Lesson Sequence for the Electric Force Inquiry Investigation

Learning Goal: **CA NGSS Standards**	**Students investigate through inquiry the electric force by exploring static electricity phenomenon and building a computer simulation in order to understand the factors that affect the Electric Force (Coulomb's Law).** **Performance Expectation** **HS-PS2-4.** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.] **Disciplinary Core Ideas: PS2.B: Types of Interactions** ▪ Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4) ▪ Forces at a distance are explained by fields permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4), (HS-PS2-5) **Cross Cutting Concepts: Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4)
Targeted Practices:	**NGSS Science and Engineering Practices** **- Using Mathematics and Computational Thinking -** Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. **- Developing and Using Models** Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). **- Engaging in Argument from Evidence** Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.
Key Vocabulary:	charge, electron, proton, Coulomb's Law, electric force, electric field, inverse square law, directly proportiona inversely proportional, charge by conduction, charge by induction, conductor, insulator, Van de Graaff generator, grounding, acceleration, mass, Newton's Laws of Motion
ELA and Math CCSS:	**RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. **RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. **WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research. **MP.2** Reason abstractly and quantitatively. **MP.4** Model with mathematics. **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.

	HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context.

Day 1:

Lesson Phase (Time)	Teacher's Role	Student's Role
Engage (30 min)	Mr. R hands out two pieces of scotch tape to all of the students in class. Then he shows the students how to adhere one piece of tape onto another piece of tape, and then how to pull them apart. This type of interaction can be seen here: https://www.youtube.com/watch?v=YIbEtIuzT8E. In doing so one piece of tape becomes positively charged and the other becomes negatively charged. Mr. R then asks students to Think/Pair/Share on what they think is happening to cause the tape to interact in this way. Mr. R is mindful that at this stage of the lesson it is important to simply listen to the student's answers as oppose to qualifying them as right or wrong.	Each student pulls the two pieces of tape apart and experiences the Electric force interaction that occurs between the two pieces of tape. Students are usually baffled by the interaction and did not expect to see this occur. Students are asked to think about what is happening and to discuss with a partner next to them in class about why the phenomenon that they see occurs. Then students are randomly called on to share their partner's thoughts on the situation.
Explore/Explain (30 min)	A brief explanation of how the Van de Graaff generator works is given and Mr. R demonstrates the generator discharging to a grounding rod. The idea of placing 10 aluminum pie tins on top of the Van de Graaff Generator and turning it on is presented to the students, but not carried out at this point. Previous to conducting the pie tin demonstration Mr. R asks students to write a paragraph predicting and explaining what they think will occur when he turns the generator on with the pie tins on top and why. Students are encouraged to draw the system and add annotations to the drawing to help develop their thinking. Mr. R asks the students to share their thinking with the students around them and then has students share out their explanations on how this works. Then Mr. R commences the pie tin demonstration. Pie tins begin to one by one repel off of the stack and fall down	After watching the Van de Graaff Generator in operation discharging excess charge to a grounding rod, students individually commit to a written prediction of what will occur to the pie tins when Mr. R turns the generator on. This informal writing assignment goes into their lab notebook. In addition to written explanation students draw what is happening including annotations that strengthen their mental models. Then after sufficient writing/drawing time, the students share their explanation with their neighboring student.

	from the top of the generator. After the demonstration occurs a class discussion of the phenomenon of pie tins repelling each other occurs and students are asked to give reasons why this happened. Mr. R asks students to circle places in their drawing that they think are accurate and put boxes around sections that they would like to now change. Then students are asked to write a paragraph explaining what actually occurred in the demonstration and reasoning behind why it may have occurred. Students are encouraged to provide evidence for their arguments here.	Students discuss the phenomenon again with their partners and then are called on randomly to share their explanations. They place circles around sections of their drawing that they think are accurate and boxes around the sections that they think may no longer be correct in their minds. Students write a description of what they think actually occurred in the demonstration and provide evidence and reasoning for these claims.

Day 2:

Explore **(30 min.)** Elaborate (1.5 hrs)	Mr. R instructs students to explore the Balloons and Static Electricity simulation from PHET (https://phet.colorado.edu/en/simulation/balloons) and to collect observations of how objects charge up and the resulting forces from this buildup of charge. They are also asked to explore the Jon Travoltage simulation from PhET. (https://phet.colorado.edu/en/simulation/john-travoltage) This provides another electrostatic phenomenon for students to draw insight from. Next, Mr. R explains to students that we are going to model the Electric Force by building a computer simulation using the simulation software NetLogo. Mr. R models how to incorporate mathematical equations into a NetLogo Simulation using an Energy Conservation model (see attached model) that the students had used previously in class. Then Mr. R asks students to list the factors that they think might be affecting the Electric Force. The students are instructed to go to lab table groups and combine the factors that affect the electric force into a possible equation for the electric force. Students should not be using the book or internet resources here. Only their insight from the previous phenomena should be shaping these mathematical models. Mr. R then asks students to create a NetLogo simulation of the electric force interaction of two charges. This particular simulation will be building off of code that was used in previous simulations that they students have constructed. I ask students to rotate who is the "pilot" and who are the "co-pilots" every 15 minutes throughout the coding portion of lesson.	Students go to the class learning platform, Edmodo, and open the PhET Electric Force Simulations from the link that he provided there. Then they proceed to collecting observations of electrostatic phenomenon in the two simulations provided. These observations are recorded in their notebook. Using a handout showing the example code on how to simulate the Conservation of Energy, students examine an example simulation that illustrates how to incorporate mathematical equations into NetLogo. The students become familiar with the idea of a global variable that can be incorporated into the Conservation of Energy model to drive the behavior of the box in the model. The students ask questions about how the Energy simulation is working and Mr. R explains it to them. Then students individually list factors that affect the Electric force. They go to groups of 4 in their lab groups and share these factors. Incorporating these factors, they decide on a mathematical equation for the Electric force. Students begin coding a simulation involving two charges. Some students code systems where the charges are stationary and others code simulations that are dynamic where one or two of the charges begin to move as a result of the electric force. They embed their mathematical model for the electric force into their simulations using the idea of global variables.

Day 3:

Explain (20 min)	Mr. R asks several students to briefly present the unfinished program that they have been building. He chooses groups that either have interesting code development or have an interesting mental model on the factors that affect the electric force. The aim of this is to share the various mathematical forms of the electric force as well as how students have gone about incorporating these equations into their simulations.	Four groups of students present their current version of their Electric Force NetLogo simulation with the class. These are brief presentations and represent the current thinking of the mathematical modeling by the students as well as the coding techniques used by the students to model the Electric Force. Students ask questions throughout the process to clarify their understanding of both the code and the electric force thinking.
Elaborate Continued (40 min)	Students are asked to continue coding their Electric Force simulations and are reminded to rotate who is the "pilot" of the simulation throughout the class period. Students are asked to submit the finished or unfinished computer simulation to Edmodo by the end of the class period.	Students continue coding their simulations. They are mindful of rotating through who is typing on the keyboard throughout the coding portion of the lesson. They submit their simulation to Edmodo by the end of the period.

Day 4:

Explore (40 min)	Mr. R sets up 4 stations for the students to cycle through. Station 1 has one ring stand with a Styrofoam insulator hanging from it by a cotton string, and another ring stand with a crumpled ball of aluminum foil hanging from it by a cotton string. This station is also accompanied with a fur pelt, glass rod, plastic rod, silk, balloons, and a metal rod. Station 2 has a close reading (See attached close reading 1) that focuses on the details of the electric force without stating the equation explicitly. Station 3 has a computer simulation (http://employees.oneonta.edu/viningwj/sims/ coulombs_law_s.html) allowing students to generate simulated distance and force data between two charges. Station 4 has another close reading (see	Students take about 10 minutes at each station to explore and experience the activity that is presented. At each station they are to document what they are seeing, write questions that arise, and collect data where appropriate. At the close reading stations, they are asked to highlight quotes from the reading that would provide evidence for their claim regarding factors that affect the electric force.

	attached close reading 2) article focused on how electric forces translate into accelerations of the charged object.	
Explain (20 min.)	After students are done cycling through the 4 stations, Mr. R asks the students to revisit their factors that affect the electric force assumptions. He asks them to prepare comments for tomorrow's Whole Class Discussion on the topic of factors that affect the electric force.	Students reflect and write about how the experience of the 4 stations is affecting their thinking in regards to factors that affect the electric force. This reflection goes into their lab notebooks.

Day 5:

Explain (90 min)	Mr. R reminds the students that they will have a Whole Class Discussion centered on the topic: What factors affect the electric force. He asks the students to take 5 minutes to review all data collected, important text from the close reading articles, and observations from station 1 that may be relevant to answering the question. He also explains to the students that their participation will go towards the class participation part of their classwork grade. During the Whole Class Discussion Mr. R purposefully removes himself from the discussion and lets the class know that he will just be an observer for this. He does not try to qualify the answers from the group during this discussion as this would interfere with the students' discourse. However, if things do go off topic he will remind students as to what this discussion is focused on.	Students discuss what factors they think affect the electric force. Students ask questions when they are confused by other students' comments. Students refer to the articles from stations 2 and 4 citing textual evidence to support their claims. Students write down the mathematical form of Coulomb's Law.

	After the discussion Mr. R reveals Coulomb's Law to the class by writing it on the white board. He shows a short YouTube video that illustrates Coulomb's Torsion Balance experiment https://www.youtube.com/watch?v=FYSTGX-F1GM. He then discusses how their models were similar and different from the law.	Students see the apparatus Coulomb used in discovering Coulomb's Law. Then they reflect on their form and contribute to the class discussion on the similarities and differences between their form and Coulomb's Law.

Day 6:

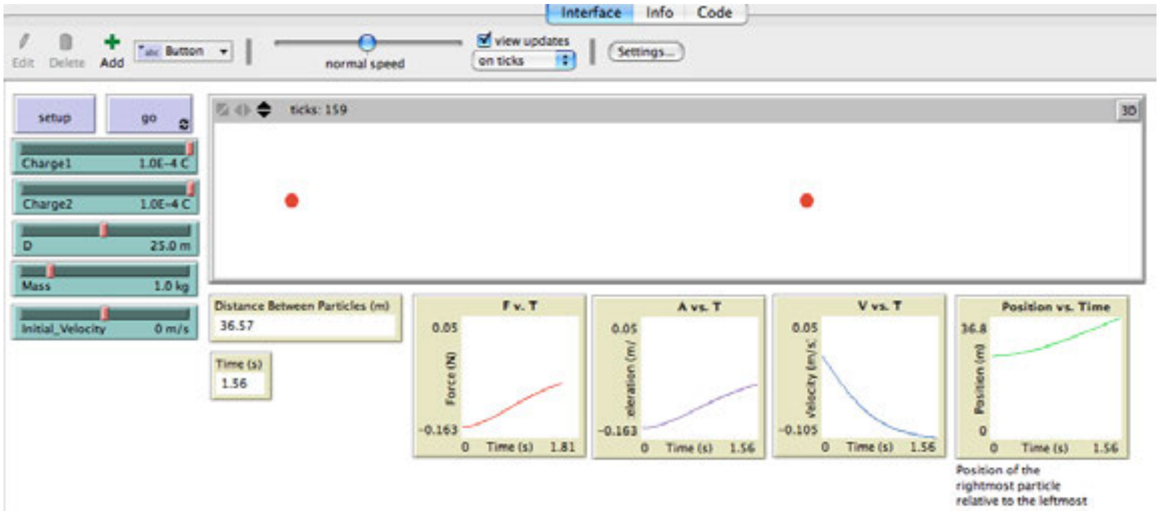
Explore (60 min)	Mr. R discusses with students that today they will utilize Coulomb's Law to calculate and predict the electrostatic forces between charges. The students engage in solving various word problems involving charge, force, and distance. Students are first asked to solve the problems independently for 30 minutes. At this point they are asked to go to their lab groups and work out the problems that were challenging by having discussions with their classmates. Mr. R moves around the room listening to the conversations between the students and helping them out when needed.	The students first work independently on applying Coulomb's Law to the various situations presented in the problem set. When students are struggling on a particular problem they spend a few minutes on it trying to figure it out and then pass to the next problem. After 30 minutes they move to their lab groups to discuss the solutions with their peers and with the support of Mr. R.

Day 7:

Evaluate (60 min)	Mr. R gives students an assessment on the learning objective that was presented at the beginning of the lesson sequence. The assessment is an individual written assessment that involves 3 key parts. The first part of the assessment is that students support claims of the factors that affect the electric force with supporting evidence and reasoning. The second part of the assessment is for students to comment lines of code from one of the student models of the NetLogo Electric Force simulations that were turned in. The third part of the assessment is for students to apply Coulomb's Law to various situations in order to solve for the electric force.	The students take an individual written assessment on the learning objective. They use their experience from the PhET simulations, exploration of the 4 stations, and whole class discussion to make claims supported by evidence and reasoning about the factors that affect the electric force. Then they explain each line of code from a portion of a NetLogo simulation on the electric force. Finally they solve problems that involve applying Coulomb's Law to situations in order to determine the Electric Force.

Student Example of a NetLogo Simulation of the Electric Force
– Entire Simulation created by 4 students in group A

Interface:



Information Tab:

WHAT IS IT?

This model is used to quantitatively simulate the intereactions between two particles with the electric force (F). The simulation uses initial conditions and Coloumb's Equation for the elctric force in order to model particle-particle interaction.

HOW IT WORKS

This model utilizes multiple equations in order to function. The basis of these equations are dictated by the globals defined within the code and in the User Interface (UI):

- [charge1] are [charge2] are globals defined in the UI and correspond to the given charge (in Coloumbs). Charge1 defines the left particle's charge and Charge2 defines the right paricle's charge. The color (via the globals [color1] and [color2]) of each particle also corresponds to its charge, with neutral displaying gray, negative displaying black, and positive displaying red.
- [D] is a UI-defined global that represents distance.
- [Mass] is defined in the UI and is uniform between the two particles.
- [Initial_Velocity] is the beginning velocity of the rightmost particle.
- [F] is defined as the electric force and is defined by Coloumb's Equation embedded into the code:
  F = k(charge1)(charge2)/(D ^ 2)
- [A] is defined as the acceleration of the rightmost particle, defined by Newton's Second Law, embedded in the code:
  F = mA
  A = F / m
- [V] is the given velocity of the rightmost particle, defined as a function of time and acceleration:
  V = (initial_velocity) + (A * T))
- [X] is the position of the rightmost particle's position. It changes depending on the velocity defined above.
- [T] represents time, as a replacement of ticks. Within the code, the value for T increases by 0.01 every 0.01 seconds. As such, T represents time in the real-world.
- [R] is the distance between two particles, which is identical to X.
- [k] is Coloumb's constant, defined as 9 * (10 ^ 9) at the setup phase of the code.

HOW TO USE IT

(1) Select values for the particle's charges and the distance between them. Choose values for their mass and the rightmost particle's initial velocity.
(2) Hit the setup button.
(3) Hit the go button to begin the simulation.

At any point during the model, the "go" button can be deslected to stop the model manually.

THINGS TO NOTICE

As the simulation is running, notice the velocity of the right particle. Is it constant or does it change? How does the movement of the particle relate to its distance from the left particle?

THINGS TO TRY

1) Make one or both charges neutral. What happens?

2) If both charges are positive, do the particles repel or attract?

3) How does the mass affect velocity? Try increasing the mass and using the graph provided to examine this relationship.

EXTENDING THE MODEL

This is a simplistic model of the electric force, with only one particle moving at a time. To extend this model, both particles can be allowed movement. In addition, more than two particles can be included in the model to demonstrate the addition of force vectors.

NETLOGO FEATURES

Note the use of [globals] at the top of the code to define variables not present in the user interface.

The most important part of this model are the relationships defined by the equations embedded in the simulation. View the "How it Works" section to see more.

RELATED MODELS

This model is most like the "Traffic Basic" model in the NetLogo Model Library. It utilizes a similar interaction between acceleration, velocity, and position for the right particle.

CREDITS AND REFERENCES

Programmed by: Joshua, Joe, Ryan, and Jace
Teacher: Mr. Reese
Tracy High School IB Physics Period 1

Code:

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Globals[F A V X T R k color1 color2]          ;Force, Acceleration, Velocity, Position, Time, Distance, constant, color charge 1, color charge 2

to setup
  ca
  reset-ticks
  ask patches[set pcolor white]               ;Sets the world to the color white
  ifelse charge1 >= 0                         ;If the charge is greater than or equal to zero, check if...
    [if charge1 = 0 [set color1 gray]         ;the charge of turtle 0 is 0 the color with be grey
     if charge1 > 0 [set color1 red] ]        ;the charge is greater than 0 the color will be red
    [set color1 black]                        ;If the charge is less than zero, color will be black
  ifelse charge2 >= 0                         ;If the charge is greater than or equal to zero, check if...
    [if charge2 = 0 [set color2 gray]         ;the charge of turtle 1 is 0 the color with be grey
     if charge2 > 0 [set color2 red] ]        ;the charge is greater than 0 the color will be red
    [set color2 black]                        ;If the charge is less than zero, color will be black
  ask patch 0 0 [sprout 1                     ;Sprout a turtle at patch coordinate: (0,0)
    [set size 1                               ;Set turtle size to 1
      set color color1                        ;Set color to whatever color 1 is
      set shape "circle"                      ;Set shape of turtle to "circle"
    ]]
  ask patch (0 + D) 0 [sprout 1               ;Sprout a turtle at patch coordinant: (0 + Displacement,0)
    [set size 1                               ;Set turtle size to 1
      set color color2                        ;Set color to whatever color 2 is
      set shape "circle"                      ;Set shape of turtle to "circle"
    ]]
  set x D                                     ;Set the x value as the slider's for distance
  set k (9 * (10 ^ 9))                        ;Defines Coloumb's Constant in a numberic value
  end

to go
  tick
  wait 0.001                                          ;Wait 0.001 of a second between ticks
  every .01 [set T T + .01]                           ;Every 0.01 seconds, set the time up by 0.01
  set R x                                             ;Set the distance between the two particles x
  set F ((- (k) * (charge1) * (Charge2)) / (R ^ 2))   ;Defines the equation for the Electrical force
  set A (F / mass)                                    ;Defines the equation for Acceleration
  set v (initial_velocity + (A * T) )                 ;Defines the equation for Velocity
  set x (x - v)                                       ;Defines the equation for Displacement
  ask turtle 1 [setxy x 0]                            ;Positions the turtle at the given x value
  if x <= 1 [ask turtle 1 [set xcor 0]                ;If the displacement is equal to or less then 1, the turtle will stop
    stop]
  if x >= 55 [stop]                                   ;If the displacement is equal to or greater than 55, the turtle will stop
end
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Name: Date:

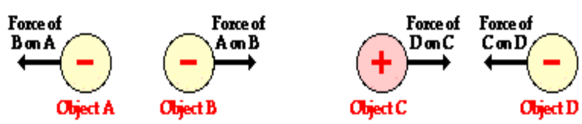
The Electric Force Close Reading # 1

Directions: Read this article specifically for any information that will help you understand the factors that affect the electric force. You are looking for evidence and reasoning that will support your claim. Highlight all relevant information with regards to this focus.

Force as a Vector Quantity

The electrical force, like all forces, is typically expressed using the unit Newton. Being a force, the strength of the electrical interaction is a vector quantity that has both magnitude and direction. The direction of the electrical force is dependent upon whether the charged objects are charged with like charge or opposite charge and upon their spatial orientation. By knowing the type of charge on the two objects, the direction of the force on either one of them can be determined with a little reasoning. In the diagram below, objects A and B have like charge causing them to repel each other. Thus, the force on object A is directed leftward (away from B) and the force on object B is directed rightward (away from A). On the other hand, objects C and D have opposite charge causing them to attract each other. Thus, the force on object C is directed rightward (toward object D) and the force on object D is directed leftward (toward object C). When it comes to the electrical force vector, perhaps the best way to determine the direction of it is to apply the fundamental rules of charge interaction (opposites attract and likes repel) using a little reasoning.

Determining the Direction of the Electrical Force Vector



Electrical force also has a magnitude or strength. Like most types of forces, there are a variety of factors that influence the magnitude of the electrical force. Two like-charged balloons will repel each other and the strength of their repulsive force can be altered by changing three variables. First, the quantity of charge on one of the balloons will affect the strength of the repulsive force. The more charged a balloon is, the greater the repulsive force. Second, the quantity of charge on the second balloon will affect the strength of the repulsive force. Gently rub two balloons with animal fur and they repel a little. Rub the two balloons vigorously to impart more charge to both of them, and they repel a lot. Finally, the distance between the two balloons will have a significant and noticeable effect upon the repulsive force. The electrical force is strongest when the balloons are closest together. Decreasing the separation distance increases the force. The magnitude of the force and the distance between the two balloons is said to be *inversely related.*

Coulomb's Law Equation

The quantitative expression for the effect of these three variables on electric force is known as Coulomb's law. Coulomb's law states that the electrical force between two charged objects is directly proportional to the product of the quantity of charge on the objects and inversely proportional to the square of the separation distance between the two objects. In equation form, Coulomb's law can be stated as

Name: Date:

The Electric Force Close Reading # 2

Directions: Read this article specifically for any information that will help you understand the factors that affect the electric force. You are looking for evidence and reasoning that will support your claim. Highlight all relevant information with regards to this focus.

The attractive or repulsive interaction between any two charged objects is an **electric force**. Like any force, its effect upon objects is described by Newton's laws of motion. The electric force - F_{elect} - joins the long list of other forces that can act upon objects. Newton's laws are applied to analyze the motion (or lack of motion) of objects under the influence of such a force or combination of forces. The analysis usually begins with the construction of a free-body diagram in which the type and direction of the individual forces are represented by vector arrows and labeled according to type. The magnitudes of the forces are then added as vectors in order to determine the resultant sum, also known as the net force. The net force can then be used to determine the acceleration of the object.

In some instances, the goal of the analysis is not to determine the acceleration of the object. Instead, the free-body diagram is used to determine the spatial separation or charge of two objects that are at static equilibrium. In this case, the free-body diagram is combined with an understanding of vector principles in order to determine some unknown quantity in the midst of a puzzle involving geometry, trigonometry and Coulomb's law. In this last section of Lesson 3, we will explore both types of applications of Newton's laws to static electricity phenomenon.

Electric Force and Acceleration

Suppose that a rubber balloon and a plastic golf tube are both charged negatively by rubbing them with animal fur. Suppose that the balloon is tossed up into the air and the golf tube is held beneath it in an effort to *levitate* the balloon in midair. This goal would be accomplished when the spatial separation between charged objects is adjusted such that the downward gravity force (F_{grav}) and the upward electric force (F_{elect}) are balanced. This would present a difficult task of manipulation as the balloon would constantly move from side to side and up and down under the influences of both the gravity force and the electric force. When the golf tube is held too far below the balloon, the balloon would fall and accelerate downward. This would in turn decrease the separation distance and lead to an increase in the electric force. As the F_{elect} increases, it would likely exceed the F_{grav} and the balloon would suddenly accelerate upward. And finally, if the *point of charge* on the golf tube is not directly under the *point of charge* of the balloon (a likely scenario), the electric force would be exerted at an angle to the vertical and the balloon would have a sideways acceleration. The likely result of such an effort to levitate the balloon would be a variety of instantaneous accelerations in a variety of directions.

Levitating a Balloon