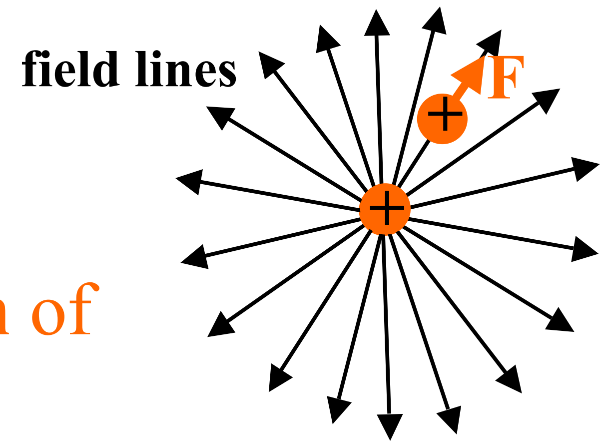
Recap: Electric Field Lines

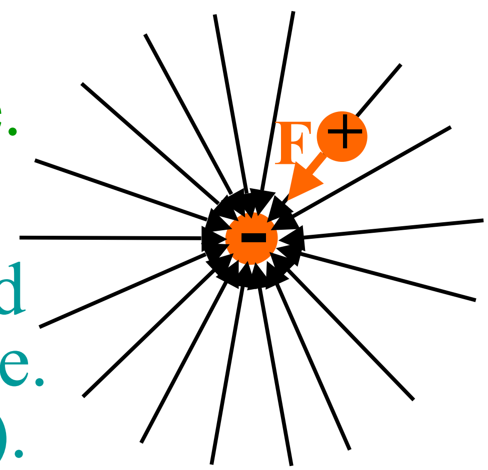
- Concept of electric field lines initially used by Michael Faraday (19th century) to aid visualizing electric (and magnetic) forces and their effects.
- James Clerk Maxwell (19th century), theoretician, formally developed the concept of field lines.

Positive Charge:



- Field lines radiate **outwards** from a +ve charge.
- Force on +ve test charge gives **direction** of field.

Negative Charge:

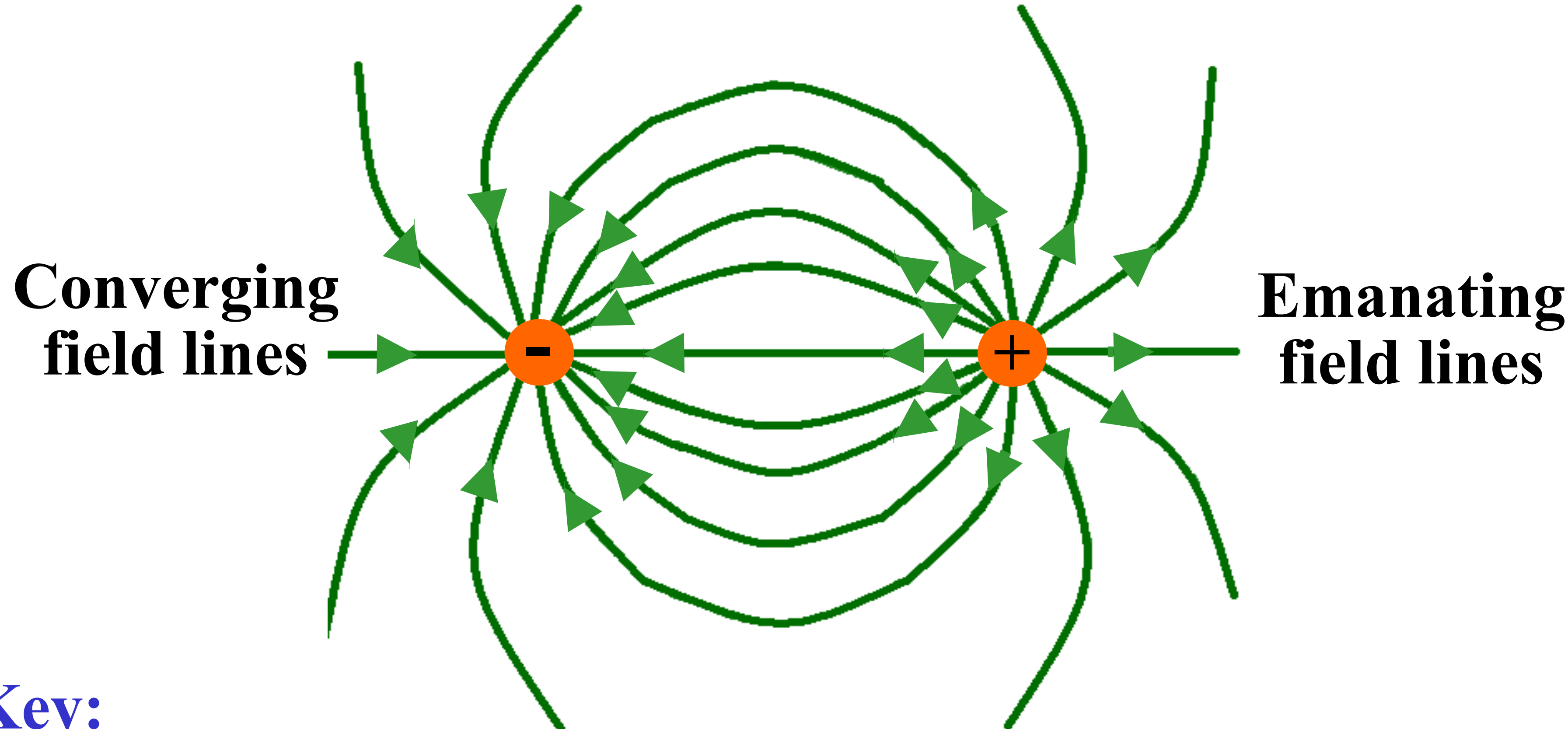


- Field lines **converge** inwards to a –ve charge.
- Force on +ve charge gives direction of field.

In both cases the strength of the electric field is given by the "**density**" of the field lines (i.e. closer together – the stronger the field /force).

Example: Electric Dipole

- Two equal but opposite sign charges:



Key:

- Field lines originate on positive (+ve) charge and end up on negative (-ve) charge.
- Field lines are perpendicular to charge surface (i.e. the direction of force).

Electrostatics 3 (Chapter 12)

Summary:

- Coulomb's Law describes the force between two charges

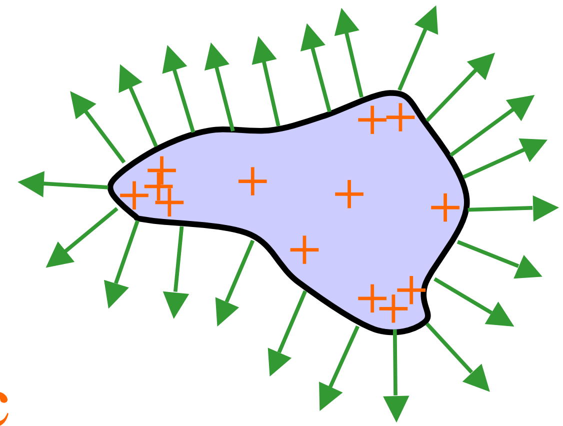
$$\mathbf{F} = \frac{k.q_1.q_2}{r^2}$$ Units: **Newtons**

- Coulomb's Law is identical in form to Newton's Gravitational Law, but force is much stronger than gravitational force and can be either attractive or repulsive.
- Electric field at a point is defined as:

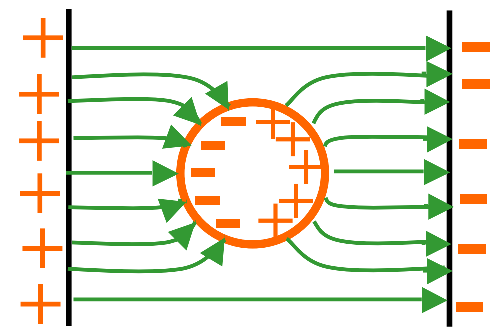
$$\mathbf{E} = \frac{F}{q}$$ Units: **N /C**

- Electric field is as vector and tells us the **magnitude** and **direction** of the **force** exerted on **charge**.
- Electric field lines are an aid to visualizing electric effects.
  - Strength of field given by "density" (number) of lines.
  - Lines go from positive to negative charge.
  - Field lines always perpendicular to conductor's surface.

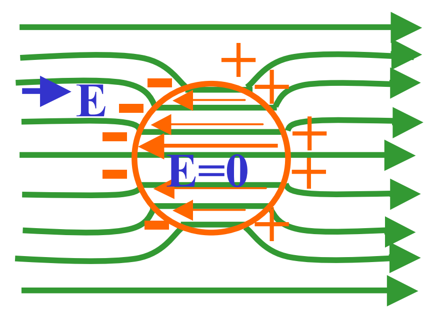
- Electric field of a charged conductor is everywhere **perpendicular** to the surface.



- Charge therefore **concentrates** on regions with small radius of curvature (i.e. points).
- Presence of a conductor distorts an electric field.

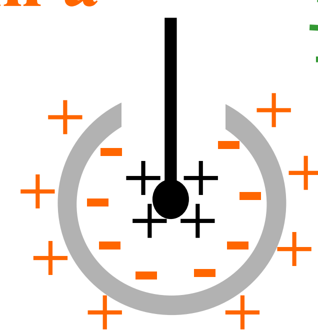


- The external field polarizes the conductor making one side negative and the other positive.
- This creates a “**self field**” inside the conductor that **cancels** out the applied field and leaves **zero** internal electric field.



Result: The electrostatic field within a conductor is always zero.

- Note: It is possible to create a field inside a hollow conductor if we insert an isolated charge inside it.



- Unlike gravity we can therefore **shield against electric fields** by surrounding the region to be isolated by a conductor.

  Examples: - Electronic components encased in metal cans.

  - Wires surrounded by braided copper sheathing.

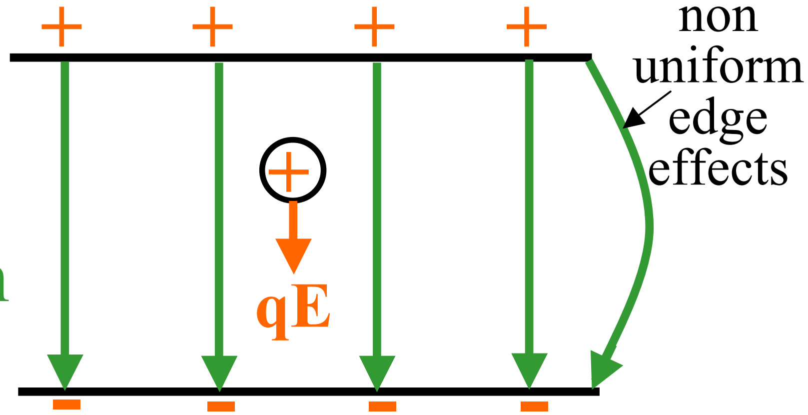
  This is why:

- We need an external antenna on a car to pick up radio waves.
- We can't pick up radio waves in tunnels and crossing bridges?
- You are safe from lightning discharges inside your car.

Electric Potential: (Voltage)

- What is **voltage?** How is it related to electrostatic potential energy?
- First let's consider the potential energy of a charged particle moving in a uniform electric field.
- **Uniform field:** electric field lines parallel and evenly spaced, i.e. field is constant in direction and strength at all points.

Parallel Plate Capacitor



- Device for storing electric charge.
- If a test charge (+ve) is placed in uniform field it will experience an electrostatic force in direction of electric field (**F = q.E**).
- If we release the charge it will accelerate towards –ve plate of capacitor. (Note: we can assume gravitational acceleration is very small in comparison to electrostatic acceleration).
- This will reduce the **potential energy** of charge (and increase its **kinetic energy**).
- Thus, to increase the electrostatic potential energy we have to do **work** on the charge moving it **against** the field direction.
- This process is analogous to changing gravitational P.E. when we lift an object against the pull of gravity.

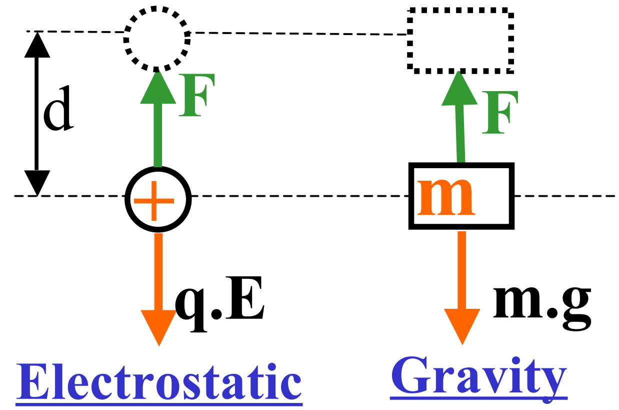
i.e. Doing work raises the P.E. in a conservative system.

- **Change in P.E.** is given by the **work done** against **electric field**.

$$\text{Work} = F.d$$

$$\Delta PE = q.E.d$$

(analogous to P.E. = m.g.h)



Result: By **doing work** on the **charge**, we can **increase** its **electrostatic potential energy**.

Electric Potential:

- We regard the +ve charge used in a capacitor as a test charge to determine how the potential energy varies with position.

❖ **The change in electric potential (voltage) is equal to change in electrostatic P.E. per unit +ve charge.**

$$\Delta V = \frac{\Delta PE}{q}$$

Units: **J /C**

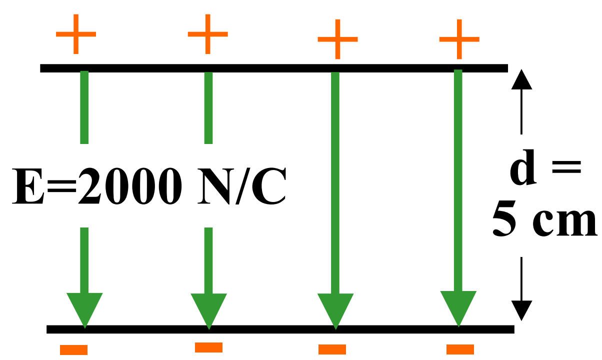
Note: This is the definition of the **volt**: **One Joule** of **work done** moving a **charge of 1 Coulomb**.

- Like the electric field we can consider the electric potential (voltage) at any point in space.
- Remember: the **change in voltage** is **equal** to **change in P.E. per unit +ve charge** (or $\Delta PE = q.\Delta V$).

Thus, voltage and electric P.E. are related but **not the same.** E.g. if ‘q’ is negative the P.E. will decrease when moved in direction of increasing voltage.

Example: Capacitor

Question: What is voltage difference?



$$\Delta V = \frac{\Delta PE}{q} = \frac{q.E.d}{q} = E.d$$

$$\Delta V = 2000 \times 0.05 = 100\ V$$

$\Delta V = E.d$

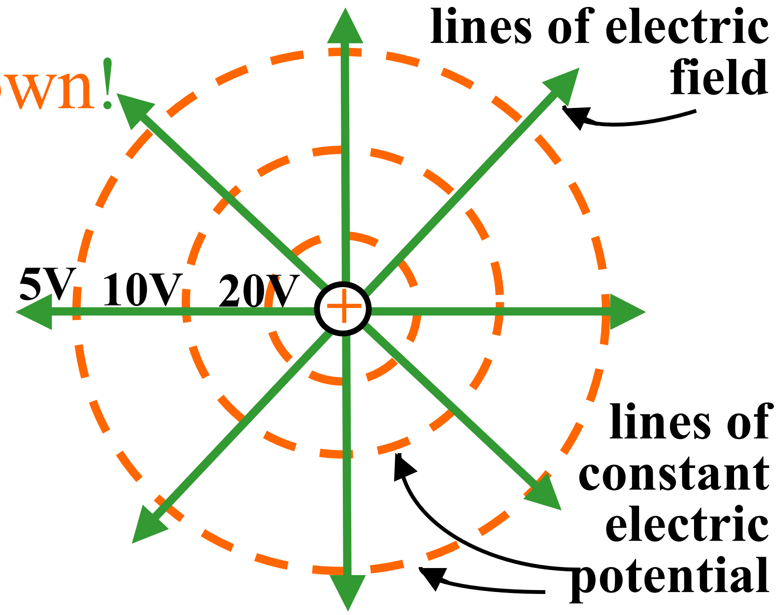
- The **voltage** will be **maximum** at the **positive plate** and will **drop 100 V uniformly** from **top** to **bottom** plate (i.e. it will be **50V** in the **center** of capacitor).

- For uniform electric fields:

$$\Delta V = E.d \qquad \left(\text{or } E = \frac{\Delta V}{d} \quad \text{Units: } V/m\right)$$

Thus, **larger fields** exhibit **larger potential drops** per meter.

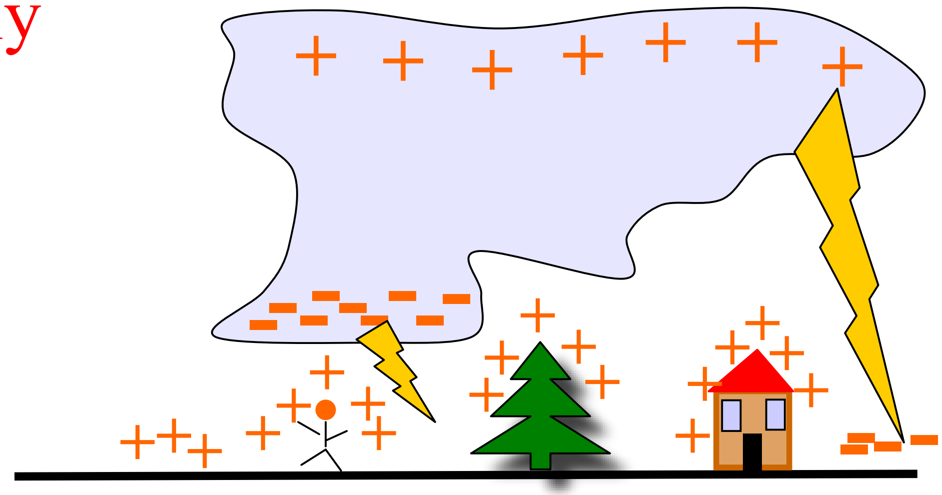
- This is the key to electrical breakdown!
- Electric potential increases as move towards charge's (+ve) origin – where electric field is largest.



Thunderstorms:

- Short lifetime 1-2 hours.
- Strong convective updrafts extend high into troposphere (altitude ~ 15 km).
- Three stages: Cumulus – cloud growth ~ 15 min
  Mature – Rain, hail, lightning
  Dissipating – subsiding air cuts off storm.

- Thunderstorms grow quickly and can be very dangerous.
- Lightning **kills** about 100 people in USA and Canada each year (and injures another 300 people).



- Causes **9000 forest fires** per year.
- Causes **10s millions $** in **damage** to power lines, transformers etc.
- During **strong convection** cloud charges up: usually –ve at base and +ve at top.
- Dry air is a very good insulator and voltages of ~ 100 million volts can be generated.
- During precipitation air breaks down and lightning strikes.
- Several types of lightning (intra cloud, cloud to ground ball, bead…)
- Only 20% is cloud to ground "fork" lightning.