

# Lab 2: Electric Fields – Coulomb Force at a Distance

## Introduction

The Coulomb force,  $F_c$ , between two charges is determined by their magnitude,  $q_1$  and  $q_2$ , and position,  $r$ . The concept of an electric field  $E=F_c/q=C Q/r^2$ , similar to a gravitational field  $g=9.8 \text{ m/s}^2 = GM/r_e^2$ , is helpful in solving problems involving complex, real world charge distributions. The electric field is independent of the charge it is acting on just as the earth's gravitational field is independent of the mass,  $m$ , it acts on. Charged particles are all around us; we are immersed in electric fields from every computer, power line, and household appliance. The sum of these electric fields interact with a charged particle,  $q$ , to exert a force,  $F = q (E_1+E_2+E_3+ \dots)$ . The principle of superposition for electric fields can be intuitively understood by the same reasoning as the superposition principle for forces. By the end of this lab, you should:

- Understand the concept of electric field from a charge
- Be able to draw the electric field lines for an ensemble of charges
- Understand electric fields in practical applications

## Materials:

50 VDC (~0.1 A) power supply

mm ruler

Gel chamber/comb apparatus

Color dye solutions

Banana leads

Buffer

Agarose

Hot mitt glove

CAUTION hot agarose will burn!

Hot plate access

CAUTION 50 VDC can kill!

**SPECIAL NOTE:** The Electrophoresis Unit is from Carolina Biological Supply Company, North Carolina, 27215. ([www.carolina.com](http://www.carolina.com))



## Experiment 2 Preparation – Step 1: the agarose gel.

(This needs to be done ASAP so that the gel will be melted by the time you need it for Experiment 2)

Take a 50 mL Pyrex flask of agarose and remove the rubber stopper. Melt the agarose by placing it on the hot plate set to 120C. The agarose will be clear when it is melted. It should not be boiled. Use the magnetic stirring bar to keep the agarose from burning on the bottom.

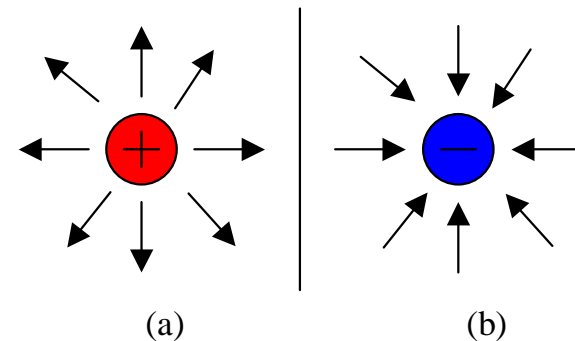
## Experiment 1 – Electric Field Lines

Electric fields are vector fields– at any point they have a magnitude and a direction. The magnitude of the field from a charge  $q$  is given by  $E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$  and for a positive charge, the direction is radially away from the charge center. For negative charges, the direction is radially toward the charge. In this experiment, use the web resource: [www.gel.ulaval.ca/~mbusque/elec/main\\_e.html](http://www.gel.ulaval.ca/~mbusque/elec/main_e.html) to investigate electric fields.

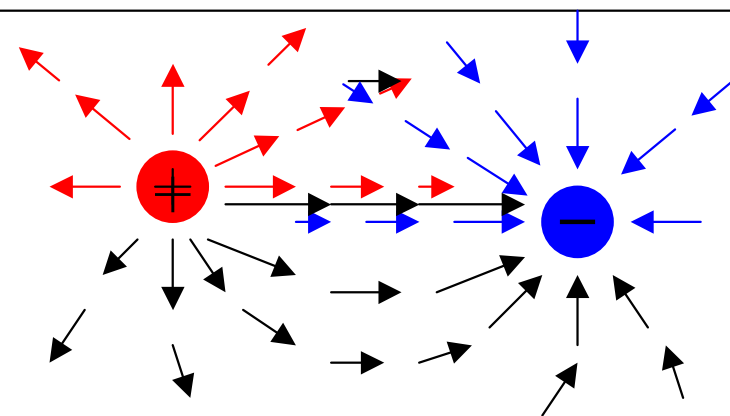
In the interactive resources you can place charges on a grid and then plot the electric field lines. You should gain an understanding of the electric field from both single and multiple charges. For example, try the following:

- One charge– positive or negative
- Two charges-- both positive, both negative, and one positive one negative
- Three or more charges of varying sign

You should record a sketch for one case each of the field from a single, double, and triple charge configuration.



Positive charges (a) have field lines emanating outwards because a positive test charge placed in the vicinity would cause a repulsive force. Conversely, negative charges (b) have inward facing lines.



The Forces and Fields from charges add like vectors. The positive field lines (red) are superimposed on the blue field lines (blue) and the resulting field is shown in black in the lower half. Several examples of the adding fields are shown explicitly.

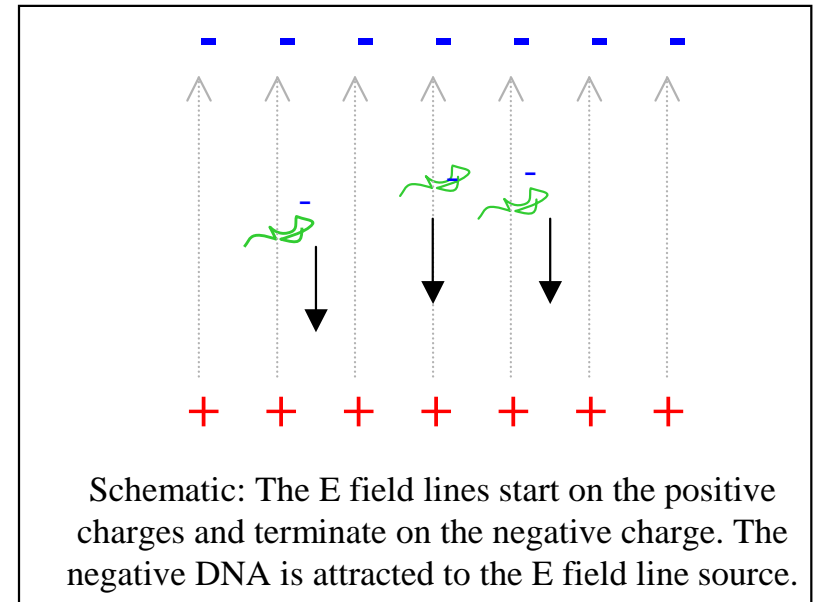
Common uses of charged particles involve millions of charges in symmetric arrangements. Calculating the force between all the charges in a pair wise fashion is very cumbersome. The use of electric fields is more intuitive and, in such cases, often makes problems easier to solve.

## Experiment 2 – Electrophoresis

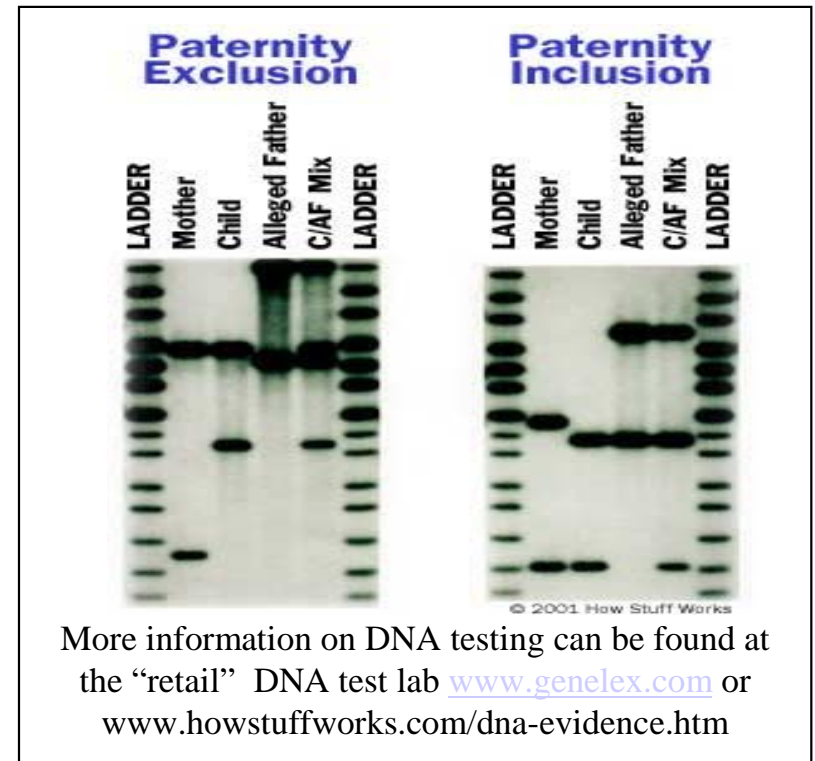
Every charged particle is interacting with all the charges in the universe in a conversation mediated by the electric field. Imagine having a charge in your hand being forced around by every charge in the universe! It turns out, you do have a charged particle in your hand ... DNA. Because DNA is negatively charged when dissolved in water, when placed in an electric field it will have a force exerted on it.

DNA fragments can vary in size from a hundred to hundreds of thousands of base pairs. In genetic engineering it is often necessary to isolate or sequence one particular piece of DNA. This analysis is done using electrophoresis. The DNA is placed in a Jello-type substance called agarose gel. Positive charges are placed on one end of the gel and a negative charges are placed at the other end.

The electric field between the charges gives a uniform force on the DNA as it is forced through the gel. In the gel, the mobility of the DNA is determined by its size; small molecules easily “navigate” through the gel matrix while bigger molecules experience a larger resistance. Measuring the size of the DNA and sequencing the base pairs is a matter of quantifying how the DNA fragments in an electric field are forced through the gel.



Schematic: The E field lines start on the positive charges and terminate on the negative charge. The negative DNA is attracted to the E field line source.



More information on DNA testing can be found at the “retail” DNA test lab [www.genelex.com](http://www.genelex.com) or [www.howstuffworks.com/dna-evidence.htm](http://www.howstuffworks.com/dna-evidence.htm)

We will be discovering the properties of electric fields by observing this electrophoresis process. For our purposes we will be using dye molecules rather than DNA molecules. (We don't want to incriminate anyone!)

### Experiment 2 – Step 1: Pouring the agarose gel.

Setup your electrophoresis unit and well comb as shown in Figure 1. Carefully pour about 10 mL of it into the electrophoresis unit to make the gel. Fill the gel to the line shown on the side of the unit - up to the top of the dividers (see Fig. 1). Do not overfill the gel and get agarose on the electrical contacts or wells around the wires. When the gel has set (about 15 minutes) carefully remove the comb by lifting it straight up to form the wells that will hold the samples. You will then have six wells where the comb was, one of which will eventually left empty.

Attach the wires and power supply to your gel. Pour buffer solution over the gel to keep it moist and help conduct the electricity. The buffer should overflow the top of the gel by a couple of mm, overflow the plastic well dividers, and flood the electrical contact wires. The buffer should be continuous to let the electricity flow. Next, load each well with about 2 micro liters of the different dyes using the pipette. Keep your hand steady while loading the well and carefully retract the pipette when the well is about  $\frac{3}{4}$  full. Do not overfill the wells. You may practice with the pipette before you try to load your gel. When you dispense the dye, do not puncture the well bottom or sides. (see figure 2). It is difficult to see the wells (Hey, no one said analyzing DNA was easy), placing a piece of dark paper under the wells can make them easier to see.

Turn up the power supply to 50 V to put charge on the wires and create an electric field. (50 V is a lot and can kill you! Do not touch the gel!). The dyes should immediately start to be forced through the gel.

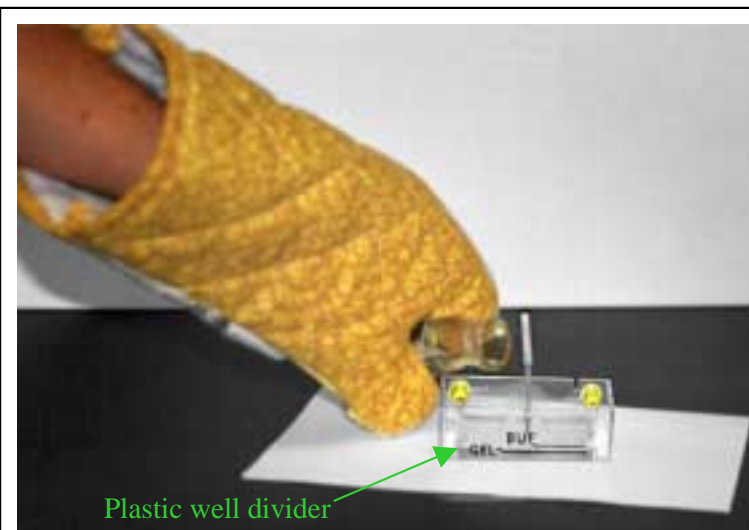


Figure 1: The unit is filled with agarose to the top of the small dividers.

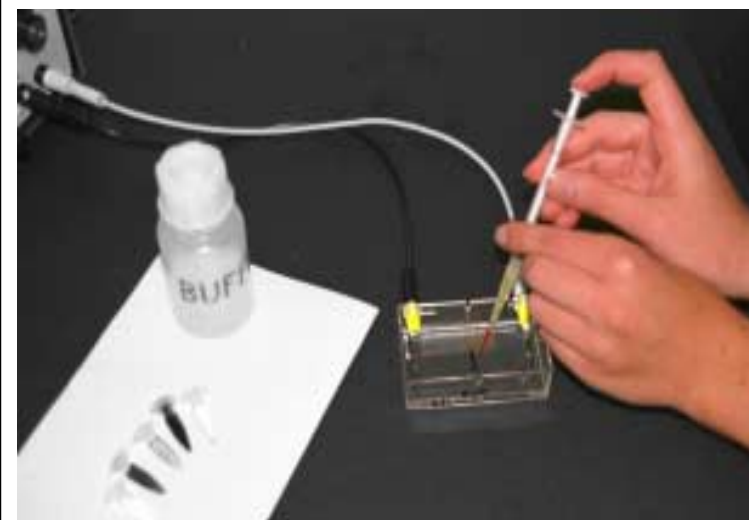


Figure 2: The wells are carefully loaded with dye.

Once the dyes have migrated a significant distance in the gel (about 20 minutes – see Fig. 4), turn off the power supply and analyze your results before the dyes diffuse into the gel.

Using the information that you have obtained from the experiment and the information given to you, answer the following questions:

- Obtain the experimental charge sign on each individual dye molecule.
- Calculate the electrostatic force that acts on each individual dye due to the electric field applied to it. The electric field is given in Volts/meter. For your experiment, E will be 50V divided by the distance between the wires.
- Estimate the charge-to-mass ratio (q/m) of each dye from the distance migrated since you know that larger charges have larger Coulomb forces and larger masses move more slowly through the agarose.
- In your final analysis attempt to describe quantitatively how a molecule of a certain weight and charge will move through the gel. It is easiest to do this graphically by plotting the data with distance (y) versus charge/mass (x).

Molecular structure of dyes and color in solution:

MYSTERY Orange:	orange-yellow
Bromphenol Blue: $C_{19}H_9Br_4O_5S^-$	blue
Safranin O: $C_{20}H_{19}N_4^+$	red-orange
Ponceau S: $C_{22}H_{12}S_4O_{13}N_4Na_2^{-2}$	dark red
Janus Green B: $C_{30}H_{31}N_6^+$	dark blue-green

Determine the charge over mass ratio, q/m of MYSTERY Orange dye from the graph.

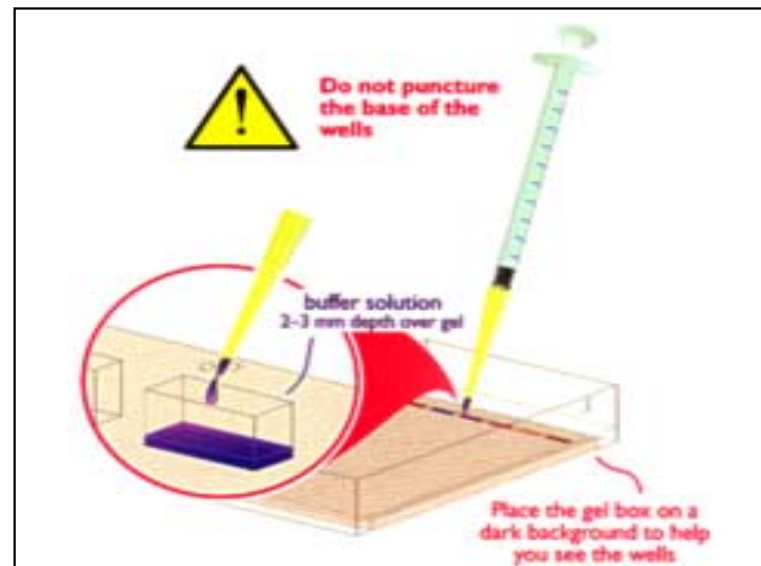


Figure 3: Cartoon of wells being loaded (used from Carolina Biological Supply).

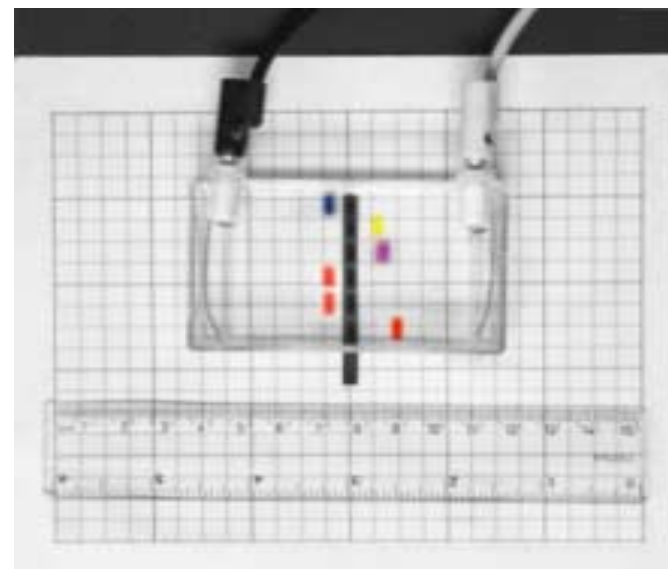


Figure 4: Picture of the electrophoresis unit after being run at 50 VDC for about 20 minutes.

## Real World Problem: Electrostatic Air Cleaners

The removal of air particles through electrostatic attraction is an application of electric fields. Particles to be removed from the atmosphere pass between wires that have a very large amount of charge placed on them. Strong electric fields surround these wires and charge the particles. Once charged, or ionized, they pass between plates that have the opposite charge. The Coulomb force attracts them to the plates and they are trapped by a filter. These air cleaners work extremely well for particles of all sizes. For particles between 0.1 and 1 microns they trap 70% of all particles. Once 3 microns is reached, they operate in excess of 95% efficiency (see [www.oznet.ksu.edu/library/hlsaf2/ncr393.pdf](http://www.oznet.ksu.edu/library/hlsaf2/ncr393.pdf)).

### Problem:

Allergies are a huge problem in the United States ([allergies.about.com](http://allergies.about.com)) and have led to a booming industry ([www.fedders.com](http://www.fedders.com), [www.dustfree.com](http://www.dustfree.com)) in electrostatic air cleaners which use the principle of...Coulomb's Law ;) Many people are allergic to very fine pollen and dust grains which are 10 microns in diameter and have a mass of  $10^{-9}$  grams.

In an air cleaners, these particles pass by the ionizing plates and are given a charge of about 1000 electrons. The cleaner pulls the air stream through it at a velocity of 3 m/s. Assume the charged plates are about 25 cm in length and there is a plate separation of at least 1 cm.

**What is the minimum electric field between the plates to ensure the pollen and dust grains are accelerated by the electric field to travel 1cm or greater and hit the collection plates, thus, being removed from the air?**

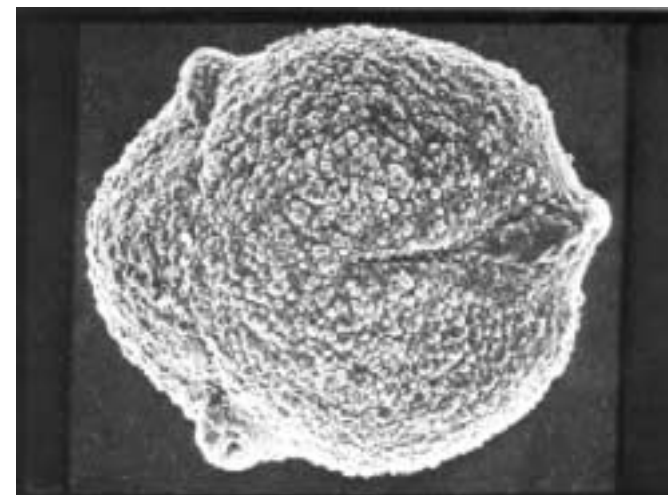
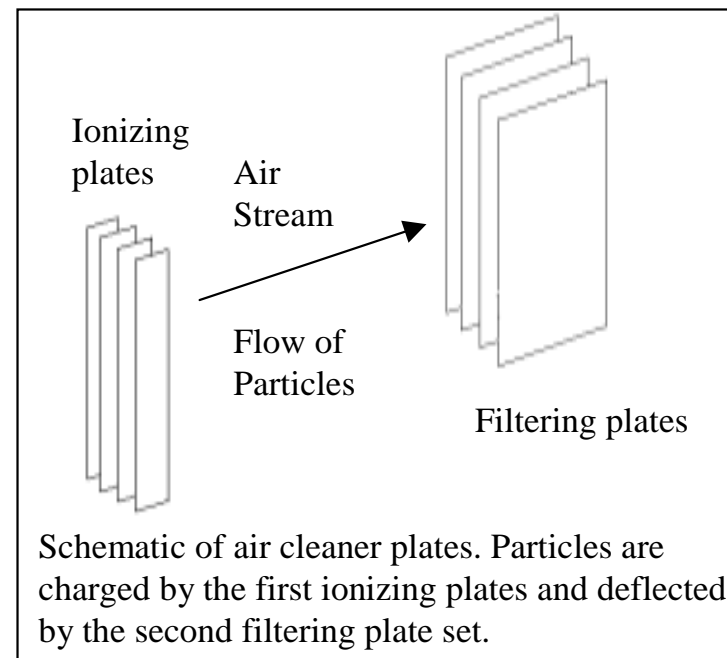


Figure: Microscope picture of an oak pollen grain. The average diameter of such grains is 24 to 38 microns.



Schematic of air cleaner plates. Particles are charged by the first ionizing plates and deflected by the second filtering plate set.