

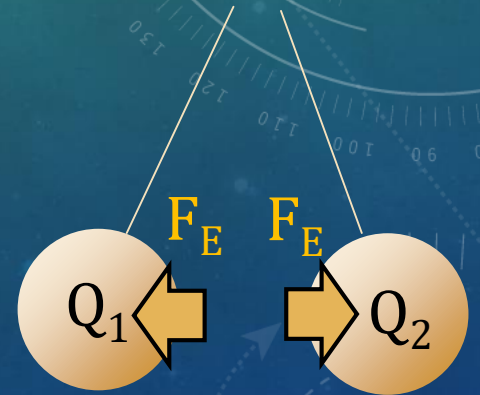
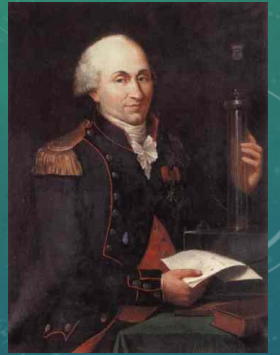
The background features a gradient from light green at the top to dark blue at the bottom. On the left side, there are several circular elements: a large scale with numerical markings from 140 to 260, and several smaller circles with arrows indicating clockwise or counter-clockwise rotation. The overall aesthetic is technical and scientific.

# ELECTRIC FORCE AND ELECTRIC FIELDS

PES 1000 – PHYSICS IN EVERYDAY LIFE

# COULOMB'S EXPERIMENT

- **Charles-Augustin de Coulomb** (1736-1806) discovered the force relationship between charged objects separated by a distance.
- He experimented with pith balls charged by induction. They had quantities like  $\pm Q$ ,  $\pm 2Q$ , etc.
- He found that the force due to electric attraction/repulsion (**electric force**) depended on:
  - Both **charge  $Q_1$**  and **charge  $Q_2$** . Greater charge caused greater force.
  - The distance,  $r$ , between centers of the balls. Force **decreased with the square of this distance**.
- Coulomb's Law (Coulomb Force for Electric Charge)
  - $F_E = \frac{k_E Q_1 Q_2}{r^2}$  where a positive result indicates repulsion, and negative denotes attraction ( $k_E$  is a constant of nature).



# COULOMB'S EXPERIMENT

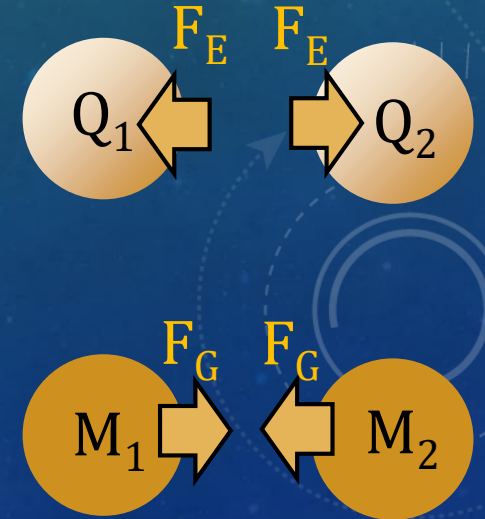
- Coulomb's Law (Coulomb Force for Electric Charge)

- $F_E = \frac{k_E Q_1 Q_2}{r^2}$  (positive = repulsion, negative = attraction)

- This is exactly the same form as Newton's Law of Universal Gravity:  $F_G = \frac{G M_1 M_2}{r^2}$

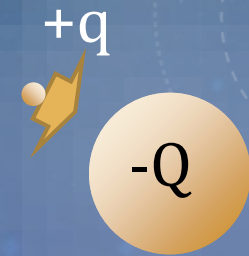
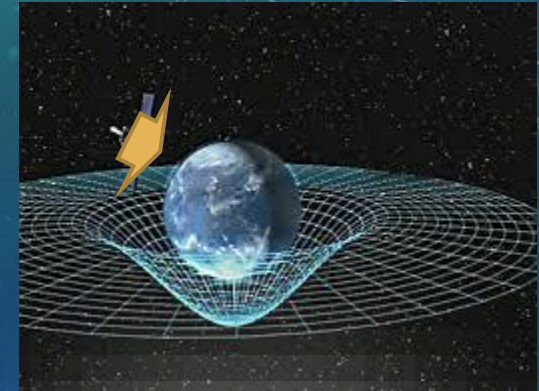
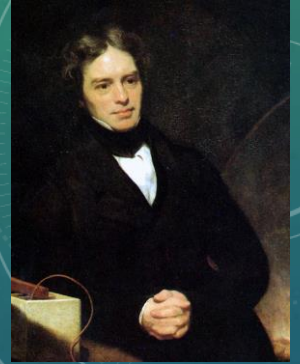
- $k_E$  is called Coulomb's constant, and has a value of  $k_E = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$

- Compare this to the Universal Gravity constant,  $G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$
    - $G$  is much smaller! It takes a lot of mass to make a little gravitational force, but not much charge to make a lot of electric force.
    - Gravity can only attract, however.



# POINT CHARGES – ELECTRIC FORCE AND ELECTRIC FIELD

- By now the question may have arisen in your mind: How can two objects affect each other without touching each other? (This is called ‘**action at a distance**’.)
- **Michael Faraday** (1791 – 1867) proposed the idea of a ‘**field**’ to explain both gravitational and electric forces:
  - A large **mass influences the space** around itself in a way that we can’t directly see, but **another mass can detect**. The other mass then reacts to the distorted space by experiencing an **attractive force**.
  - This works in the same way for charge. **Charge distorts the space** around itself. Other **charge reacts to this distortion** by experiencing an **attractive or repulsive force**.

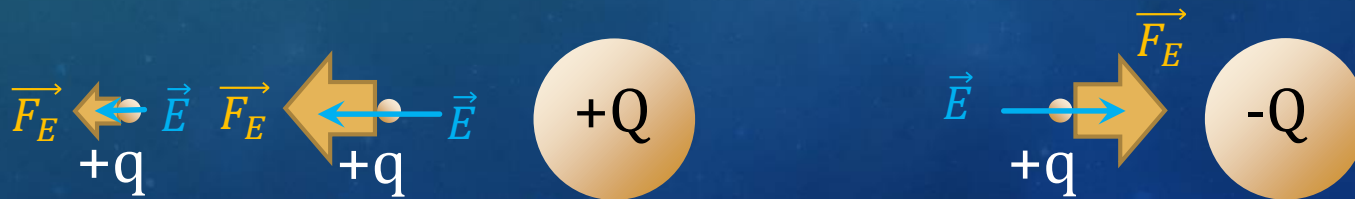


# POINT CHARGES – ELECTRIC FORCE AND ELECTRIC FIELD

- The field has a strength that is related to the strength of the force it causes on a small unit of **positive** charge (a test charge).
- The electric field at that point is a **vector**, and it is in the **direction of the force** it causes on the **positive** test charge.
- The electric field points in the direction a **positive** charge would be pushed.

$$E = \frac{F_E}{q} = \frac{k \cdot Q \cdot q / r^2}{q} = \frac{k_E Q}{r^2}$$

- The **electric field** depends only on the **source charge**, **Q**, not the testing charge.

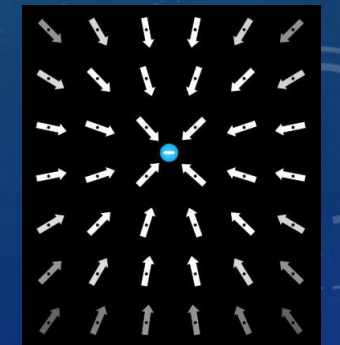
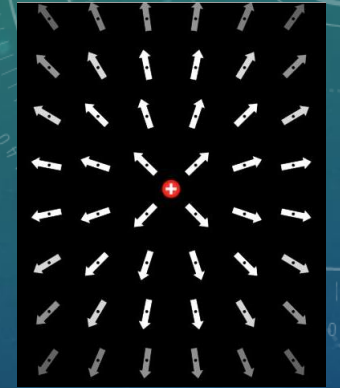


# INTERESTING CHARGE DISTRIBUTIONS – A POINT CHARGE

- Where do we see this type of charge?
  - Positive or negative ions
  - Isolated protons or electrons

## Electric Field Diagrams

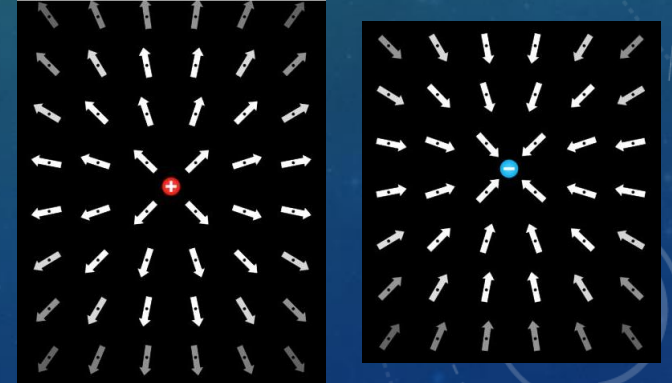
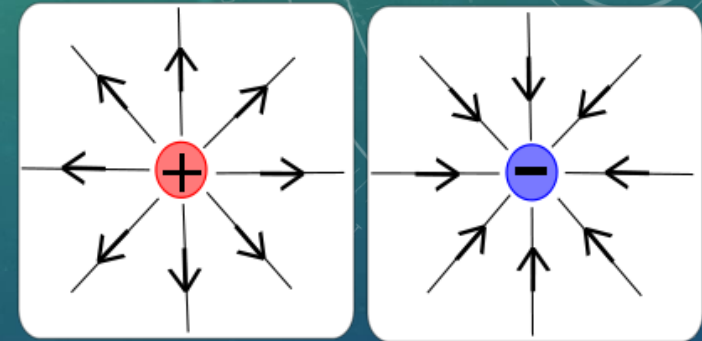
- Point-by-point
  - One way to draw this kind of complicated field is to lay out a grid of points surrounding the charge, then draw an **arrow at each point** that indicates the **size** and **direction** of the electric field there.
  - This is a tedious process to do by hand, but a computer can do it easily.



# INTERESTING CHARGE DISTRIBUTIONS – A POINT CHARGE

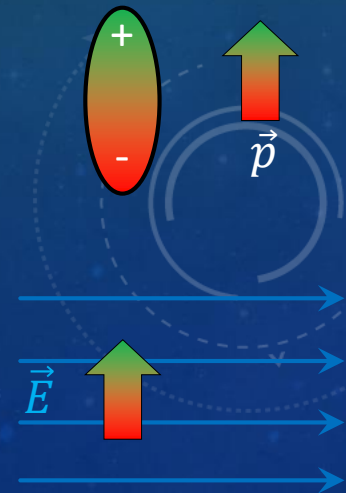
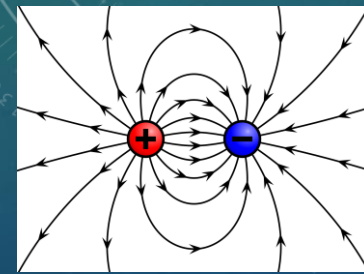
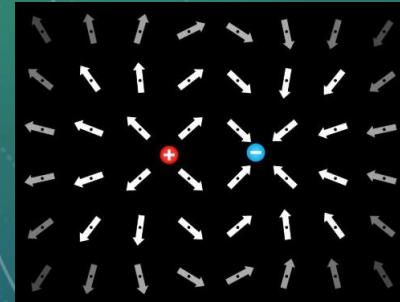
## Electric Field Diagrams

- The classical way to draw fields is to draw lines that connect the arrows you would find with the point-by-point method. These lines follow certain rules:
  - **Field lines start on positive charges** (or at infinity) and **end on negative charges** (or infinity). They are directed from positive charge to negative charge.
  - Field lines **cannot cross** each other.
  - The **density** of field lines indicates **relative strength** of the field. Where the lines get closer together, the field is stronger.



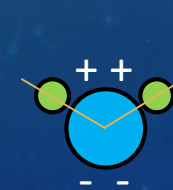
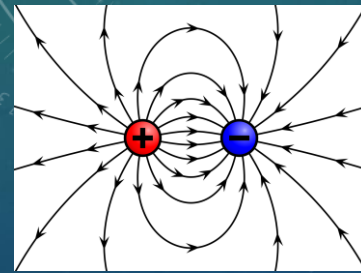
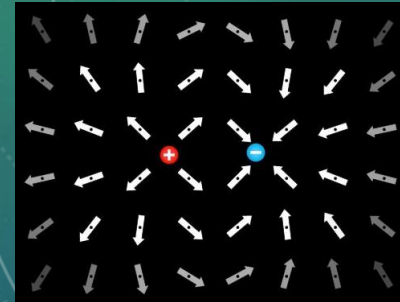
# INTERESTING CHARGE DISTRIBUTIONS - DIPOLE

- In an **electric dipole** there are **two equal but opposite charges** separated by a distance.
- Lines begin on positive charge and end on negative charge.
- A **dipole vector**,  $\vec{p}$ , can be used to represent the dipole. Its strength is (positive charge)\*(separation distance), and is directed from the negative charge to the positive charge.
- How does a dipole react to an external electric field?
  - The **dipole vector tries to line up** with the external field.



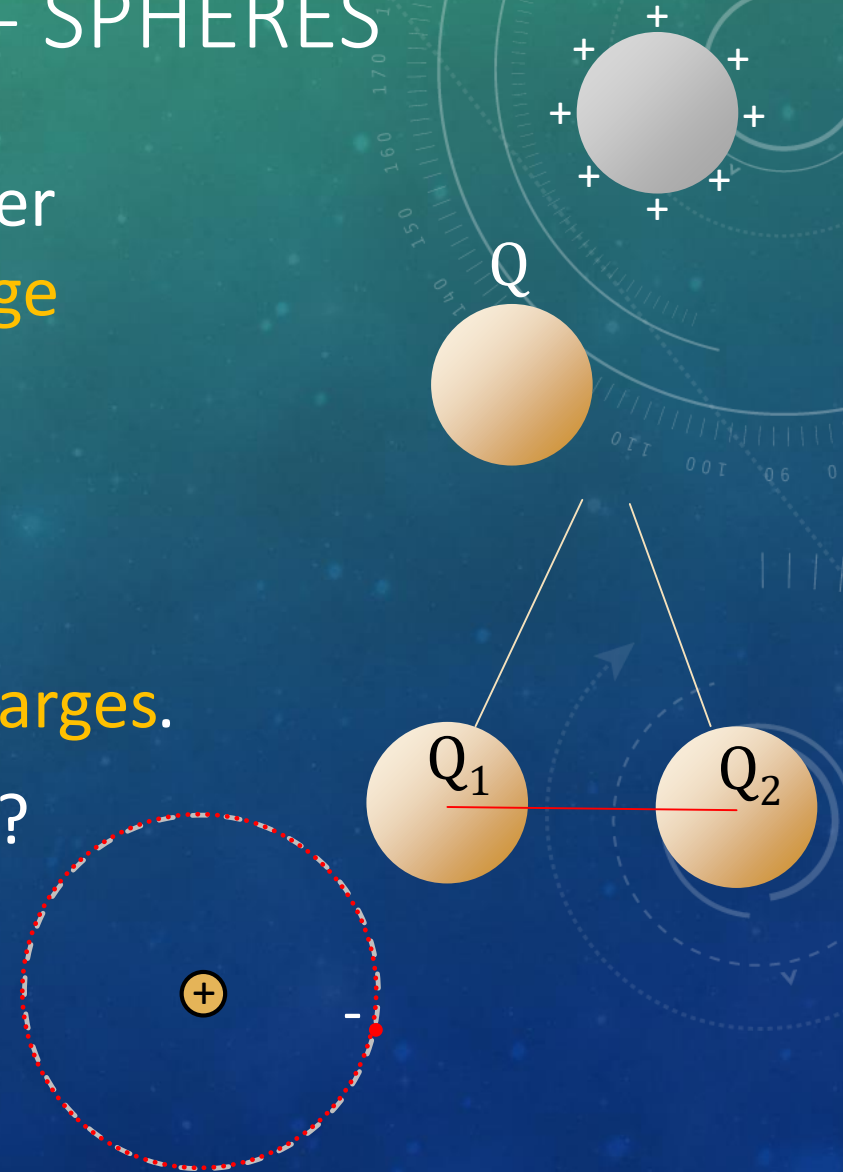
# INTERESTING CHARGE DISTRIBUTIONS - DIPOLE

- Where do we see dipoles?
  - **Water** is one of the most prevalent dipolar molecule. Its chemical structure causes it to naturally have a polarization.
  - Consequences:
    - Water can collect ions from its environment (removes 'static cling').
    - When water freezes, the poles tend to line up, taking up more volume, so ice is less dense than water and it floats.



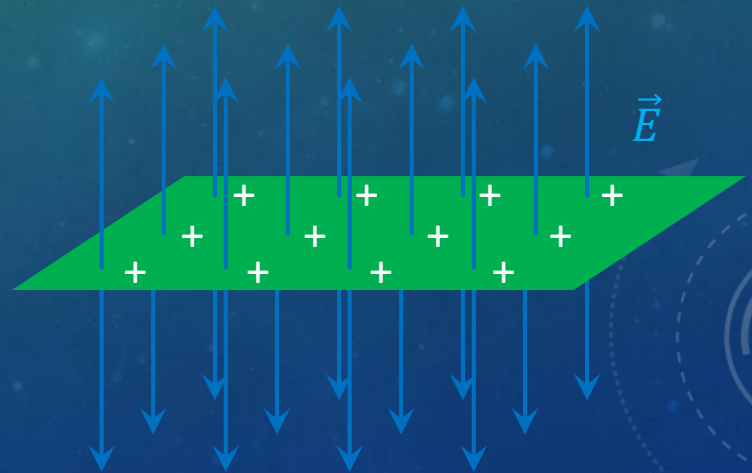
# INTERESTING CHARGE DISTRIBUTIONS - SPHERES

- When charge is placed on **spherical object** (either insulator or conductor), we found that the **charge distributes itself equally around the surface**.
- The spherical charge behaves as if were all concentrated at the center of the sphere.
- **Spheres of charge react as if they were point charges.**
- Where do we see spherical charge distributions?
  - The pith balls in Coulomb's experiment.
  - Electron shells around atoms.



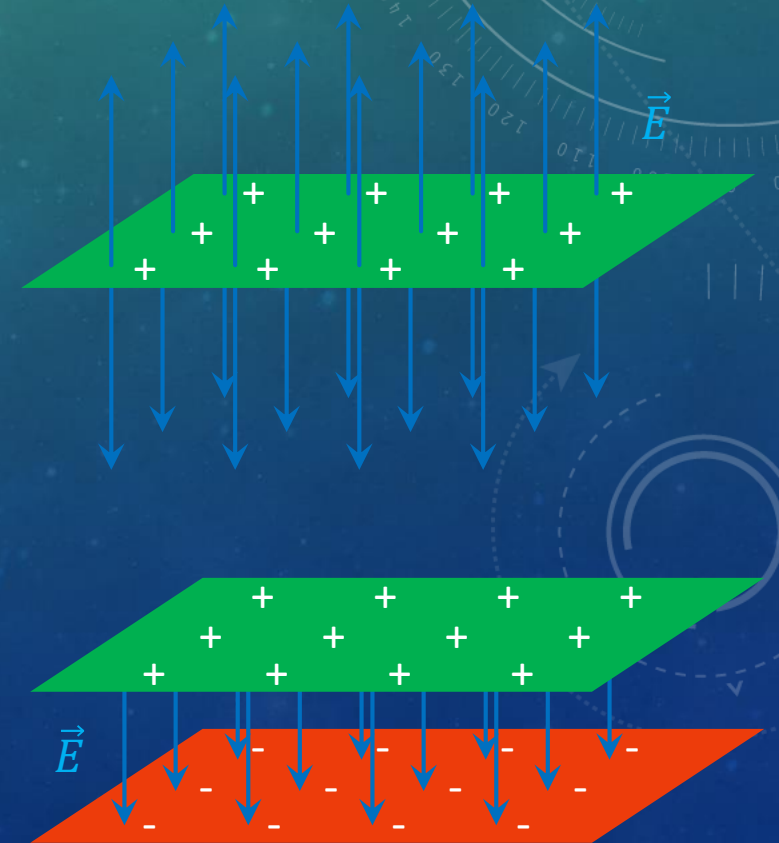
# INTERESTING CHARGE DISTRIBUTIONS – INFINITE SHEETS

- If charge is distributed evenly across a **large flat sheet**, the electric field it produces is special.
  - The field is **constant** and the field lines are **parallel** everywhere near the sheet.
  - This is called a *uniform electric field*.



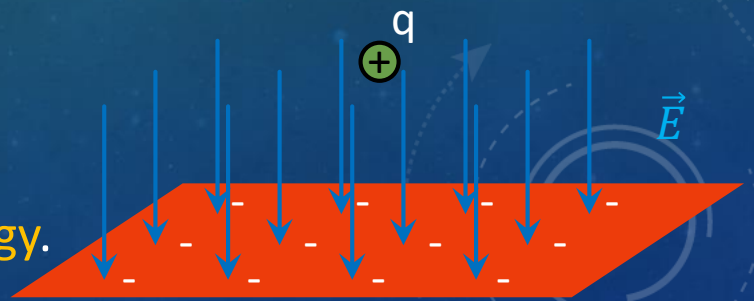
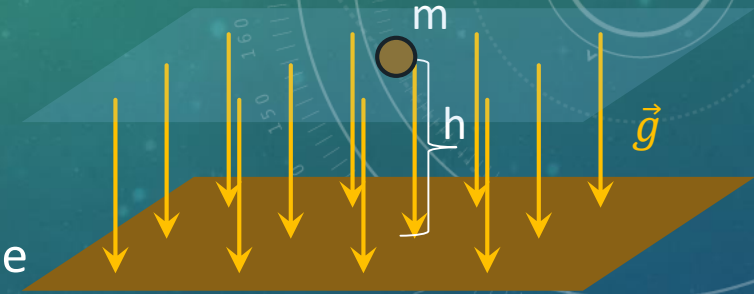
# INTERESTING CHARGE DISTRIBUTIONS – INFINITE SHEETS

- Where do we see it?
  - If we are very near any charged surface, it appears essentially flat and uniform in the local region.
  - Two **parallel plates** can be oppositely charged. This is called a **capacitor**, and we'll talk about it more later.
    - The field between the plates contains the electric field, and the field outside the plates is zero. This is useful for many experiments and also everyday devices.



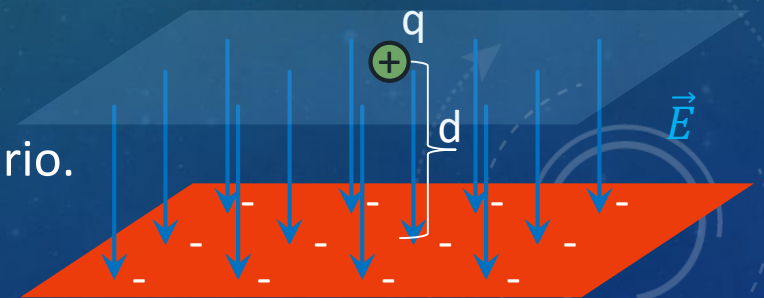
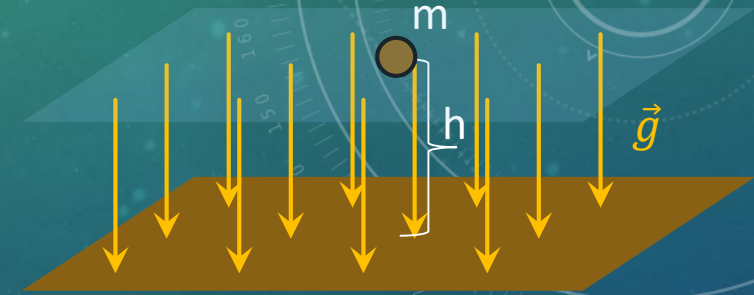
# POTENTIAL ENERGY – GRAVITY AND ELECTRIC

- There are many parallels between **gravity fields** and **electric fields**:
  - Near the surface of the Earth, gravity pulls on masses with equal force and in the downward direction everywhere. **Gravity forms a uniform field near the surface.**
  - A mass in this field ‘detects’ the field as a **force** (weight).
  - This is equivalent to an infinite plane of negative charge acting on a positive charge.
  - A mass at a height above the ground has **gravitational potential energy**.
    - $P_G = m \cdot g \cdot h$
    - If the mass is anywhere else at this same height, it has an equal potential. The plane parallel to the ground at this same height is called an **equipotential**.



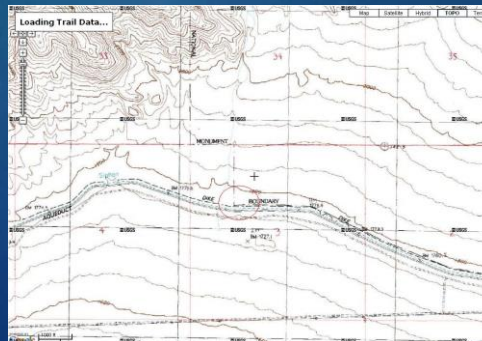
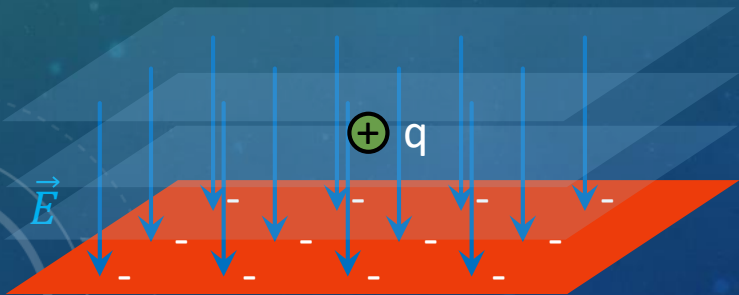
# POTENTIAL ENERGY – GRAVITY AND ELECTRIC

- Gravitational Potential Energy:
  - $P_G = m \cdot g \cdot h$
- Electrical Potential Energy:
  - A charge at some distance,  $d$ , from the plane of charge has electrical potential energy.
  - $P_E = q \cdot E \cdot d$
  - There is also an equipotential plane for the charged plane scenario.
- Important Differences:
  - Gravity can only attract.
  - Electric force can be huge compared to weight.



# EQUIPOTENTIALS

- These are equipotentials near an infinite charged sheet.
  - These are equivalent to elevations on a topographic map.
  - It takes effort (**energy**) to move *between* equipotentials.
  - It takes little to **no energy** to move *along* an equipotential.
- Charged spheres and points
  - The equipotentials are spheres centered around the charge.
- Equipotential lines **never cross** and are **perpendicular to the field**.



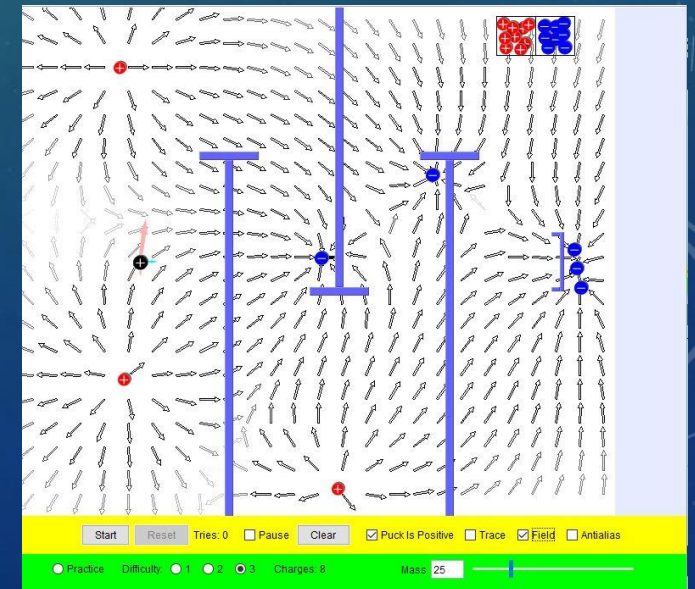
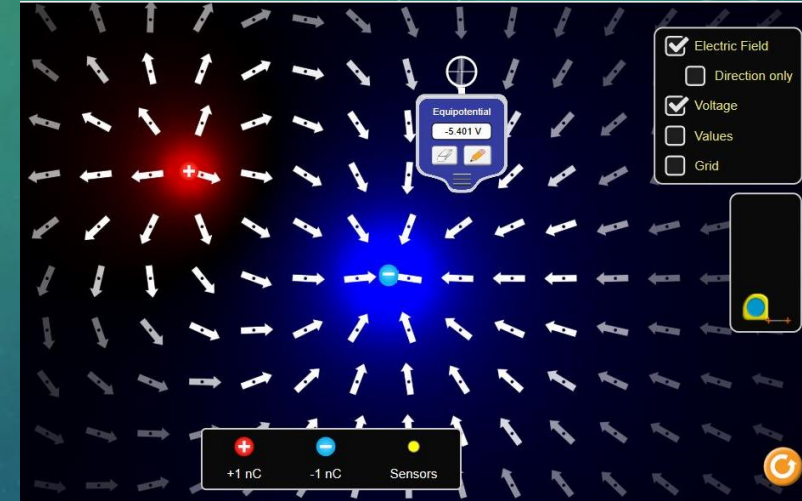
# VOLTAGE

- Voltage is defined as **electric potential energy per unit charge**.
  - Variable:  $V$  or  $\Delta V$
  - Units: Volts (V)
  - For a uniform electric field,  $E$ , the voltage is: 
$$V = \frac{q \cdot E \cdot d}{q} = E \cdot d$$
  - The energy required to move **1 Coulomb** of charge through **1 Volt** of potential is **1 Joule**.
- Think of **voltage** as ‘motivation for charge to move’.



# ELECTRIC FIELD SIMULATIONS

- Link to **Charges and Fields** simulation:
  - [https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields\\_en.html](https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html)
  - Try these things:
    - Place first one, then two, then more positive charges at one spot. How does the electric field change?
    - Make your own dipole. Put one positive and one negative charge in the space. Use the voltage sensor to find where there is zero potential.
    - Place two positive charges in the space, separated by some distance. Place a yellow sensor to measure the field at that point. Try to find where the field is zero (no arrow coming out of the sensor).
- Link to **Electric Field Hockey** simulation:
  - <https://phet.colorado.edu/en/simulation/legacy/electric-hockey>
  - Try this: There are three difficulty levels. Place positive and negative charges on the field in order to get the positively charged puck into the goal without hitting the sides. (Level 3 is hard!)



# CONCLUSION

- **Electric charge influences the space** around itself. Other charge is able to interact with that space by means of attractive or repulsive force.
- The **electric field** at any point is the direction a force would be on a positive charge at that point.
- The **electric field** in the region around a charge can be illustrated using **field lines**.
- Some **distributions of charge** have interesting electric fields. These include points, spheres, and sheets of charge.
- **Equipotentials** are surfaces that have the **same electric potential energy** for a given charge there. It takes **little energy to move along one**, but **significant energy to move between** equipotentials.
- **Voltage** is the **electric potential energy per unit charge**, and characterizes the motivation for a charge to move.