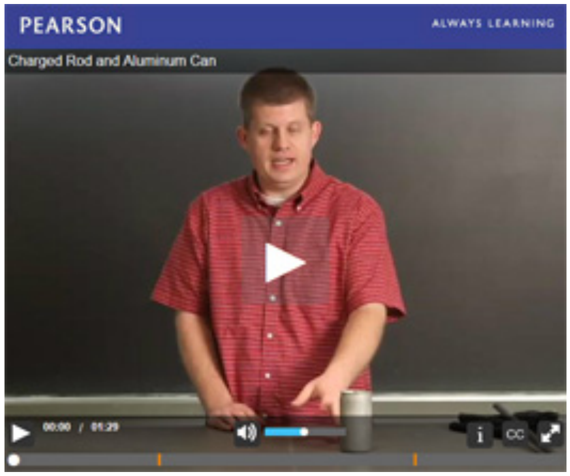
## HW due 5/23 (extended to 5/25 due to drop/add)

**Due: 7:00am on Wednesday, May 25, 2016**

To understand how points are awarded, read the Grading Policy for this assignment.

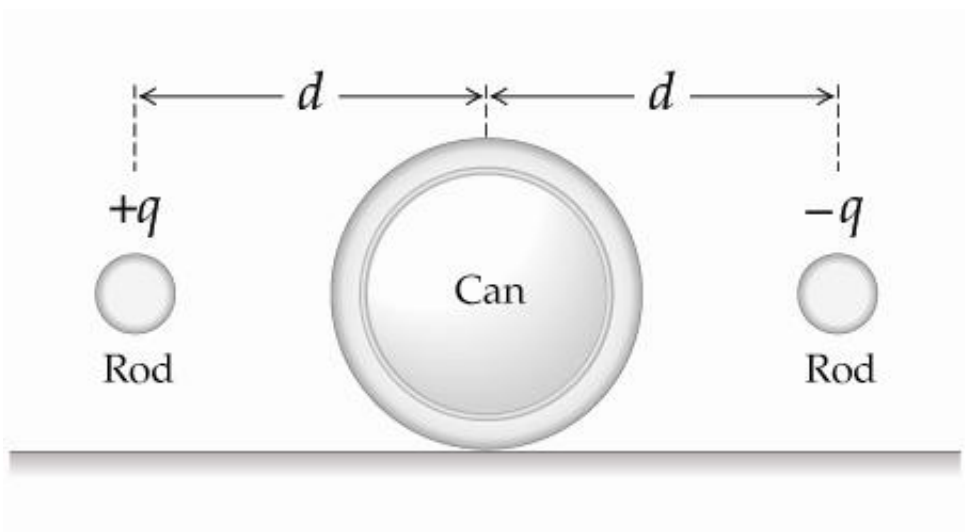
# Video Tutor: Charged Rod and Aluminum Can

First, launch the video below. You will be asked to use your knowledge of physics to predict the outcome of an experiment. Then, close the video window and answer the questions at right. You can watch the video again at any point.




### Part A

Consider the situation in the figure below, where two charged rods are placed a distance $d$ on either side of an aluminum can. What does the can do?




**Hint 1.** How to approach the problem.

This problem asks you to think about *induced* charge on the surface of an object and the resulting *polarization force*.

To get started, draw a diagram. Draw the induced *surface* charges on the outside of the can. Next, draw a force diagram (free-body diagram) to show the forces exerted *on* the can. Aluminum is a conductor.

ANSWER:

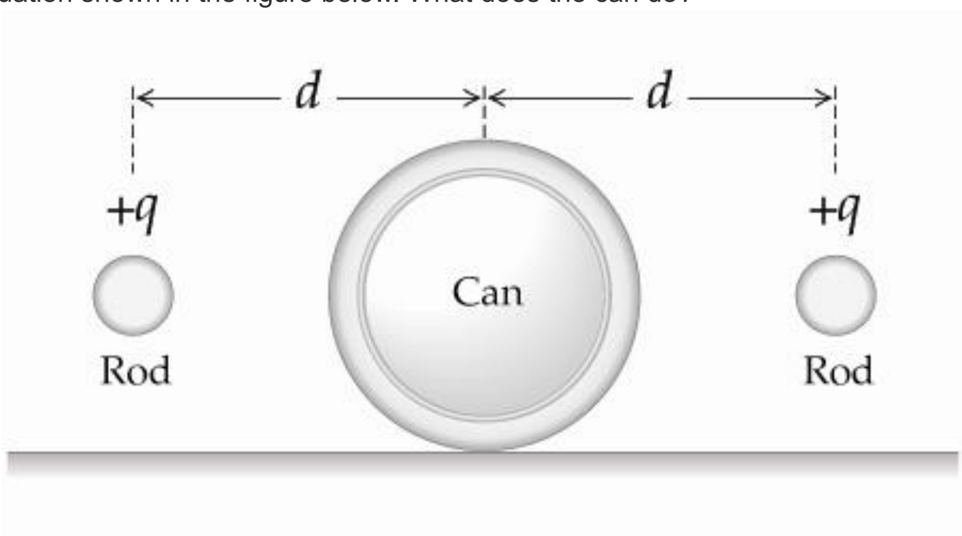
- Stays still
- Rolls to the left
- Rolls to the right

**Correct**

The positively charged rod induces a negative charge on the left side of the can, creating an attractive force between the rod and the can. However, the negatively charged rod induces an equal positive charge on the right side of the can, which creates an attractive force between the can and that rod. The net force acting on the can is *zero*.

## Part B

Now, consider the situation shown in the figure below. What does the can do?




ANSWER:

- Stays still
- Rolls to the right
- Rolls to the left

**Correct**

The polarization force is always attractive, so the can does not move.

### Part C

Using the setup from the *first* question, imagine that you briefly touch the *negatively* charged rod to the can. You then hold the two rods at equal distances on either side of the can. What does the can do?

**Hint 1.** How to approach the problem.

This problem asks you to consider what happens to a conductor after being touched by a charged object. What charge will the can have after being touched?

ANSWER:

- ○ Rolls away from the positively charged rod
- ◉ Rolls toward the positively charged rod
- ○ Does not move

**Correct**

The can acquires a net negative charge after being touched, so it is then attracted to the positively charged rod.

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## Coulomb's Law Tutorial

**Learning Goal:**

To understand how to calculate forces between charged particles, particularly the dependence on the sign of the charges and the distance between them.

Coulomb's law describes the force that two charged particles exert on each other (by Newton's third law, those two forces must be equal and opposite). The force $F_{21}$ exerted *by* particle 2 (with charge $q_2$) *on* particle 1 (with charge $q_1$) is proportional to the charge of each particle and inversely proportional to the square of the distance $r$ between them:

$$\vec{F}_{21} = \frac{k\,q_2\,q_1}{r^2}\ \hat{r}_{21},$$

where $k = \frac{1}{4\pi\epsilon_0}$ and $\hat{r}_{21}$ is the unit vector pointing *from* particle 2 *to* particle 1. The force vector will be parallel or antiparallel to the direction of $\hat{r}_{21}$, parallel if the product $q_1\,q_2 > 0$ and antiparallel if $q_1\,q_2 < 0$; the force is *attractive* if the charges are of opposite sign and *repulsive* if the charges are of the same sign.

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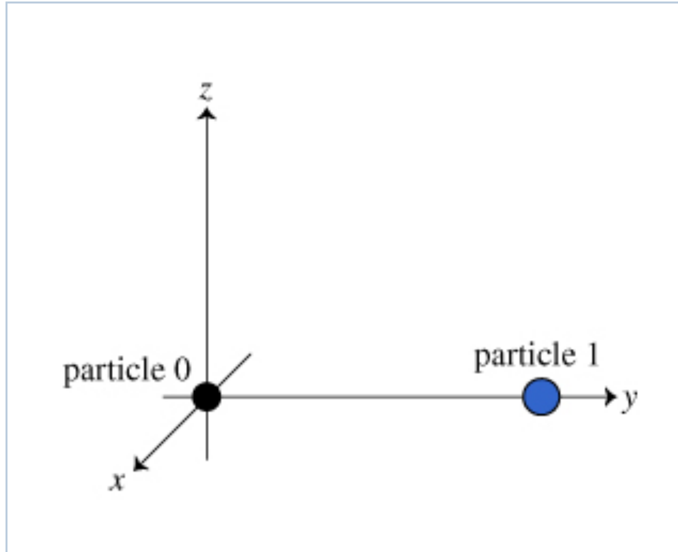
### Part A

Consider two positively charged particles, one of charge $q_0$ (particle 0) fixed at the origin, and another of charge $q_1$ (particle 1) fixed on the *y*-axis at $(0,\ d_1,\ 0)$. What is the net force $\vec{F}$ *on* particle 0 *due to* particle 1?

**Express your answer (a vector) using any or all of $k$, $q_0$, $q_1$, $d_1$, $\hat{i}$, $\hat{j}$, and $\hat{k}$.**




ANSWER:

$\vec{F}$ = $-k\frac{|q_0 q_1|}{{d_1}^2}\hat{j}$

**Correct**

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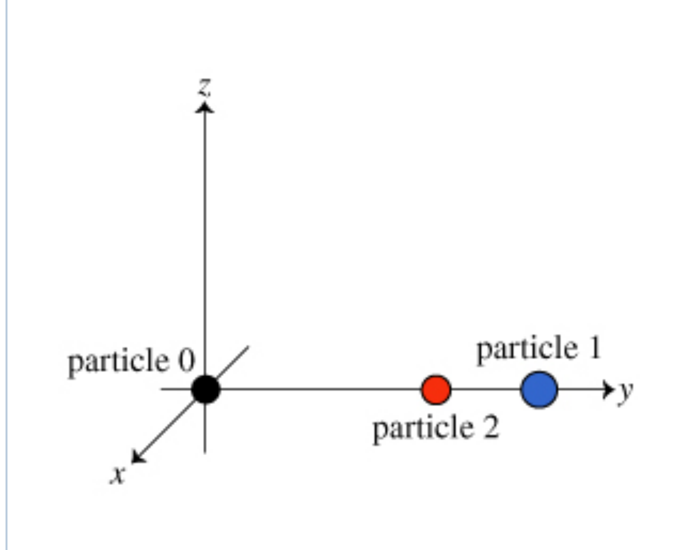
## Part B

Now add a third, negatively charged, particle, whose charge is $-q_2$ (particle 2). Particle 2 fixed on the *y*-axis at position $(0,\, d_2,\, 0)$. What is the new net force *on* particle 0, *from* particle 1 and particle 2?

**Express your answer (a vector) using any or all of $k$, $q_0$, $q_1$, $q_2$, $d_1$, $d_2$, $\hat{i}$, $\hat{j}$, and $\hat{k}$.**




ANSWER:

$\vec{F}$ = $-k\frac{|q_0 q_1|}{{d_1}^2}\hat{j}+k\frac{|q_0 q_2|}{{d_2}^2}\hat{j}$

**Correct**

## Part C

Particle 0 experiences a repulsion *from* particle 1 and an attraction *toward* particle 2. For certain values of $d_1$ and $d_2$, the repulsion and attraction should balance each other, resulting in no net force. For what ratio $d_1/d_2$ is there no net force on particle 0?

**Express your answer in terms of any or all of the following variables: $k$, $q_0$, $q_1$, $q_2$.**

ANSWER:

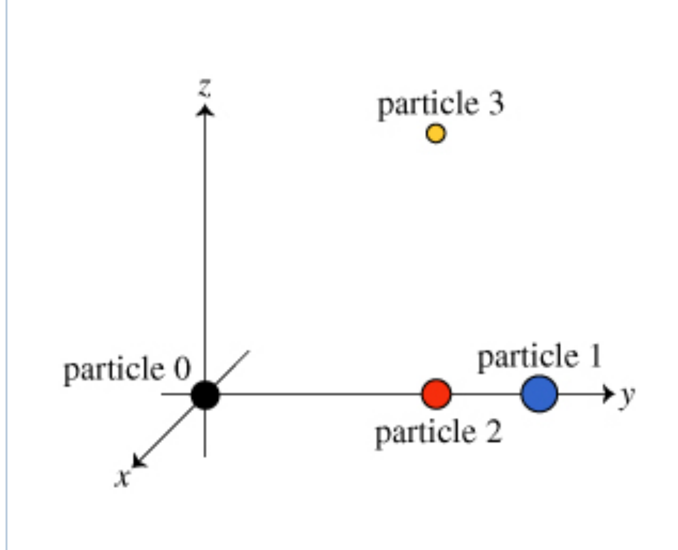
$d_1/d_2$ = $\frac{\sqrt{q_1}}{\sqrt{q_2}}$

**Correct**

## Part D

Now add a fourth charged particle, particle 3, with positive charge $q_3$, fixed in the *yz*-plane at $(0,\ d_2,\ d_2)$. What is the net force $\vec{F}$ on particle 0 due *solely* to this charge?

**Express your answer (a vector) using $k$, $q_0$, $q_3$, $d_2$, $\hat{i}$, $\hat{j}$, and $\hat{k}$. Include only the force caused by particle 3.**




**Hint 1.** Find the magnitude of force from particle 3

What is the magnitude of the force on particle 0 from particle 3, fixed at $(0,\ d_2,\ d_2)$?

**Express your answer using $k$, $q_0$, $q_3$, $d_2$.**

**Hint 1.** Distance to particle 3

Use the Pythagorean theorem to find the straight line distance between the origin and $(0,\ d_2,\ d_2)$.

ANSWER:

$F_3 = \frac{kq_0q_3}{2{d_2}^2}$

**Hint 2.** Vector components

The force vector points from $q_3$ to $q_0$. Because $q_3$ is symmetrically located between the *y*-axis and the *z*-axis, the angle between $\hat{r}_{30}$, the unit vector pointing *from* particle 3 *to* particle 0, and the *y*-axis is $\pi/4$ radians. You have already calculated the magnitude of the vector above. Now break up the force vector into its *y* and *z* components.

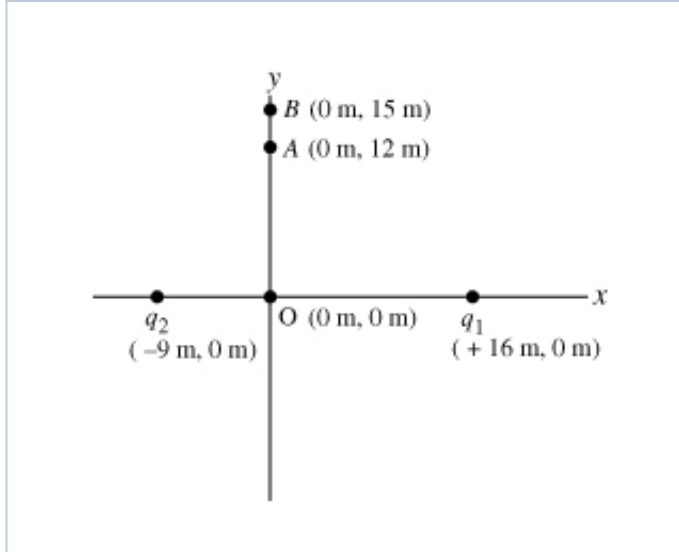
ANSWER:

$\vec{F} = -k\frac{|q_0q_3|}{(\sqrt{2}d_2)^2}\frac{\sqrt{2}}{2}\hat{j} - k\frac{|q_0q_3|}{(\sqrt{2}d_2)^2}\frac{\sqrt{2}}{2}\hat{k}$

**Correct**

# Electric Field due to Multiple Point Charges

Two point charges are placed on the *x* axis. The first charge, $q_1$ = 8.00 $\mathrm{nC}$ , is placed a distance 16.0 $\mathrm{m}$ from the origin along the positive *x* axis; the second charge, $q_2$ = 6.00 $\mathrm{nC}$ , is placed a distance 9.00 $\mathrm{m}$ from the origin along the negative *x* axis.




## Part A

Calculate the electric field at point A, located at coordinates (0 $\mathrm{m}$, 12.0 $\mathrm{m}$ ).

**Give the *x* and *y* components of the electric field as an ordered pair. Express your answer in newtons per coulomb to three significant figures.**

### Hint 1. How to approach the problem

Find the contributions to the electric field at point A separately for $q_1$ and $q_2$, then add them together (using vector addition) to find the total electric field at that point. You will need to use the Pythagorean theorem to find the distance of each charge from point A.

### Hint 2. Calculate the distance from each charge to point A

Calculate the distance from each charge to point A.

**Enter the two distances, separated by a comma, in meters to three significant figures.**

ANSWER:

$r_{A1}, r_{A2}$ = 20.0,15.0 $\mathrm{m}$

### Hint 3. Determine the directions of the electric fields

Which of the following describes the directions of the electric fields $\vec{E}_{A1}$ and $\vec{E}_{A2}$ created by charges $q_1$ and $q_2$ at point A?

ANSWER:

- ◉ $\vec{E}_{\rm A1}$ points up and left and $\vec{E}_{\rm A2}$ points up and right.
- ○ $\vec{E}_{\rm A1}$ points up and left and $\vec{E}_{\rm A2}$ points down and left.
- ○ $\vec{E}_{\rm A1}$ points down and right and $\vec{E}_{\rm A2}$ points up and right.
- ○ $\vec{E}_{\rm A1}$ points down and right and $\vec{E}_{\rm A2}$ points down and left.

### **Hint 4.** Calculate the components of $\vec{E}_{\rm A1}$

Calculate the *x* and *y* components of the electric field $\vec{E}_{\rm A1}$ at point A due to charge $q_1$.

**Express your answers in newtons per coulomb, separated by a comma, to three significant figures.**

#### **Hint 1.** Calculate the magnitude of the total field

Calculate the magnitude of the field $E_{\rm A1}$ at point A due to charge $q_1$ only.

**Express your answer in newtons per coulomb to three significant figures.**

ANSWER:

$E_{\rm A1}$ = 0.180 $\rm N/C$

#### **Hint 2.** How to find the components of the total field

Once you have found the magnitude of the field, use trigonometry to determine the *x* and *y* components of the field. The electric field of a positive point charge points directly away from the charge, so the direction of the electric field at point A due to charge $q_1$ will be along the line joining the two. Use the position coordinates of $q_1$ and point A to find the angle that the line joining the two makes with the *x* or *y* axis. Then use this angle to resolve the electric field vector into components.

ANSWER:

$E_{{\rm A1}x}, E_{{\rm A1}y}$ = -0.144,0.108 $\rm N/C$

### **Hint 5.** Calculate the components of $\vec{E}_{\rm A2}$

Calculate the *x* and *y* components of the electric field at point A due to charge $q_2$.

**Express your answers in newtons per coulomb, separated by a comma, to three significant figures.**

#### **Hint 1.** Calculate the magnitude of the total field

Calculate the magnitude of the field $E_{\rm A2}$ at point A due to charge $q_2$ only.

**Express your answer in newtons per coulomb to three significant figures.**

ANSWER:

$E_{\mathrm{A2}}$ = 0.240 $\mathrm{N/C}$

**Hint 2.** How to find the components of the total field

Once you have found the magnitude of the field, use trigonometry to determine the *x* and *y* components of the field. The electric field of a positive point charge points directly away from the charge, so the direction of the electric field at point A due to charge $q_2$ will be along the line joining the two. Use the position coordinates of $q_2$ and point A to find the angle that the line joining the two makes with the *x* or *y* axis. Then use this angle to resolve the electric field vector into components.

ANSWER:

$E_{\mathrm{A2}x}, E_{\mathrm{A2}y}$ = 0.144,0.192 $\mathrm{N/C}$

ANSWER:

$E_{\mathrm{A}x}, E_{\mathrm{A}y}$ = 0,0.300 $\mathrm{N/C}$

**Correct**

## Part B

An unknown additional charge $q_3$ is now placed at point B, located at coordinates (0 $\mathrm{m}$, 15.0 $\mathrm{m}$ ).
Find the magnitude and sign of $q_3$ needed to make the total electric field at point A equal to zero.

**Express your answer in nanocoulombs to three significant figures.**

**Hint 1.** How to approach the problem

You have already calculated the electric field at point A due to $q_1$ and $q_2$. Now find the charge $q_3$ needed to make an opposite field at point A, so when the two are added together the total field is zero.

**Hint 2.** Determine the sign of the charge

Which sign of charge $q_3$ is needed to create an electric field $\vec{E}_{\mathrm{A3}}$ that points in the opposite direction of the total field due to the other two charges, $q_1$ and $q_2$?

ANSWER:

- positive
- negative

**Hint 3.** Calculating the magnitude of the new charge

Keep in mind that the magnitude of the field due to $q_3$ is $E_{\rm A3} = kq_3/r_{\rm A3}^2$, and the field must be equal in magnitude to the field due to charges $q_1$ and $q_2$.

ANSWER:

$q_3$ = 0.300 $\rm nC$

**Correct**

**Score Summary:**

Your score on this assignment is 100%.
You received 15 out of a possible total of 15 points.