Lesson 10: Electric Fields

Just like the force due to gravity, the force due to electric charges can act over great distances.

- Keep in mind that most forces we deal with in everyday life are ***not*** like this.
  - We mostly deal with "**contact forces**"… objects touch each other directly in order to exert a force on each other.
  - For example, a tennis racket hits a tennis ball
- The idea of even considering forces that could happen without anything touching ("**action at a distance**") was very difficult for early scientists to accept, from Aristotle to Newton.
  - It is necessary though, if you are going to be able to explain a falling ball, or two positive charges pushing away from each other.

The British scientist Michael Faraday came up with the idea of a **field** and applied it to the study of electrostatics.

Illustration 1: Michael Faraday

- A **field** is sometimes defined as a sphere of influence. An object within the **field** will be affected by it.
  - Think of how you talk about countries in social studies... large, powerful nations can have an influence on nearby countries. Usually as you get further away from the powerful nation, the influence they have on other countries decreases.
  - Or think about being near your gym bag after playing a soccer game. Sitting right next to it the stink is pretty intense (yuck!), but as you move away the smell isn't quite so bad.

There are two kinds of fields...

1. **Scalar Fields**: magnitude but no direction

   Example 1: Heat field from a fire: If you stand by a campfire, you can measure the magnitude (temperature) of the field with a thermometer; if you are close to the fire you will measure a stronger field (higher temperature), but if you move away the field strength decreases (lower temperature). You would **not** be saying anything about a direction, like "25ºC South".

2. **Vector Fields**: magnitude and direction

   Example 2: A gravity field is a measure of the Newtons exerted per kilogram of mass *towards the centre* of another mass.

Electric fields are vector fields that exist around any charge (positive or negative).

- If one charge is placed near a second charge, the two fields will "touch" and exert a force on each other.
  - Note: the field is ***NOT*** a force, but it does exert a force! It's just like if you watch a person pushing a box; we don't say the person *is* a force, just that he is *exerting* a force.
- This meant that physicists had a mathematical way of showing how a force could be transferred over a distance without anything actually touching.
  - This model is not considered to be complete, but it is good enough for the way we need to look at things for the time being.

How can we detect and measure the electric field around a charge?

- The easiest way is to place another known charge near by and see how it reacts.
- We do need to be careful since both the charges have their own fields that will interact with each other, so that would affect your results.
    - Physicists have defined something called a **test charge** as the mathematically perfect charge that could be brought near another charge (the **source charge**) to measure the **source charge's** electric field.
        - The **test charge** is an infinitely small, **positive** charge. It is a mathematical creation… they don't really exist.
        - Since it is infinitely small, it has a super small electrical field of its own, so we will treat it as having no electric field. This is good, since we don't have to be concerned with its electric field affecting the results.
        - It is usually given the symbol q, just like any other charge.

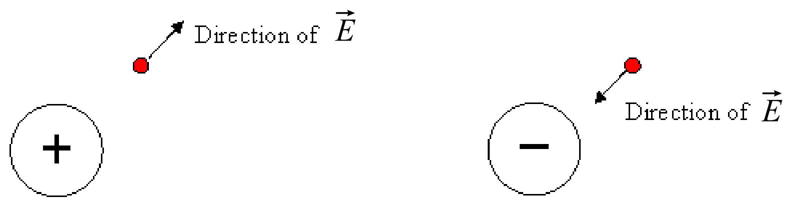

Illustration 2: Direction of electric field near positive and negative charges.

Since a **test charge** is ***always*** **positive...**

- if we see the **test charge** move **towards** the **source charge**, we know that the **source charge** must be **negative**
- if the **test charge** moves **away** from the **source charge**, then the **source charge** must be **positive**.

Example 1: You have a **steel ball** that has an unknown charge on it (this is your **source charge**). When you place a **test charge** to the right of the **source charge**, you see the **test charge** move away, to the right. **Determine** if the **steel ball** is positive or negative.

Since the **test charge** is positive (like always), it would only be repelled by another positive object. The **source charge** (the **steel ball**) must therefore be positive.

Measuring Electric Fields

According to Coulomb's Law, the force exerted on the **test charge** must be directly proportional to its own charge and the **source charge**...

$$F_e \propto q_1 q_2$$

where we assume that q_2 is the **test charge**, which we will rename to simply q...

$$F_e \propto q_1 q$$

If you divide the force by the charge on the **test charge**, you get a new formula.

$$\vec{E} = \frac{F_e}{q}$$

$\vec{E}$ = electric field (N/C)
F = force (N)
q = charge on **test charge** (C)

Warning!
There are two very important things to notice about this formula as it appears on the data sheet.
First, the **arrow** above "E" in the formula shows this is the **vector** measurement of **field**; Without the arrow it is the **scalar** "**energy**." You ***must*** write the arrow above "E" in this formula, since you are otherwise showing it as energy.
Second, the data sheet does not show "q" as being anything special (like a test charge). You need to remember that this formula uses the charge of the object testing the field, not making it. More on this idea after the following example.

Example 2: I place a 3.7 C test charge 2.7m to the right of a -7.94C source charge. If there is an attractive force of 3.62e10 N acting on the test charge, **determine** the field strength of the source charge at that location.

We don't need the distance to figure this question out. It is important to know that the test charge is to the right of the other charge, since we need to give a direction.

$$\vec{E} = \frac{F_e}{q} = \frac{3.62e10}{3.7} = 9\,783\,783\,784 = 9.8e9\ N/C \quad [left]$$

The field points left because that's the direction the test charge is being pulled. By definition, the direction of an electric field is the direction a ***positive*** test charge is pushed or pulled.

Super Important Note!

One of the most important things to remember when using this formula is which charge is used. Do you use the source charge that is creating the field, or the test charge that is placed nearby to measure the field. The answer, as shown in Example 4, is the test charge. But this is often something that students forget or mix up. There is a way to remember.

Let's keep in mind that you've already studied fields when you learned about gravity in Physics 20. We can look at the parallels between the following two formulas to remember things about each of them.

$g=\frac{F_g}{m}$	$\vec{E}=\frac{F_e}{q}$
g = measurement of the ***gravitational*** field strength F_g = the force acting on the small object m = mass of the small object (like a person), ***not*** the large object (like the earth) *This formula measures the amount of force per unit mass.*	$\vec{E}$ = measurement of the ***electric*** field strength F_e = the force acting on the test charge q = the charge of the test charge, ***not*** the source charge making the electric field *This formula measures the amount of force per unit charge.*

When you use the formula $F_g = mg$ you (usually) use a small mass that is sitting on or near a planet that is creating the gravitational field, not the mass of the planet. The charge in the formula $\vec{E}=\frac{F_e}{q'}$ is the small test charge sitting near the bigger sourcecharge that is making the electric field.

The electric field around a source charge will be different at different locations around the charge.

- Further away from the charge, the magnitude of the force will decrease. We know this from Coulomb's law...

$$F_e \alpha \frac{1}{r^2}$$

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- The direction will also be different...

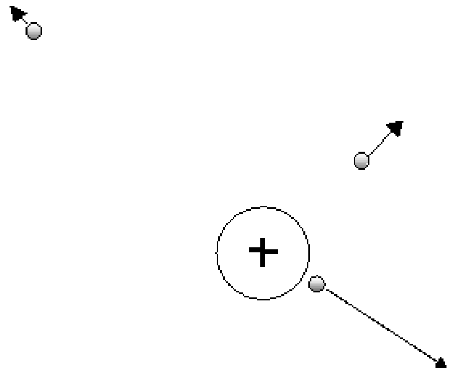

Illustration 3: Different directions and magnitudes of electric field strength at different positions around a charge.

Example 3: A force of 2.1 N is exerted on a 9.2e-4 C test charge when it is placed in an electric field created by a 7.5 C charge. If the force is pushing it West, **determine** the electric field at that point.

Notice that the direction of the field is to the West. Since the positive test charge is being pushed to the West, the field must point in th same direction.

$$\vec{E}=\frac{F_e}{q}=\frac{2.1}{9.2\text{e-}4}=2282.608=2.3\text{e}3\ \text{N/C}[\text{West}]$$

Example 4: If a positive test charge of 3.7e-6 C is put in the same place in the electric field as the original test charge in the last example, **determine** the force that will be exerted on it.

$$\vec{E}=\frac{F_e}{q}$$

$$F_e=\vec{E}q=2.3\text{e}3(3.7\text{e-}6)=0.00844565=8.4\text{e-}3\ \text{N}[\text{West}]$$

Example 5: You now place a -4.81e-2 C charge at that spot in the electric field. **Determine** the force acting on this charge.

This time we put a negative charge in the electric field. We just calculate the absolute value to find the magnitude of the force, then reason out that if a positive charge is being pushed to the West, a negative charge will be pushed to the East.

$$\vec{E}=\frac{F_e}{q}$$

$$F_e=\vec{E}q=2.3\text{e}3(4.81\text{e-}2)=109.793=1.1\text{e}2\ \text{N}[\text{East}]$$

There is another way to measure electric field strength based on a combination of the formula we've already got and Coulomb’s Law...

$$\vec{E}=\frac{F_e}{q} \qquad F_e=\frac{kq_1q_2}{r^2}$$

- In the formula we will assume that q_1 is the source charge that is making the field, and q is the test charge.
- Coulomb's Law can now be substituted into the field formula to get…

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$$\vec{E}=\frac{F_e}{q}=\frac{\left(\frac{k\,q_1 q}{r^2}\right)}{q}=\frac{k\,q_1\,q}{r^2}\left(\frac{1}{q}\right)=\frac{kq_1}{r^2}$$

- This gives us our new electric field formula:

$$|\vec{E}|=\frac{kq_1}{r^2}$$

$|\vec{E}|$ = electric field (N/C)
k = Coulomb's Constant
q_1 = source charge making the electric field (C)
r = distance from the charge (m)

- So you will use the **source charge** that is actually producing the field as q_1.
- This is great! Now you don't have to rely on some imaginary thing like a test charge to calculate the field around a source charge!
- We also need to be careful about calculating the absolute value, since we need to make a decision on the direction of the field based on the info in the particular question we are working on.

Super Important Note!

Just as we were able to find a connection between electrostatics and gravity a couple pages back, we can do the same thing with our new formula.

$g=\frac{GM}{r^2}$	$\vec{E}=\frac{kq_1}{r^2}$
g = measurement of the ***gravitational*** field strength G = gravitational constant M = mass of body producing gravitational field r = distance from centre of body	$\vec{E}$ = measurement of the ***electric*** field strength k = Coulomb's constant q_1 = charge of source charge producing electic field r = distance from centre of body

Example 6: A tiny metal ball has a charge of –3.0e-6 C. **Determine** the magnitude and direction of the electric field it produces at a point, **P**, 30cm away.

$$\vec{E}=\frac{kq_1}{r^2}=\frac{8.99e9\,(3.0e\text{-}6)}{0.30^2}=299\,666.667=3.0e5\text{ N/C}$$

Warning!
Get used to names for a particular spot like "P", since sometimes we may want to relate what you're doing in a question to several spots, like "P", "D", and "A".

- Remember the electric field is always defined as being in the direction that a **positive** test charge would move.

- Since the source charge producing this field is **negative**, a **positive** charge would be attracted towards it.
- **This field points *towards* the metal ball**. That's the direction you would state.

Multiple Source Charges Creating Electric Fields

You will run in to problems where several source charges are interfering with each other to make one electric field.

- Simply calculate the individual electric fields, and then add them as vectors, taking into account directions and angles as necessary.
- Handle these questions like a vector problem from Physics 20. All you want to calculate by the end is a resultant.

Example 7: Two negatively charged spheres are arranged as shown in the diagram below. Determine the electric field strength at a point exactly half ways in between.

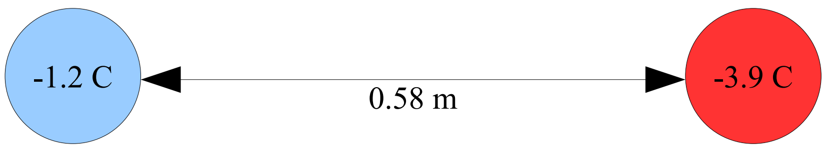

Illustration 4: Charge arrangement for Example 8.

First we figure out the electric field caused by each charge *individually* at the point half ways in between.

$$\left|\vec{E}_b\right| = \frac{kq_1}{r^2} = \frac{8.99e9(1.2)}{0.29^2} = 1.2827586e11 \qquad \left|\vec{E}_r\right| = \frac{kq_1}{r^2} = \frac{8.99e9(3.9)}{0.29^2} = 4.1689655e11$$

Now we will take into account the directions and add them as vectors. In both cases the source charge is negative, so the electric field created by both source charges point towards themselves. So, the electric field of the **blue** source charge points to the **left** (we'll say it's **negative),** while the **red** source charge has a field pointing to the **right** (so it will be **positive**).

$$\vec{E}_{total} = \vec{E}_b + \vec{E}_r$$
$$\vec{E}_{total} = -1.2827586e11 + 4.1689655e11 = 2.8862069e11 = 2.9e11\ \mathrm{N/C}$$

The electric field is 2.9e11 N/C [right].

Homework

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