Teachers Guide for set of Electric Fields Mini-Games
by
Embodied Games, LLC

Special thanks to Mina C. Johnson-Glenberg, Colleen Megowan-Romanowicz, and Agatha Anderson

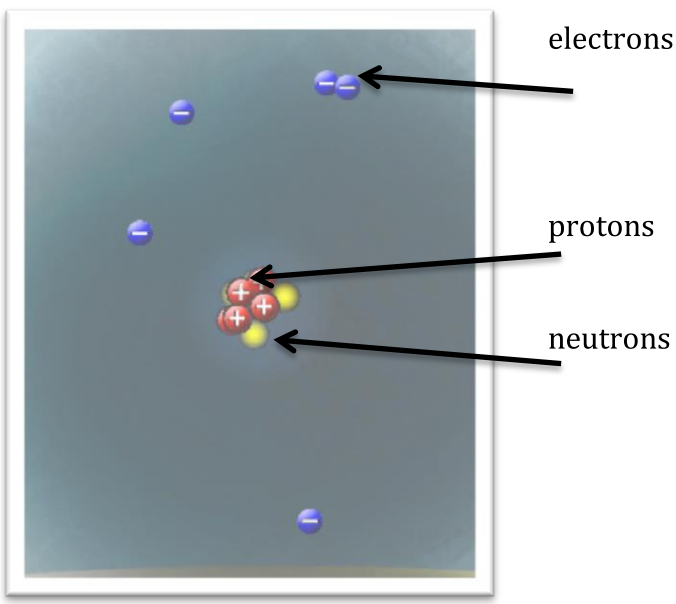
This is a series of mini-games created as an experiment and so short comic scenes have been retained as well as some "experimental type language".
If you plan to use the games that are activated with the Microsoft *Kinect* (version 1) then email info@embodied-games.com for that specialized second set of instructions

Game 1 – Electron Counter

Matter is made of atoms. Charge is a property of matter. There are two types of charge: positive and negative.

An electron carries a negative charge. A proton carries a positive charge. A neutron is a neutral particle. It carries neither a positive nor negative charge.

Atoms are made of protons, neutrons and electrons..



Within an atom, neutrons and positively charged protons are located in the nucleus. Negatively charged electrons orbit the nucleus. In order to determine the overall or "net" charge of an atom, you merely find the sum of positive and negative charges. (The number of neutral charges does not affect the net charge.)

We use a positive whole number (+1) to represent a positive charge, and a negative whole number (-1) to represent a negative charge.

So, an atom with 3 protons (+3) and 1 electron (-1) would have a net charge, or q_{net}, of +2.

GAMEPLAY:
The electrons are in a blue blur in the jar as they spin.
Students can grab NEW electrons with the mouse from the bottom left of the screen and place them into the jar.
To delete electrons, students can grab a spinning electron and toss it out of the jar anywhere on the screen. When ready to sum hit the CALCULATE button on the right side of the screen.

Games 2, 3 and 4 - Meter Made, Vector van Gogh and Push Me –Pull U

This set of three games explores the properties of charges and the importance of understanding what a vector is. They can be played in any order.

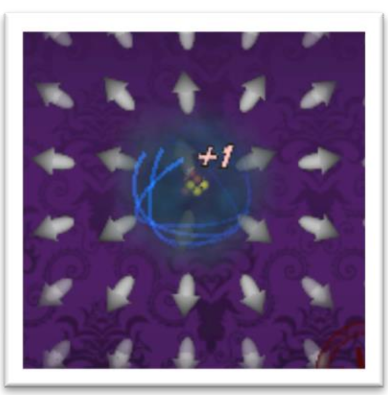
Attraction and Repulsion.
There are some basic properties of charge we use to enable our understanding of electric fields (E-Fields):

Charged particles exert a force on one another. Opposite charges attract, so these charges move towards each other.

Like charges repel, so these charges move away from each other.

But how can charge in one location be affected by the presence of a charge elsewhere?

Every charged particle creates its own electric field around it. As you can see from the image, an electric field extends in all directions and to an infinite distance. But, the field is strongest when closest to the charge creating the field.



An electric field is always directed away from a positively charged particle and towards a negatively charged particle.

Because of the field, charged particles can interact even though they are not in contact with one another.

A relationship exists among:

- the strength of the electric field created by a charged particle
- the magnitude of the charge for that particle and
- the distance from the particle

This relationship can be described in words:

- The strength of the electric field of a particle is directly proportional to its net charge
  (Meaning: the larger the net charge, the stronger the electric field)
- The strength of the electric field in inversely proportional to the square of the distance between charged particles
  (Meaning: the greater the distance from a charge, the weaker the electric field it exerts on another charged particle)

The relationship can be expressed mathematically:

$$F \propto (q_1 * q_2)/ r^2$$

q_1 = net charge of particle 1
q_2 = net charge of particle 2
r = distance between the two particles – note it is squared
$\propto$ means "is proportional to"

We will get back to this version of Coulomb's Law.

Vectors.
A vector is a symbol—an arrow—that represents both magnitude and direction.

When used to represent an electric field, the **length** of the arrow represents the strength (or magnitude) of the electric field, while the **direction** of the arrow represents the direction of the electric field.

The tail of the arrow is placed at the point in space where the electric field is being defined.

If a positively charged particle (called a "test charge") is placed into the field at that point, it would move in the direction indicated by the arrow.

If a negatively charged particle (test charge) is placed into the field at that point, it would move in a direction opposite to that indicated by the arrow.

<u>Game 4 Pull Me - Pull U- Game *focus on Movement*</u>

A charged particle will experience an electromagnetic force if placed in the electric field of another charged particle.

A relationship exists among:

- the strength of the electromagnetic force between the two particles
- the net charge for each particle and
- the distance between the two particles

The relationship can be expressed mathematically:

$$F \propto (q_1 * q_2) / r^2$$

q_1 = net charge of particle 1
q_2 = net charge of particle 2
r = distance between the two particles

We are careful to call this a "relationship" and not Coulomb's Law explicitly because we have left out the very small constant, $k = 8.99 \times 10^9$ N m^2 C^{-2}. For novice students it can be confusing to include the constant.

This relationship can also be described in words:

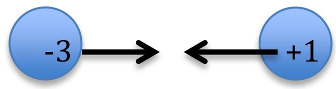
- The Force between charges is directly proportional to the product of the net charges of each particle
  (Meaning: As the net charge of each particle increases, the force they exert on each other increases.)

- Force is inversely proportional to the square of the distance between the two particles
  (Meaning: As the distance between the two particles increases, the force they exert on each other decreases in a non-linear fashion.)

When both particles carry a positive net charge, they will *repel* each other. Their product will yield a *positive* force value.

When both particles carry a negative net charge, they will *repel* each other as well. Yet, their product will yield a *positive* force value.

When the particles carry opposite charges, they will *attract* each other. Their product will yield a *negative* force value. (Note: The absolute value is used in Coulomb's Law.)



So, when the product of the charges is positive, there is a repulsive force between the particles. When the product of the charges is negative there is an attractive force between the particles.

<u>Game 5 – Mitey Fields</u>

When a net force acts on charged particles, they undergo an acceleration, or change in velocity. As the particles move, the distance between them changes, and the electromagnetic force changes. A change in the electromagnetic force will result in a change in acceleration.

Sometimes charged particles can move around freely. This is generally true of electrons (they are almost 2000 times less massive than protons). Protons are also bound to neutrons within the nucleus by the "strong nuclear force".

In order to simplify calculations, we will treat a charged particle as "pinned" or fixed in one location.

The game Mitey Fields starts with a short tutorial on how to place and activate charges to create an E-field. The player is then able to move "Mitey", a mischievous, escaped mite with a charge of +1. In an embodied manner the students then drag and place "pinned" charges anywhere on the screen and can observe the multiple vectors in the changing E-field by clicking on the "sunglasses" icon.

There are multiple levels in this game that can help students learn about forces. The interactions are based on Coulomb's Law so that acceleration and electrostatic forces are represented accurately.

Students will learn:

- And receive reinforcement that like charges repel each other
- That opposite charges attract each other
- That the magnitudes of the pinned charges affect the acceleration of the unpinned charge (Mitey)
- That distance affects positive acceleration and negative acceleration
- The E-field is highly interactive, all charges affect each other into infinity

You should remind students that the game disregards gravity. It is clearly a 2D simplification of our universe's 3D E-field. The goal is to encourage students to visualize the multiple charge interactions in a game-like manner.

Distance between charges is a factor in play, and a component in Coulomb's Law - the **denominator** is the square of the distance between the two charged particles.

The game mechanic allows students to explore how the magnitude of the charges affects how Mitey moves through the field – essentially the **numerator** in Coulomb's Law which is the product of the two charges. The **valence of the charges** (whether they are positive or negative) is also taken into account with direction that Mitey travels.

You may also want to discuss with students constant velocity.
Will Mitey move with a constant velocity in the presence of another charge?

Higher Levels with Gold Bars – In the later levels, students will see gold bars. The bars allow the E-field to pass through, but not the larger atom called Mitey. These levels encourage learners to conceptualize curves in the E-field. Some students will enjoy trying again and again to get Mitey in the hole. Others will stop after a couple of tries, that perseverance is just a trait of the player, it is not to be penalized.

Also, play around with the *sunglasses icon* (top left – "vector view").

<u>Game 6 – Scuff+Spark</u>

Friction, Induction, Charge Separation

Ions are charged atoms. They are created when electrons are added to or removed from an atom. This process of creating ions is known as "ionization".

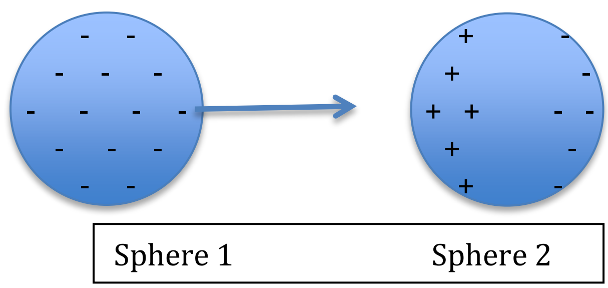
Although there are several ways to ionize an atom, we will consider two methods: friction and induction.

<u>Friction:</u>
Friction can cause electrons to leave one object and move to the other. Generally, objects are neutral. So if electrons leave one object, that object has a greater number of protons than electrons, making it positively charged.

The object that gained electrons now has a greater number of electrons than protons and is negatively charged.

<u>Induction</u>:
During the process of induction, a charged object is placed near a neutral conductor. If the charged object is a negatively charged sphere, then the electrons in the neutral object will be repelled and move to the far side of the neutral object. Some of the electrons leave the protons behind, so that one side of the object is positively charged and the other is negative, but the total number of protons and electrons remains the same.

Imagine Sphere 1 below is a finger with an excess of electrons on it, and Sphere 2 is a door knob. This movement of electrons in Sphere 2 away from the hand is what happens when a negatively charged hand reaches for a metal knob!

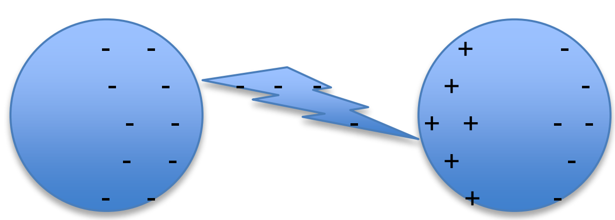


Electrons could only leave their object if there is a conductive pathway connected to the object. This would allow the electrons to move even further away from the negatively charged Sphere 1 (or finger).

When a negatively charged object moves closer to a neutral object, the electrons on the neutral object are repelled, leaving the protons behind. Therefore, the side closest to the negative object is positively charged. If the objects carry a large amount of charge, they create a strong electric field.

The E-field between the positive side and the negative object can become large enough to ionize the air between the objects.

Ionized air is conductive, allowing electrons to pass freely between the charged and neutral objects. The passage of electrons through the air forms a “spark”.



In the game, students use the tracking pad or mouse over the track area (or the 's' key) to simulate friction and accumulate electrons on the virtual finger. (This can be compared to walking across a carpet on a dry day and picking up electrons!)

They should be encouraged to notice what happens when they build up more electrons on the finger.
Does the finger need to be closer or farther from the door knob for a spark to occur with more electrons?

The interactive simulation shows electrons building up via friction in real time. The game includes four trials, the q_{net} of the doorknob changes each time. The interactive display of Coulomb's Law as a relation (without *k*) dynamically changes on screen.

<u>You might ask your students to make predictions:</u>

Will they need to scuff more or less to build up q_{net} on the finger?
Is that represented by the numerator or denominator in Coulomb's Law?

Notice how close they need get to the doorknob to make a spark appear.
Is that represented by the numerator or denominator in Coulomb's Law?

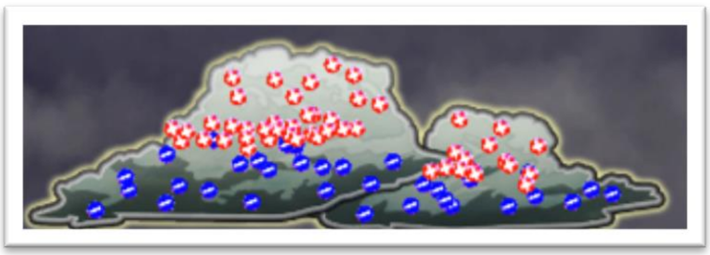
What happens to the electrons on the door knob, inside the metal what do they predict is happening as the hand comes closer and closer? Explain it.
What IS a spark exactly?!

Game 7 Dragon Shockra

In this final game in the series of E-field lessons, players progress rapidly through levels of increasing difficulty. The goal is to feed the hungry dragon lighting strikes. Other charged objects in the world can steal the strikes though, and watch out for the evil birds.

The goal is for students to understand the conditions necessary for a lightning strike.

Within a storm cloud, charges separate. Positive charges move to the top of the cloud while negative charges move to the bottom.



The cloud creates an electric field and repels the electrons in the earth's surface. As more charges separate, the electric field becomes stronger.

Remember that distance will also affect the strength of the E-field. So charges that are close to the cloud will encounter a stronger E-field.

The electric field also causes the air between the cloud and surface to become ionized. Ionized air provides a pathway for the negative charges to move from the cloud to the earth's surface. Once this connection is established, negative charges move **very** rapidly and produce a large spark; we call that lightning.

The relationship of Coulomb's Law will help players understand the conditions before a lightning strike can occur so they can position the dragon correctly. Each level lasts for two minutes. Remind students to note their scores after each game play.

Gameplay:
Student will use the mouse (or their right hand if using *Kinect 2* –second version of *Kinect*) to manipulate the dragon icon to receive lightning strikes – that is what she eats! The slider allows students to set the difficulty level via speed and number of evil birds!

Hitting a bird takes away points.

Ask students, under what conditions will the trees be hit?
Where should they sit when in the middle of a lightning storm?

Students will learn:

- The bottom of the cloud is measured on screen and its changing q_{net} is displayed
- This q_{net} alters with charge separation
- Knowledge of Coulomb’s Law will aid them in positioning the dragon for the maximum number of lightning strikes, and not allow other positively charged components to steal the strike
- Lightning requires certain conditions of E-field magnitude and distance to be met