Coulomb's Law – ID: 9747

By Charles W. Eaker

Time required
45 minutes

Topic: Electricity and Magnetism

- *Use Coulomb's law to solve problems of force between electric charges.*
- *Solve problems involving point charges and force using vector addition.*
- *Solve problems for the strength and direction of an electric field.*

Activity Overview

In this activity, students explore the relationship between force, charge, and distance for two charged particles, i.e., Coulomb's law. Students observe how force changes with distance by moving a charged particle. By fitting the data collected for force vs. distance to a power regression equation, students determine that electrical force is inversely proportional to distance squared. After determining the dependence of electrical force on charge, the students are able to write the Coulomb's law equation. Next, students see how force changes with like and unlike charges. The activity ends with an application of Coulomb's law to solve a problem involving two charged particles and a test charge.

Materials

To complete this activity, each student will require the following:

- *TI-Nspire™ technology*
- *pen or pencil*
- *blank sheet of paper*

TI-Nspire Applications

Graphs, Geometry, Notes

Teacher Preparation

Before carrying out this activity, review the units of force and electrical charge. You may also want to review the representation of forces with vectors.

- *The screenshots on pages 2–6 demonstrate expected student results. Refer to the screenshots on pages 7 and 8 for a preview of the student TI-Nspire document (.tns file).*
- ***To download the .tns file, go to education.ti.com/exchange and enter "9747" in the search box.***

Classroom Management

- *This activity is designed to be **teacher-led** with students following along on their handhelds. You may use the following pages to present the material to the class and encourage discussion. Note that the majority of the ideas and concepts are presented only in **this** document, so you should make sure to cover all the material necessary for students to comprehend the concepts.*
- *Students may answer the questions posed in the .tns file using the Notes application or on blank paper.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

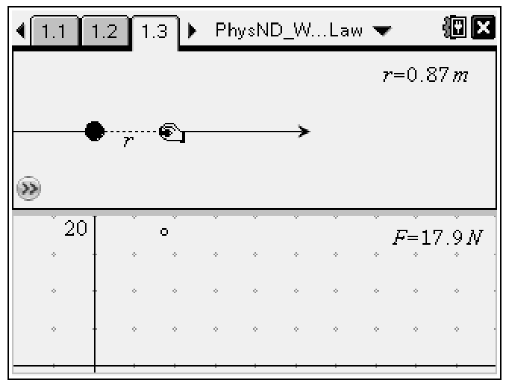
The following questions will guide student exploration in this activity:

- How is electrical force related to the distance between charged particles?
- How is electrical force related to the magnitudes of the charges of separated particles?
- How do the signs of the charges affect electrical force?

In problem 1 of the activity, students vary the separation of two charged particles. They observe the change in electrical force with varying separation. With a manual data capture of force and distance data, a graph of force vs. distance, and a power regression, students determine the mathematical relationship between force and distance. In problems 2 and 3, students will vary the charge of the particles. This leads to the writing of Coulomb's law. Problem 4 is an investigation of the effects of like and unlike charges. In the final part of the activity, students move a test charge around two charged particles, one with a known charge and the other with an unknown charge, and observe the net force on the test charge. They are then asked to determine the unknown charge.

Problem 1 – Electrical force and distance

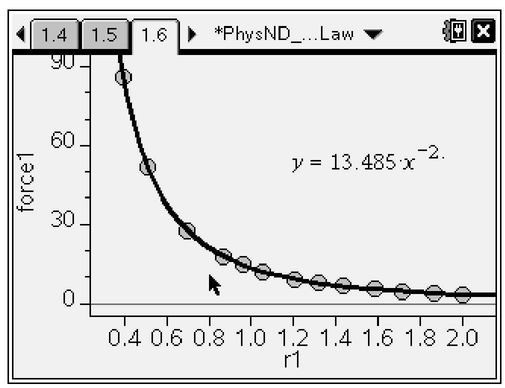
Step 1: Students should open the file **PhysND_Week30_CoulombsLaw.tns** and read the first two pages. Page 1.3 shows two positively charged particles separated by a distance *r*. Students should drag the smaller particle to vary the separation between the two charged particles. Then, they should answer question 1.



Q1. Describe how *F* changes as *r* changes.

A. F *increases as* r *decreases.*

Step 2: Next, students should return to page 1.3 and do a manual capture of force and distance data. To capture a data point, students should press ctrl . . Students should capture at least 10–15 data points. The data will be stored in the spreadsheet on page 1.5. On page 1.6, students should make a graph of **force1** vs. **r1**. Then, they should use the **Power Regression** tool (**Menu > Analyze > Regression > Show Power**) to find a power regression that fits the data. Then, they should answer questions 2 and 3.



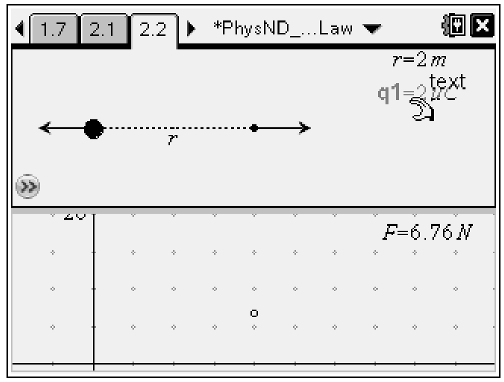
Q2. Write the equation for electrical force (*F*) as a function of distance (*r*).

A. $F = \dfrac{13.485}{r^2}$

Q3. What type of relationship is this? What are some other phenomena that show a similar relationship?

A. *It is an inverse-square relationship. Encourage student discussion of other inverse-square phenomena, such as gravitational force vs. distance and light intensity vs. distance.*

Problem 2 – Effects of changing one charge on electrical force



Step 1: Next, students should move to page 2.1 and read the text there. Then, they should move to page 2.2, which again shows two positively charged particles separated by a distance *r*. In this simulation, *r* is fixed, but students can vary the charge on the smaller particle (**q1**). Students should vary **q1** and observe the effects on *F*. Then, they should answer questions 4 and 5.

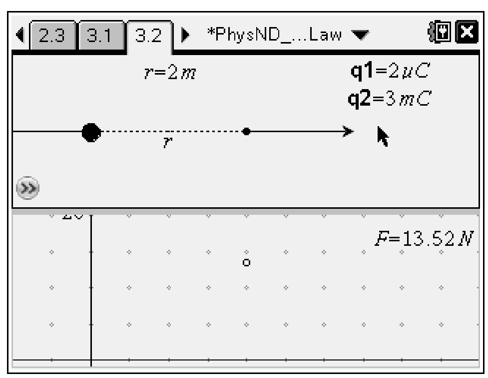
Q4. If **q1** is doubled, from +1 to +2 μC, what is the effect on the force?

A. *The force doubles.*

Q5. Describe how doubling **q1** would affect the equation relating *F* and *r*.

A. *The value of the constant would change, but the functional form would remain the same—that is, it would still be an inverse-square relationship.*

Problem 3 – Effects of changing both charges on electrical force



Step 1: Next, students should move to page 3.1 and read the text there. Then, they should move to page 3.2, which shows two positively charged particles separated by a distance *r*. In this simulation, students can vary the charges of both particles (**q1** and **q2**). Students should vary **q1** and **q2** and observe the effects on *F*. Then, they should answer questions 6–9.

Q6. If the charges on both particles are doubled, what is the effect on the force?

A. *The force increases by a factor of four.*

Q7. What do these data indicate about the relationship between the charges on two particles and the electrical force between them?

A. *The data suggest that force is proportional to the product of the charges. Encourage students to discuss why this must be the case.*

Q8. Write an equation for electrical force F in terms of q_1, q_2, and r. Let the constant of proportionality be k.

A. $F = k\frac{q_1 \bullet q_2}{r^2}$*; encourage student discussion on how to derive this equation.*

Q9. What are the numerical value and units of k?

A. *To solve this problem, students should first solve the equation they derived above for* k*, as shown below:*

$$k = \frac{F \bullet r^2}{q_1 \bullet q_2}$$

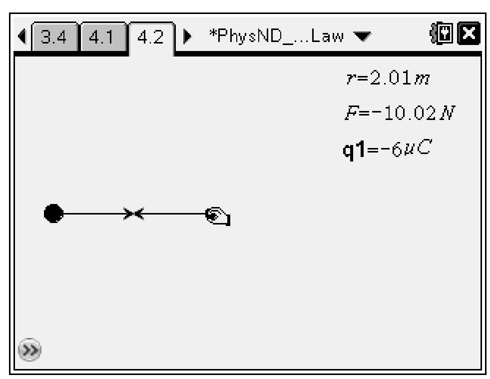
Then, students should use the simulation on page 3.2 to obtain specific values for F, r, q_1, *and* q_2 *and use these values to calculate the value of* k*. For example, if* r *= 2 m,* $q_1 = 1 \times 10^{-6}$ *C, and* $q_2 = 1.5 \times 10^{-3}$ *C, then* $F = 3.38$ *N. Therefore,* $k = 9 \times 10^9$ $N{\cdot}m^2/C^2$*, as shown below:*

$$k = \frac{(3.38\ N)(2\ m)^2}{(1 \times 10^{-6}\ C)(1.5 \times 10^{-3}\ C)}$$

$$= 9 \times 10^9\ N \bullet m^2/C^2$$

Problem 4 – The effect of the signs of the charge on electrical force

Step 1: Next, students should move to page 4.1 and read the text there. Then, they should examine the simulation on page 4.2, which shows two charged particles separated by a distance *r*. In this simulation, **q1** is negative. Students should vary *r* by dragging the smaller point and observe the effects on *F*. Then, students should vary **q1** and observe the effects on *F*. They should then answer questions 10–13.



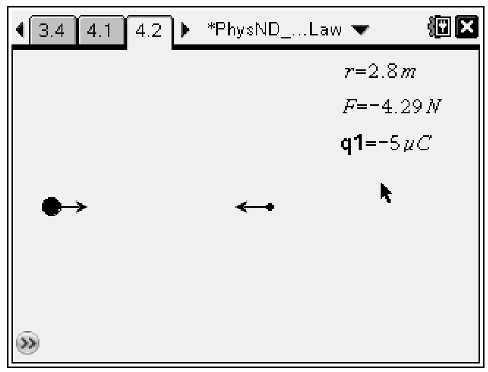
Q10. How are the electrical force and the force vectors in this simulation different from those on pages 1.3, 2.2, and 3.2?

A. *The force in this simulation is negative; it was positive in the other simulations. The force vectors in this simulation are pointing toward each other. In the other simulations, the force vectors pointed away from each other.*

Q11. Are these particles being attracted or repelled by each other? How is this different from the previous simulations?

A. *In this simulation, the particles are attracted to each other. In the other simulations, they were repelled by each other.*

Q12. Use Coulomb's law to determine the charge (**q2**) on the larger particle.



A. *First, solve the Coulomb's law equation for* q_2, *as shown below:*

$$q_2 = \frac{F \cdot r^2}{k \cdot q_1}$$

Then, substitute specific values to solve for q_2. *For example, if* $r = 2.8$ *m,* $q_1 = -5 \times 10^{-6}$ *C, and* $F = -4.29$ *N, then* $q_2 = 7.5 \times 10^{-4}$ *C, as shown below:*

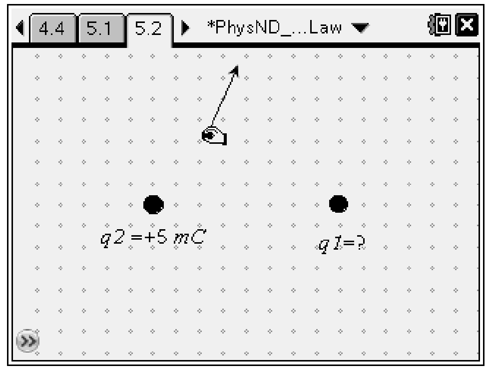
$$q_2 = \frac{(-4.26\ N)(2.81\ m)^2}{(9 \times 10^9\ N \cdot m^2/C^2)(-5 \times 10^{-6}\ C)}$$

$$= 7.5 \times 10^{-4}\ C$$

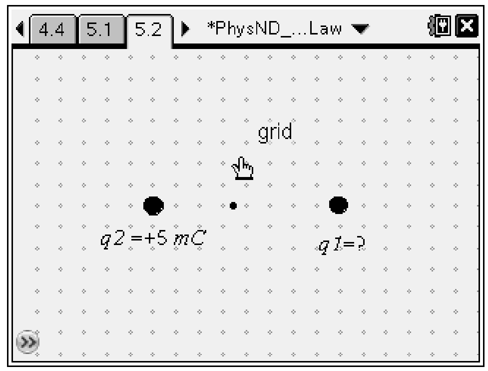
Q13. What is always true about the electrical force vector for each particle, regardless of the magnitude or sign of the charge on the particles?

A. *The magnitude of the force vector is always the same for both particles.*

Problem 5 – Using a test charge



Step 1: Next, students should read the text on page 5.1 before moving to page 5.2, which shows a movable test charge and two fixed point charges. The vector attached to the test charge indicates the net electric force on the test particle due to **q1** and **q2**. Students should move the test charge and observe the electric force vector. Then, they should answer questions 14–16.



Q14. Is the charge of the test particle positive or negative? Explain your answer.

A. *Charge **q2** is positive, and the electrical force vector of the test charge points away from particle 2. Like charges repel. Therefore, the test charge must also be positively charged.*

Q15. At what point is the net force on the test particle equal to zero?

A. *The net force is zero when the test charge is between the particles and a little closer to particle 1. The distance between the test charge and particle 1,* r1, *is about 3.5 units. The distance between the test charge and particle 2,* r2, *is about 4.5 units.*

Q16. Use Coulomb's law to determine **q1**.

A. *At the point where the net force is zero, F1 = F2, where* F1 *is the force on the test charge due to* q_1 *and* F2 *is the force on the test charge due to* q_2*, as shown below:*

$$F1 = k\frac{q_1 q_{test}}{r_1^2} \qquad F2 = k\frac{q_2 q_{test}}{r_2^2}$$

Setting these equations equal to each other and rearranging gives an equation for q_1*.*

$$\cancel{k}\frac{q_1 \cancel{q_{test}}}{r_1^2} = \cancel{k}\frac{q_2 \cancel{q_{test}}}{r_2^2}$$

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2}$$

$$q_1 = \frac{q_2 r_1^2}{r_2^2}$$

Substituting values from the simulation yields $q_1 = \dfrac{q_2 r_1^2}{r_2^2} = \dfrac{(5\ mC)(3.5)^2}{(4.5)^2} = 3\ mC$.

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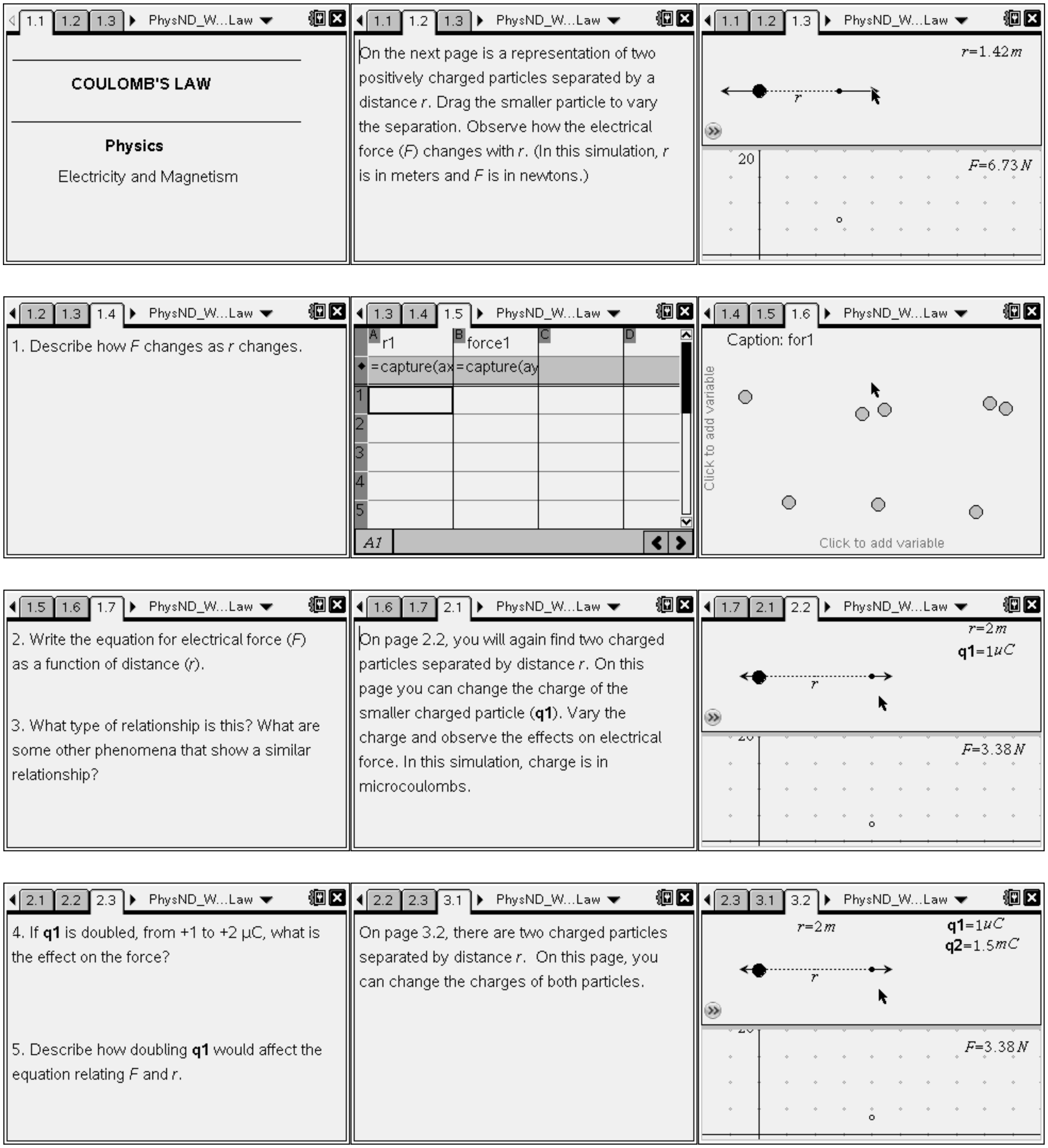
(Student)TI-Nspire File: *PhysND_Week30_CoulombsLaw.tns*



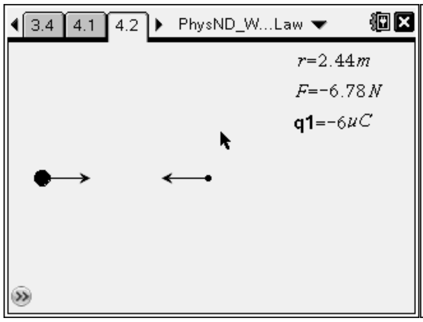
6. If the charges on both particles are doubled, what is the effect on the force?

7. What do these data indicate about the relationship between the charges on two particles and the electrical force between them?

8. Write an equation for electrical force *F* in terms of *q1*, *q2*, and *r*. Let the constant of proportionality be *k*.

9. What are the numerical value and units of *k*?

The equation you have written is known as Coulomb's law. The constant *k* is Coulomb's constant. The next page shows two charged particles. However, there is something very different about the force and the force vectors.



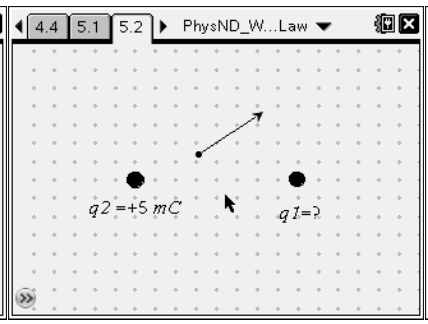
10. How are the electrical force and the force vectors in this simulation different from those on pages 1.3, 2.2, and 3.2?

11. Are these particles being attracted or repelled by each other? How is this different from the previous simulations?

12. Use Coulomb's law to determine the charge (**q2**) on the larger particle.

13. What is always true about the electrical force vector for each particle, regardless of the magnitude or sign of the charge on the particles?

On the next page is an interesting problem involving three charged particles. The small particle is a movable test charge. The vector attached to this particle indicates the net electric force on the test particle due to **q1** and **q2**. Change the position of the test charge, and observe the electric force vector.



14. Is the charge of the test particle positive or negative? Explain your answer.

15. At what point is the net force on the test particle equal to zero?

16. Use Coulomb's law to determine **q1**.