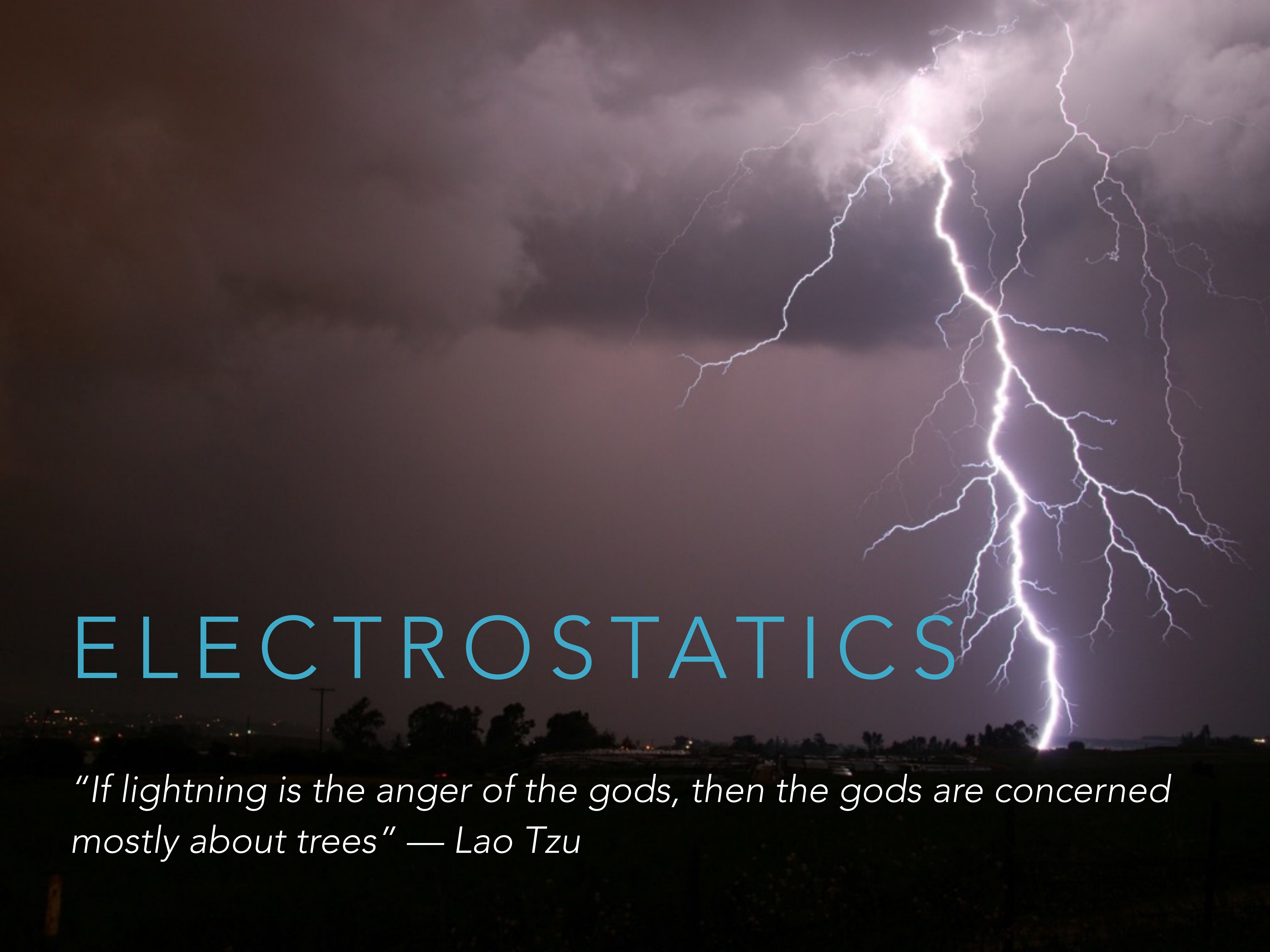


ELECTROSTATICS

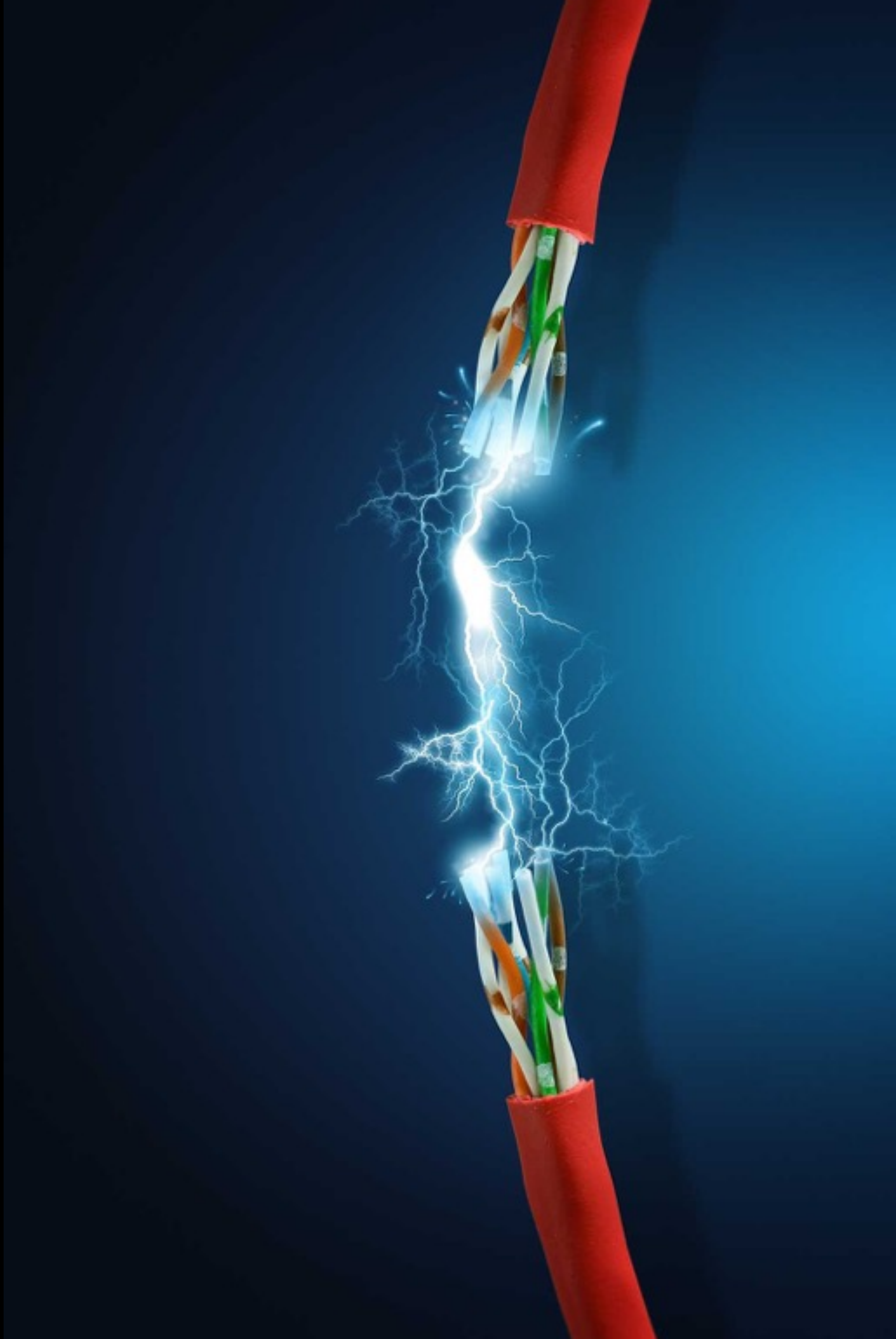
"If lightning is the anger of the gods, then the gods are concerned mostly about trees" — Lao Tzu

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

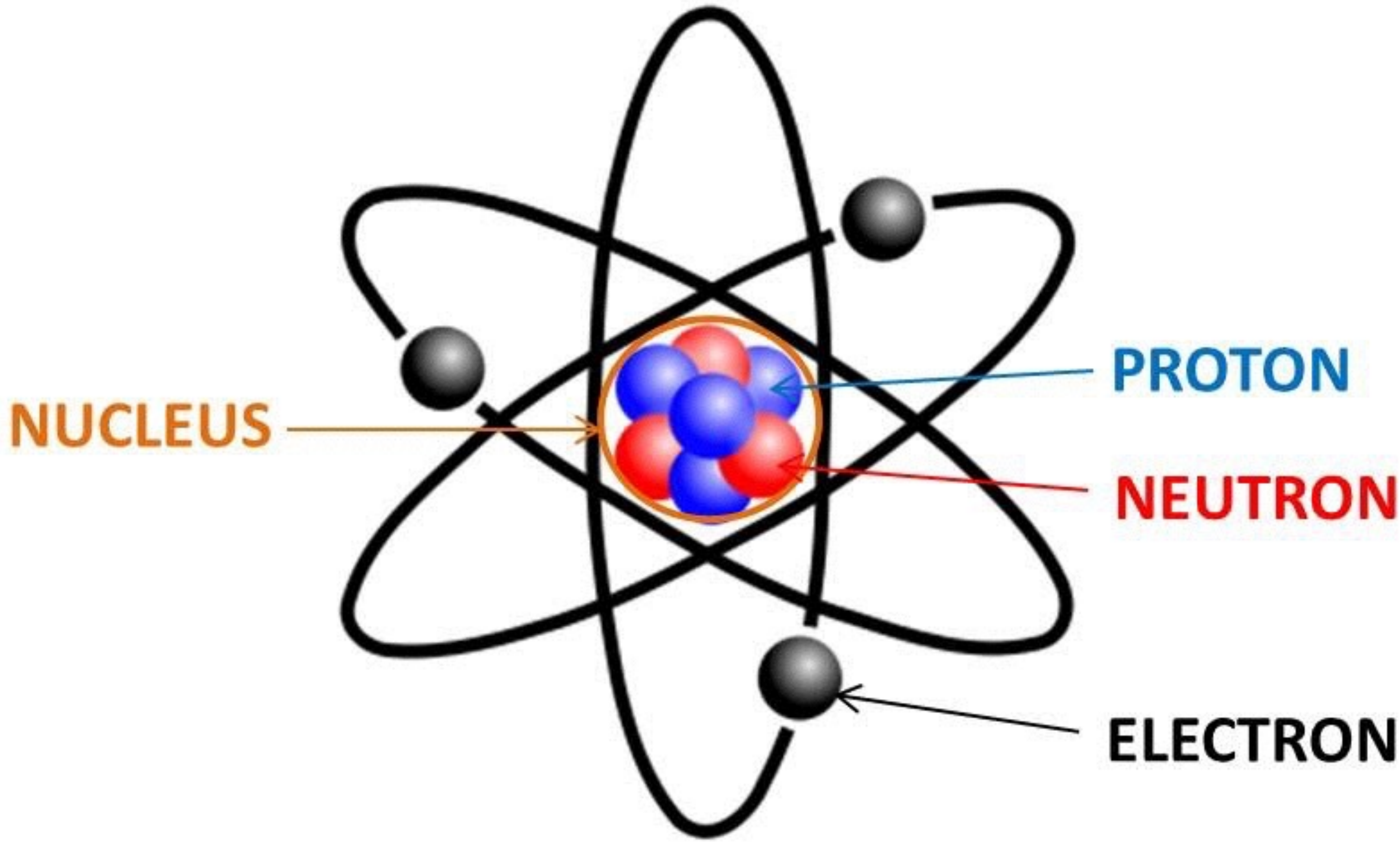
Force	Particles Experiencing	Force Carrier Particle	Range	Relative Strength*
Gravity acts between objects with mass	all particles with mass	graviton (not yet observed)	infinity	much weaker
Weak Force governs particle decay	quarks and leptons	W^+, W^-, Z^0 (W and Z)	short range	
Electromagnetism acts 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

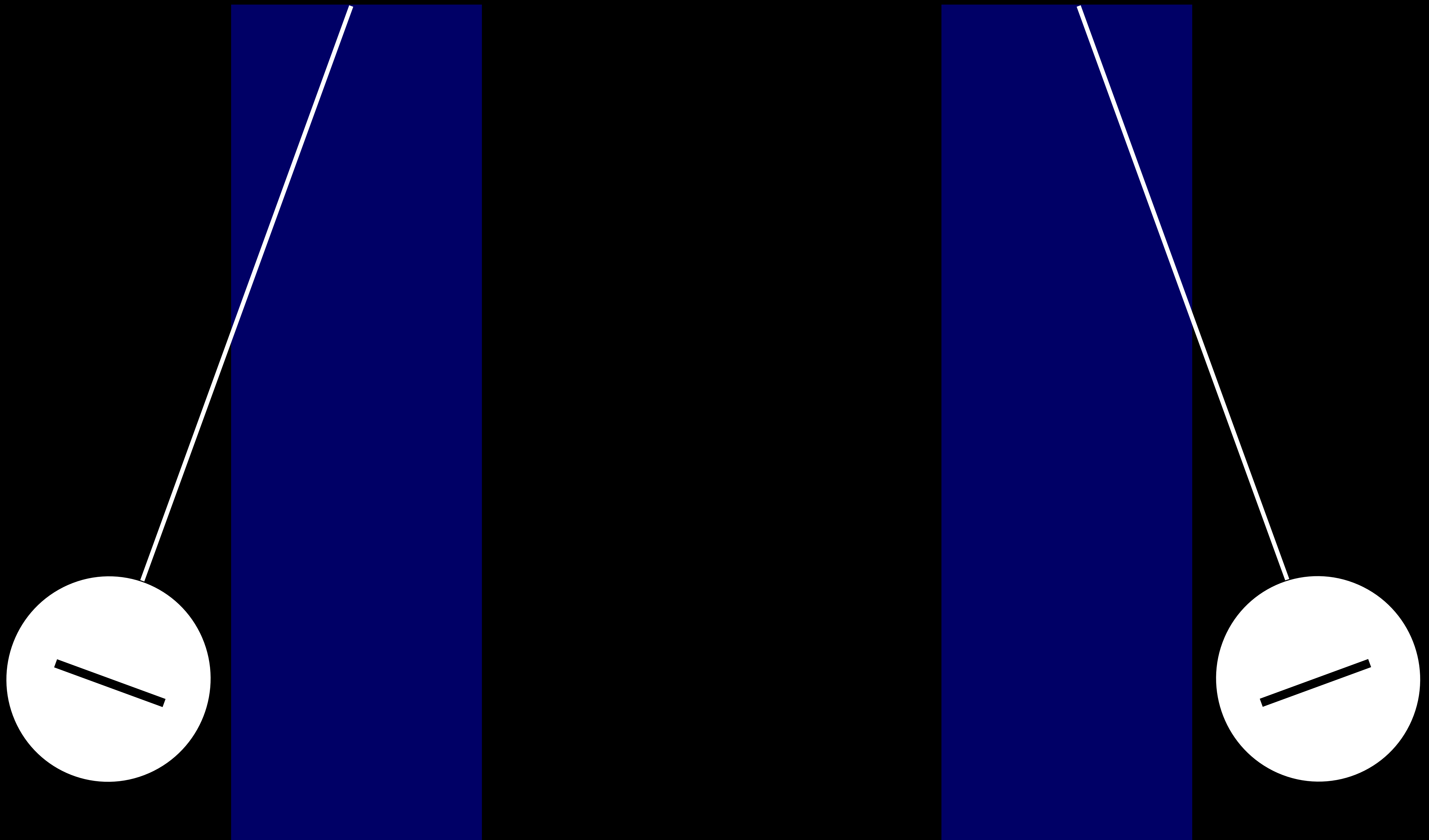


CHARGE

- 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**)

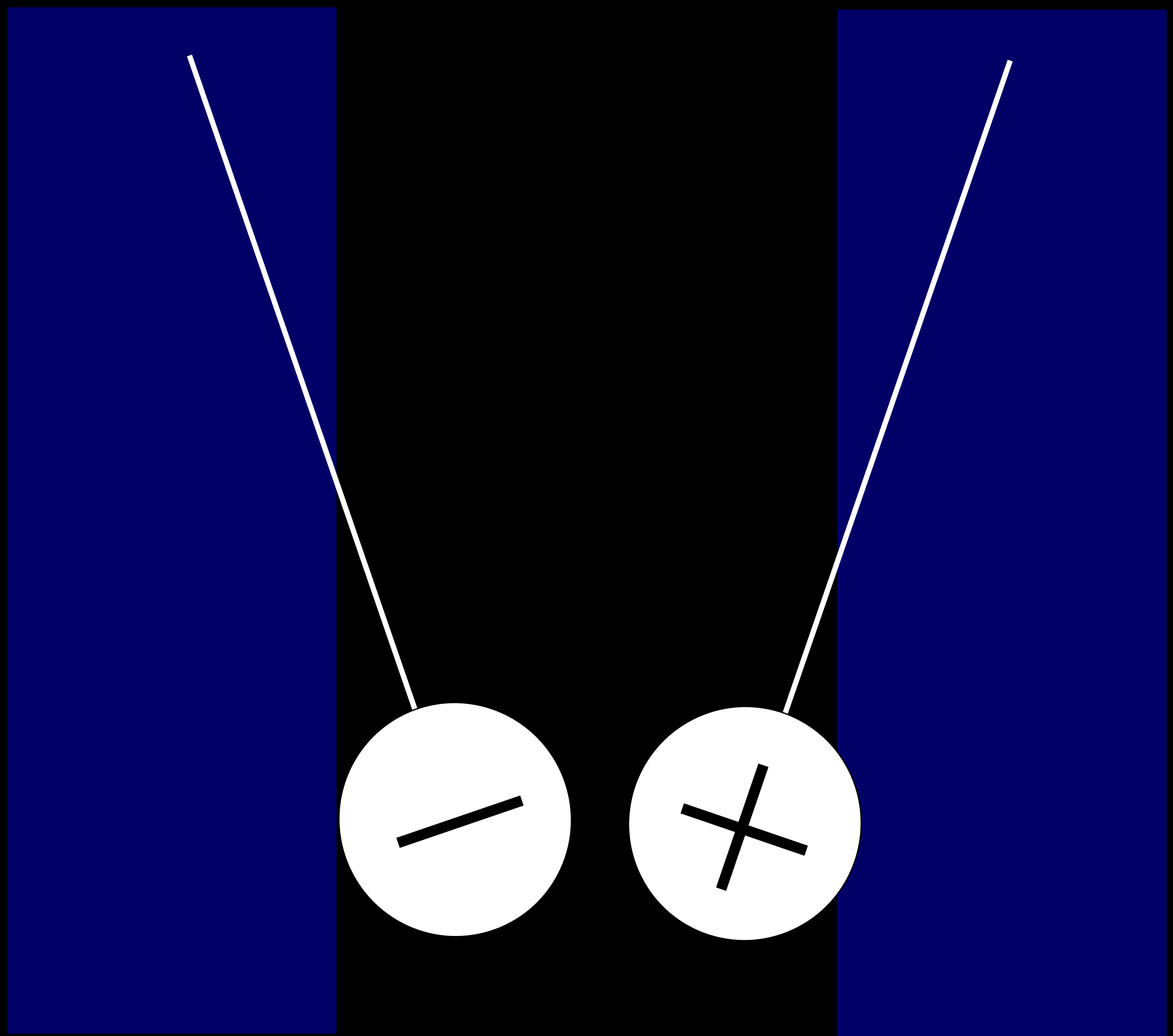
CHARGE

LIKE CHARGES REPEL



CHARGE

OPPOSITE CHARGES ATTRACT

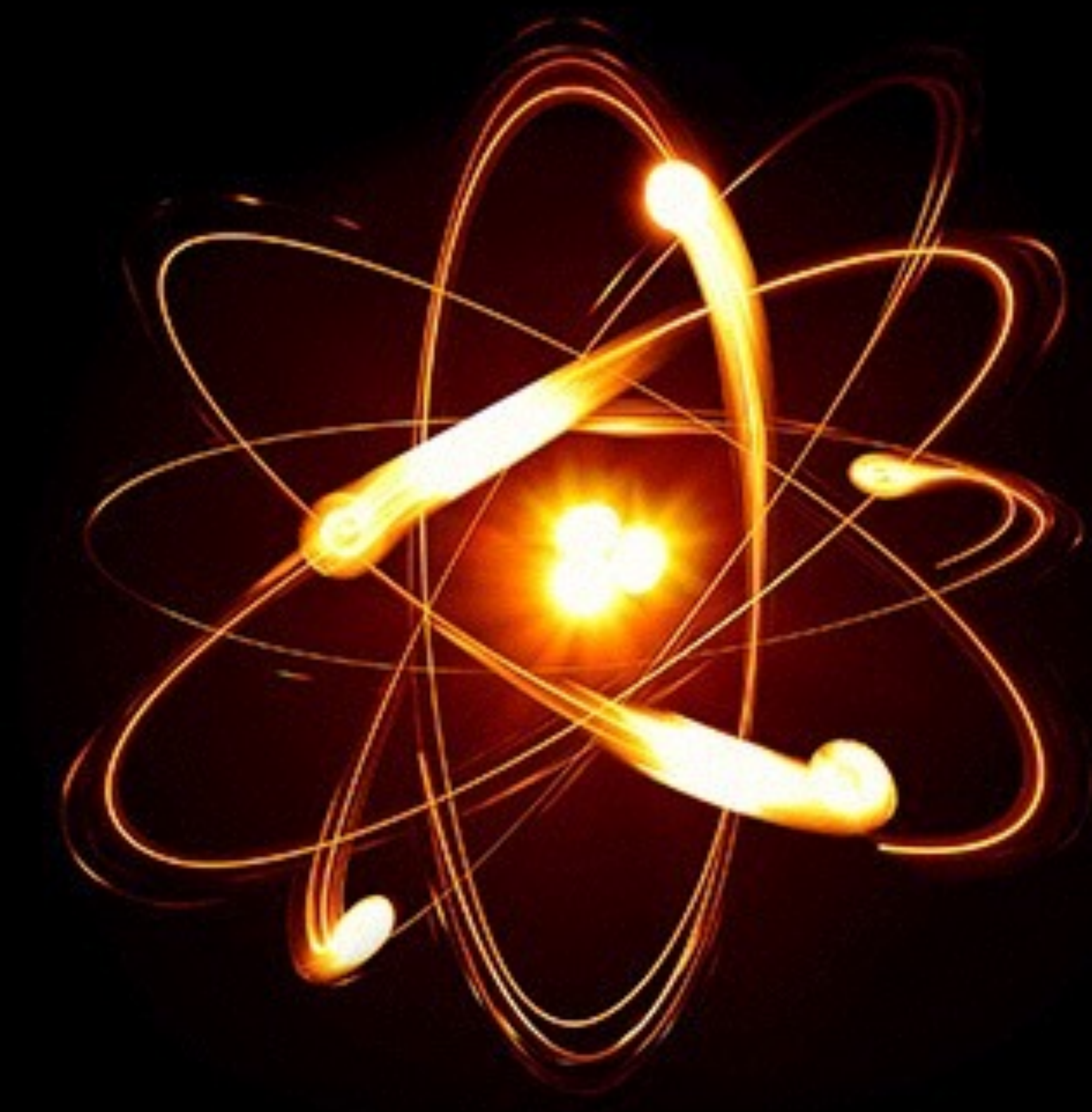


QUANTIZATION OF CHARGE

- $e^- = -1.6\times10^{-19}$ 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

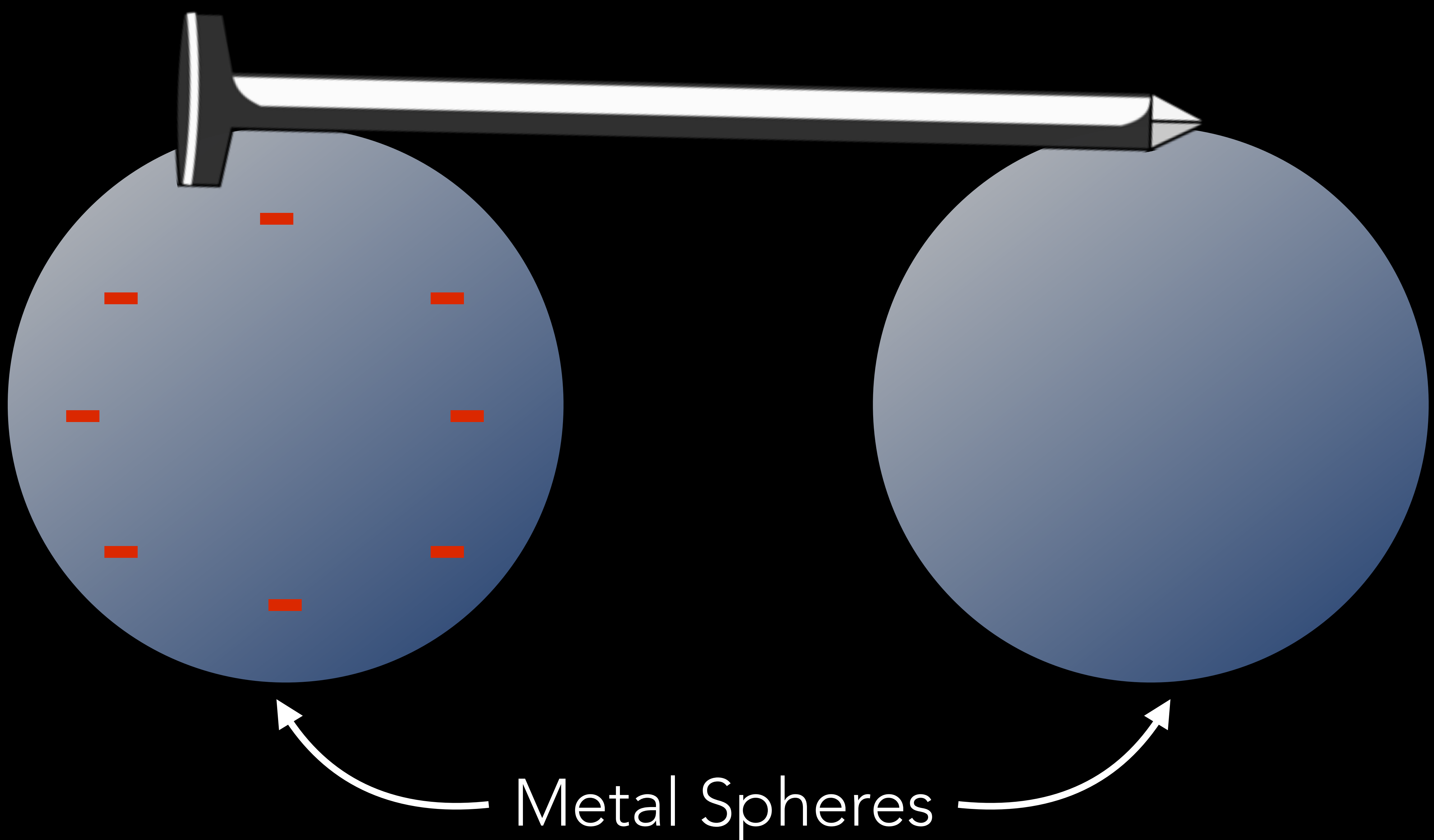
CHARGE AND EVERYDAY OBJECTS

	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

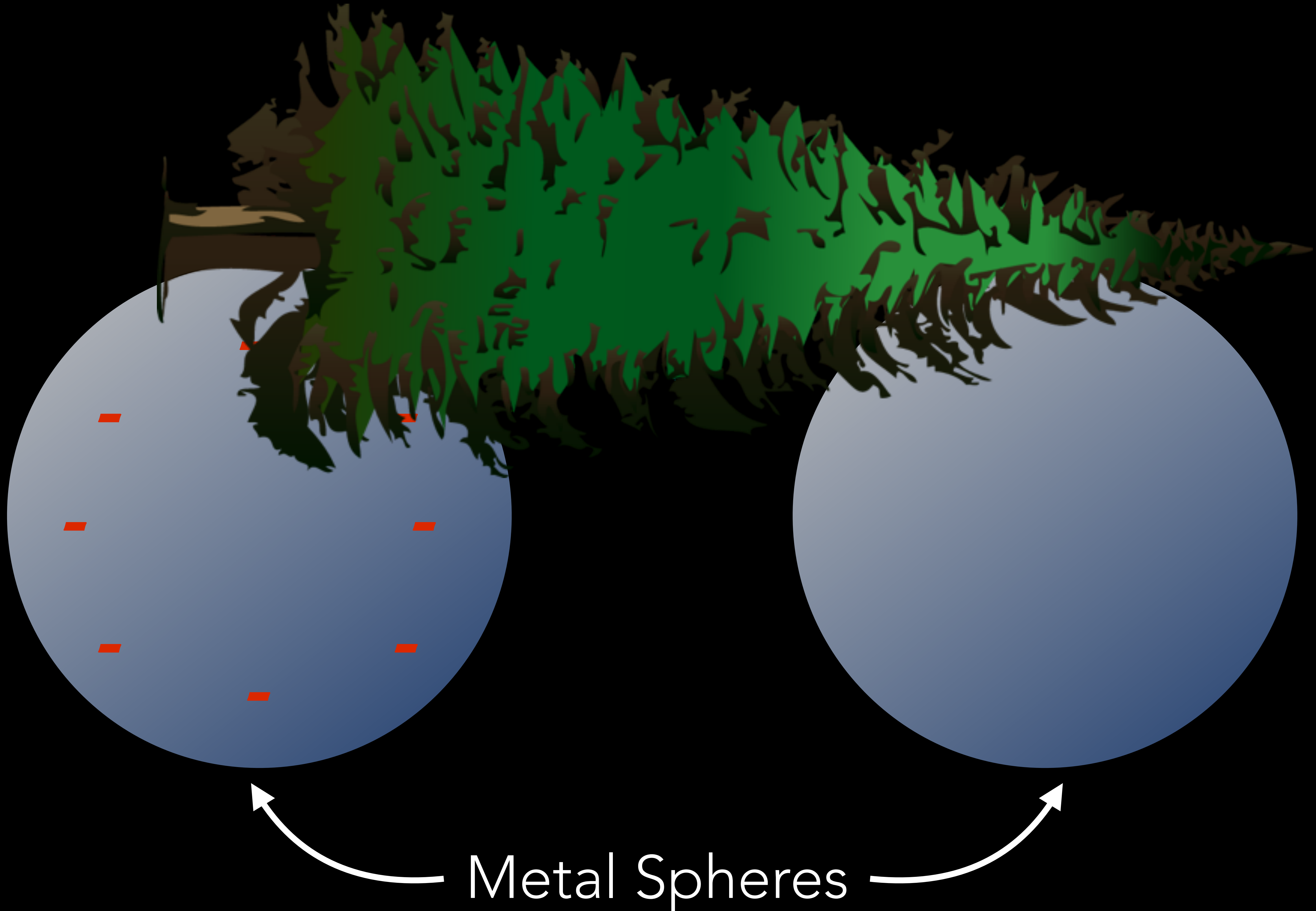
THE LAW OF CONSERVATION OF ELECTRIC CHARGE

- **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

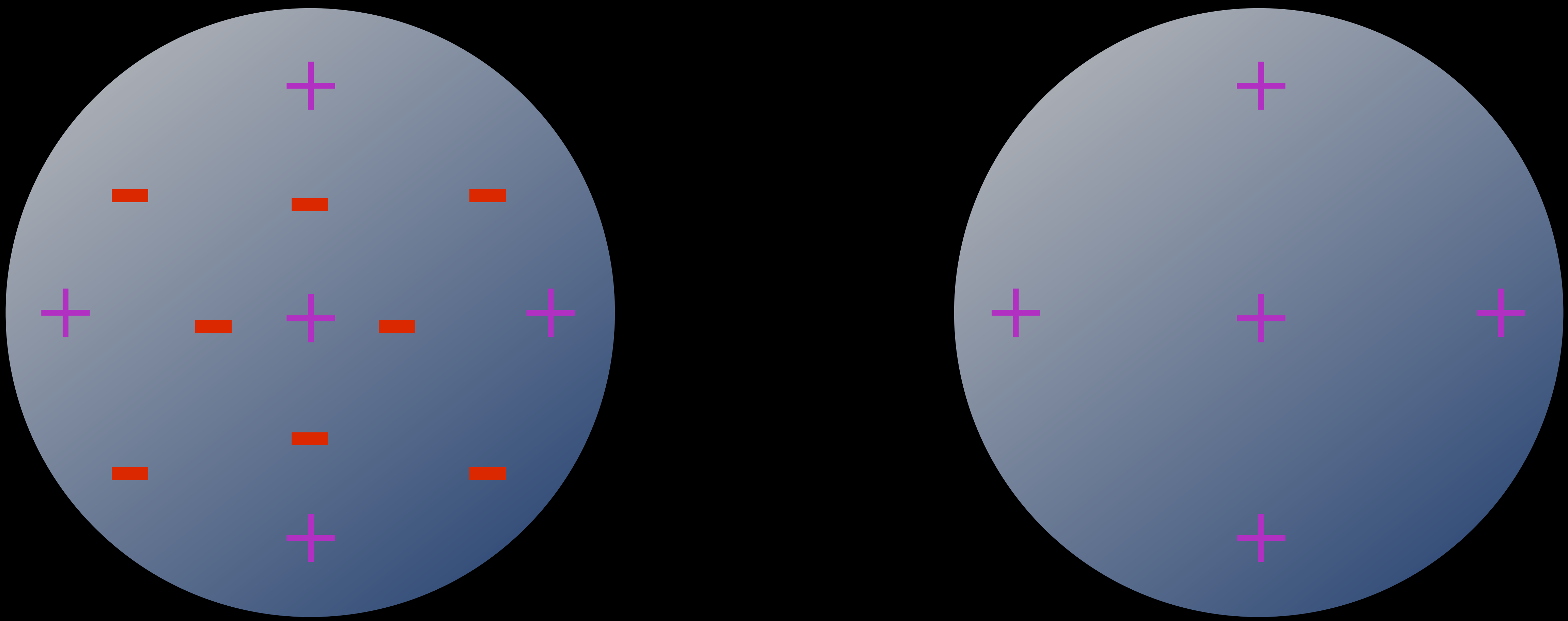
  1. Conduction

  2. Induction

  3. Friction

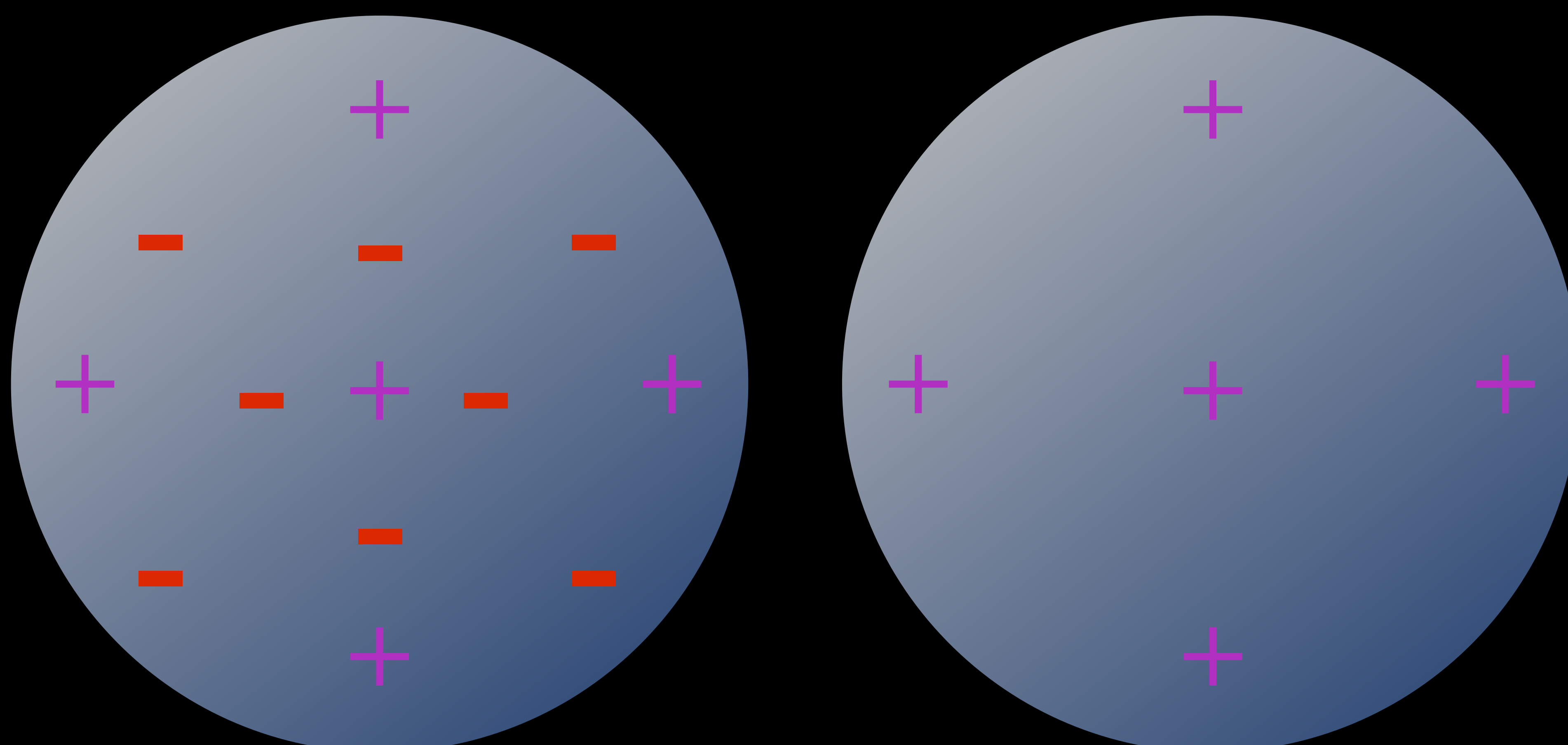
HOW TO MOVE CHARGES

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



HOW TO MOVE CHARGES

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

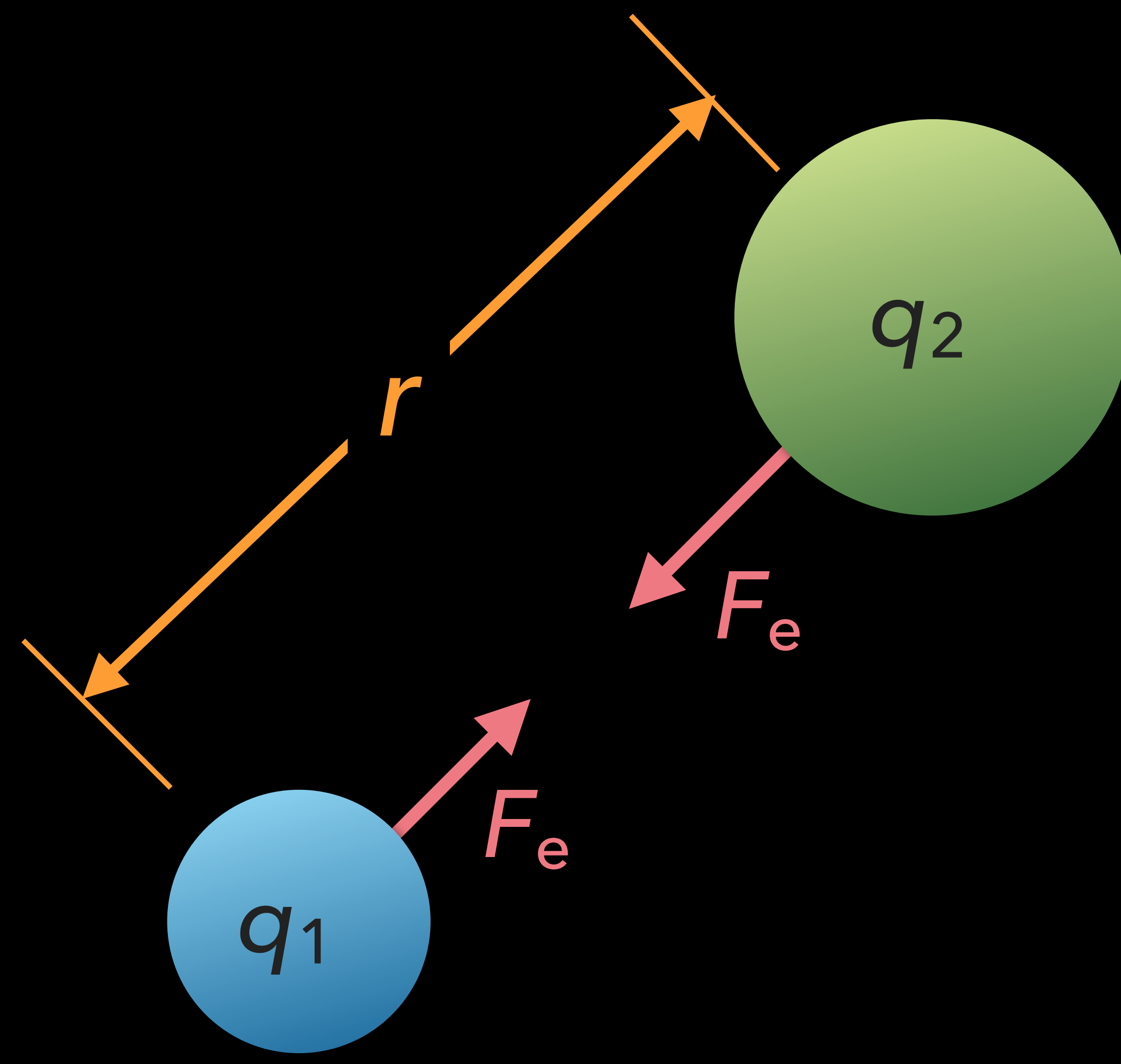


HOW TO MOVE CHARGE

- 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

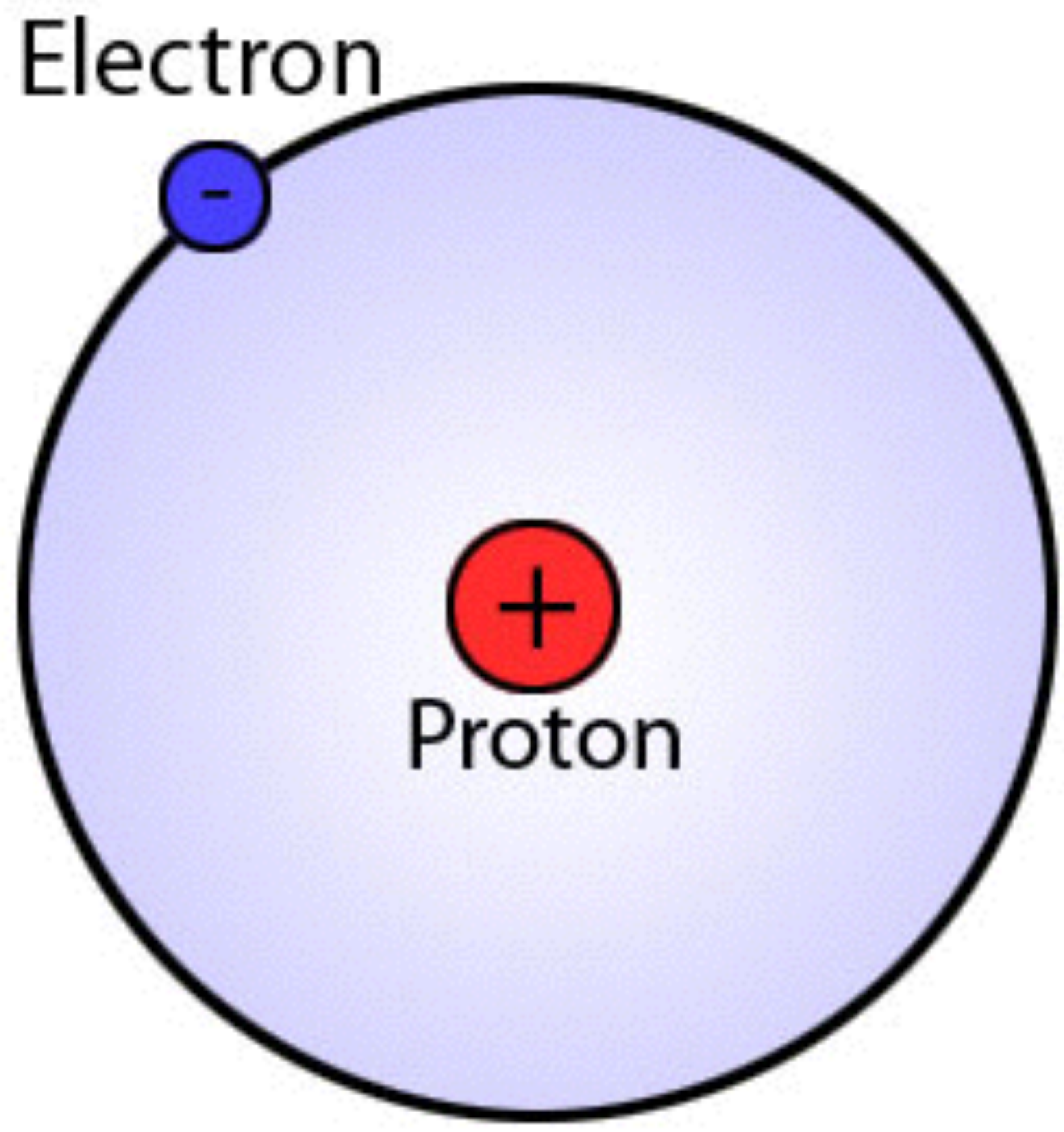
- $F_e = \frac{kq_1q_2}{r^2}$ Inverse square law!
  - $k = 9.0 \times 10^9$ Nm^2/C^2
- If F_e is positive, the force is *repulsive*
- If F_e is negative, the force is *attractive*

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*

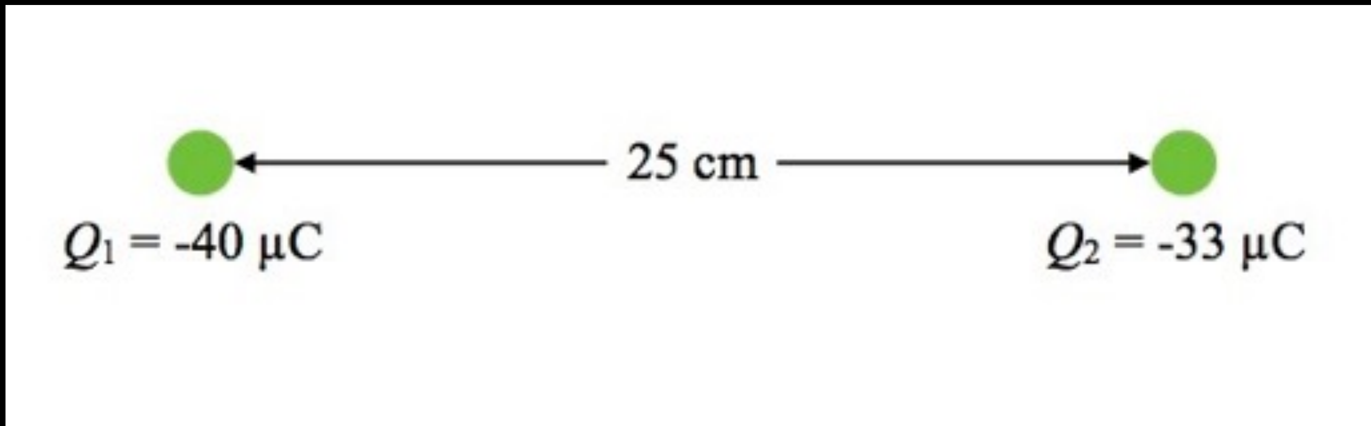
EXAMPLE 1

- 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.* $F_e = -8.2\times10^{-8}\ N$



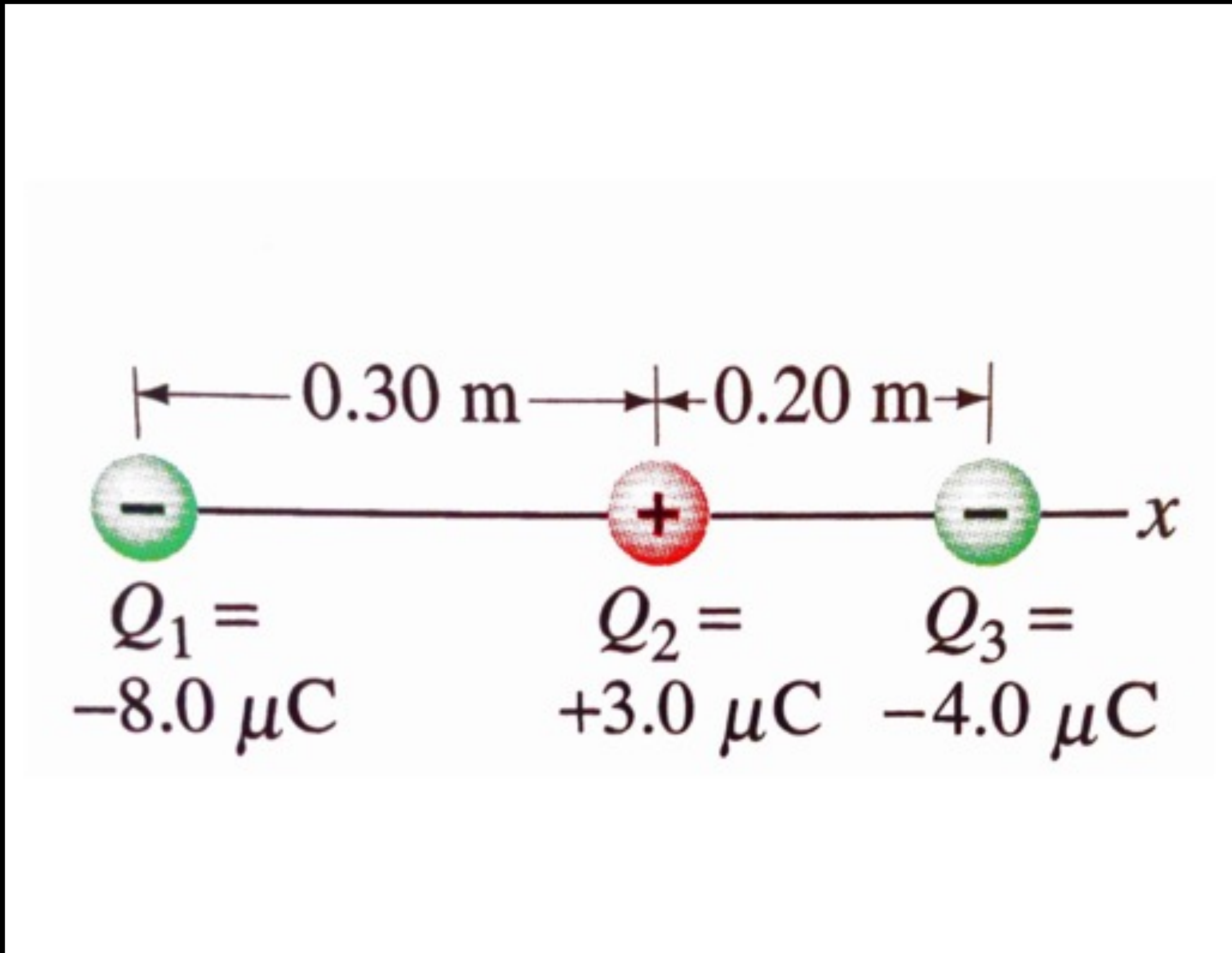
EXAMPLE 2

- Determine the magnitude and direction of the coulomb force on charge 1 due to charge 2.
  - *Ans.* $\mathbf{F}_{12}$ *= 190 N to the left*



EXAMPLE 3

- 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 two charges.
  - *Ans.* ***F*** *= 1.5 N to the left*



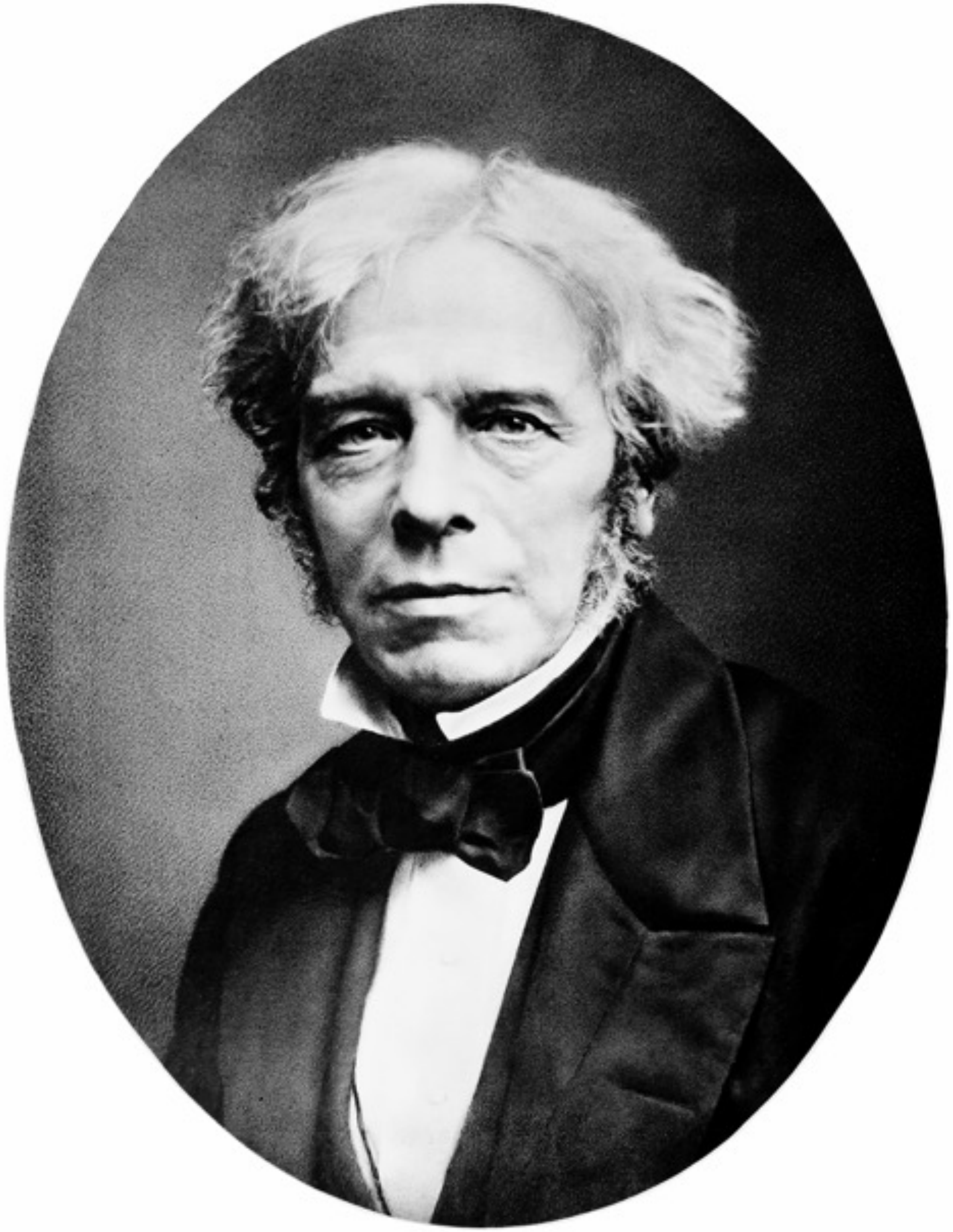
SANITY CHECK

- 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?

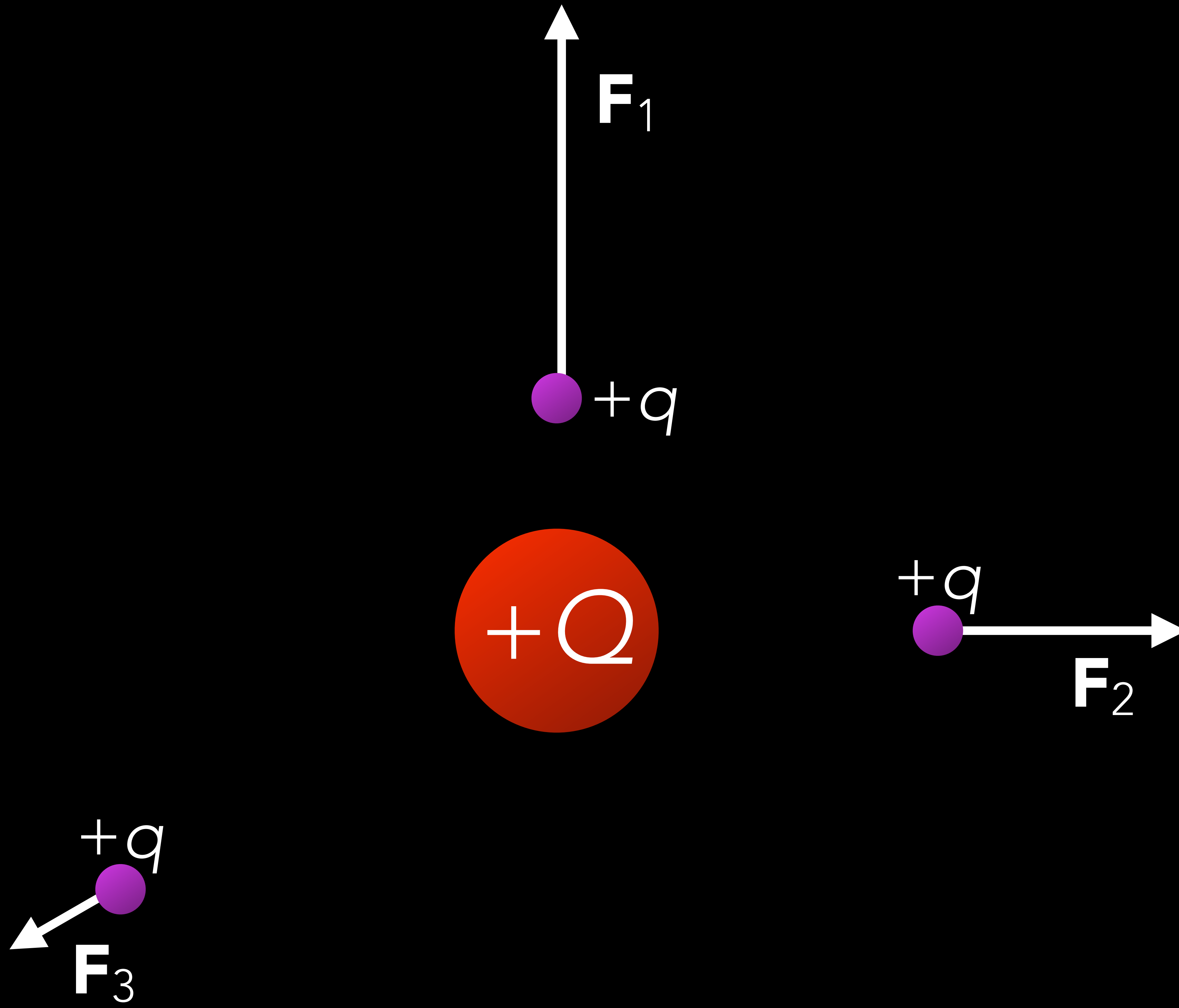
- *They're both the same!* (Newton's Third Law)

ELECTRIC FIELDS

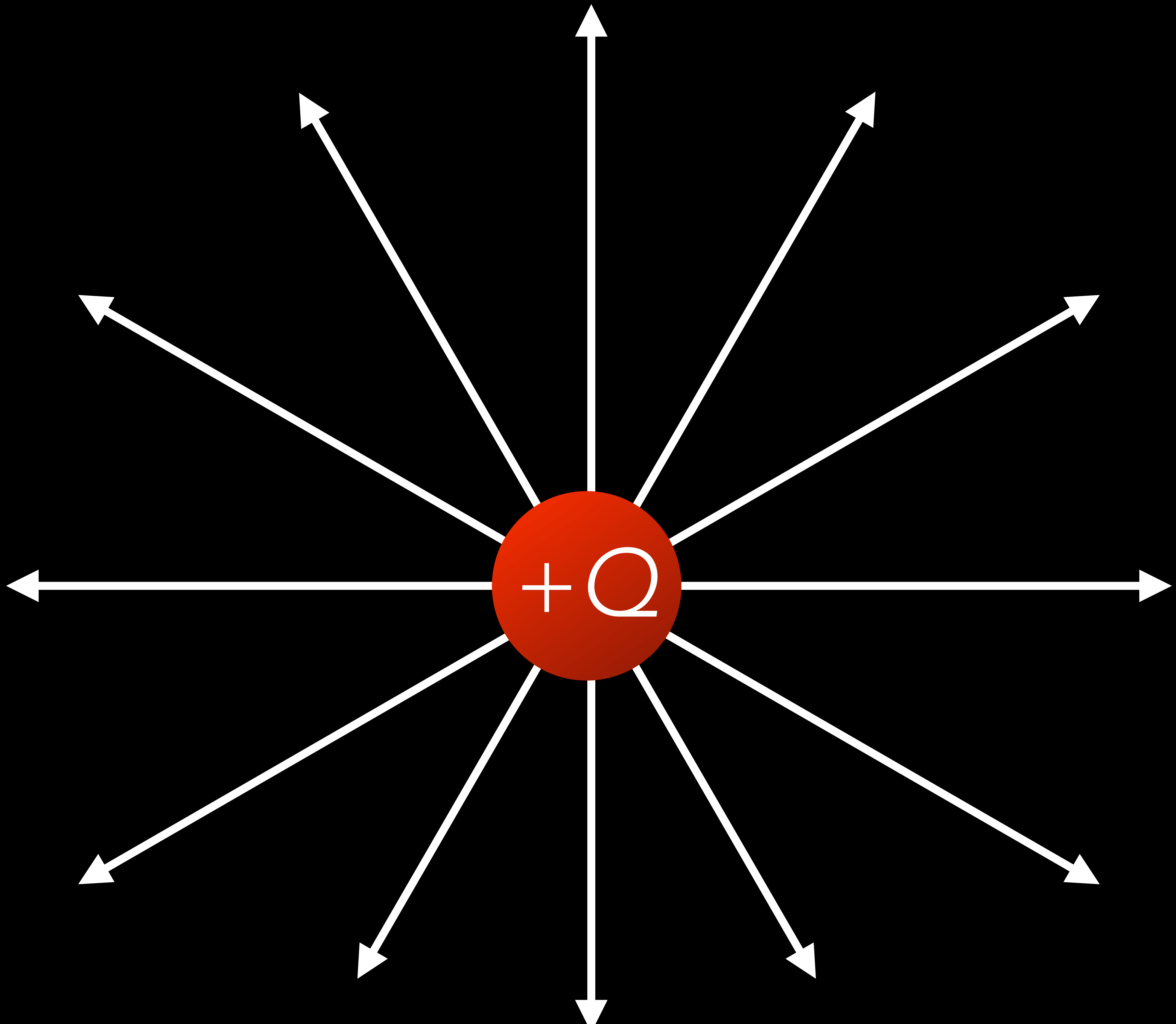
- Like the force of gravity, the electrical force acts at a distance
- In the early 1800s, British scientist Michael Faraday developed the concept of ***electric fields*** to help model the behavior of electrical forces
    - In physics, a field is a region of influence (in this case, we mean the influence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



ELECTRIC FIELDS

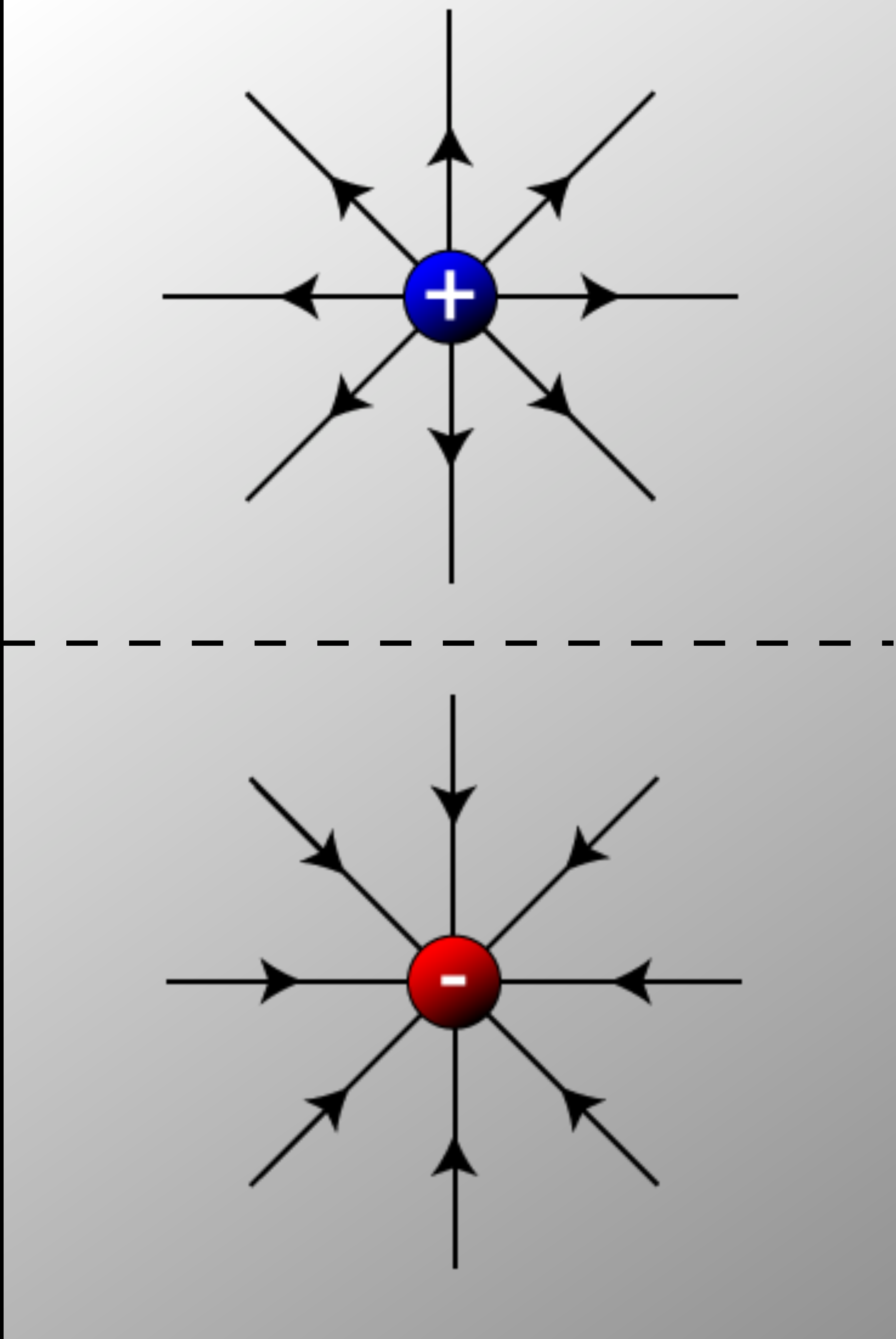


ELECTRIC FIELDS



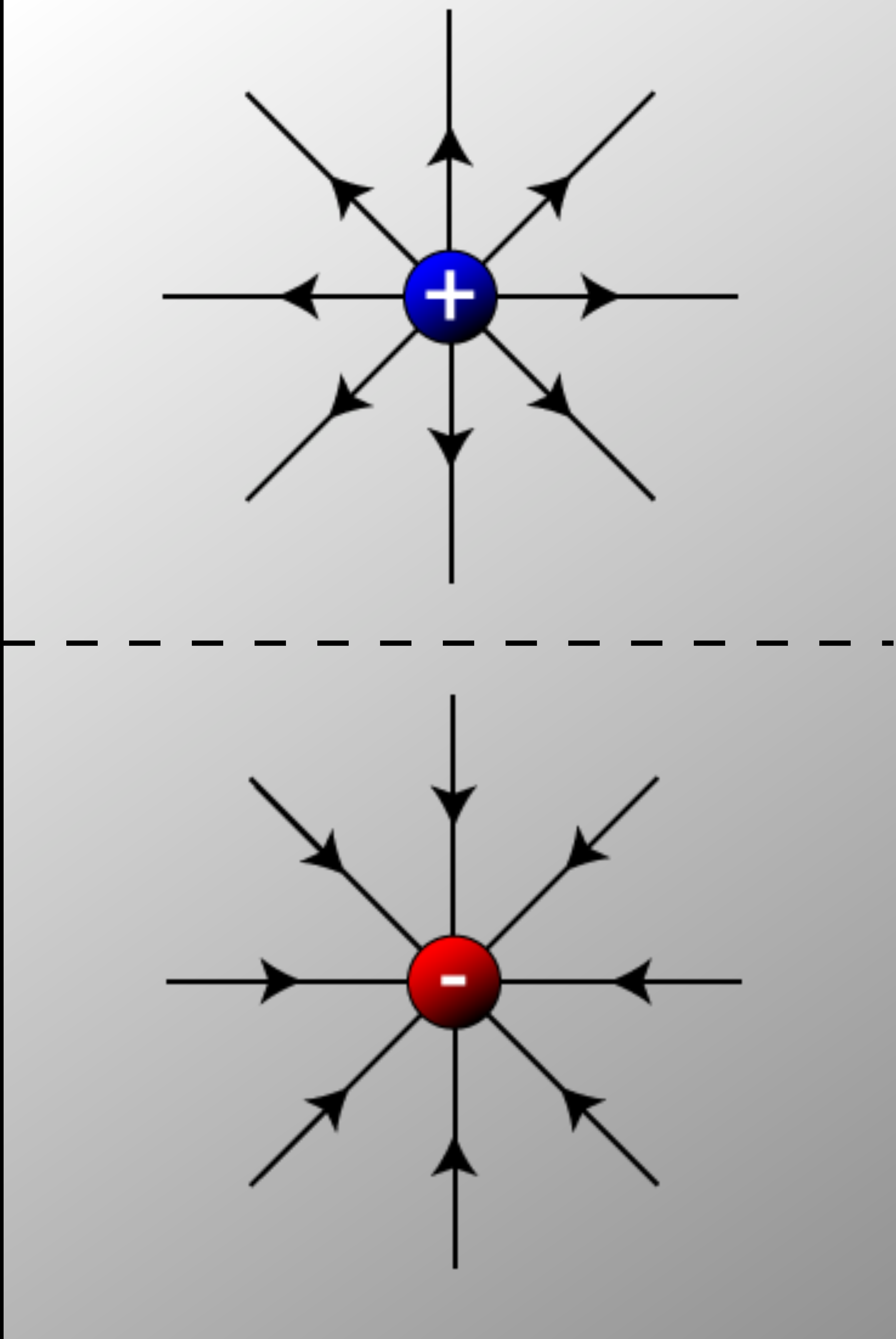
ELECTRIC FIELDS

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



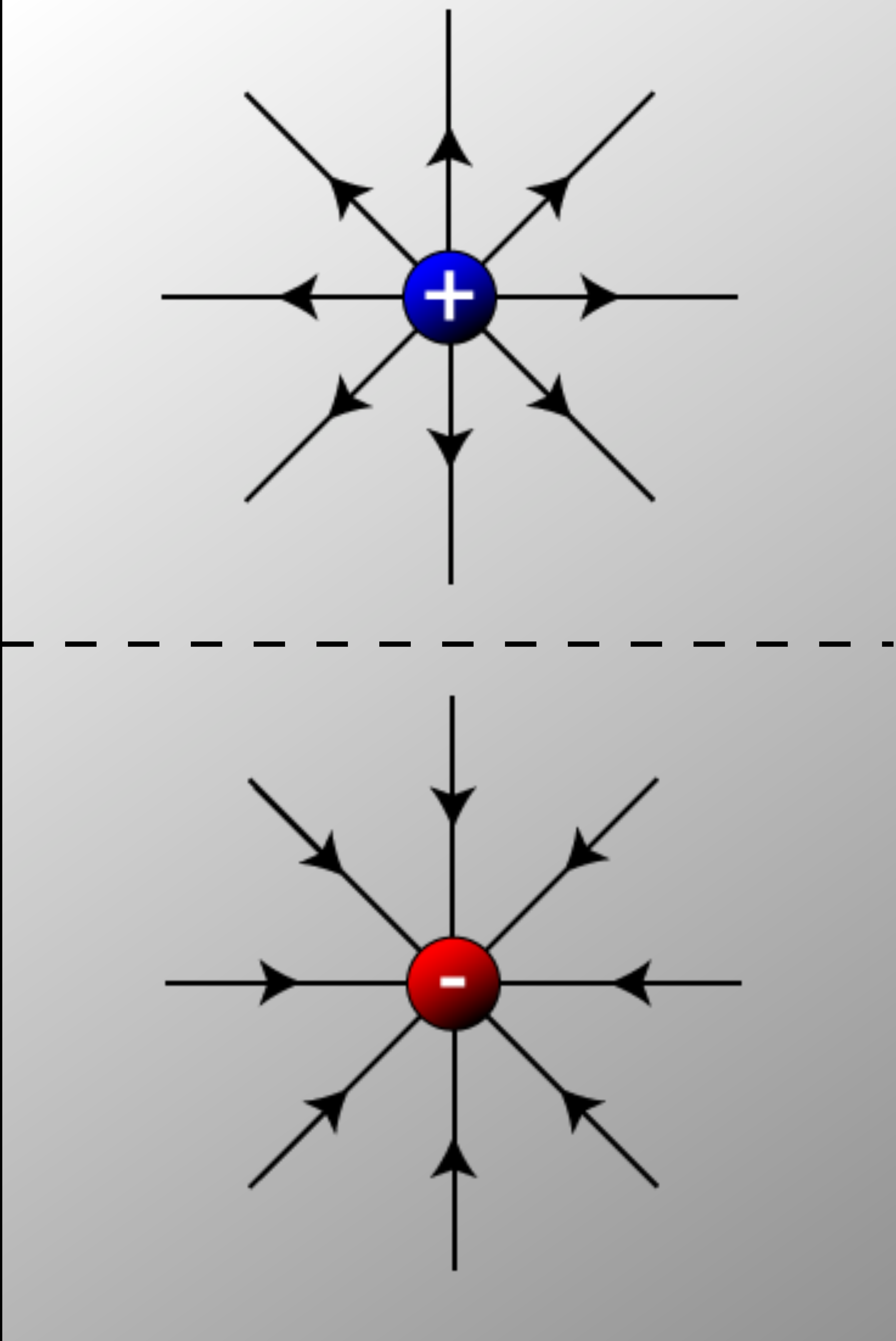
EXAMPLE 4

- 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*



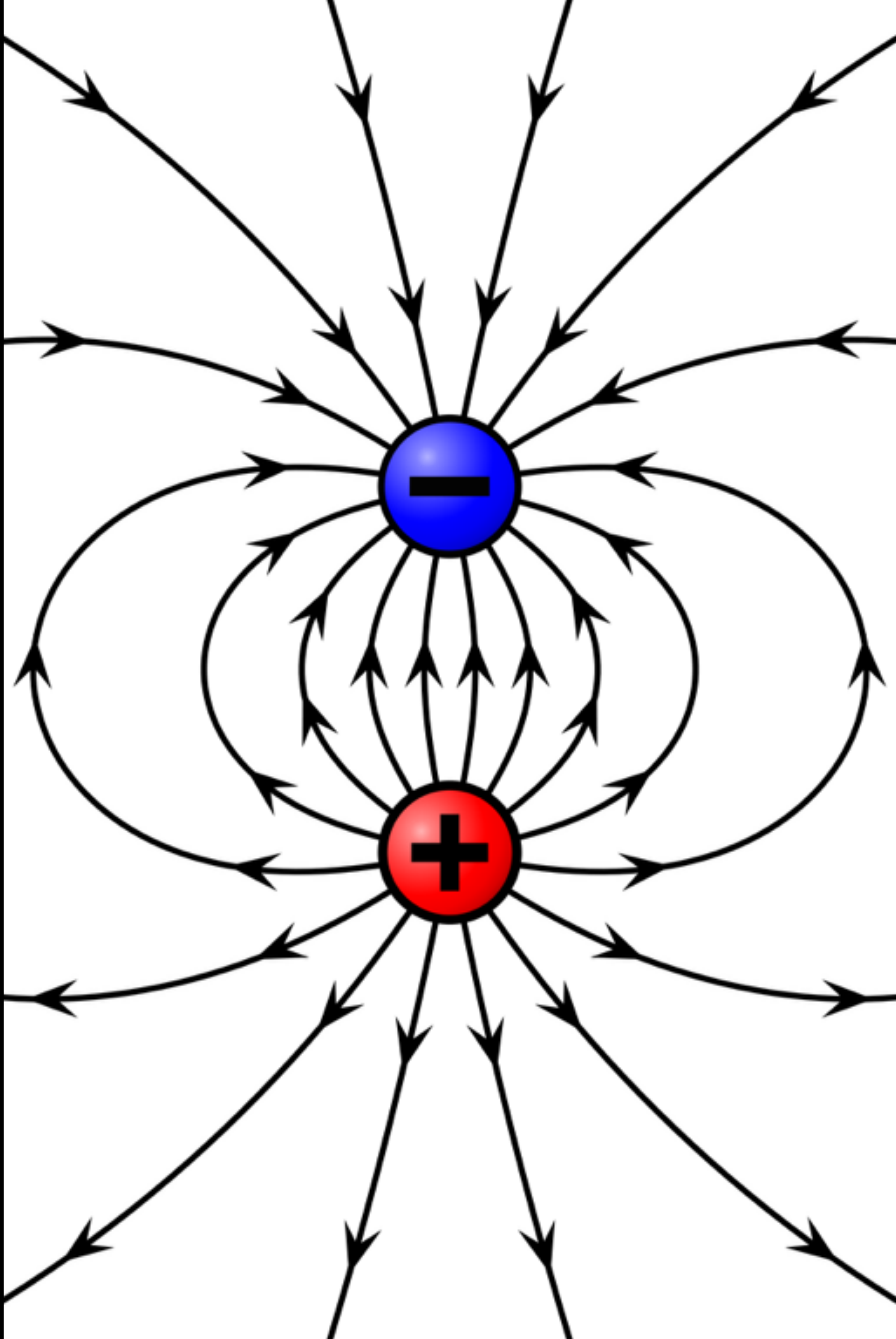
EXAMPLE 5

- Calculate the magnitude and direction of the electric field at a point 30 cm to the right of a point charge $Q = -3.0\times10^{-6}$ C
  - *Ans.* $\mathbf{E} = 3.0\times10^{5}$ *N/C to the left*



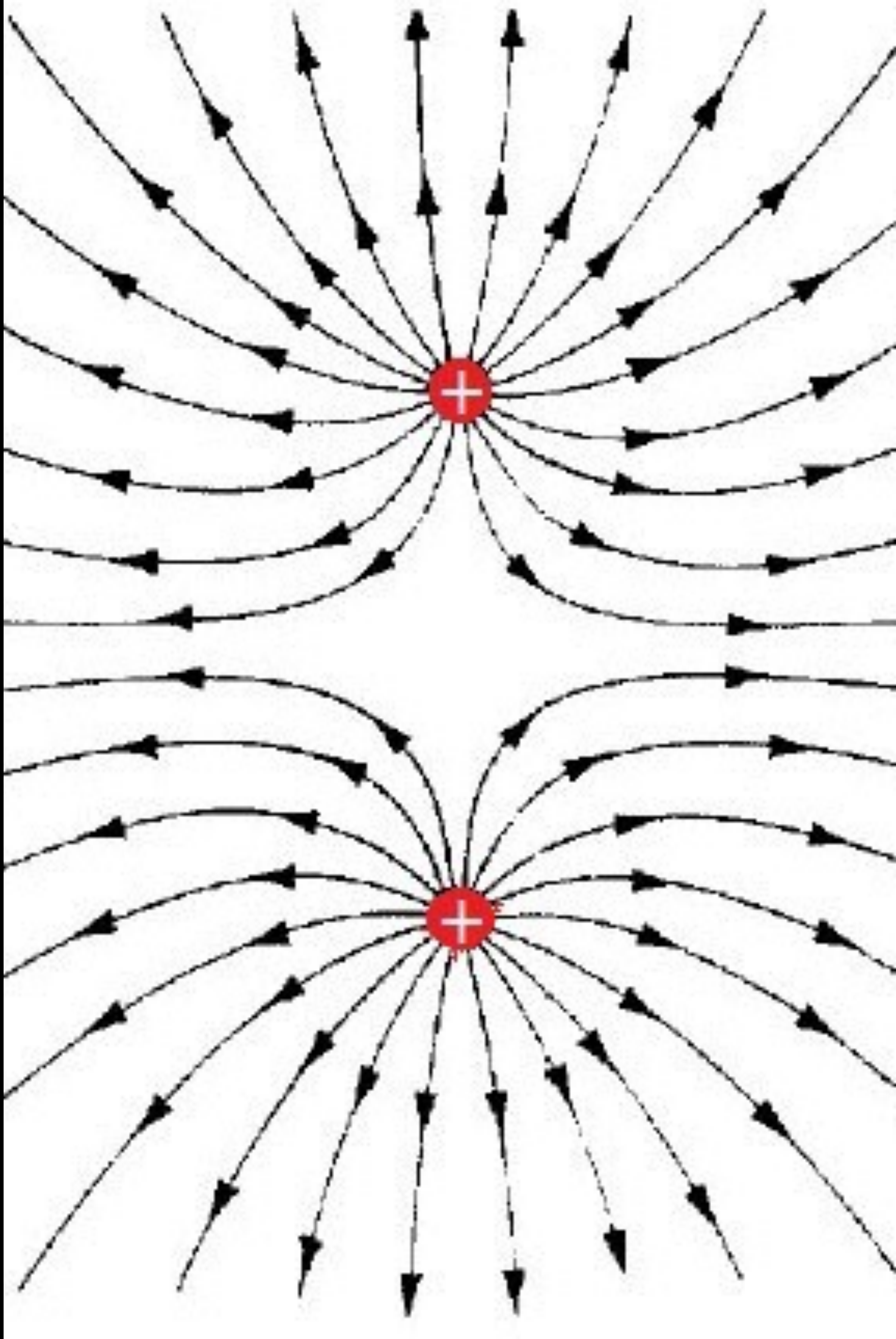
ELECTRIC FIELDS

- ***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)



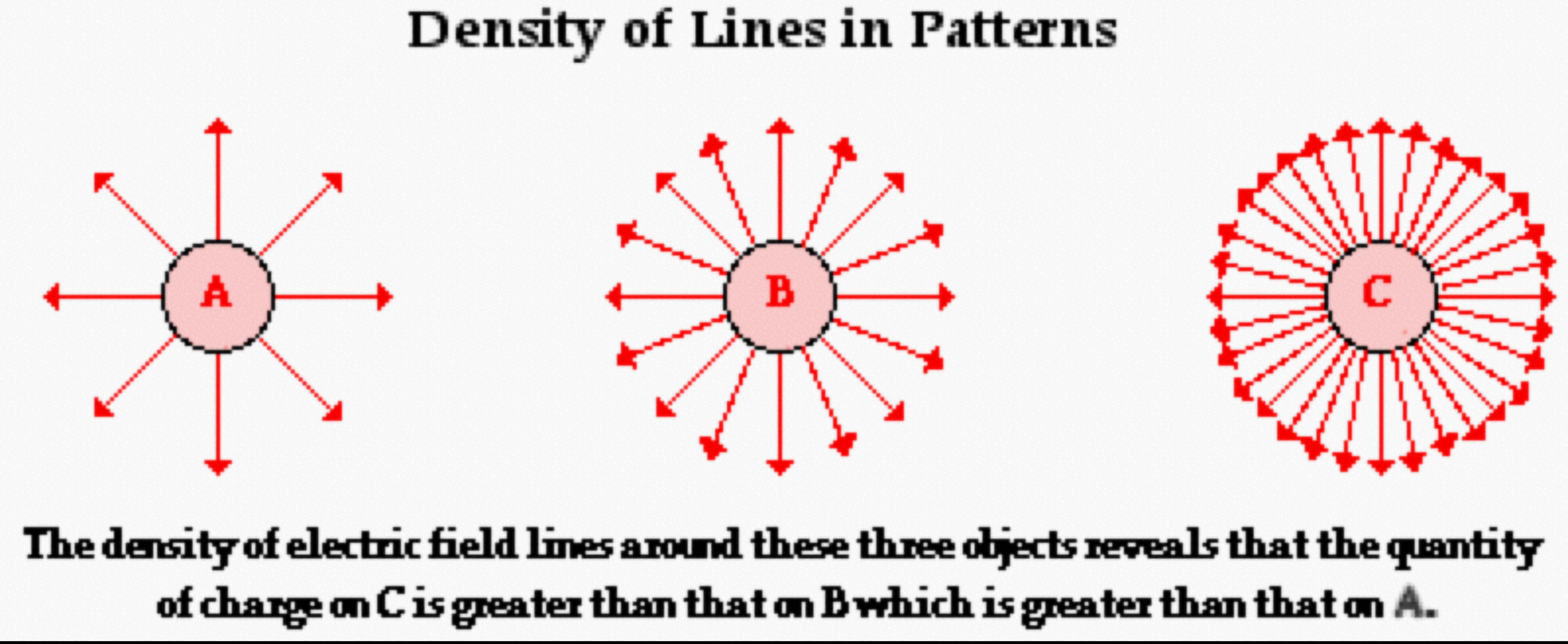
ELECTRIC FIELDS

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



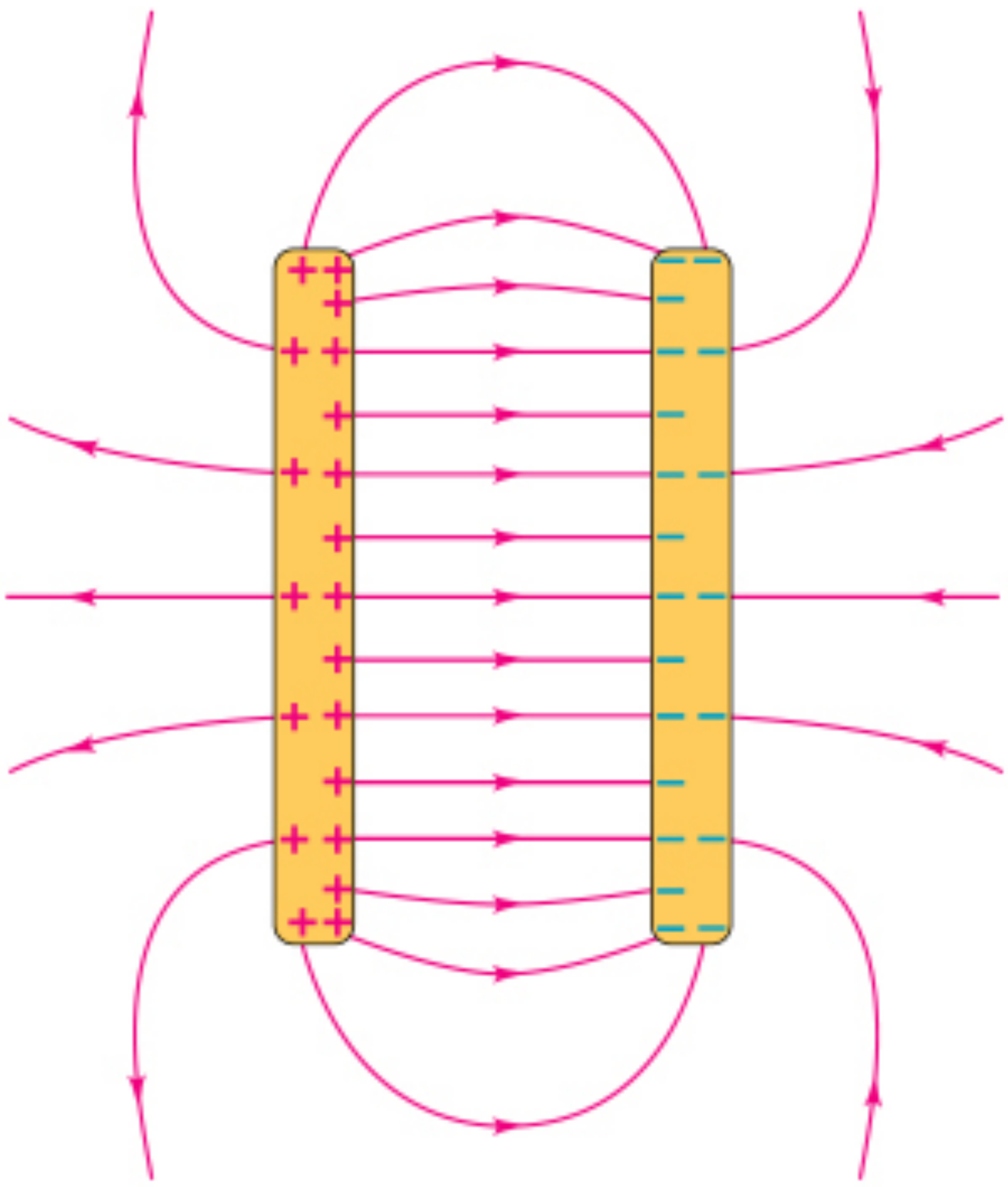
ELECTRIC FIELDS

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



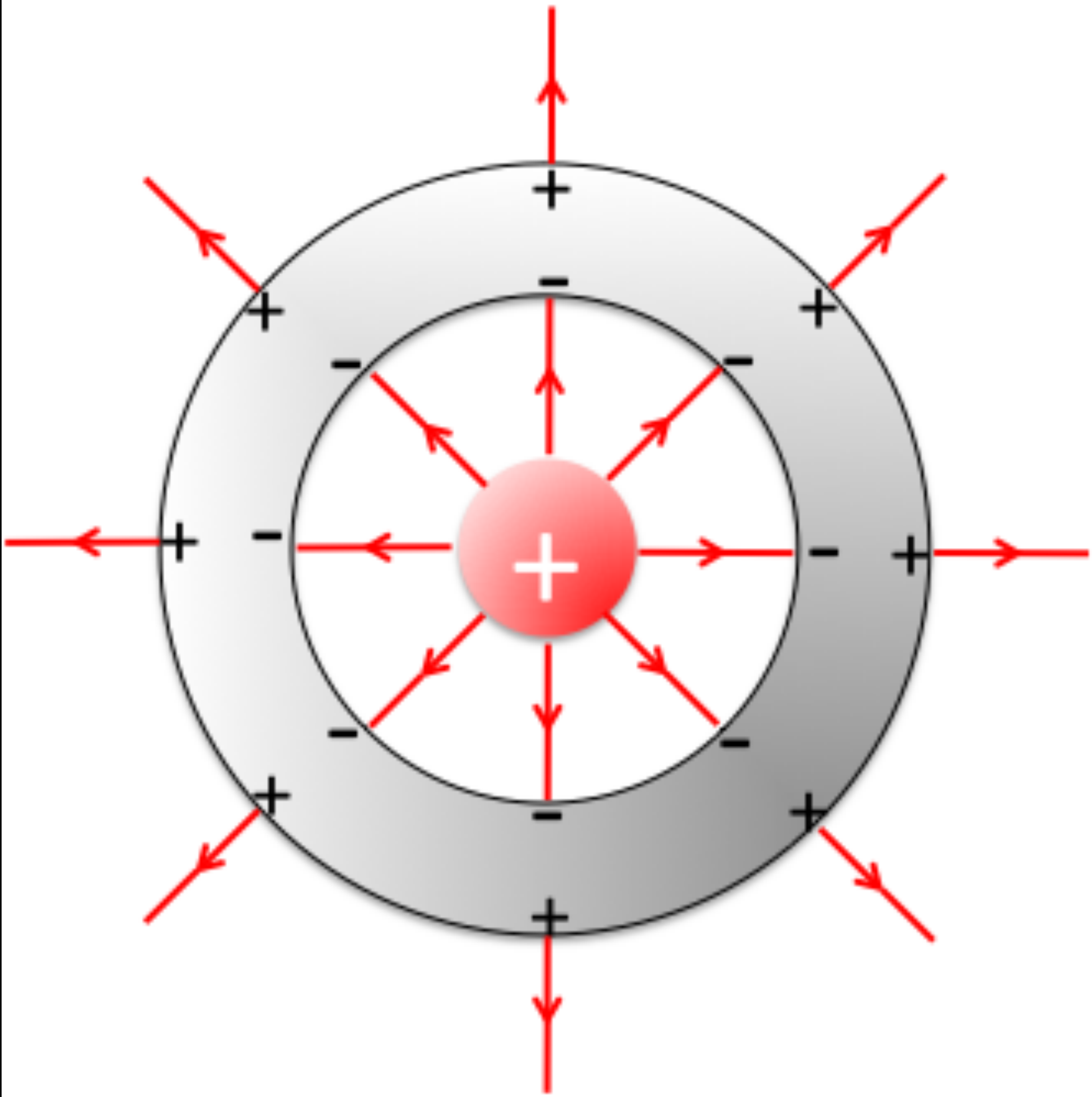
ELECTRIC FIELDS

- 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

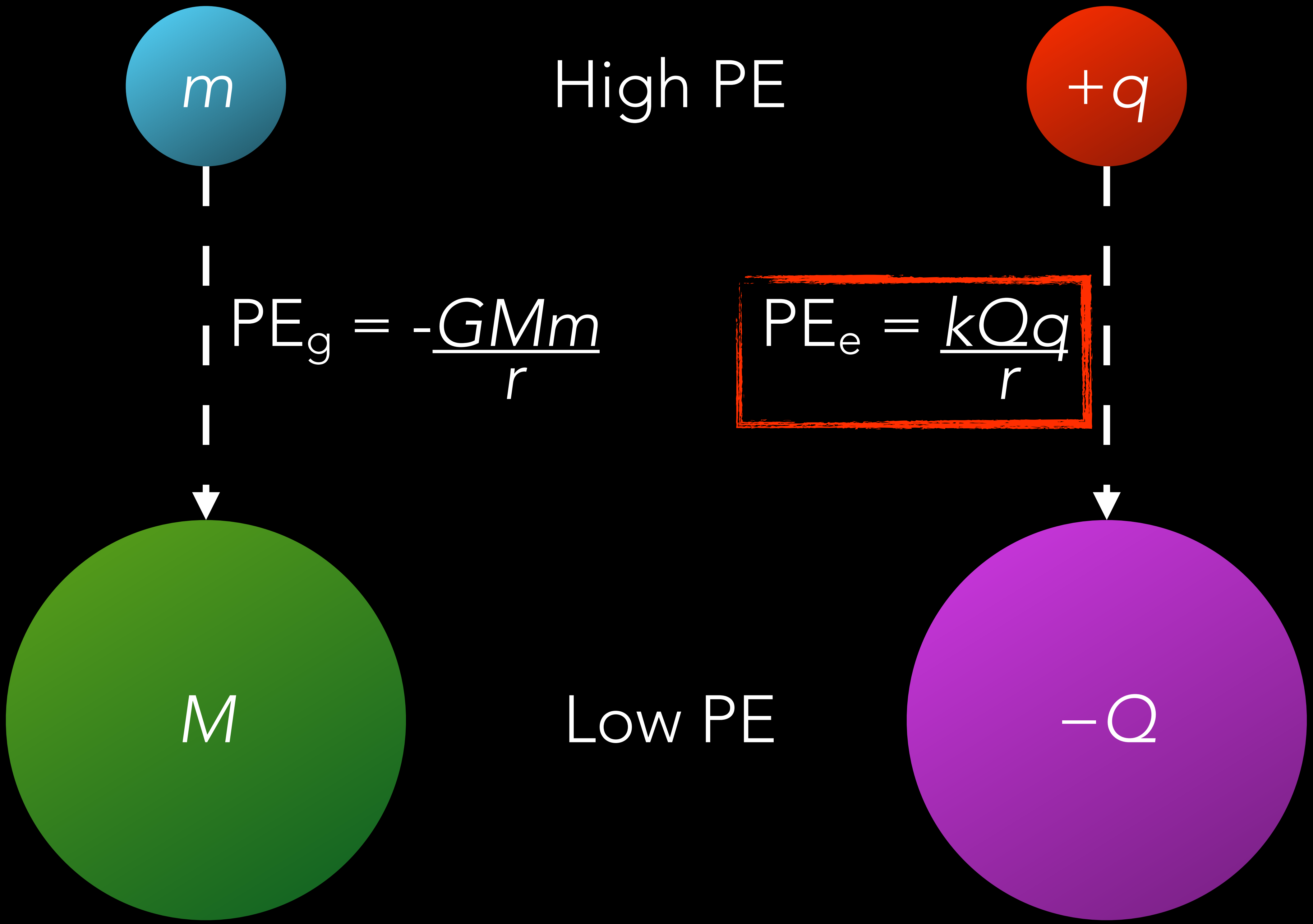


SANITY CHECK

- 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.

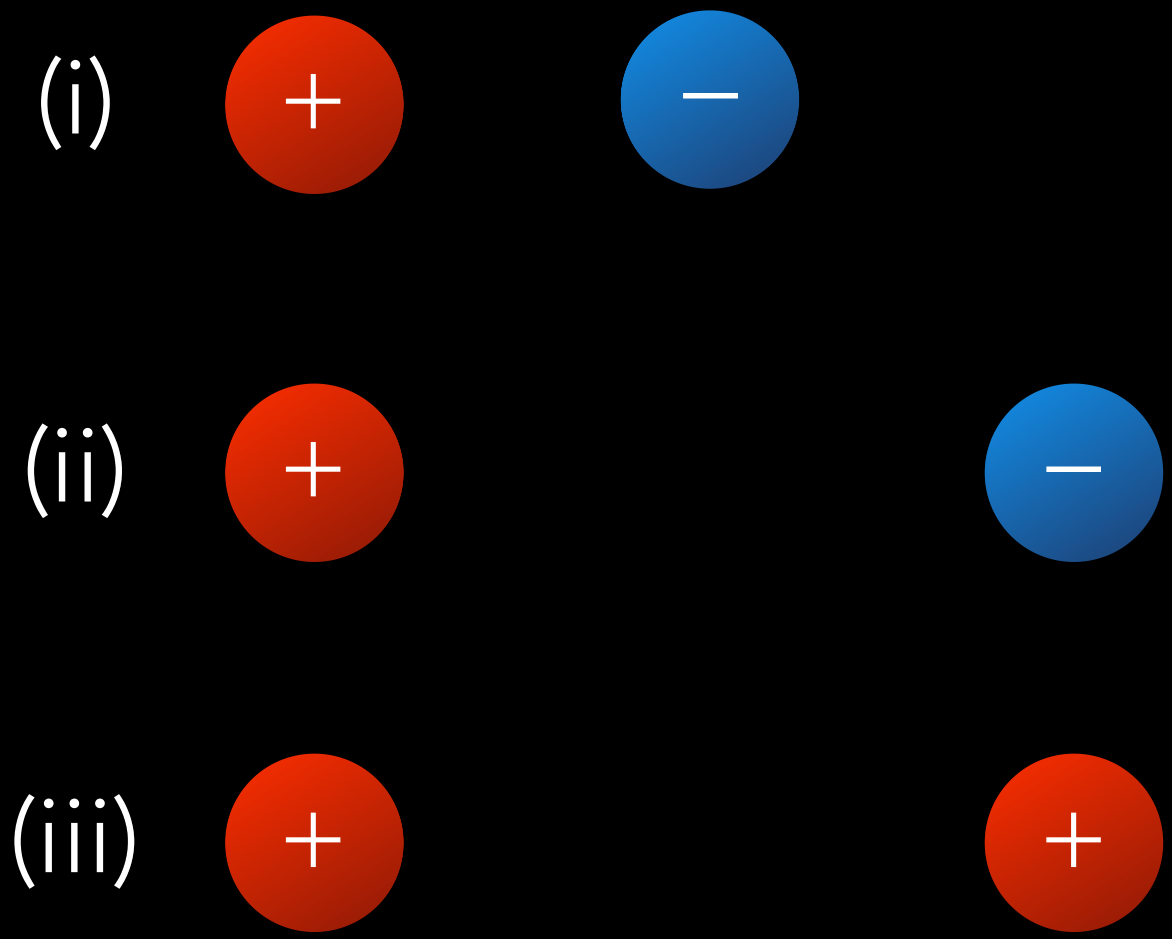
FARADAY CAGE

ELECTRIC POTENTIAL ENERGY



SANITY CHECK

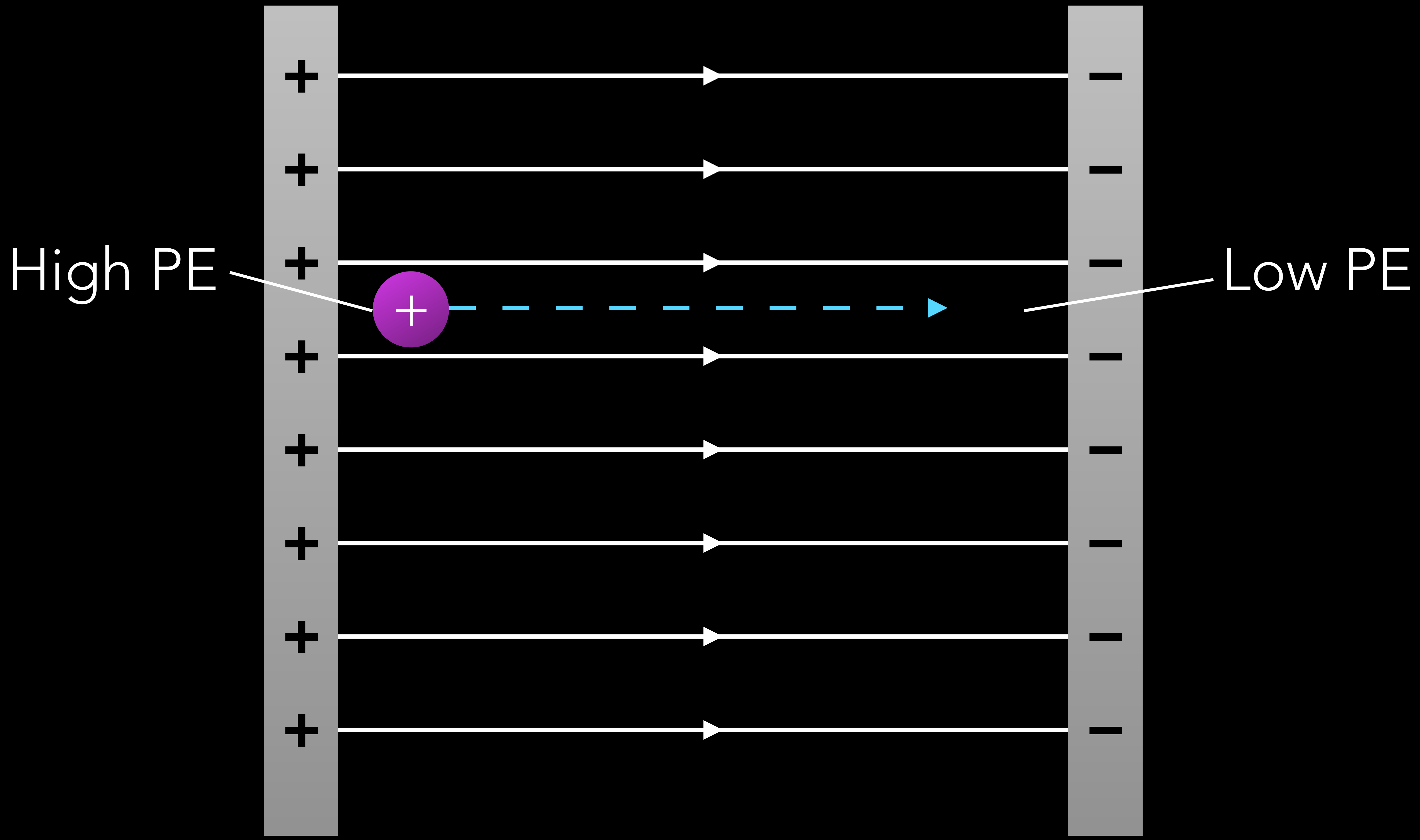
- Rank the three pairs of charges from most positive potential energy to most negative potential energy
  - *Ans. (iii) positive, (ii) negative, (i) most negative*
- Which set requires the most work to separate to infinity?
  - *Ans. Set (i) since it's the most negative*



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 ($m = 9.1 \times 10^{-31}$ kg) as a result of this acceleration?

a) Ans. $\Delta PE = -8.0 \times 10^{-16}$ *J*

b) Ans. $v = 4.2 \times 10^{7}$ *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.* $\Delta PE = -8.0 \times 10^{-16}$ J

   c) *Ans.* $v = 9.8 \times 10^{5}$ m/s

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

ELECTRIC POTENTIAL & ELECTRIC FIELD

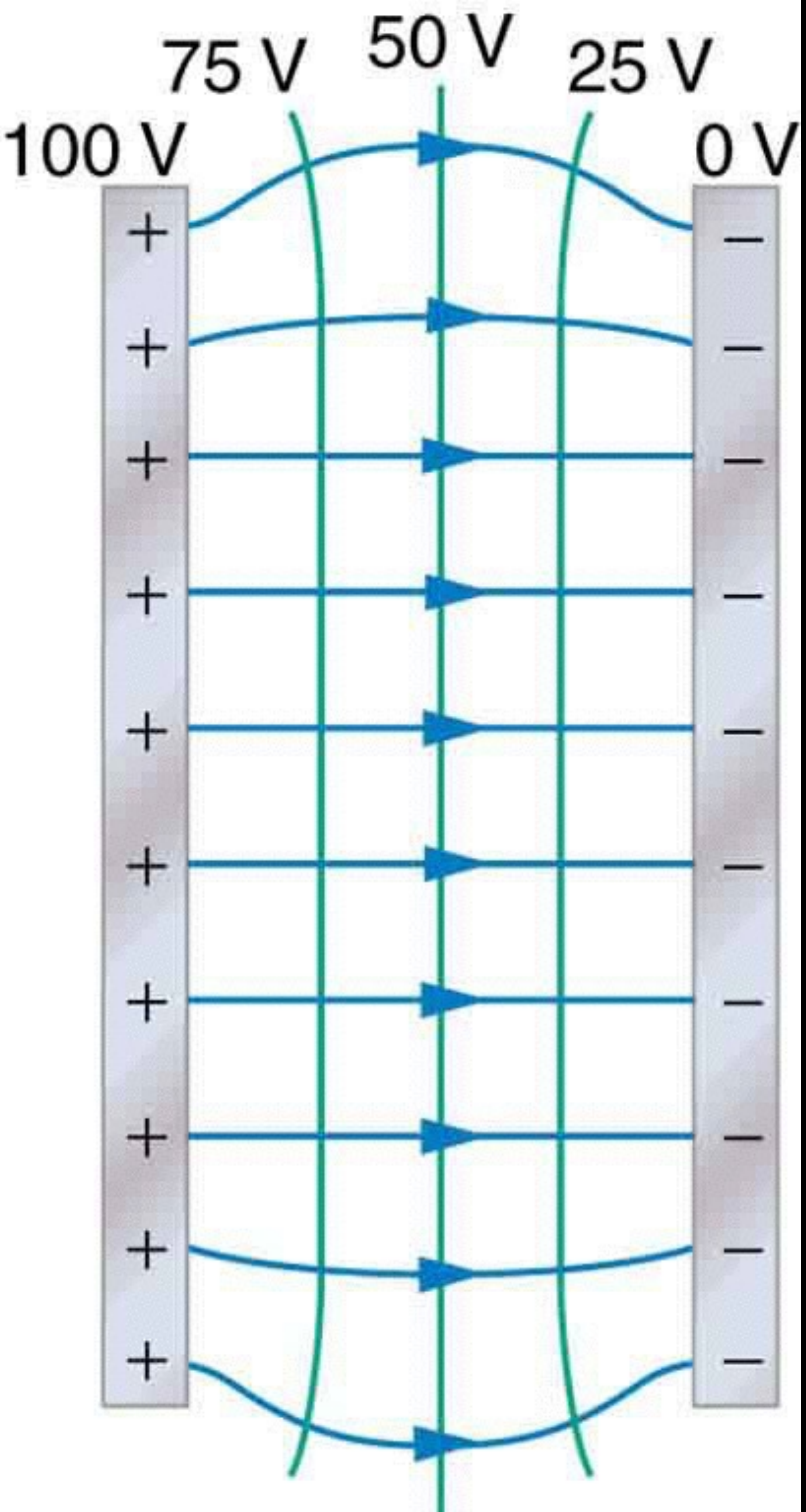
- Electric field is a vector
- but electric potential is a scalar
- $E = \Delta V/d$

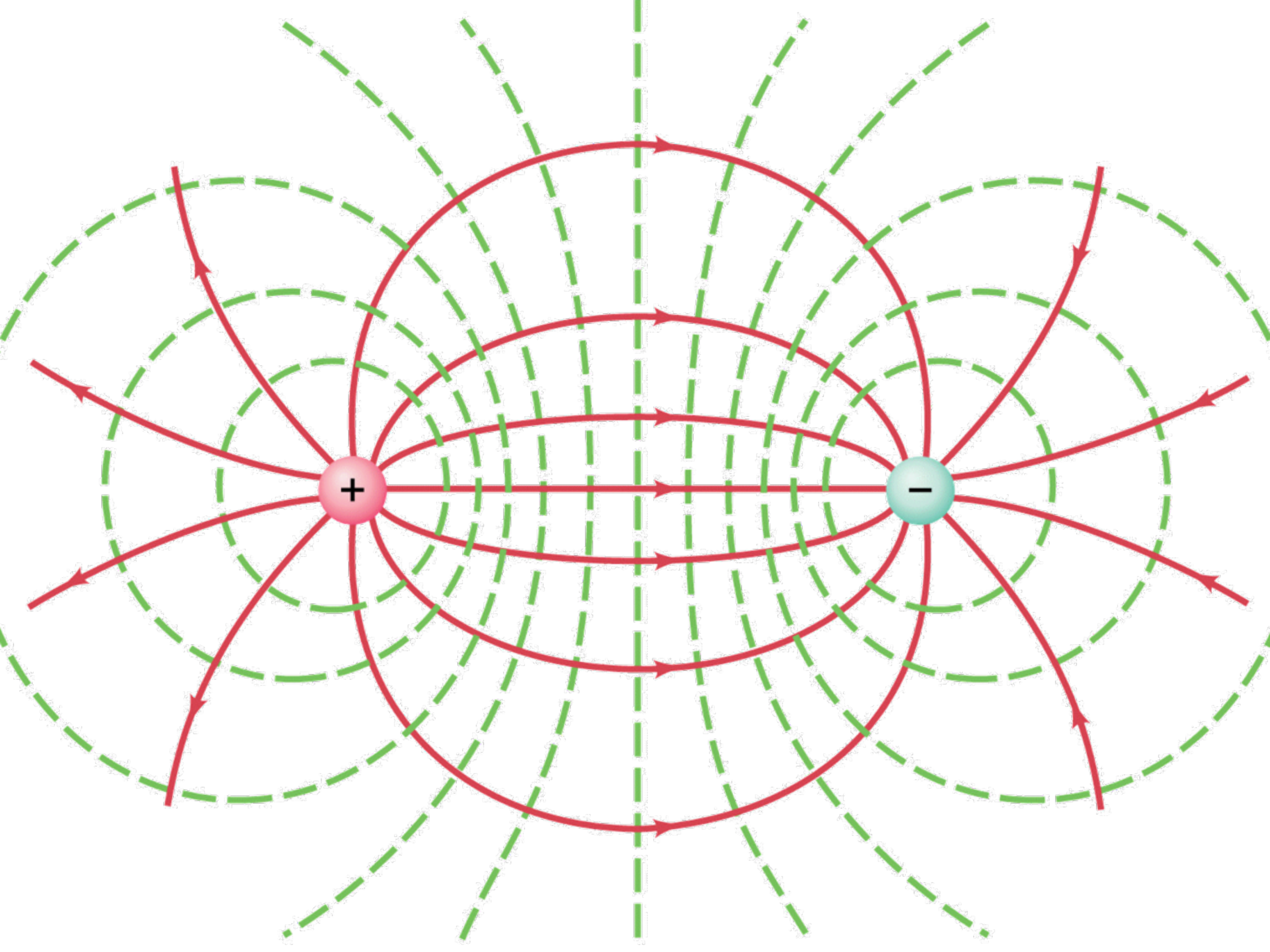
EXAMPLE 7

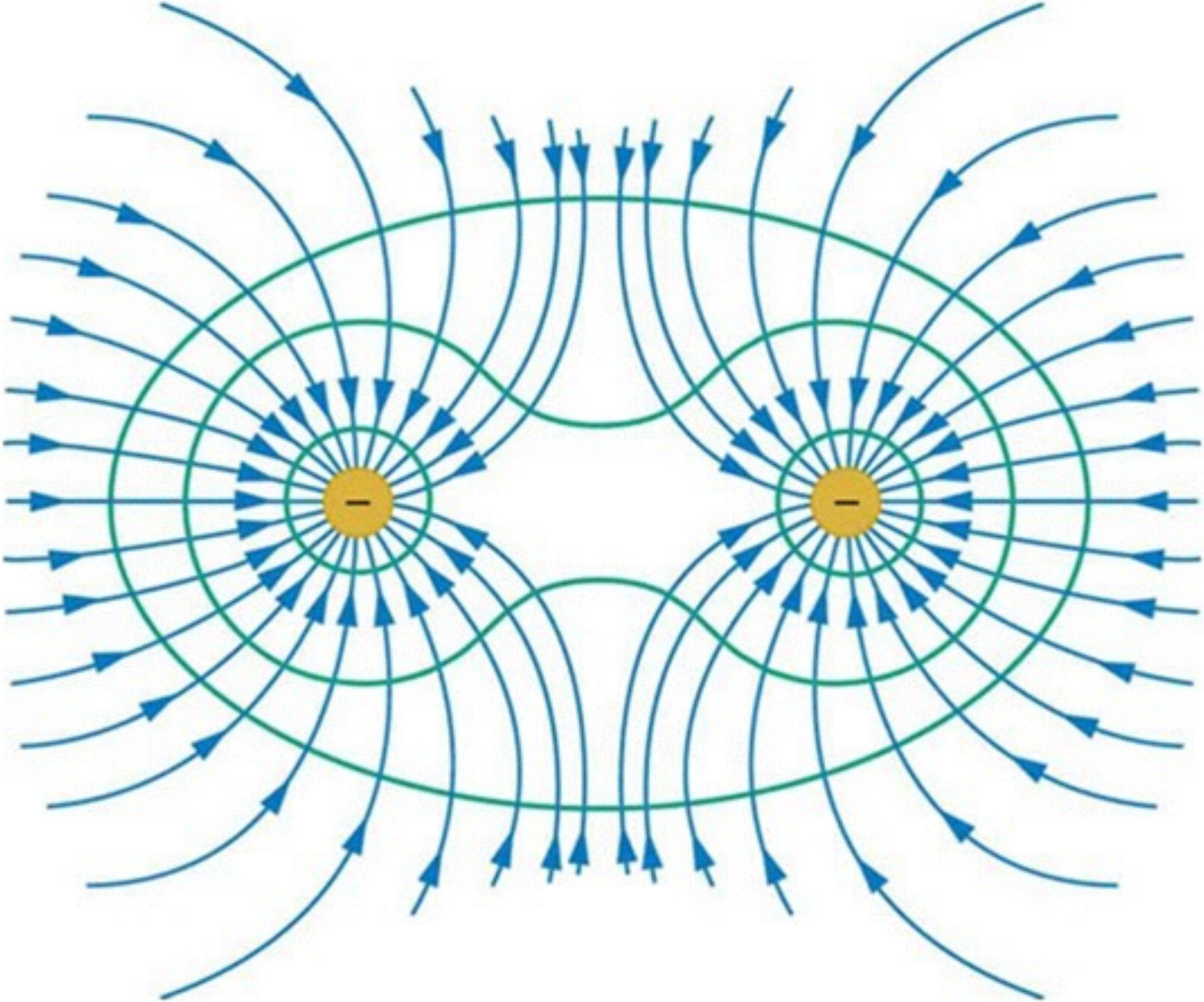
- Two parallel plates are charged to a voltage of 50 V. If the separation between the plates is 0.050 m, calculate the electric field between them.
  - *Ans. E = 1000 N/C*

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





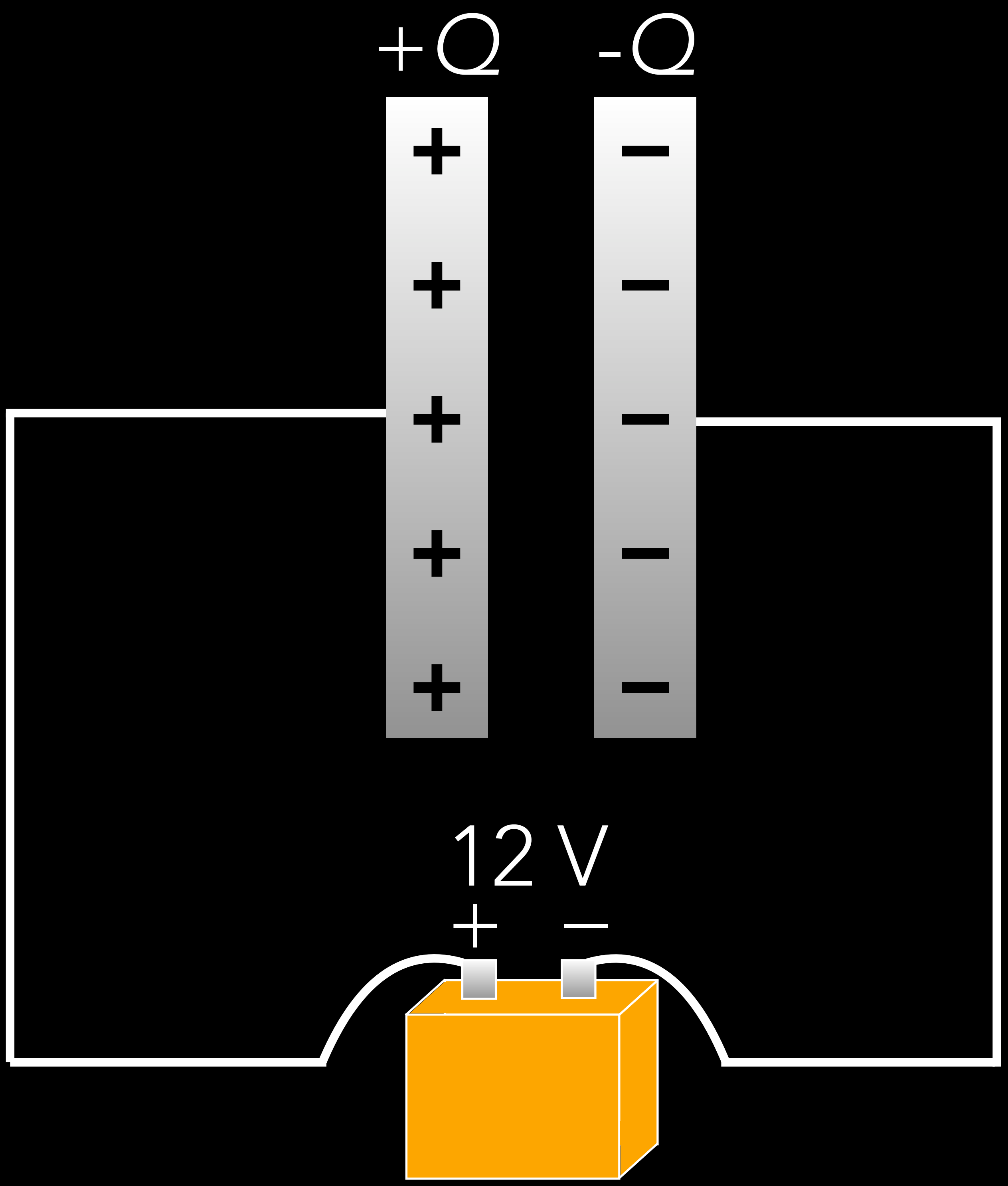


CAPACITANCE

- 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

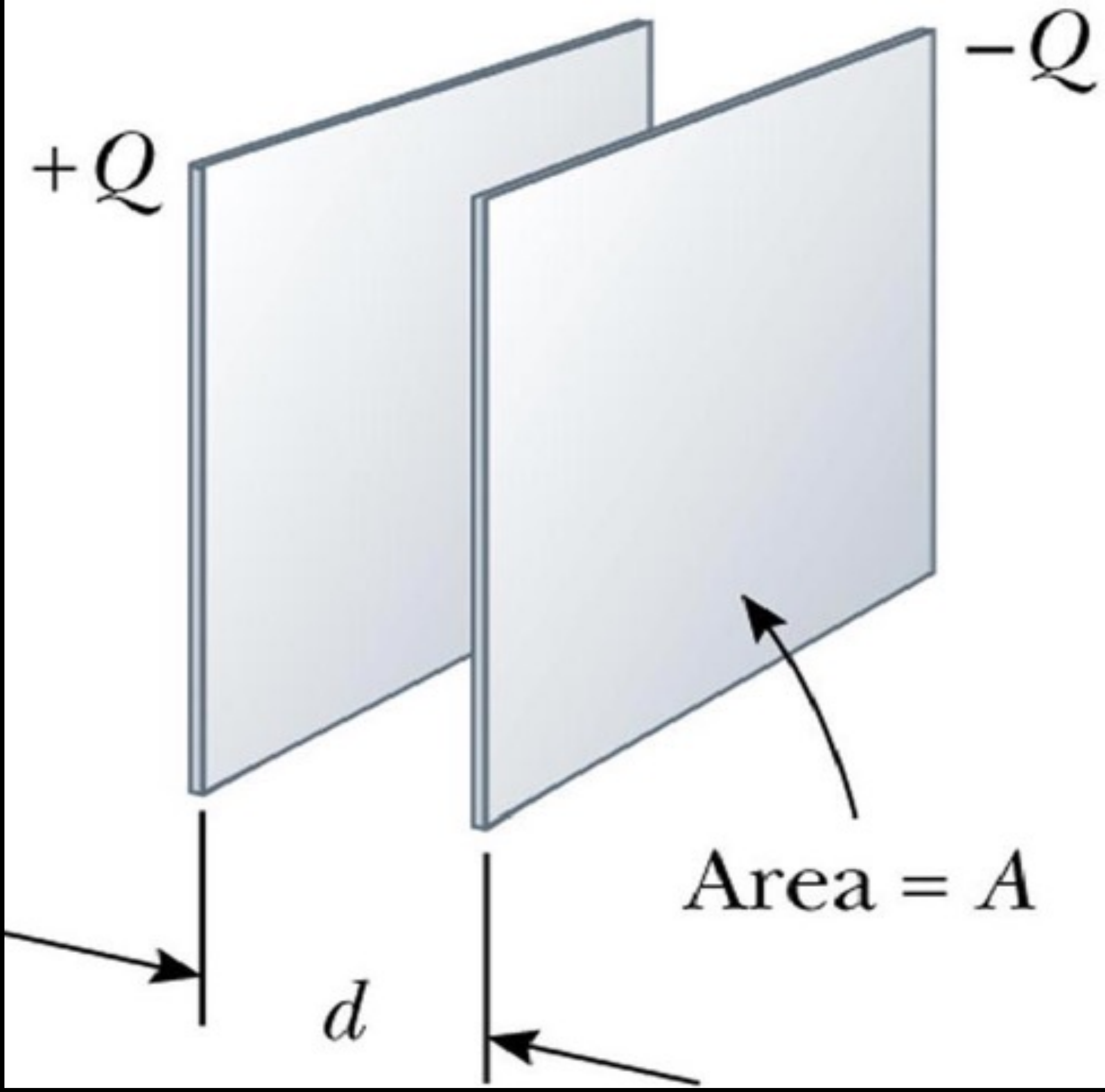
CAPACITANCE

- $Q = CV$
  - 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?

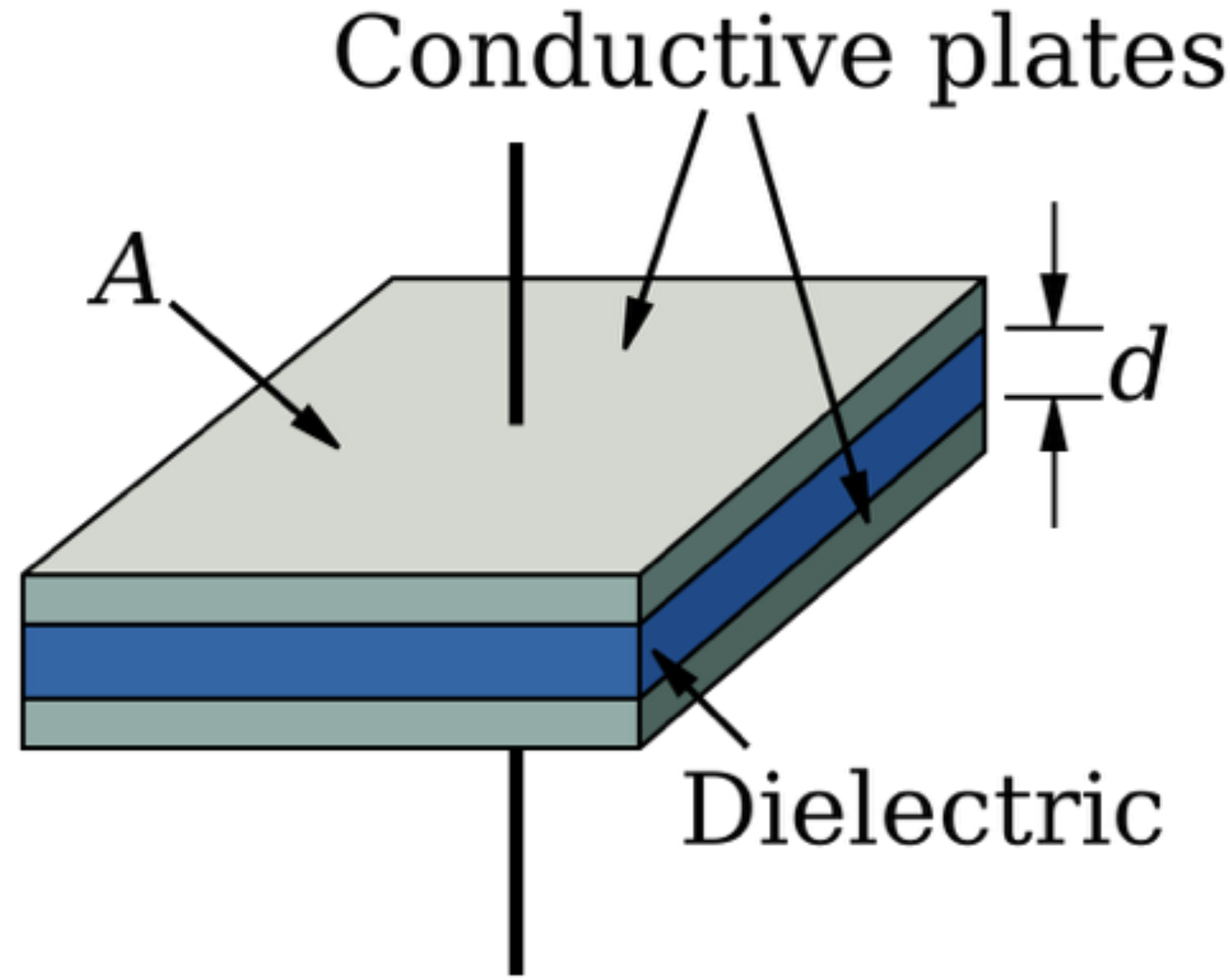
  a) *Ans.* $C = 53\ pF$

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

  c) *Ans.* $E = 1.2 \times 10^{4}\ N/C$

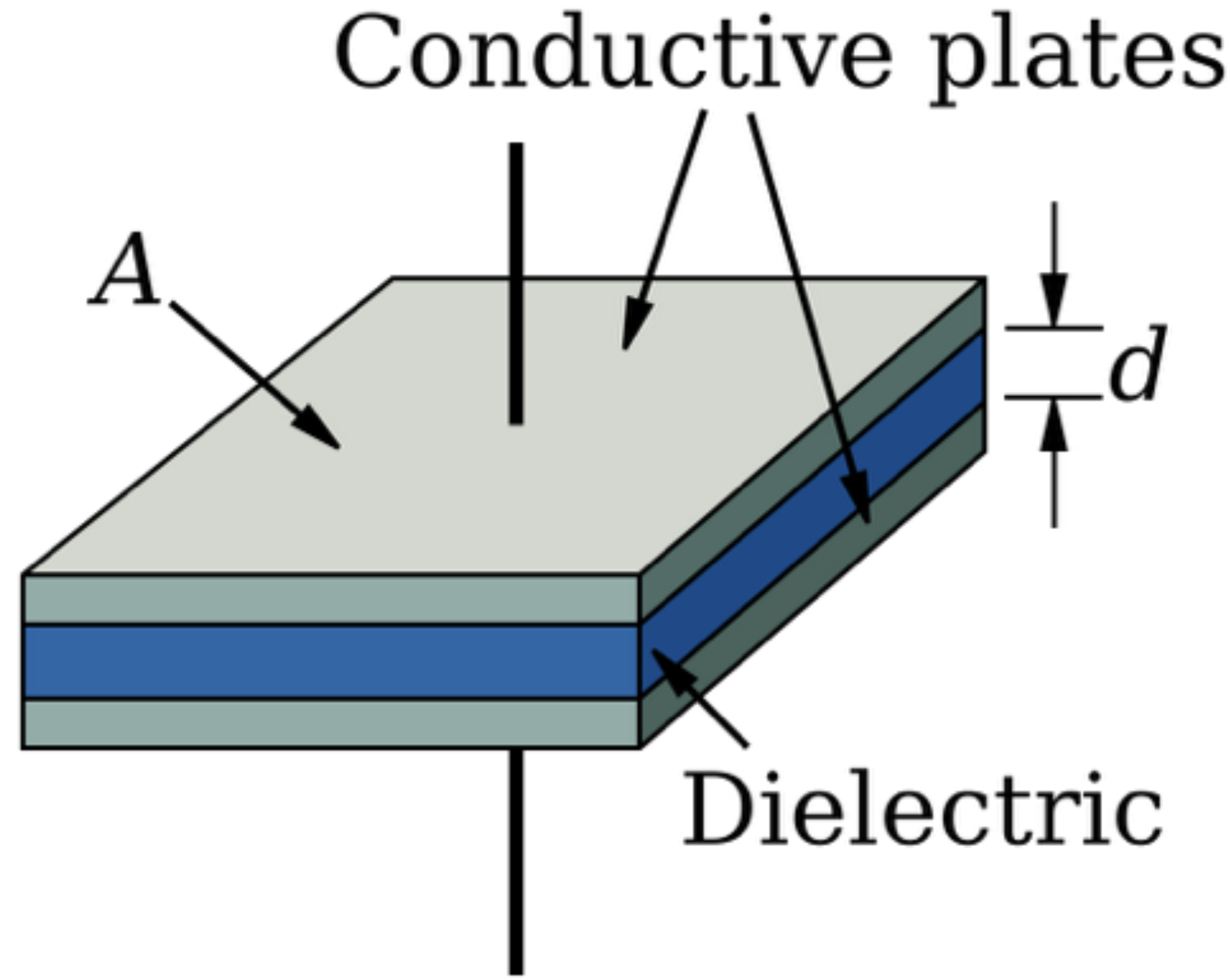
DIELECTRICS

- 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

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

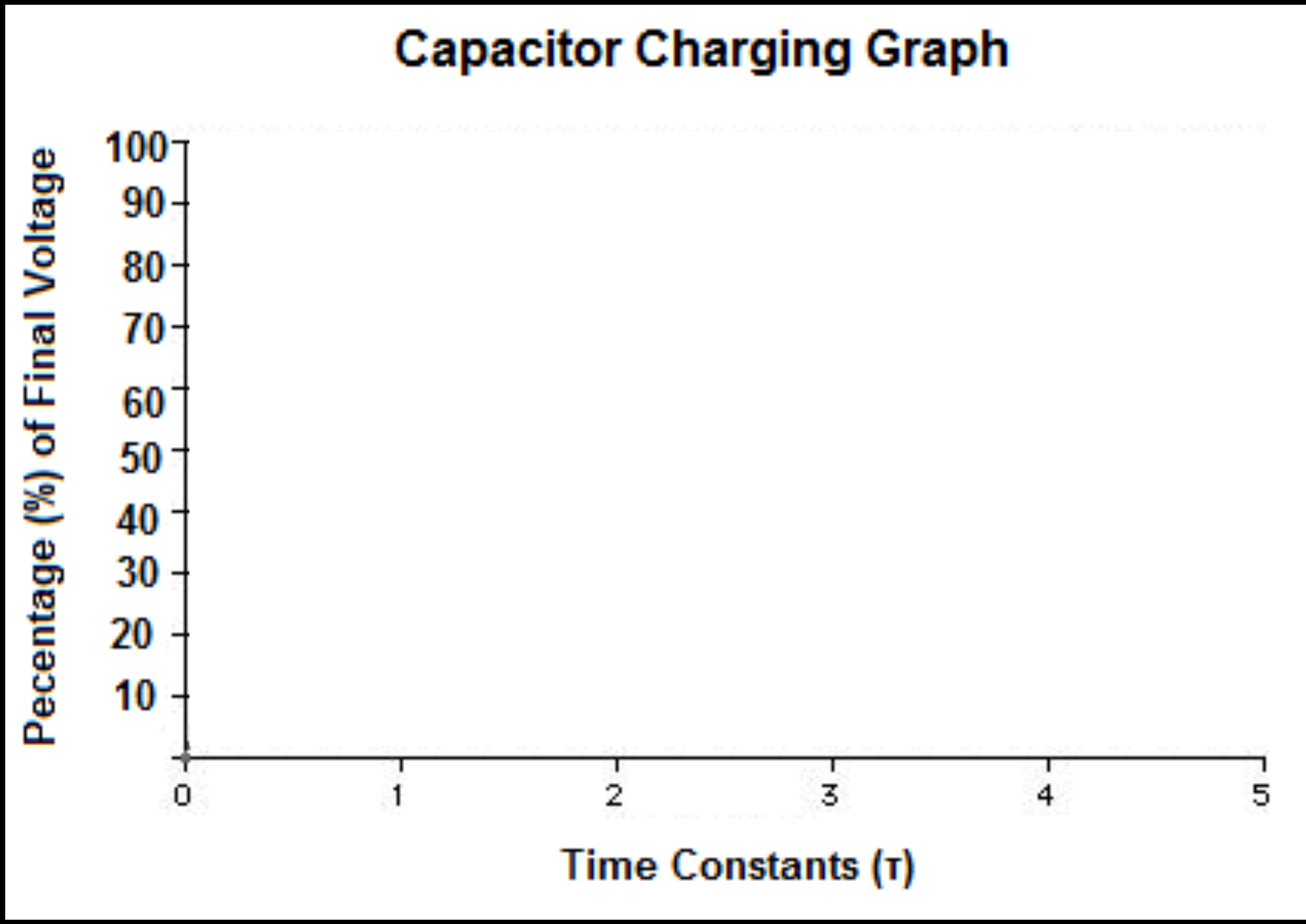
SANITY CHECK

- 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