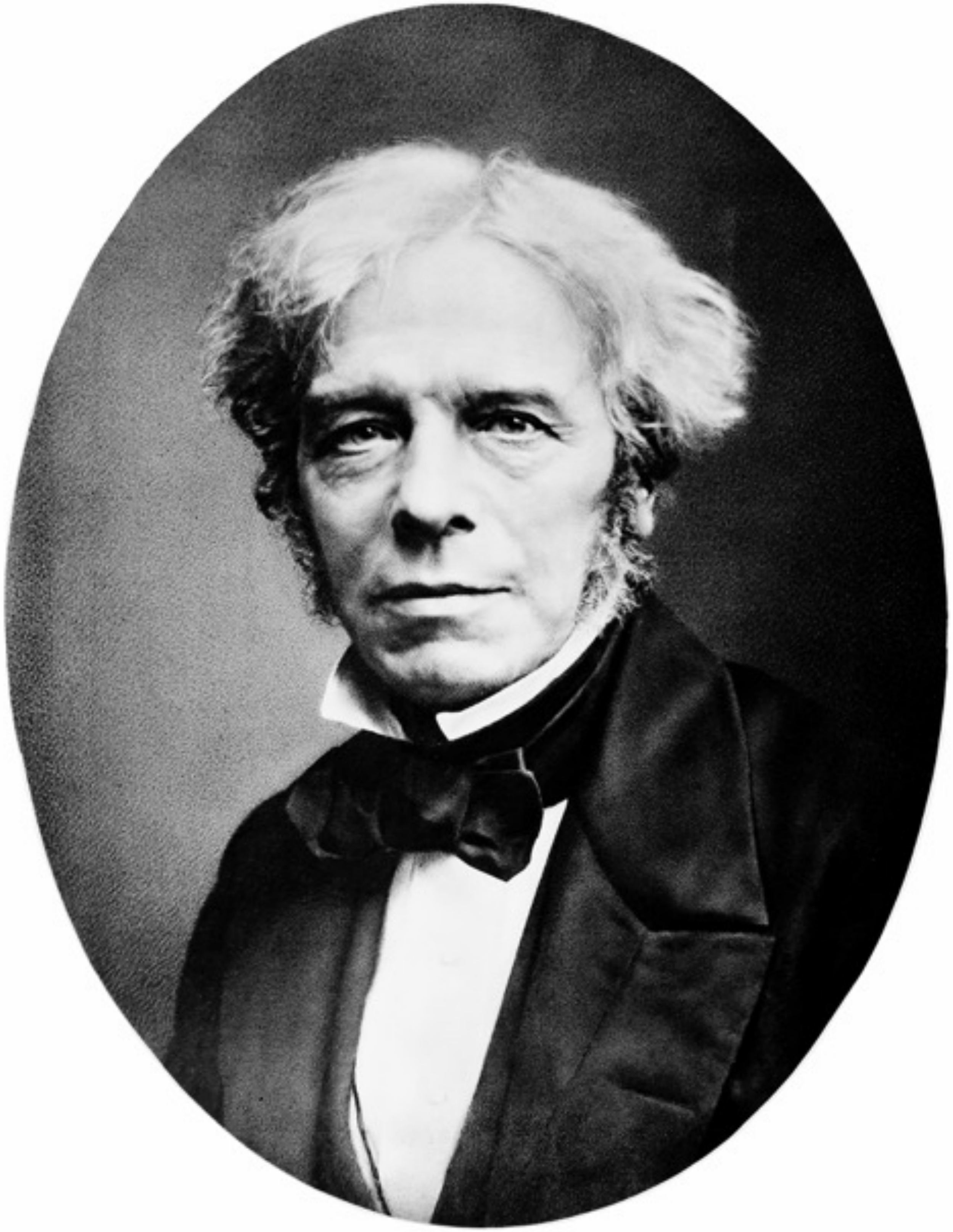
SANITY CHECK

- Two positive point charges, $Q_1 = 50\ \mu C$ and $Q_2 = 1\ \mu C$, are separated by a distance ℓ. Which is larger in magnitude, the force that Q_1 exerts on Q_2 or the force that Q_2 exerts on Q_1?

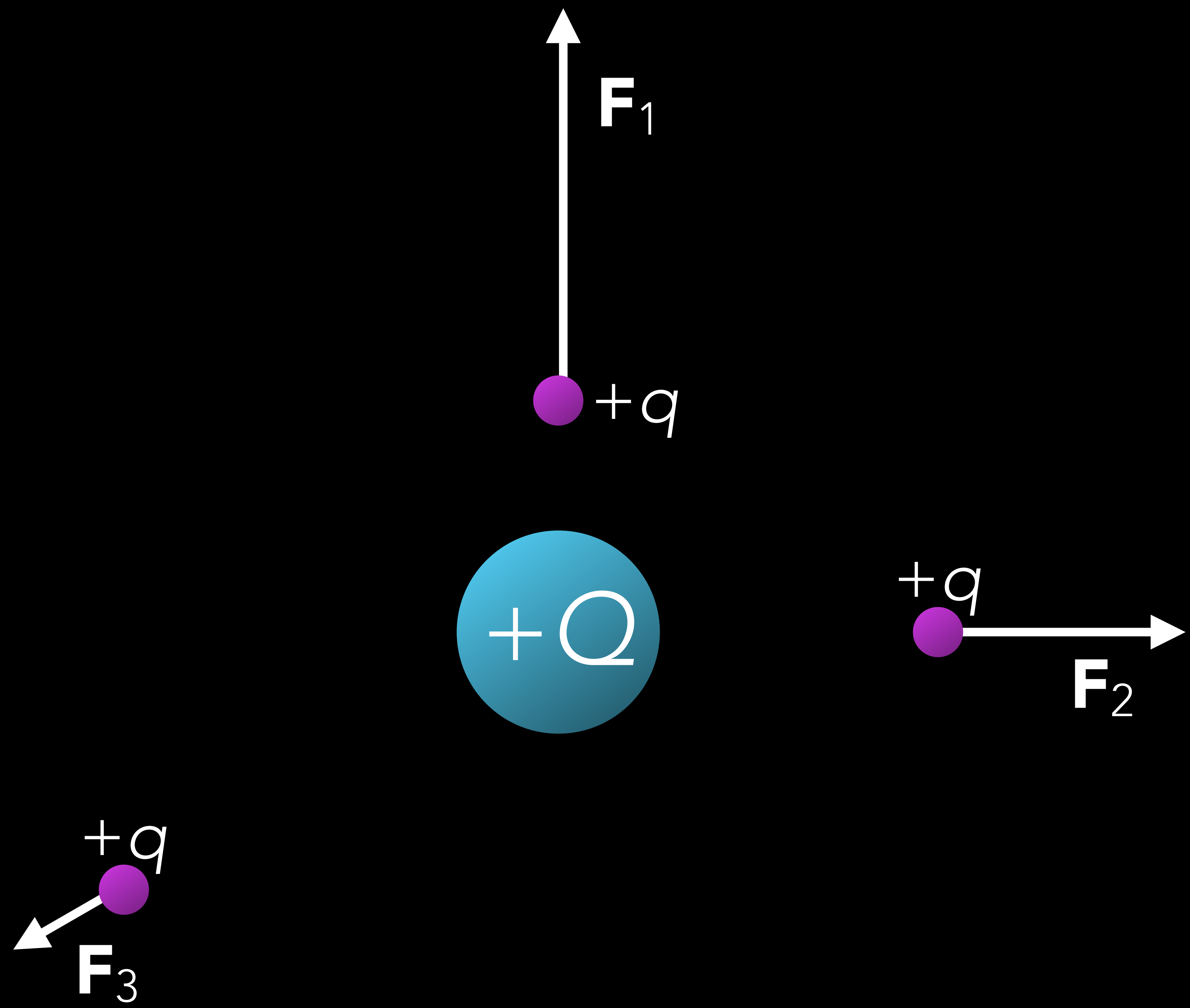
- *They're both the same!* (Newton's Third Law)

ELECTRIC FIELDS

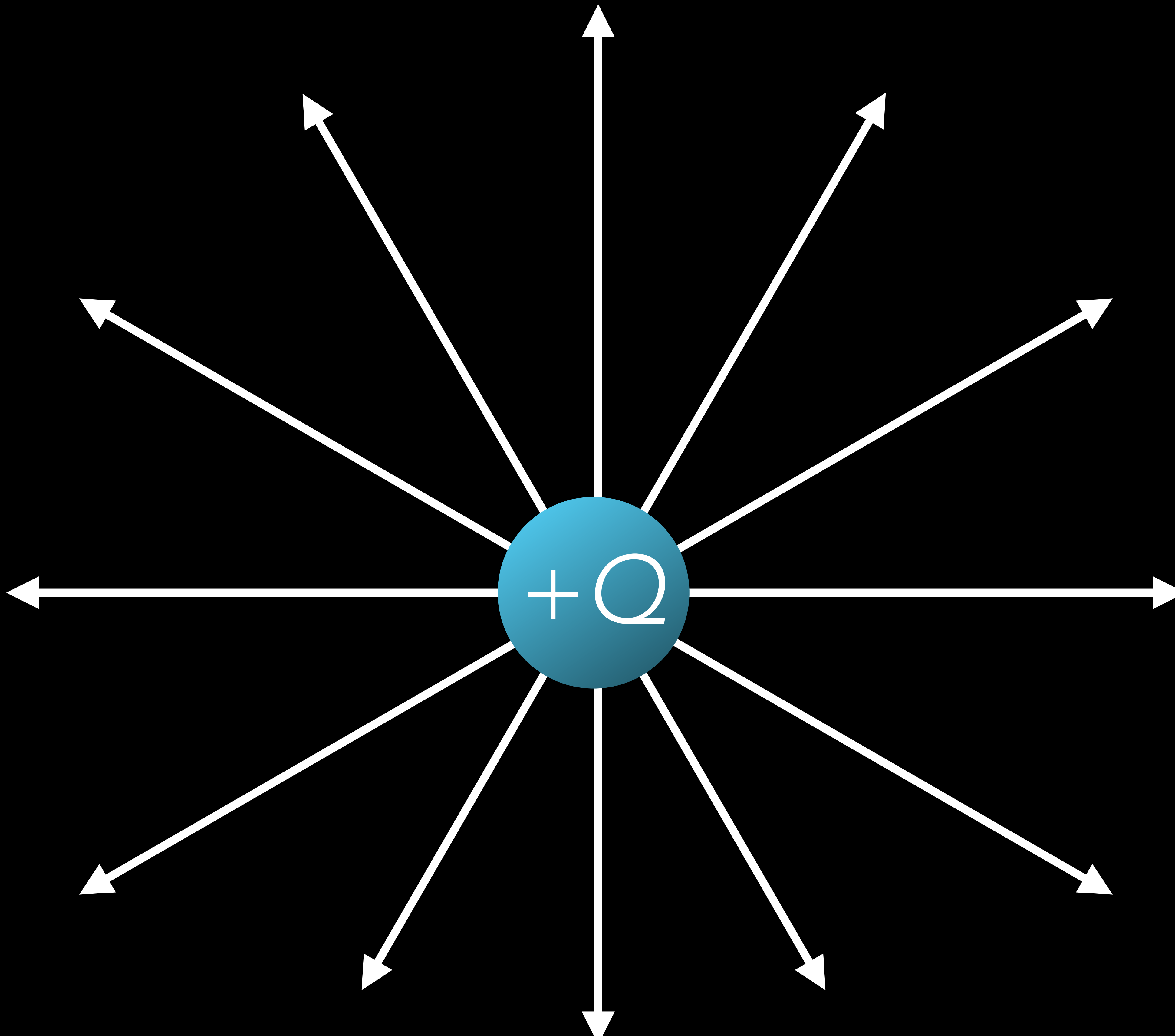
- Like the force of gravity, the electrical force acts at a distance
- In the early 1800s, British scientist Michael Faraday developed the concept of ***electric fields*** to help model the behavior of electrical forces
  - In physics, a field is a region of influence (in this case, we mean the influence of an electrical force)



ELECTRIC FIELDS

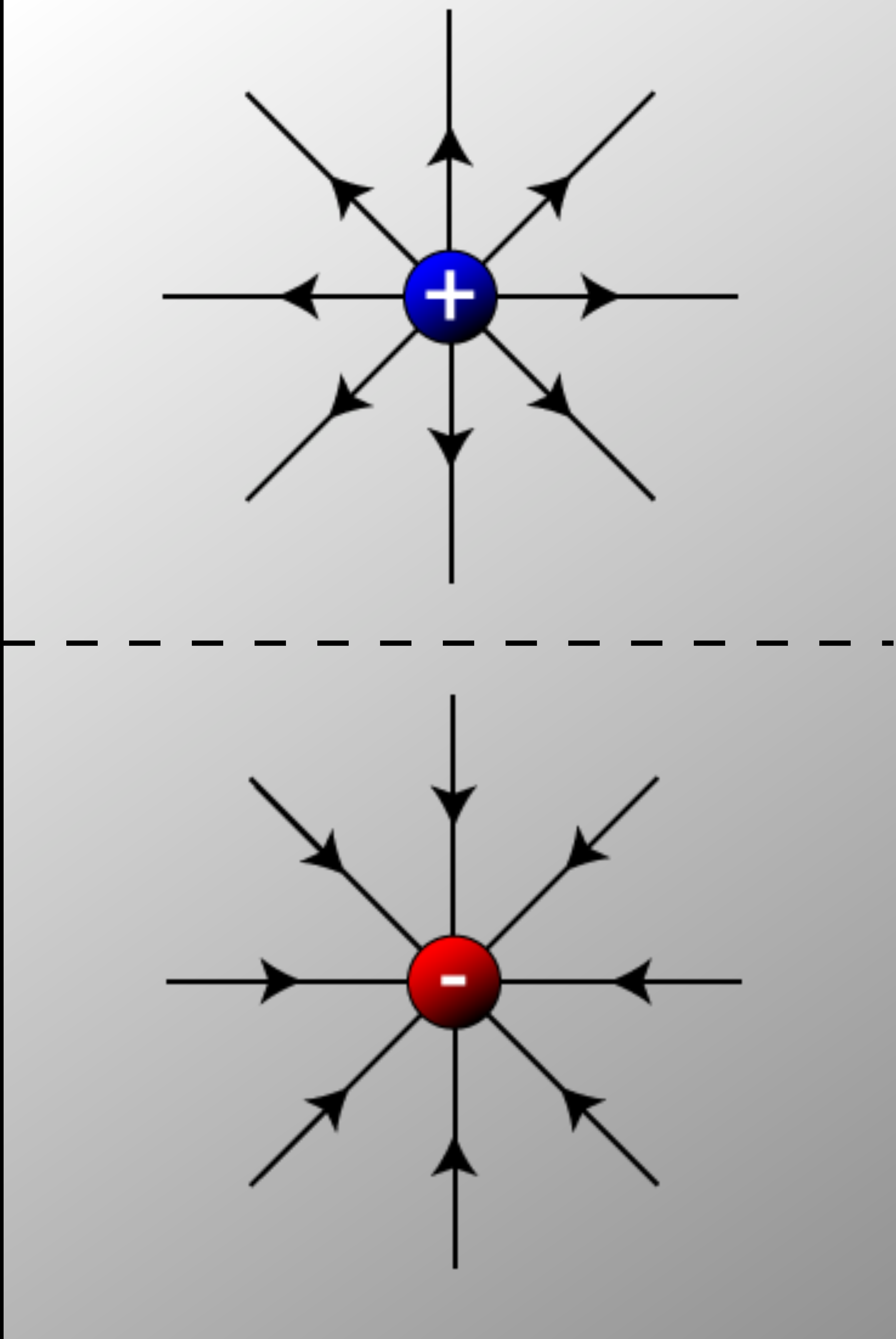


ELECTRIC FIELDS



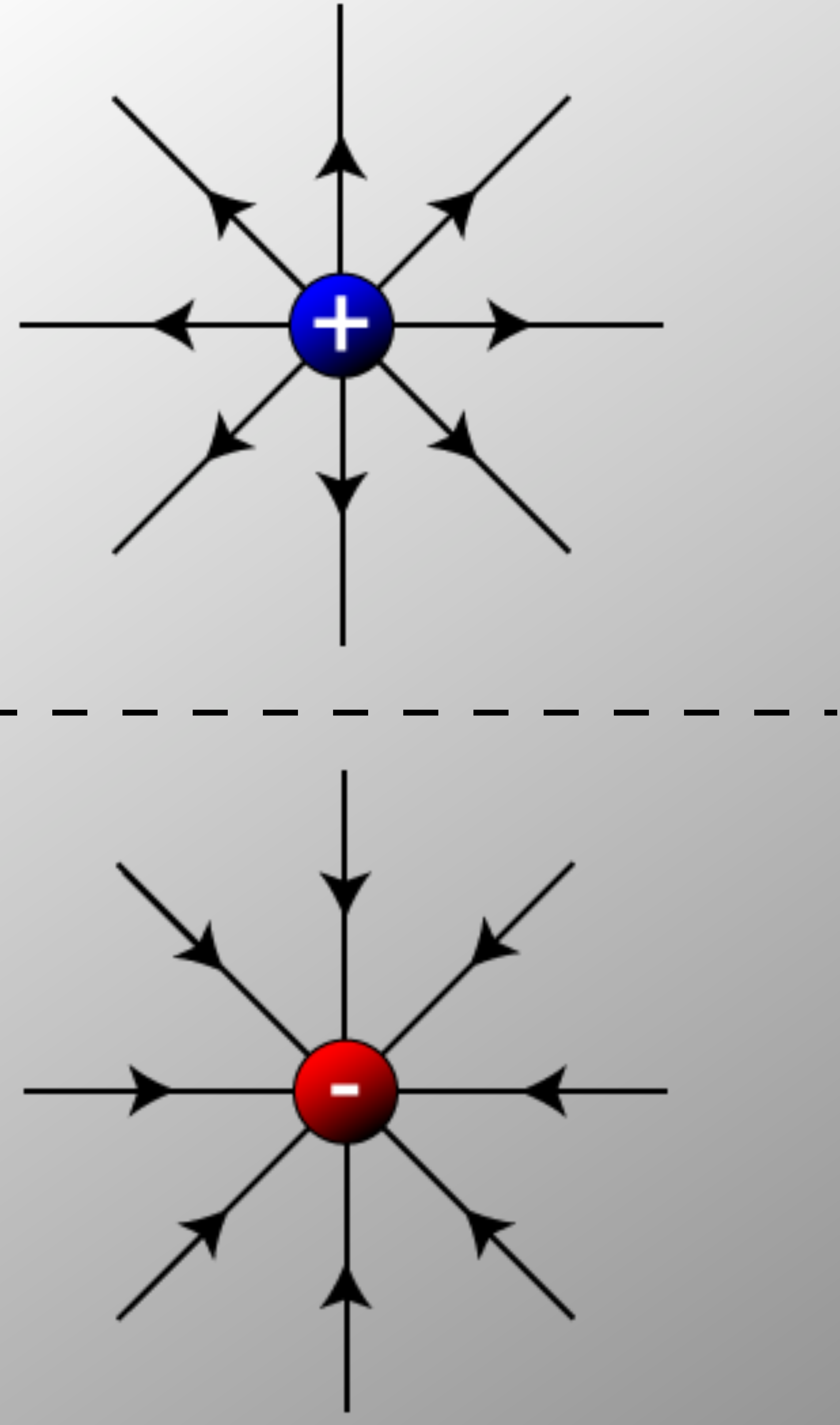
ELECTRIC FIELDS

- $\mathbf{E} = \mathbf{F}/q$
  - Measured in N/C
- $E = kQ/r^2$
  - *q* is the charge *feeling* the field
  - *Q* is the charge *creating* the field



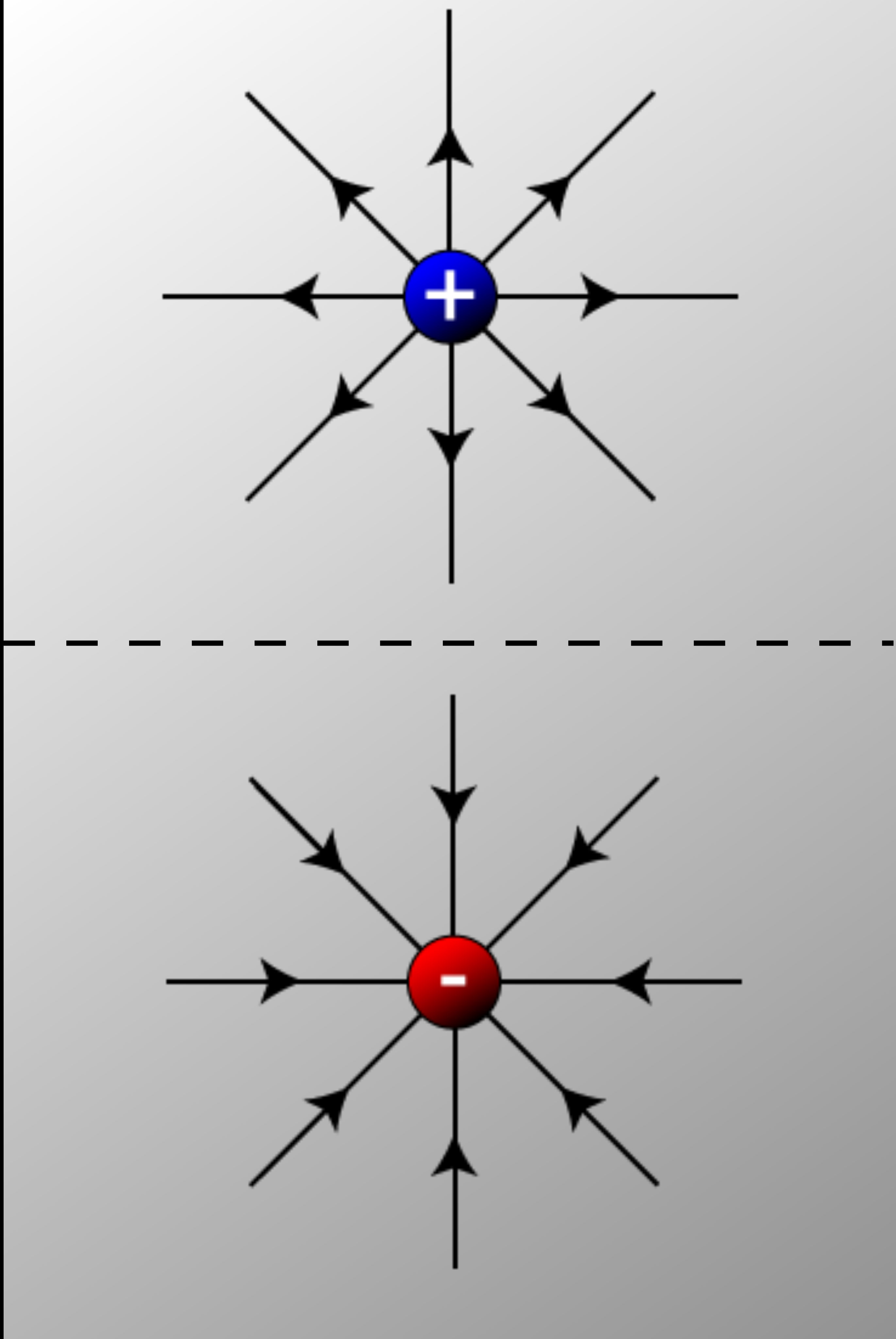
EXAMPLE 4

- What is the magnitude and direction of the electric force on an electron in a uniform electric field of strength 3500 N/C that points due east?
  - *Ans.* $\mathbf{F} = 5.6\times10^{-16}$ *N to the west*



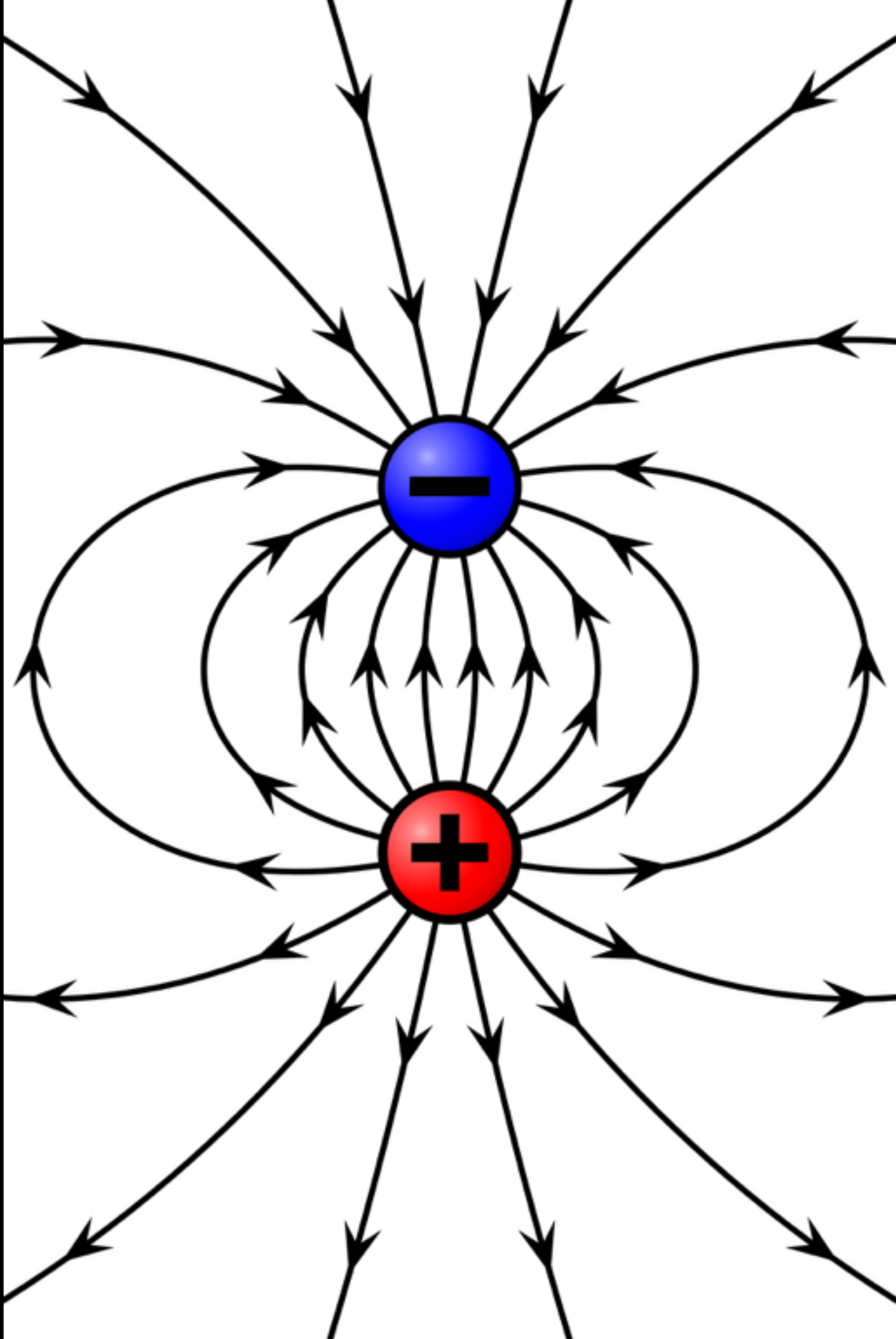
EXAMPLE 5

- Calculate the magnitude and direction of the electric field at a point 30 cm to the right of a point charge $Q = -3.0 \times 10^{-6}$ C
  - *Ans.* $\mathbf{E} = 3.0 \times 10^{5}$ *N/C to the left*



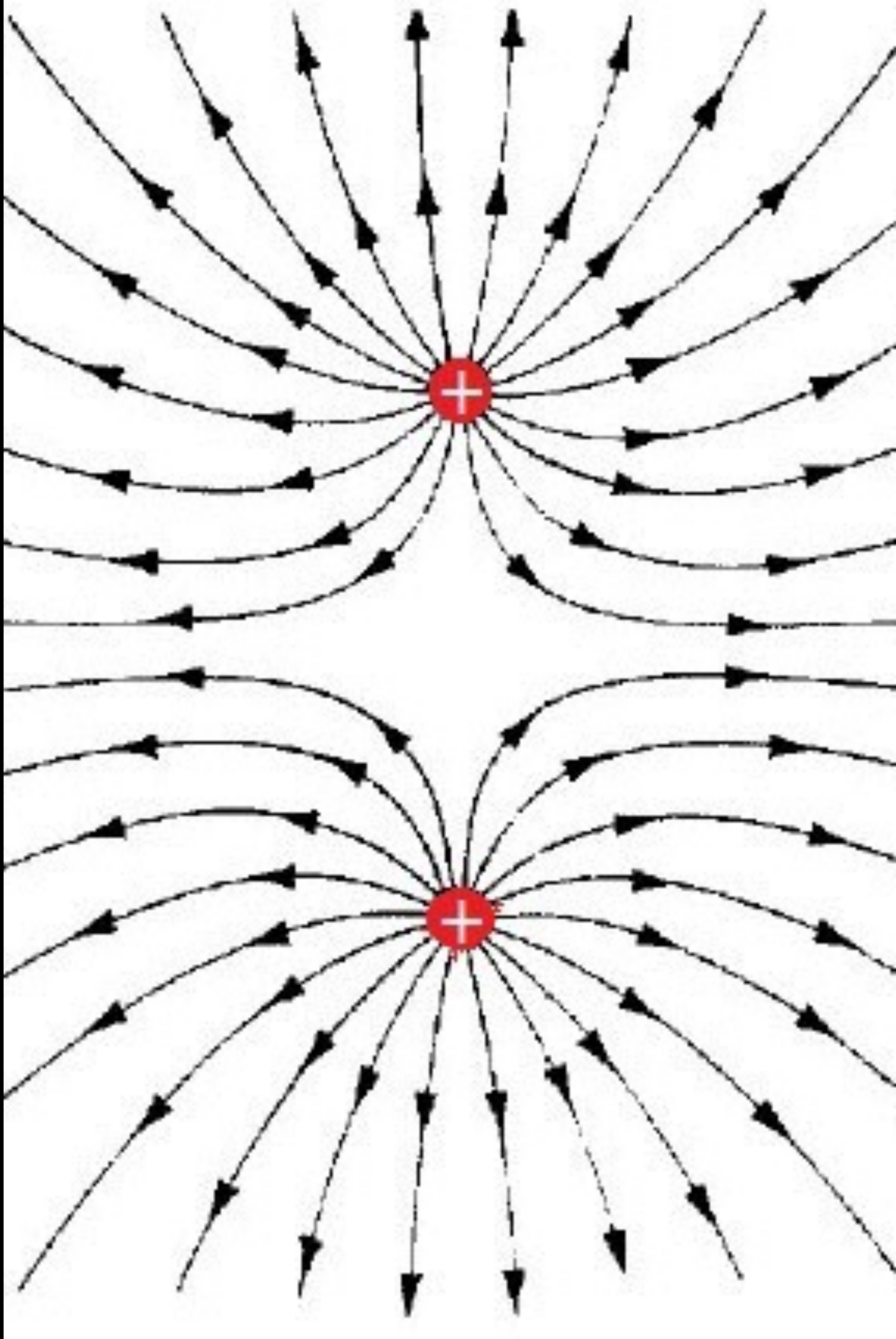
ELECTRIC FIELDS

- ***Electric field lines*** are drawn to indicate the direction of the force due to the given field on a *positive* test charge
    - Field lines always point from positive to negative
    - Field lines never cross (since a force can only point in one direction at a time)



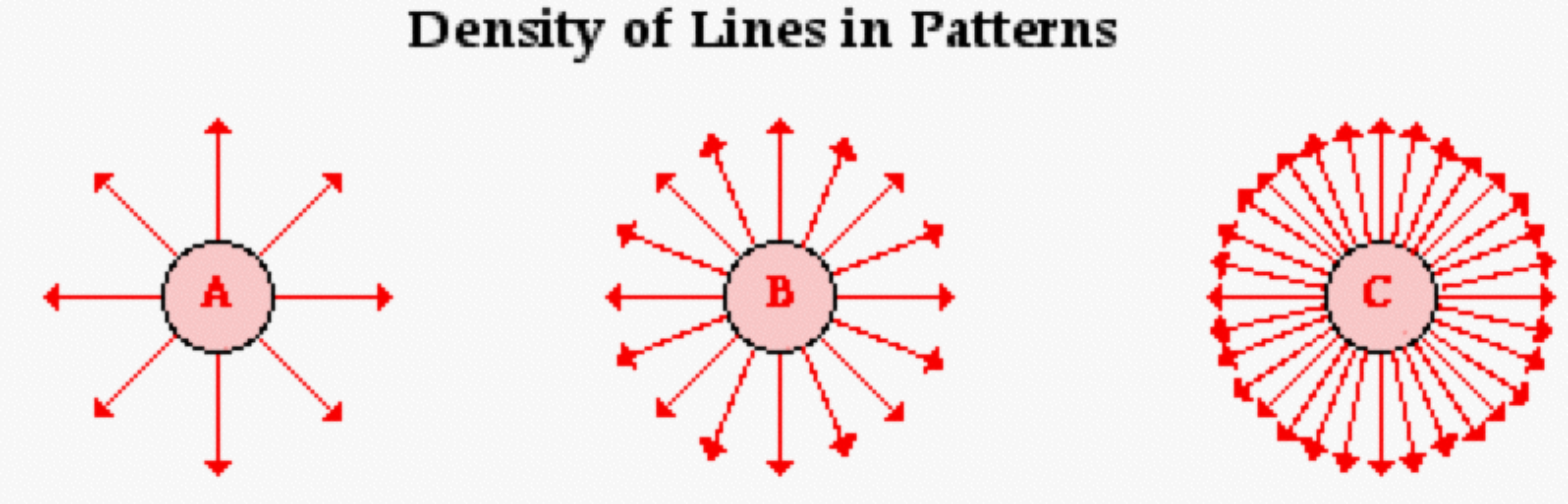
ELECTRIC FIELDS

- Field lines point *radially* toward or away from the charges
    - Perpendicular to the surface of the charged conductors



ELECTRIC FIELDS

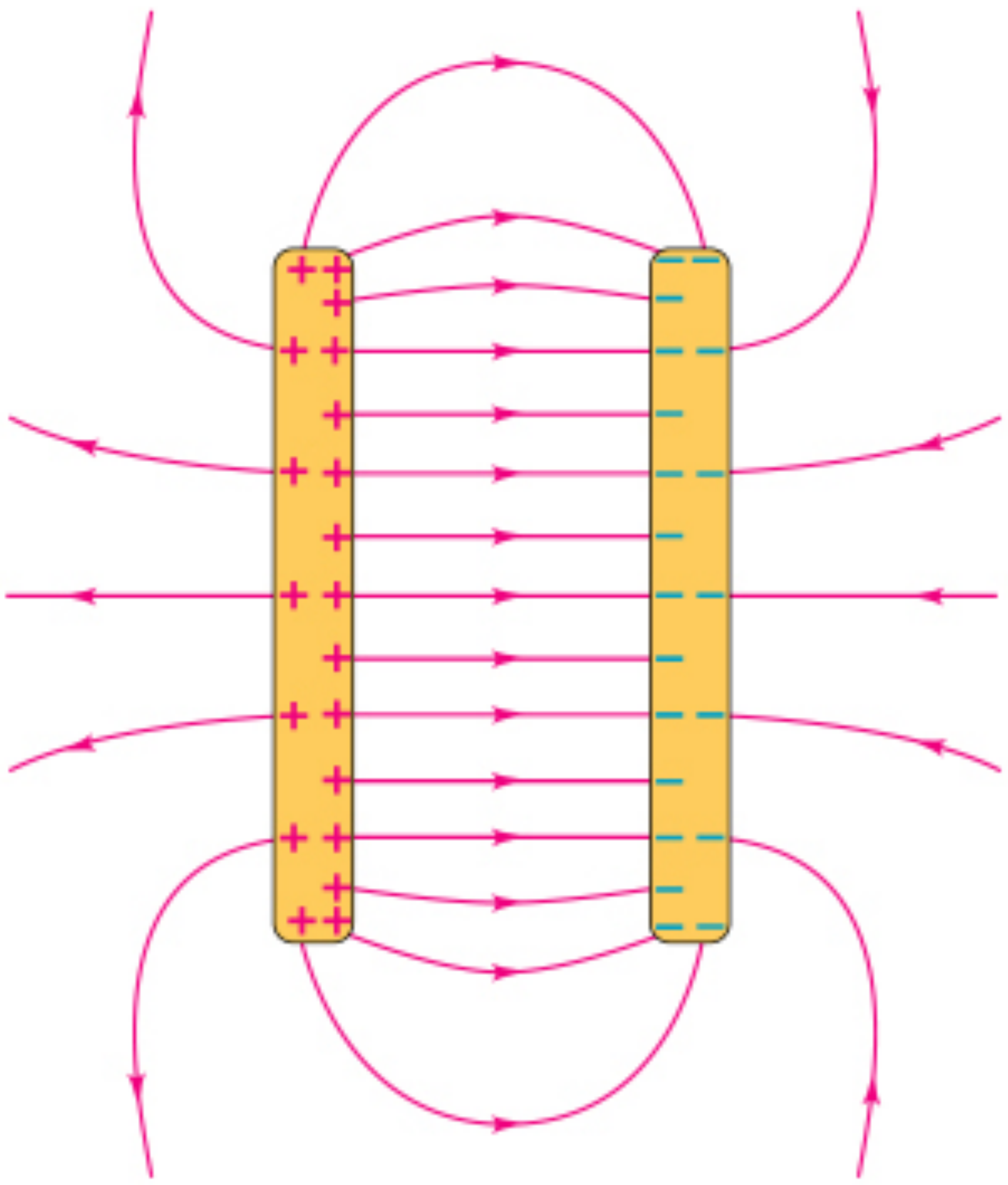
- The density of the field lines is proportional to the magnitude of the electric field



The density of electric field lines around these three objects reveals that the quantity of charge on C is greater than that on B which is greater than that on A.

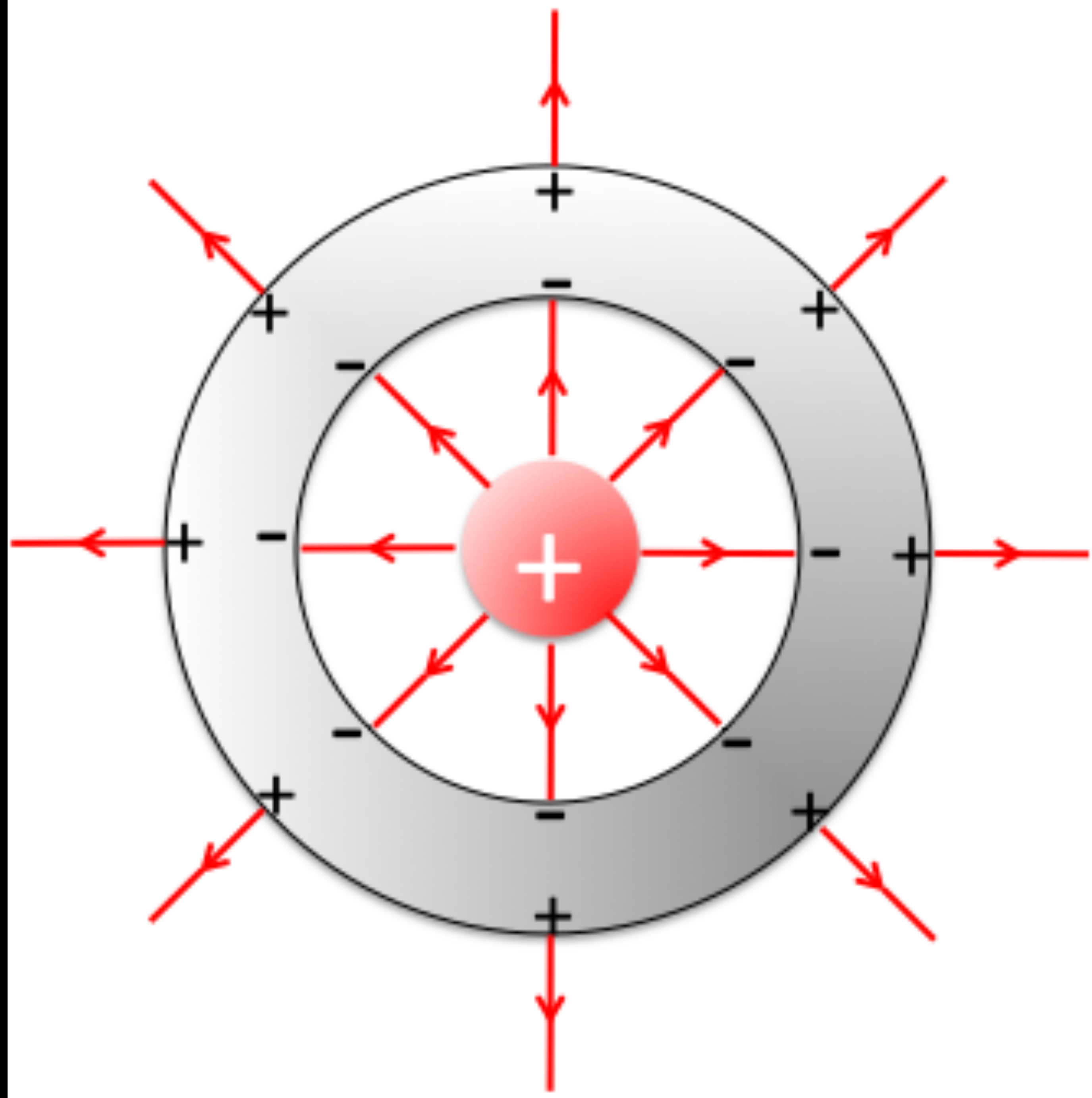
ELECTRIC FIELDS

- The electric field is constant between two oppositely charged, parallel plates
- The field lines between them will be drawn parallel and equally spaced



ELECTRIC FIELDS

- The electric field inside a good conductor is zero (in a static situation)
  - Any net charge on a good conductor distributes itself on the surface

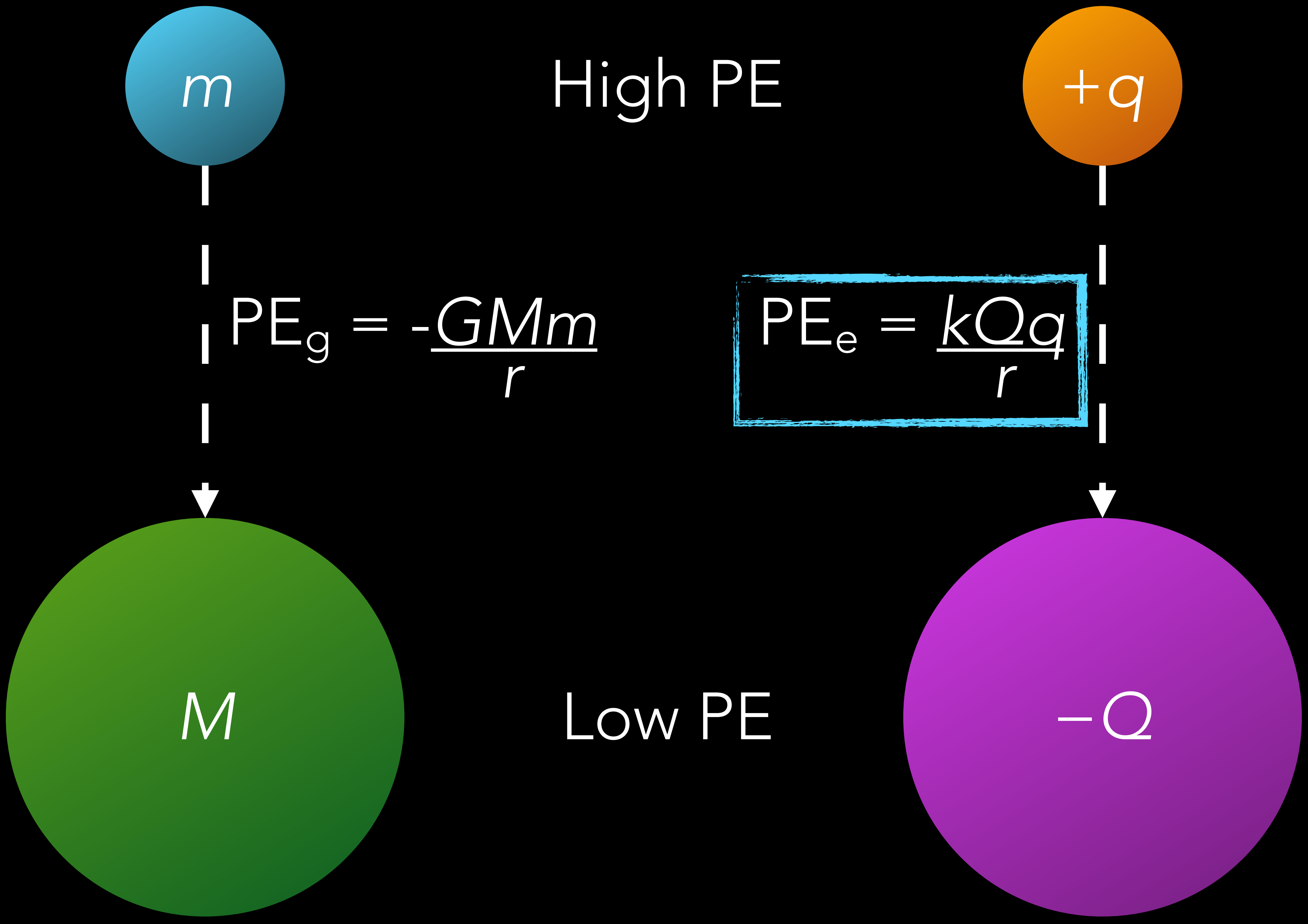


SANITY CHECK

- How much should you panic if your airplane is struck by lightning?
  - *Don't panic!* The exterior of the plane is a good conductor. Therefore the electric field inside the plane will be *zero*, shielding the passengers and equipment inside from the effects of the lightning.

FARADAY CAGE

ELECTRIC POTENTIAL ENERGY

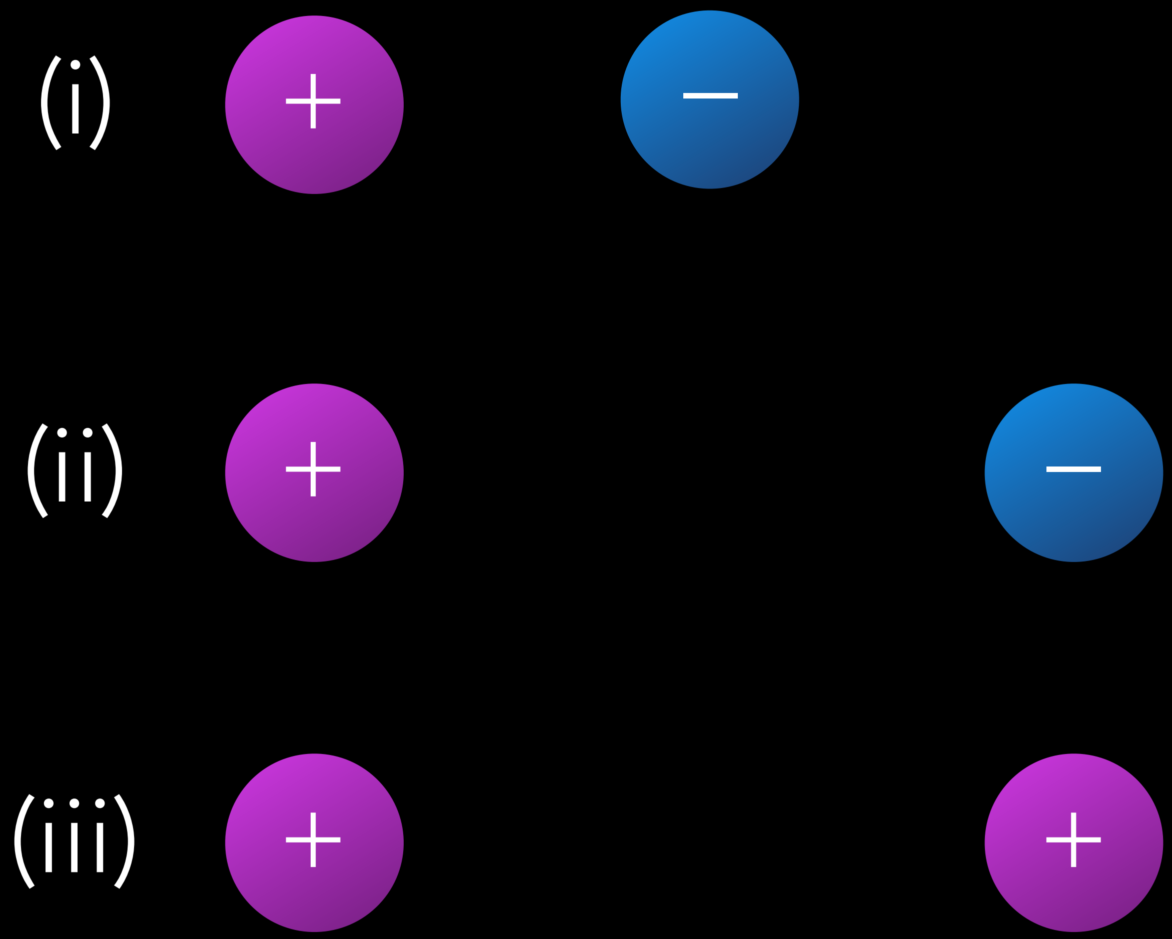


$$PE_g = -\frac{GMm}{r}$$

$$PE_e = \frac{kQq}{r}$$

SANITY CHECK

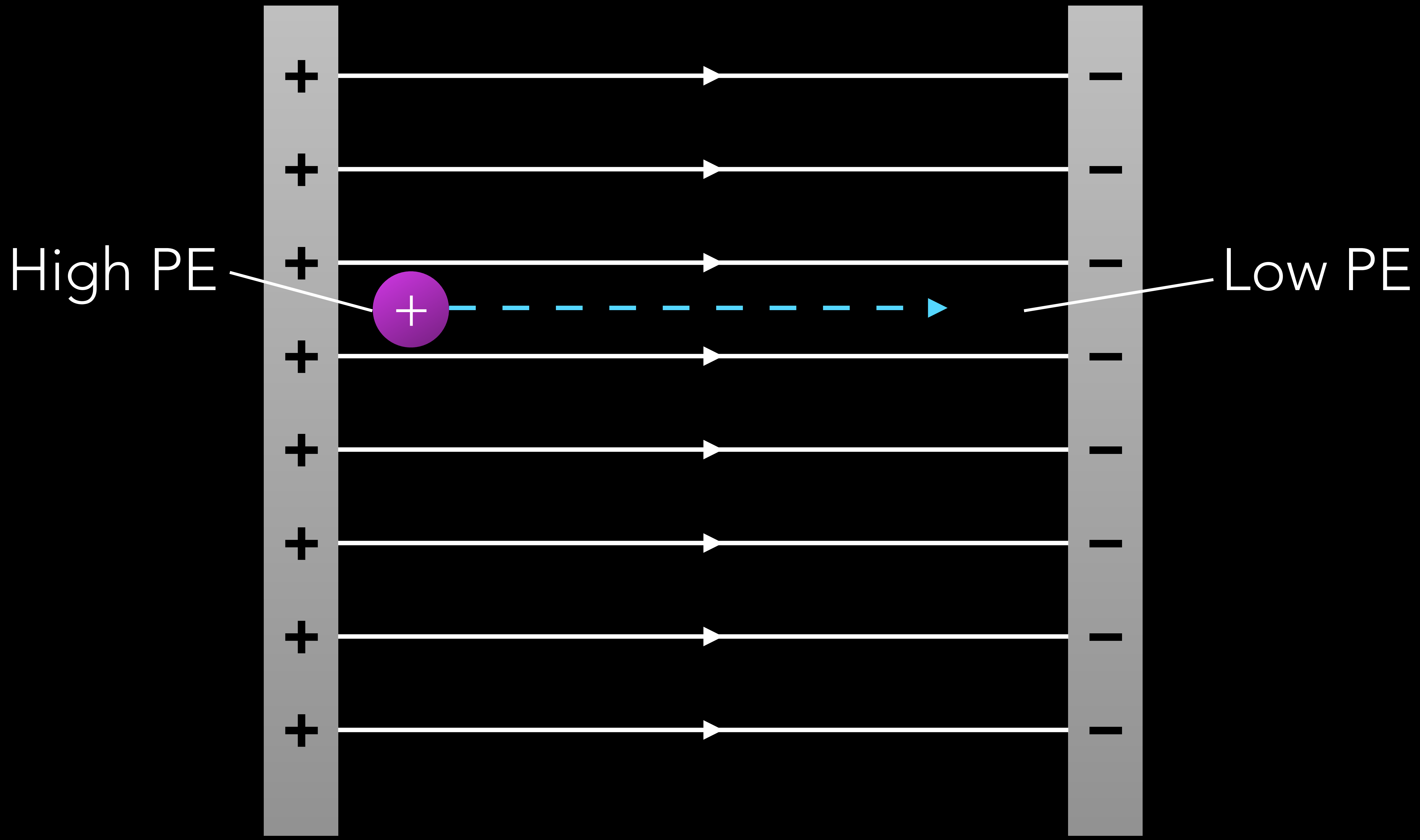
- Rank the three pairs of charges from most positive potential energy to most negative potential energy
  - *Ans. (iii) positive, (ii) negative, (i) most negative*
- Which set requires the most work to separate to infinity?
  - *Ans. Set (i) since it's the most negative*



ELECTRIC POTENTIAL

1.5 V

ELECTRIC POTENTIAL



ELECTRIC POTENTIAL

- $\Delta V = \Delta PE_e / q$
- $V = kQ/r$ ← (for a point charge)
    - Measured in ***volts*** (**V**)
    - Called ***electric potential***
    - or ***potential difference***
    - or ***voltage***

THINGS TO NOTE

- Don't confuse electric potential with electric potential *energy*.
  - electric potential is potential energy *per charge*
- Like PE, $V = 0$ can be chosen arbitrarily
  - It's the *difference* between two points that has physical meaning
- Positive charges move from high voltage to low. Negative charges move from low voltage to high.

EXAMPLE 6

- Supposed an electron in an old school TV picture tube is accelerated from rest through a potential difference $\Delta V =$ +5000 V.

a) What is the change in potential energy of the electron?

b) What is the speed of the electron ($m = 9.1\times10^{-31}$ kg) as a result of this acceleration?

a) Ans. $\Delta PE = -8.0\times10^{-16}$ J

b) Ans. $v = 4.2\times10^{7}$ m/s

EXAMPLE 6 CONT.

c) Repeat for a proton (m = 1.67×10^{-27} kg) that accelerates through a potential difference of ΔV = -5000 V

   c) *Ans.* $\Delta PE = -8.0\times10^{-16}$ J

   c) *Ans.* $v = 9.8\times10^{5}$ m/s

- *Note: energy doesn't depend on mass, only on charge and voltage. Speed* does *depend on mass.*

ELECTRIC POTENTIAL & ELECTRIC FIELD

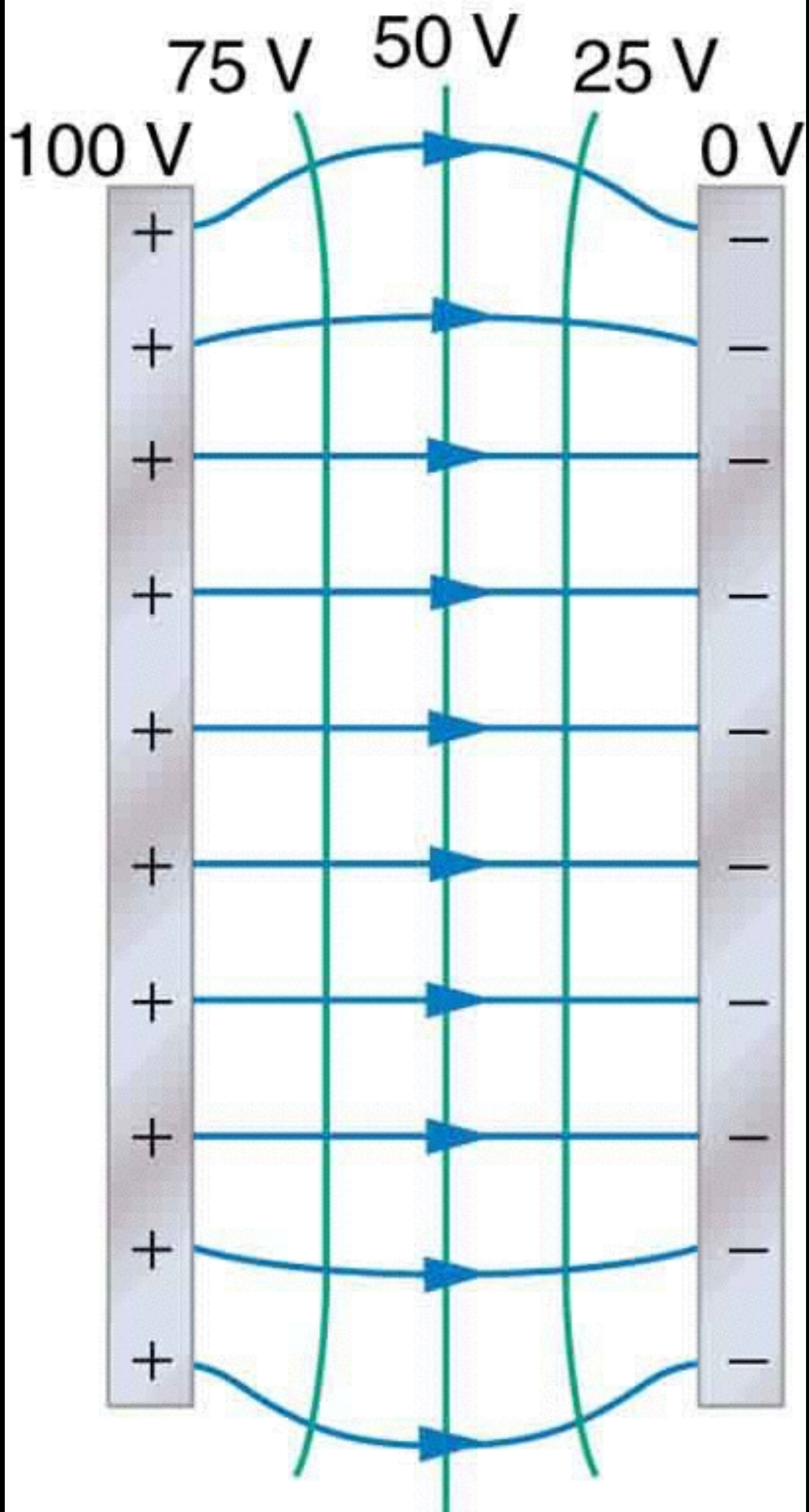
- Electric field is a vector
- but electric potential is a scalar
- $E = \Delta V/d$

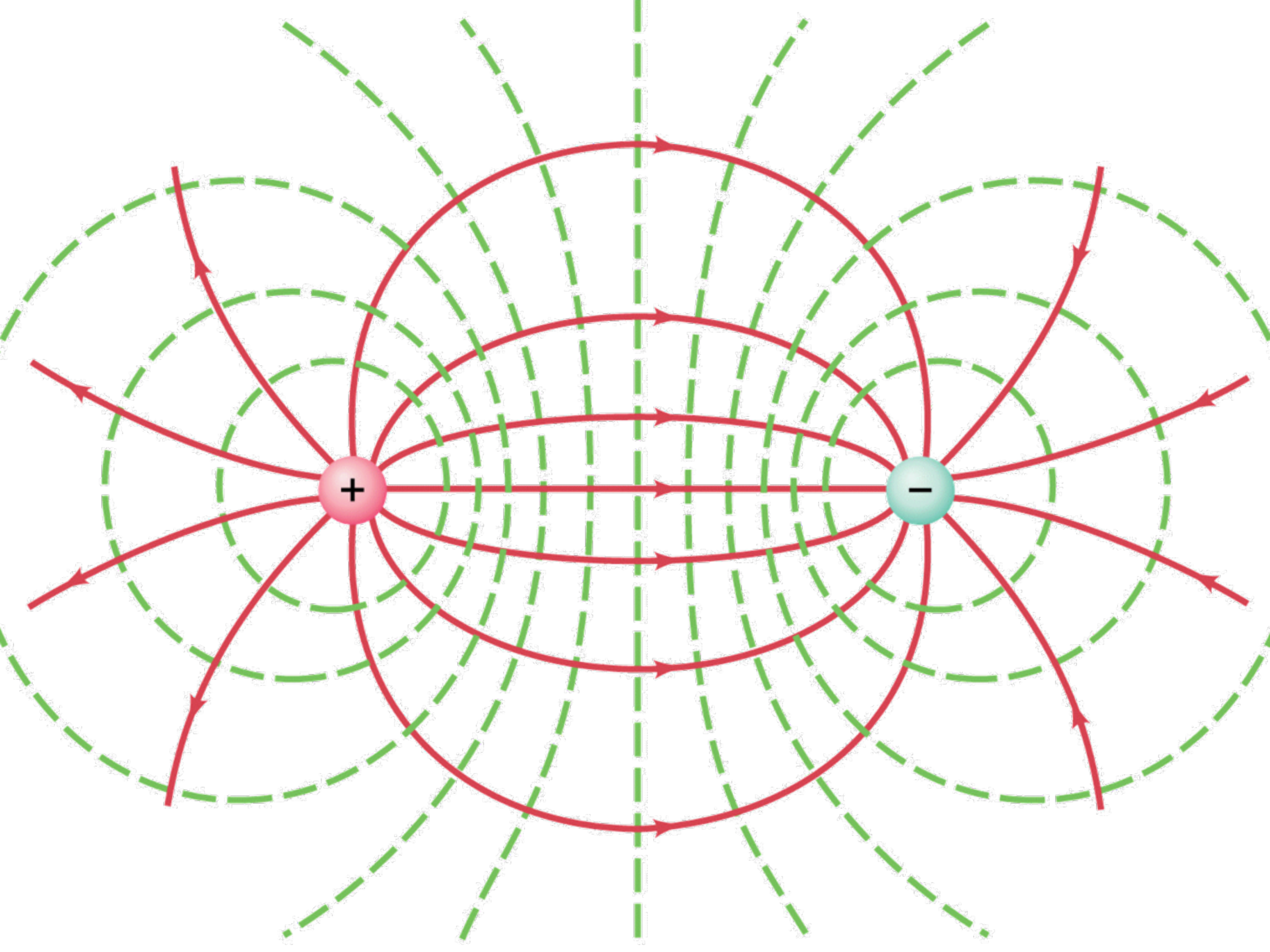
EXAMPLE 7

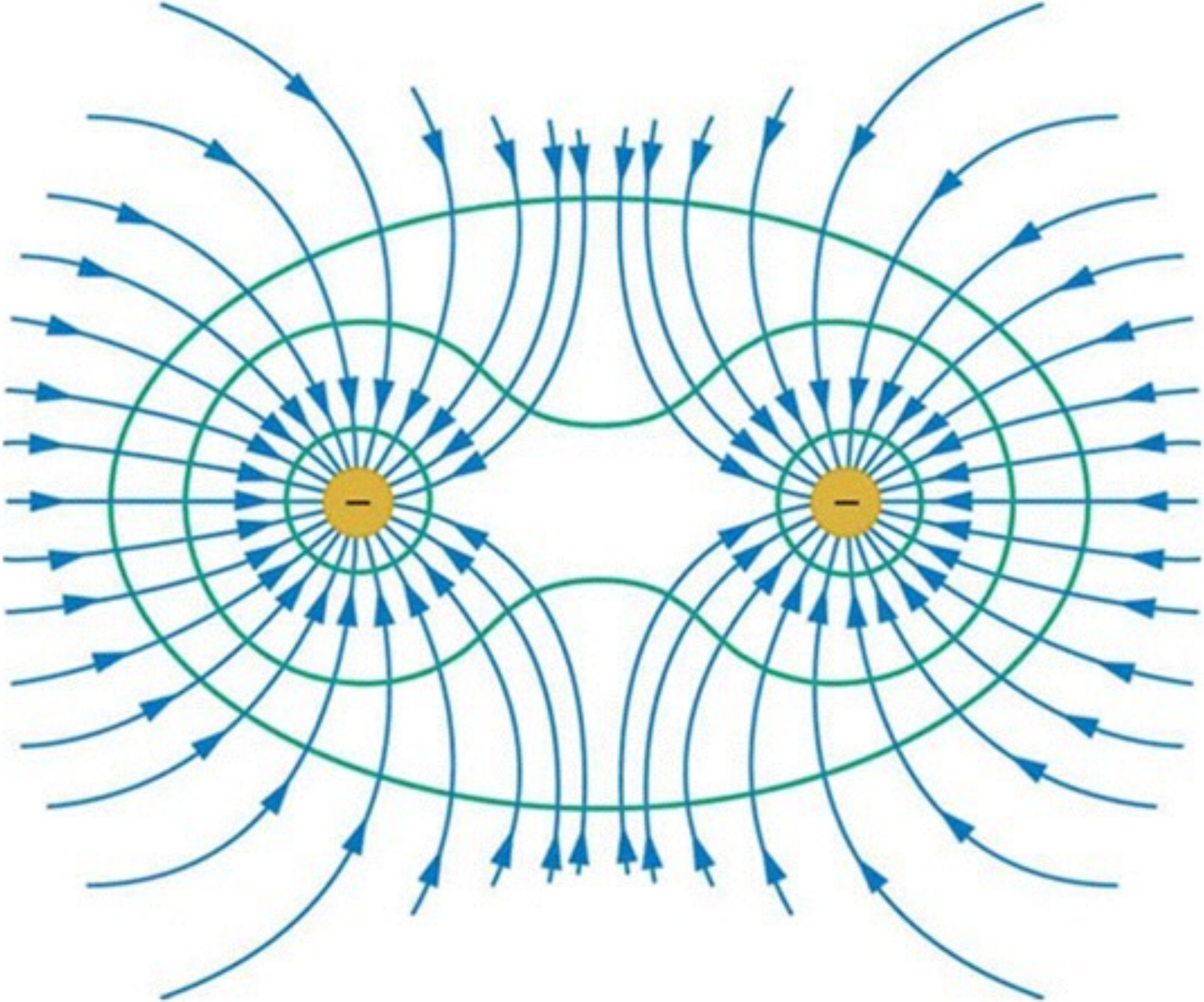
- Two parallel plates are charged to a voltage of 50 V. If the separation between the plates is 0.050 m, calculate the electric field between them.
  - *Ans. E = 1000 N/C*

EQUIPOTENTIAL LINES

- Electric potential can be represented diagrammatically by drawing ***equipotential lines***
  - Or ***equipotential surfaces*** in 3D
  - These are lines or surfaces along which the voltage is the same
- An equipotential surface must be perpendicular to the electric field at any point





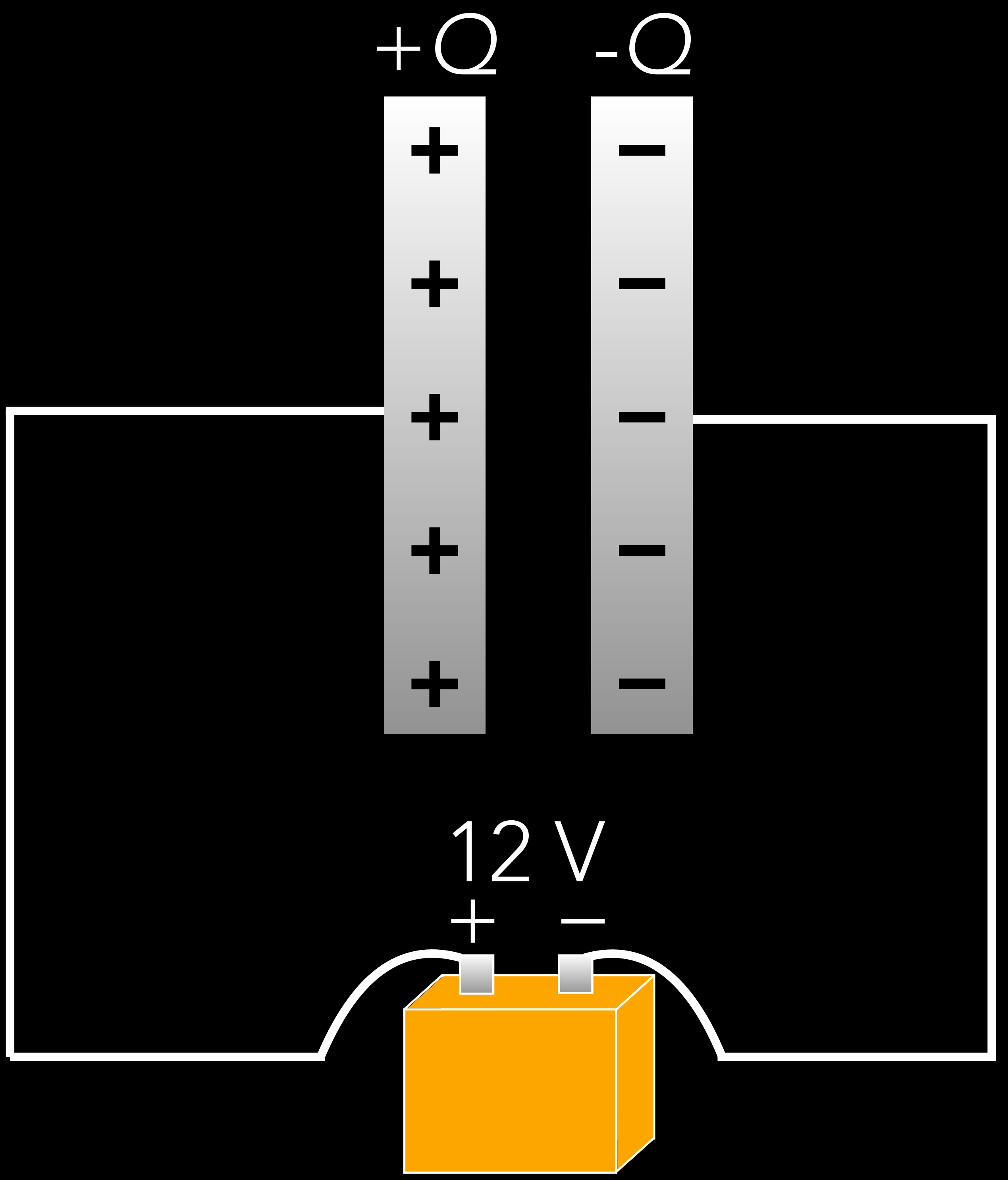


CAPACITANCE

- A ***capacitor*** is a device that can store electric charge
- Consists of two conducting objects (usually plates or sheets) placed near each other *but not touching*
- Uses:
    - camera flash
    - computer backup power
    - block power surges
    - memory in computer's RAM

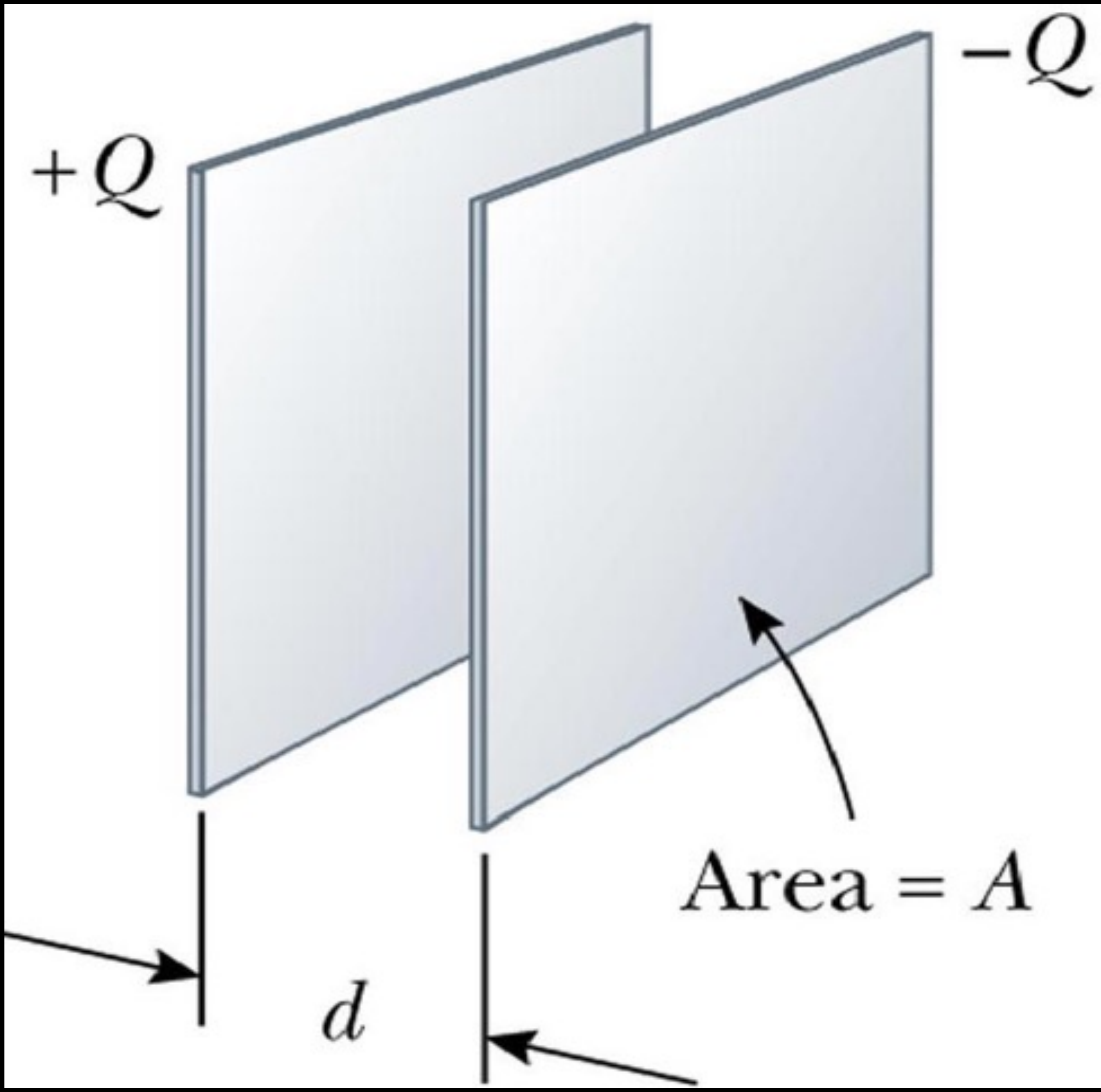
CAPACITANCE

- $Q = CV$
  - C is the ***capacitance***
    - Measured in ***farads*** (**F**)
  - Most capacitors have capacitance between 1 pF and 1 μF
  - The charge on the plates will always be equal and opposite



CAPACITANCE

- The capacitance of a capacitor depends on how its built
- $C = \varepsilon_0 A/d$
    - ($\varepsilon_0 = 8.85\times10^{-12}\ C^2/Nm^2$)



EXAMPLE 8

a) Calculate the capacitance of a capacitor whose plates are 20 cm × 3.0 cm and are separated by a 1.0-mm gap.

b) What is the charge on each plate if the capacitor is connected to a 12-V battery?

c) What is the electric field between the plates?

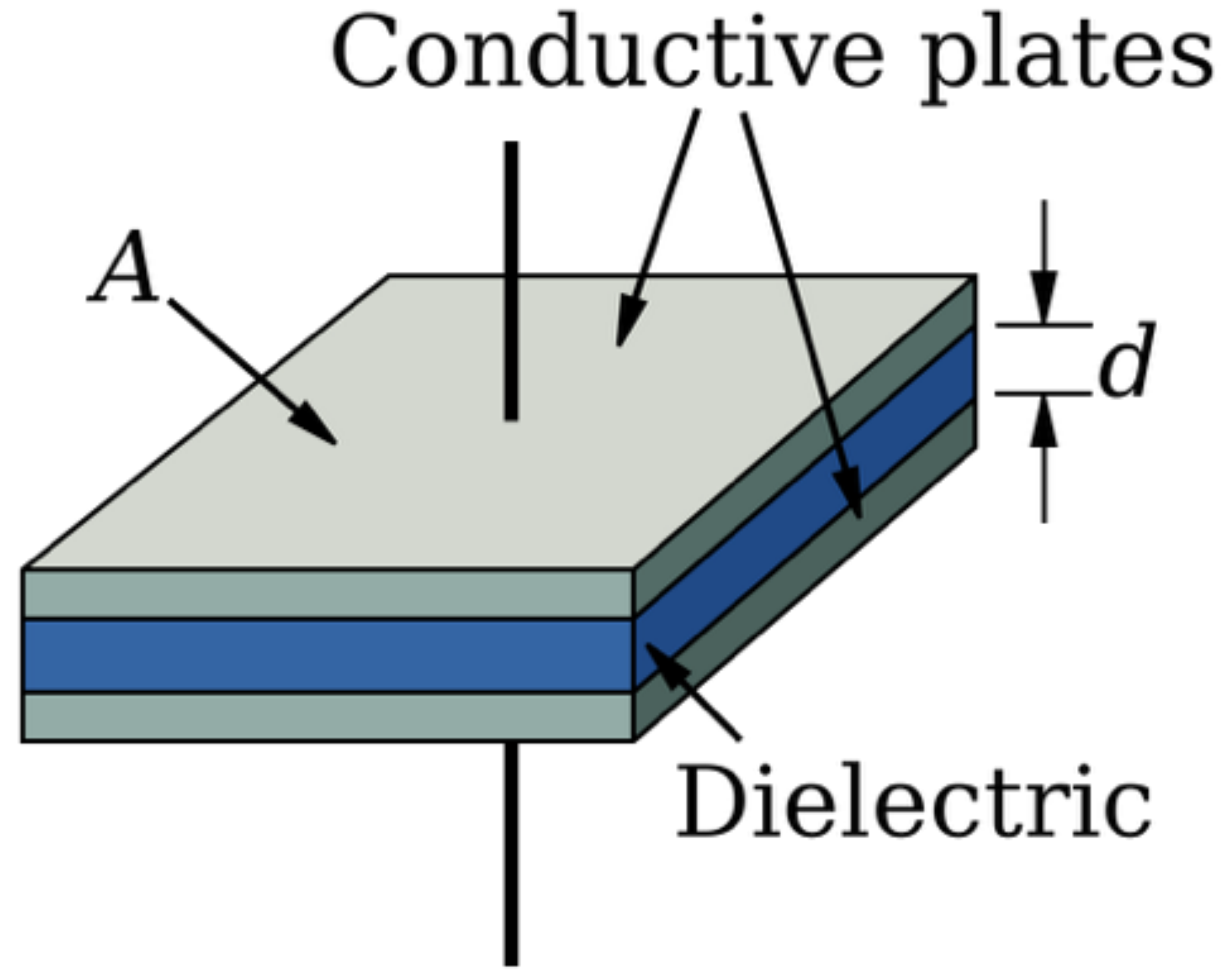
a) Ans. $C = 53\ pF$

b) Ans. $Q = 6.4\times10^{-10}\ C$

c) Ans. $E = 1.2\times10^{4}\ N/C$

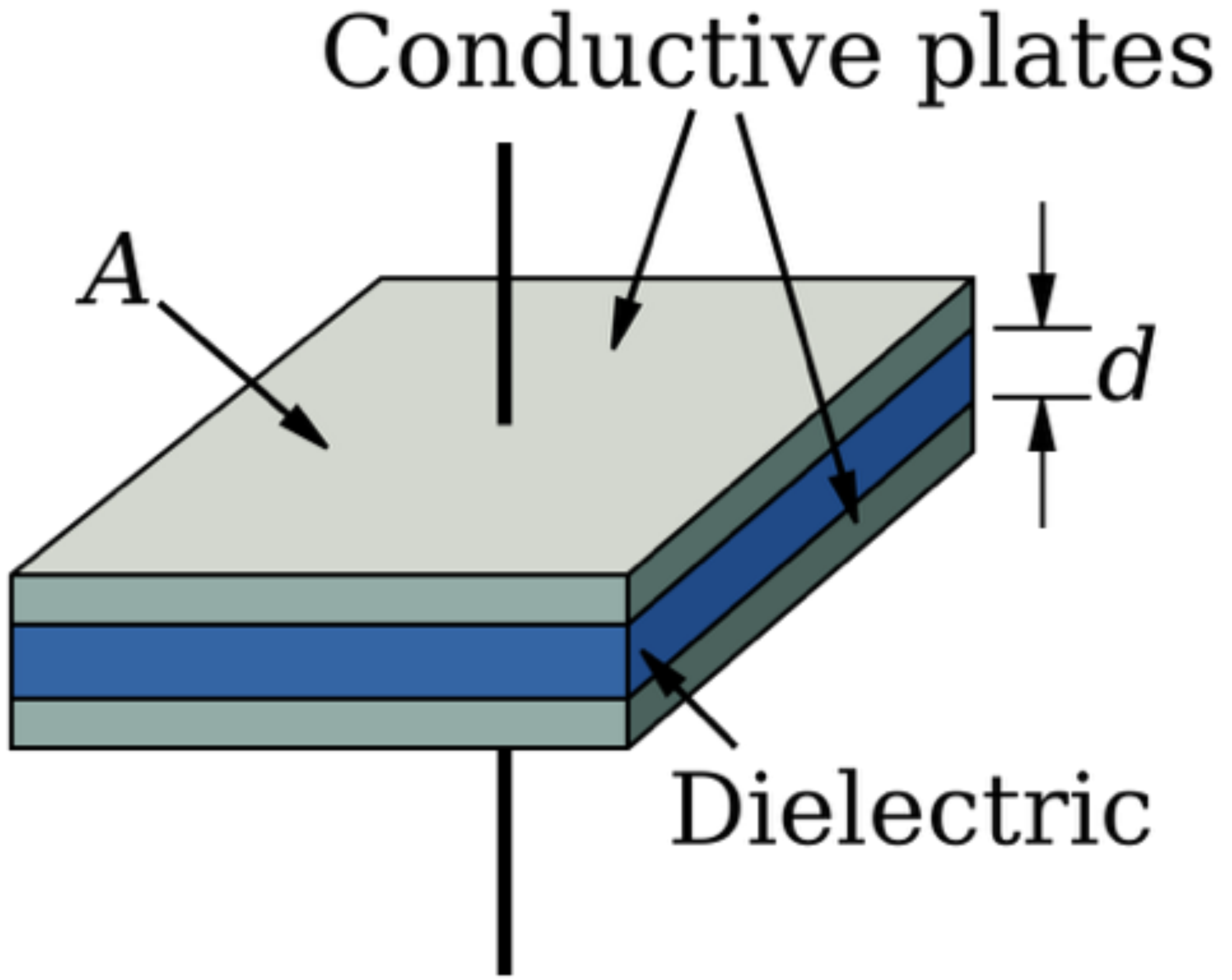
DIELECTRICS

- The capacitance can be raised further by inserting a ***dielectric*** between the plates
  - A dielectric is an insulating sheet sandwiched between the two conducting capacitor plates



DIELECTRICS

- Advantages:
  - has a higher breakdown voltage than air
  - allows the plates to be placed closer together without touching
  - increases capacitance by a factor *K*



DIELECTRICS

MATERIAL	DIELECTRIC CONSTANT, *K*
Vacuum	1.0000
Air (1 atm)	1.0006
Paraffin	2.2
Rubber, hard	2.8
Vinyl	2.8–4.5
Paper	3–7
Quartz	4.3
Glass	4–7
Porcelain	6–8
Ethyl alcohol	24
Water	80

$$C = K\varepsilon_0 A/d$$

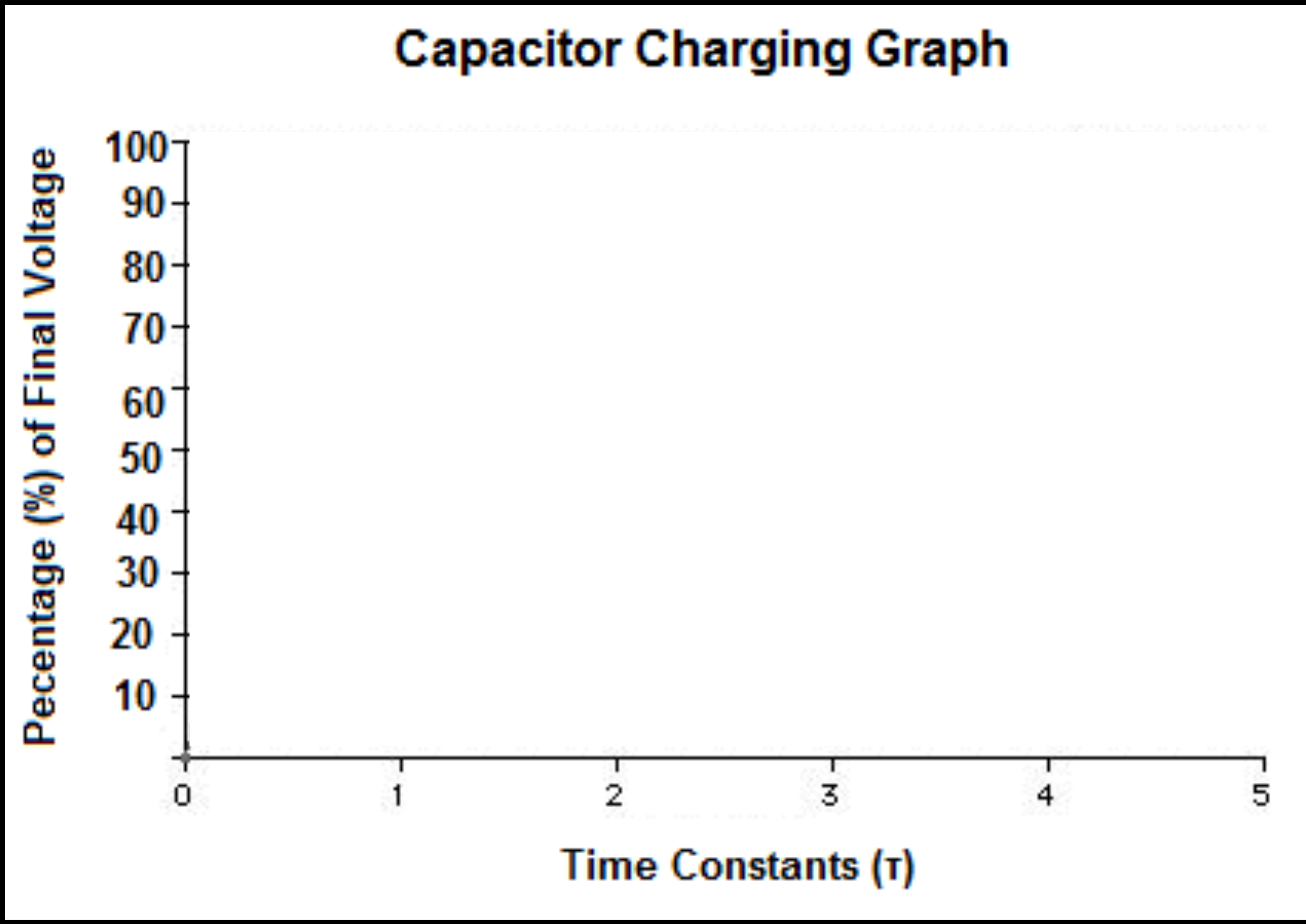
SANITY CHECK

- A capacitor consisting of two plates separated by a distance *d* is connected to a battery of voltage *V* and acquires a charge *Q*. While it is still connected to the battery, a slab of dielectric material is inserted between the plates of the capacitor. Will *Q* increase, decrease, or stay the same?

    - *Q will increase*

STORING ELECTRICAL ENERGY

- A charged capacitor stores electric energy
- Energy stored = work done charging
- $U_C = \frac{1}{2}QV$
  $= \frac{1}{2}CV^2$
  $= \frac{1}{2}Q^2/C$



EXAMPLE 9

- A camera flash unit stores energy in a 150 μF capacitor at 200 V. How much electrical energy can be stored?
    - *Ans.* $U_C = 3.0\ J$

LIGHTNING

- They say lightning strikes the tallest things around…
- So how *does* lightning pick its targets?

LIGHTNING

- As a storm builds, water and ice rise and fall within the cloud, rubbing against each other, and charging the particulates through friction
- Negative charge accumulates on the bottom surface of the storm cloud
- Loose electrons in the ground are repelled away, leaving the ground with a net positive charge

LIGHTNING

- The lightning strike begins with a branching bundle of charge — the “leader” — descending from the cloud
- The leader carries comparatively little current — on the order of 200 amps
- Meanwhile, another leader of positive charge rises from the ground

LIGHTNING

- The leaders "leap" through ~45-m intervals at a time
- When the leaders from the cloud and ground connect, they create a conductive path through which electric current can flow. This is the lightning.
- The lightning bolt carries roughly 20,000 amps of electric current

LIGHTNING

https://www.youtube.com/watch?v=6MUYsIjTKvk

LIGHTNING

https://www.youtube.com/watch?v=8waV48897o4

LIGHTNING

- The lightning bolt rapidly heats the air around it
- The excited air particles give off light, which we see as a blinding flash
- The hot air expands rapidly, creating a shock wave, which we hear as the clap of thunder