

Section 8

WHAT IS THE CAUSE OF DISTANT-ACTION EFFECTS?

INTRODUCTION

This section will further revise and improve the model of battery-driven charge flow in circuits. Quantitative features will be added which make the model even more powerful.

INVESTIGATION ONE: DOES CHARGE INFLUENCE PRESSURE ACROSS GAPS?

8.1 Activity: Circuit with a conducting “island”

Part of the circuit in Figure 8.1 is an “island” containing two bulbs and their connecting wires, situated between two identical capacitors (A and B). We will call this part of the circuit a “conducting island,” because charge cannot flow into or out of it through the insulating layers inside the capacitors.

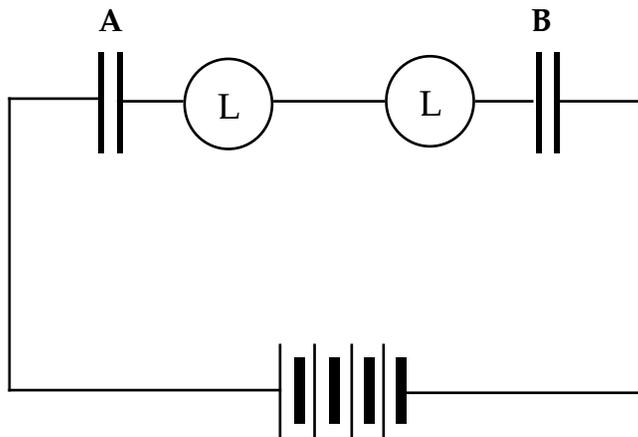


Figure 8.1
ELECTRIC CIRCUIT WITH A “CONDUCTING ISLAND”

1. Do you think the bulbs in the “island” will light when you connect the last wire? Write your prediction below, based on the compressible fluid model. Explain your reasoning.

Join with another lab group to build the circuit in Figure 8.1 with two 25,000 μf capacitors (A and B) and four cells in the battery pack. First, use a wire to discharge each capacitor. Then connect the capacitors in series, with two long bulbs between the capacitors, and observe the bulbs when you make the final connection to the battery. Repeat the experiment by reopening the circuit and discharging each capacitor with a wire.

2. Do the bulbs light? If they do light, are they brightest right after the connection is made or at some later time?

3. If the bulbs light, use a compass to compare direction and magnitude of current in the island with direction and magnitude in all the wires of the circuit. What do you observe?

4. What have you observed that cannot be explained by the model of battery driven charge flow that we have developed in our earlier work?



8.2 Commentary: Reviewing the compressible fluid model of charge flow

Up to this point we have built a conceptual model in which pressure difference in a fluid of mobile charge causes charge flow through a resistor. However, there is no way for the battery to drive charge into or out of the conducting island in the circuit of Figure 8.1. So our model envisions no way for the charge in the island to become compressed or depleted – and no way to create pressure differences that could drive charge through the bulbs in the island. Therefore, the model predicts there will be no bulb lighting in the conducting island.

In Activity 8.1 we saw that this prediction of the model is false. Clearly, something is wrong with our model. But should we abandon a model that works perfectly well everywhere except in conducting islands? And if we were to do that, how would we find a different explanation for all the correct predictions of the old model?

Let's try instead to revise and improve the model — in a way that will make it valid also for conducting islands. We start by applying the compressible fluid model to the bulb lighting that actually does occur in the “island” part of the circuit, and see if that suggests ideas about improvement:

- 1) Glowing bulbs indicated that charge was being driven through the island.
- 2) To make that happen, pressure differences were being created in the island.
- 3) These differences were not caused by charge entering and leaving the island.
- 4) The cause must have been charge accumulation and depletion in capacitor plates located outside the island.

This line of reasoning suggests that we can improve the model by adding the following new feature to the model:

Charges located outside the island influence pressure inside the island.

This added feature of the model is called “distant action”. The distant action of the two kinds of charge is assumed to work in the following specific manner:

Excess (+) charge makes electric pressure higher in a conductor across a gap.

Excess (-) charge makes electric pressure lower in a conductor across a gap.

This added feature of the model is at present only a proposal. It must be tested to determine **if** it can explain what happens in a variety of situations.

8.3 Activity: More work with the pie plate capacitor and neon bulb

To obtain direct experience with (+) and (-) charges raising and lowering pressure values across gaps, we return to the rubbed insulators and neon bulb that we worked with in Section 7. Set up the capacitor made of two aluminum pie plates, and rub a foam picnic plate on a sheet of acrylic.

You will soon be asked to grip the acrylic with excess (+) charge by the edges, and hold it up in the air a little above the top capacitor plate (about half a centimeter.) This situation creates a gap between the top capacitor plate and the (+) charge on the acrylic. Note also the larger gap between the bottom capacitor plate and the (+) charge on the acrylic.

One partner should now hold the charged acrylic up above the top capacitor plate as in Figure 8.3a. The other partner should then touch the free wire from the bulb to the top capacitor plate.

1. Was the pressure in the top capacitor plate higher than, lower than, or the same as the pressure in the bottom plate? What is the evidence?

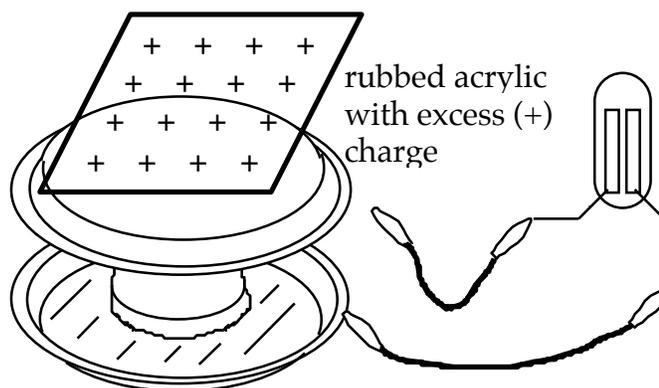


Figure 8.3a

**(+) ACRYLIC HELD
UP ABOVE THE TOP
CAPACITOR PLATE**

**NEON BULB
RESTING ON
THE LAB TABLE**

Use a wire to discharge the capacitor, and then repeat this experiment. Do this as many times as you need, in order to be certain about the observed result.

One partner should now hold the negatively charged foam about half a centimeter above the top capacitor plate as in Figure 8.3b. The other partner should then touch the free wire from the bulb to the top capacitor wire plate.

2. Was the pressure in the top capacitor plate higher than, lower than, or the same as the pressure in the bottom plate? What is the evidence?

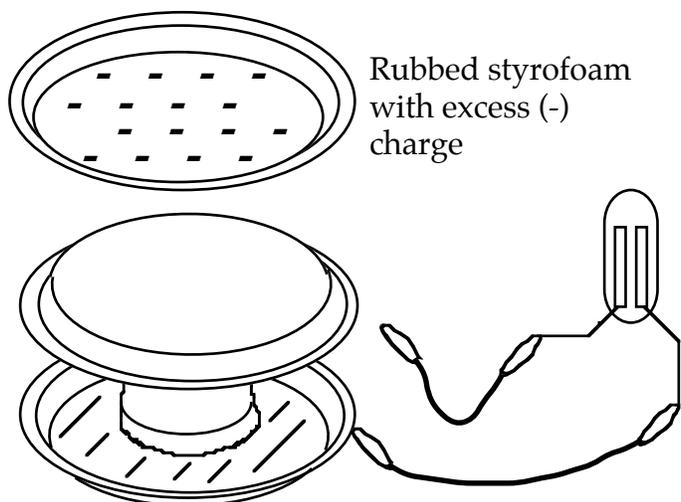


Figure 8.3b
(-) STYROFOAM HELD UP ABOVE THE TOP CAPACITOR PLATE **NEON BULB RESTING ON THE LAB TABLE**

3. Do accumulations of excess (+) and (-) cause a change in the electric pressure in nearby conductors across gaps – YES or NO? What is the evidence?

4. Does it matter how wide the gap is – YES or NO? Explain in detail.

5. Does it matter how far the rubbed plate is from the top pie tin? Test by experiment.

This decreasing strength of the effect with increasing distance from the cause tells us that the idea of a distant pressure-raising effect is making sense. That is the way the world works in all the cases that we know about. Example: A flame that raises the temperature in your nearby hand will raise the temperature less when your hand is farther away from the flame.

INVESTIGATION TWO: WHAT IS BRIDGING THE GAPS TO CAUSE CHANGE?

8.4 Commentary: The “pressure halo” idea

What enables charge located outside the island to cause pressure changes inside the island, without actually entering the island and being compressed there? Are there some kind of invisible structures attached to charges outside the island, that bridge the gaps and cause pressure changes inside the island? There is a possibly useful analogy in the external influence of flames and ice:

- A candle flame is surrounded by a zone of higher-than-normal temperature.

Your finger placed in this zone is made hotter without the flame touching it.

The temperature decreases toward normal at a large distance from the flame.

- A chunk of ice is surrounded by a zone of lower-than-normal temperature.

Your finger placed in this zone is made colder without the ice touching it.

The temperature increases toward normal at a large distance from the ice.

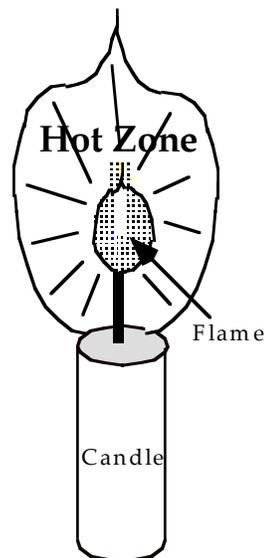


Figure 8.4
TEMPERATURE HALO
AROUND CANDLE FLAME

We will use the name “halo” for external zones of influence. For example, we will say there are “temperature halos” in the space around candle flames or chunks of ice. The temperature halo in the space around a candle flame is illustrated in Figure 8.4.

By analogy, we will assume there are “pressure halos” in the space around charges. These halos influence the electric pressure in any conductor that is placed in them.

- Excess (+) charge has a pressure halo that raises electric pressure in conductors. A conductor in this halo has its pressure raised without the charge touching it. The pressure is less and less above normal at greater distances from the charge.
- Excess (-) charge has a pressure halo that lowers electric pressure in conductors. A conductor in this halo has its pressure lowered without the charge touching it. The pressure is less and less below normal at greater distances from the charge.

8.5 Activity: Visualizing pressure halos around (+) and (-) charges

Figure 8.5a shows the distribution of pressure-raising capability in the halo around an object with excess (+) charge. Points where the halo has equal pressure-raising capability are connected by a dashed line. The dashed lines are like atmospheric pressure contours or equal-temperature contours on a weather map. The numbers compare the pressure-raising capability of different parts of the halo.

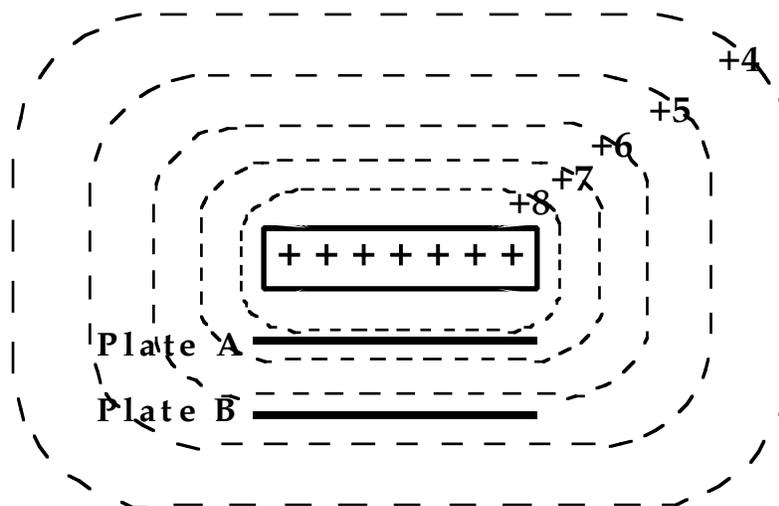


Figure 8.5a
PRESSURE HALO AROUND AN OBJECT WITH EXCESS (+) CHARGE

Figure 8.5a also shows two uncharged metal plates labeled A and B, which are placed at different distances from the positively charged object.

1. Which metal plate (A or B) is predicted to be at higher pressure?
2. If a neon bulb is connected to the plates, will positive charge move through the bulb in the A-to-B direction or in the B-to-A direction? Which bulb electrode will glow?
3. Refer to Activity 8.3a. Do your results agree with this hypothesis?

Figure 8.5b shows the distribution of pressure-causing capability in a halo around an object with excess (-) charge. Negative numbers by the dashed lines compare the pressure-lowering capability of different parts of the halo. In the numerical scheme used in Figures 8.5a and 8.5b, normal pressure would be represented by zero.

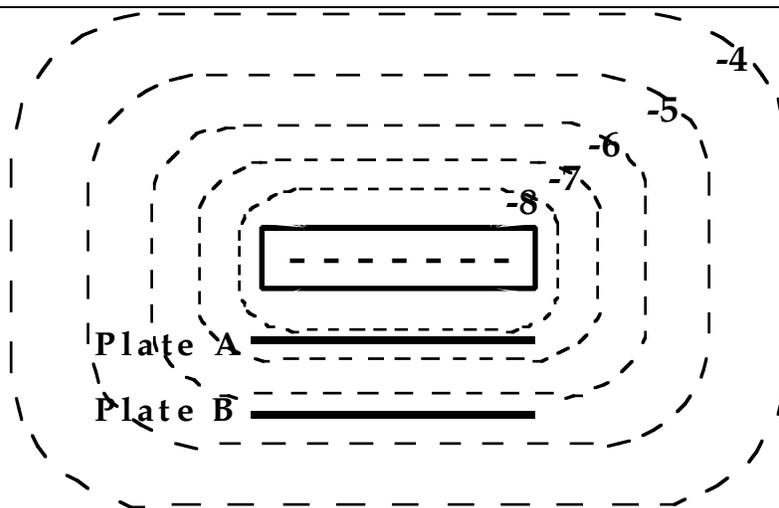


Figure 8.5b
PRESSURE HALO AROUND AN OBJECT WITH NEGATIVE CHARGE

4. Which metal plate (A or B) is predicted to be at higher pressure?

5. If a neon bulb is connected to the plates, will positive charge move through the bulb in the A-to-B direction or in the B-to-A direction? Which bulb electrode will glow?

6. Refer to Activity 8.3b. Do your results agree with this hypothesis?

7. Suppose the neon bulb is removed after the experiments in questions 2 and 5, and then the object with excess (+) or (-) charge is taken away. Describe the type of excess charge that will remain on each of the metal capacitor plates.

8. Suppose the plates are again connected through the neon bulb. Is the direction of positive charge flow from A to B or from B to A? Why? Which electrode will glow?

To be confident that you understand what these diagrams represent, you may want to re-do Activity 8.3 with the pie plate capacitor while referring to these figures.

8.6 Activity: More work with the island circuit

Pressure halos have been hypothesized as the mechanism of distant action. Let's find out how much this mechanism can explain about the island circuit in Activity 8.1. Set up the circuit without the wire between the bulbs, as in Figure 8.6a. Assume the battery drives transient flow that leaves excess (+) charge on the left plate of capacitor A and excess (-) charge on the right plate of capacitor B as shown.

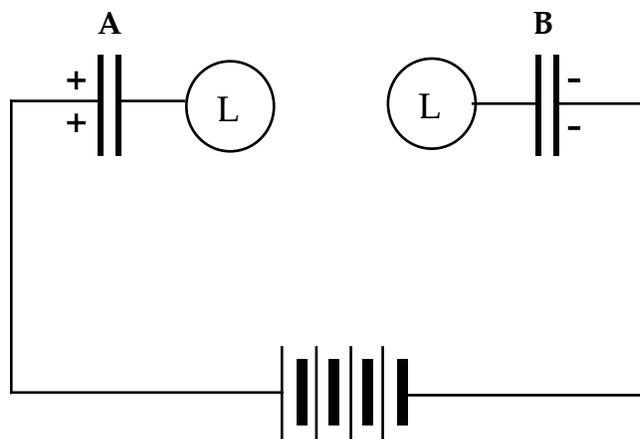


Figure 8.6a
INCOMPLETE "CONDUCTING ISLAND"
CIRCUIT

1. Use a high resistance (digital) voltmeter to measure the pressure difference across each capacitor, across each bulb, and between the unconnected bulb socket clips. **Be certain the capacitor is completely discharged before constructing this circuit.** Record your measurement here.
2. How does the pressure difference between the unconnected bulb socket clips compare with the pressure difference across the battery?
3. Color code this circuit.
4. Use the pressure halo idea to explain the distribution of pressure values.

Now connect the missing wire in the conducting island, and watch the bulbs light.

5. Draw starbursts on Figures 8.6b, 8.6c and 8.6d to describe the bulb lighting you observe. Color code these figures to explain the causes of the bulb lighting.

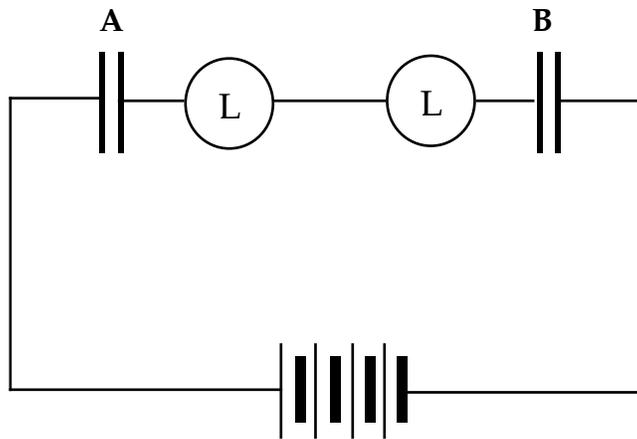


Figure 8.6b
COMPLETED CIRCUIT AT INSTANT OF CONNECTION

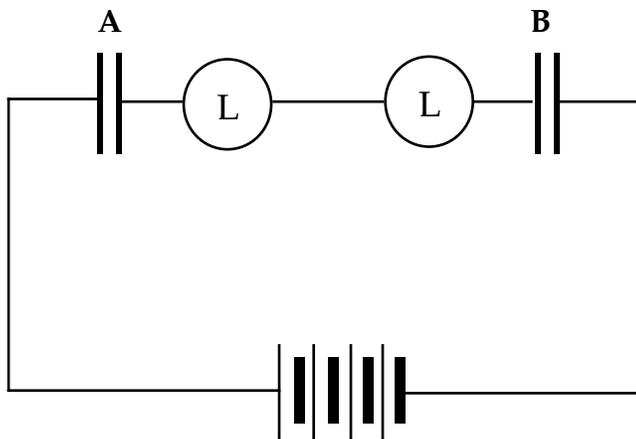


Figure 8.6c
SOME TIME LATER WHILE BULBS ARE STILL LIT

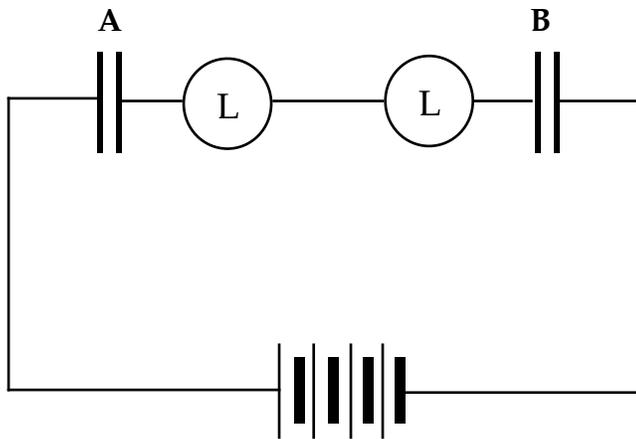


Figure 8.6d
AFTER A LONG TIME HAS ELAPSED

6. Describe how halos of charges in the extreme left and extreme right capacitor plates are acting across the gaps in the capacitors to cause the pressure changes in the island which cause the bulb lighting over time that you have observed.

INVESTIGATION THREE: HOW TO QUANTIFY THE HALO OF A CAPACITOR

8.7 Commentary: From “electric pressure” to “electric potential”

We have shown that a model in which charge flow is driven by pressure halos around (+) and (-) charges can successfully predict the behavior of the very complex island circuit. Note that adding the pressure halo feature – like adding a second kind of charge – does not require that we abandon the compressible fluid model. The new model is simply the old one with added features that make it usable in a greater variety of situations. For most circuits, we can simply use the original model without even having to think about the new features.

Nevertheless, the fact that charge can influence electric pressure across gaps means that electric pressure is very different from air pressure. A pressure halo in empty space around charge is not a region where actual electric pressure exists — because there is no matter for pressure to exist in. Instead, a pressure halo has a property with the potential to do what electric pressure does. This property behaves exactly like actual electric pressure in any conducting body that is placed in the halo.

The term “potential electric pressure” can capture the idea of a condition in space that acts like actual electric pressure in matter. For historical reasons, however, the term “electric potential” has become standard usage among scientists. This is often shortened to “potential” – just as “electric pressure” is shortened to “pressure.” Also, “potential difference” sometimes seems overly long and is called “voltage”.

It is worth noting here that a single charge can have potential, even if there is no actual electric pressure. An analogy could be a single atom having high energy (because of high temperature) but not be under pressure.

Though the term “halo” is not used by professionals, we will continue to use it in this manual. We will do this because there is no professional term that adequately captures the idea of a non-material “thing” in the space around a charge accumulation. From now on we will use the term “potential halos” rather than “pressure halos”.

When charge is placed in a region of electric potential, the charge experiences electric pressure, and will start to move towards a region of lower potential and experience lower pressure. This also means that charge placed in a region of electric potential acquires the energy associated with that potential and will move toward a region of lower potential and lower energy.



8.8 Commentary: Quantifying the halo of an “ideal” capacitor

How is the halo of a charged capacitor related to the halos of each of the individual plates? Think about the simplest possible case – a capacitor with plates that are very large, very thin, and perfectly flat – which is called an “ideal” capacitor. When this capacitor is charged, there will be large uniform parallel sheets of (+) and (-) charge.

It is useful to develop a quantitative description of a charged capacitor’s halo. To achieve this, we will need to add two quantitative features to our model of charge flow in circuits:

Principle #1 – a description of the halos of individual (+) and (-) charged sheets

Principle #2 – a rule for combining these to form the halo of a whole capacitor

The long history of electricity research has discovered the specific forms of these features that are needed to solve the problem. Later on, you can verify that these forms enable the model to make correct predictions. The quantitative principles are:

- 1) The potential varies with distance from a sheet in direct proportion to distance.
- 2) The potential at each point is the sum of potentials due to the (+) and (-) sheets.

Figures 8.8a and 8.8b demonstrate Principle #1. They show the potential varying by one volt for each one centimeter increase of distance from a sheet of charge. The halo in Figure 8.8a has HIGH electric potential – becoming less and less high at greater and greater distance from the individual sheet of (+) charge. The halo in Figure 8.8b has LOW electric potential – becoming less and less low at greater and greater distance from the individual sheet of (-) charge.

Figure 8.8c demonstrates Principles #1 and #2. It shows the potential at each point – on a line perpendicular to the plates – as the numerical sum of the potentials at that point due to the presence of both (+) and (-) charge sheets.

As you can verify by looking at Figure 8.8c, there are potential differences between every pair of points in the space between the capacitor plates. But note that there are no potential differences in the external space. This is quantitative proof that the forms of quantitative features (1) and (2) that were proposed above are correct.

The following exercise will help you look more closely at this issue.



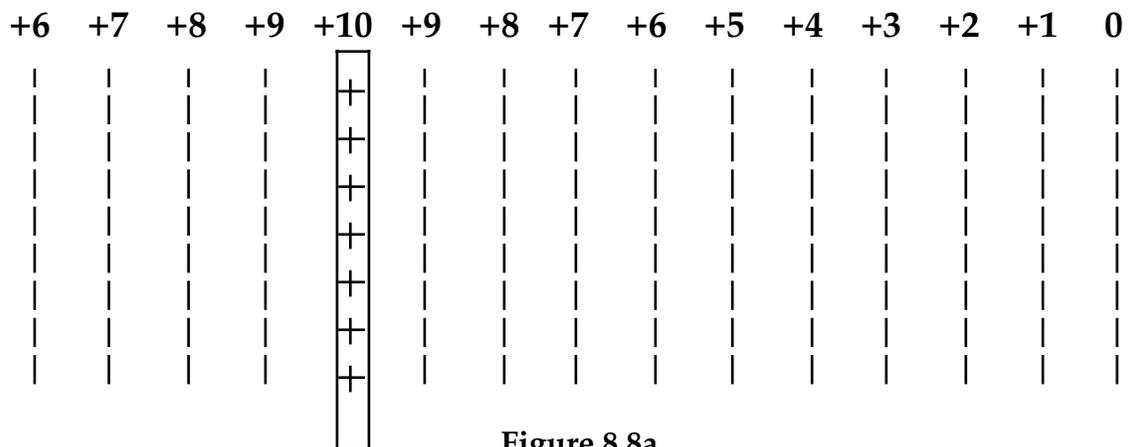


Figure 8.8a
ELECTRIC POTENTIAL NEAR A LARGE SHEET OF (+) CHARGE

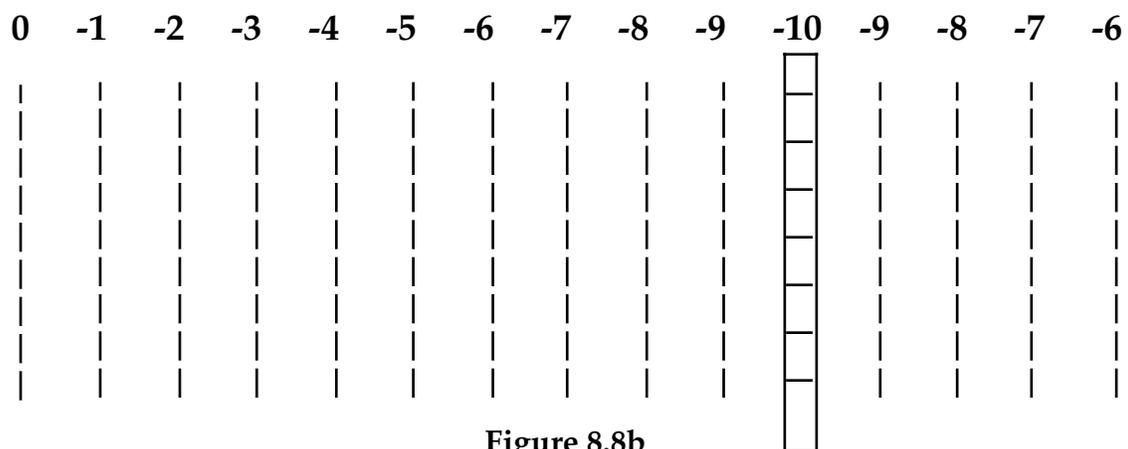


Figure 8.8b
ELECTRIC POTENTIAL NEAR A LARGE SHEET OF (-) CHARGE

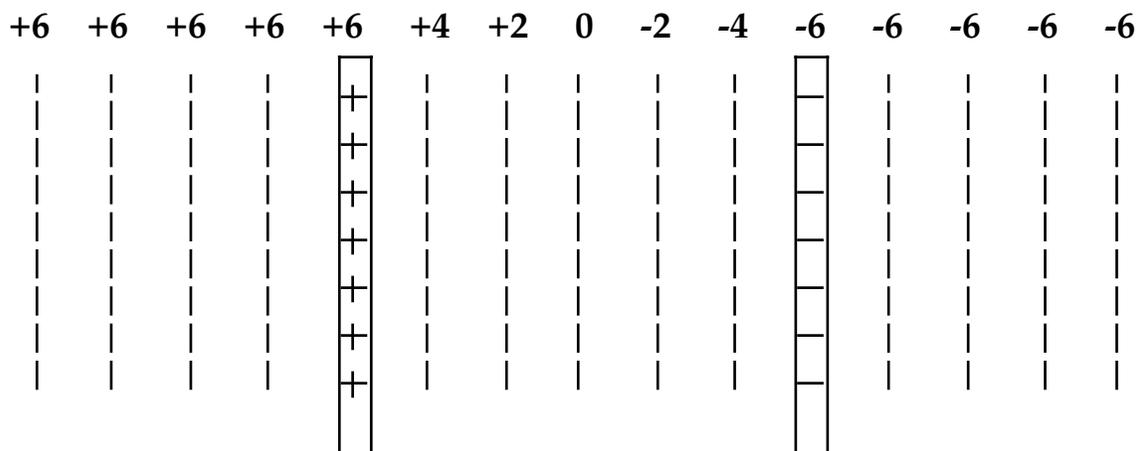


Figure 8.8c
ELECTRIC POTENTIAL OF A CHARGED CAPACITOR WITH THIN PLATES

8.9 Exercise: Adding electric potentials

For each of the following questions, look at the values for the electric potential due to the arrangement of charged plates in Figure 8.8c.

1. When both plates are present, explain why the value of the electric potential is:
 - a) positive on the far left and negative on the far right.
 - b) the same at all points to the left of both plates; the same at all points to the right of both plates
2. Explain why the value of the electric potential in Figure 8.8c:
 - a) changes from position to position in the region between the plates.
 - b) changes at double the rate compared to when only the positive plate is present.
3. What is the potential difference between any two points along a wire that is:
 - a) led in from the left and connected to the positive plate?
 - b) led in from the right and connected to the negative plate?
4. In question 3, what would be the value of the electric potential in the wire connected to:
 - a) the positive plate?
 - b) the negative plate?
5. In question 3, would charge flow, or would there be no flow, in:
 - a) the wire connected to left hand plate? Explain why.
 - b) the wire connected to right hand plate? Explain why.

8.10 Activity: Verifying the quantitative features of the model

1. Use the same coloring scheme for electric potential that we have been using for electric pressure – to color code the capacitor plates and wires in Figure 8.10.

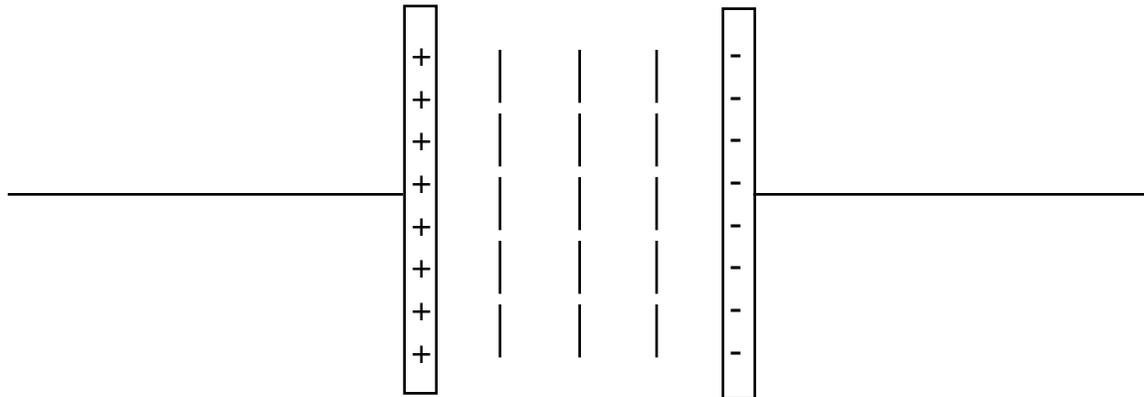


Figure 8.10
CAPACITOR PLATES WITH WIRES ATTACHED

2. Color the dashed lines – representing planes of uniform potential – in the space between the plates.

3. Does the coloring you have done describe what you already knew to be true about a charged capacitor and wires connected to it? Explain.

4. Refer to the two quantitative features suggested in Commentary 8.8. Are they supported by evidence from prior investigations?

INVESTIGATION FOUR: HOW DO HALOS MAKE POINT PARTICLES MOVE?

You have seen that the electric potential halo around a charged object can raise or lower the electrical pressure in conductors at different locations in the potential halo, and cause charge to flow and neon bulbs to light. You have also seen that in order to account for the distant action effects of charge we have had to modify our model of electrical interactions. In order to extend the model farther, you will now do some experiments that help to understand the effects of the potential halo on tiny charged objects.

8.11 Exercise: Electrical pushing and pulling

Your teacher will provide materials to be used in investigating how insulators with excess (+) and (-) charge push on each other.

Recall that in Section 7, in the experiment with the pie plate capacitor and the neon bulb, you determined that the rubbed acrylic plate had pressure-raising (+) charge and the rubbed foam plate had pressure-lowering (-) charge.

Rub the acrylic sheet with a foam plate, and then hold these hanging from their edges.

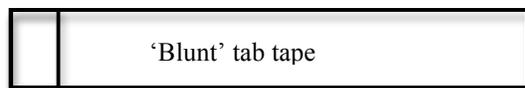
- Bring the acrylic and foam near each other. Observe the effects.
- Bring two of the rubbed foam plates near each other. Observe.
- Bring two of the rubbed acrylic sheets near each other. Observe.

1. What can you say about the effect of a positive plate on a negative plate?
2. What can you say about the effect of a negative plate on a negative plate?
3. What can you say about the effect of a positive plate on a positive plate?

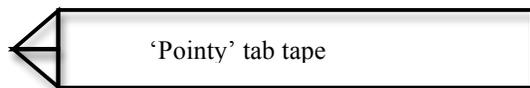
From a roll of Scotch™ Magic™ tape, fold about a half centimeter of the end of the tape back on itself to form a “blunt” tab (Figure 8.11a). Unroll about 8 cm of tape (about four finger widths), tear the tape off the roll, and hold it by the tab.

Now make a second piece of tape about the same length, first folding the corners of the end back on themselves to form a “pointy” tab.

Stick the pointy tab tape on top of the blunt tab tape, so the **sticky** side of the pointy tape is stuck to the **slick** side of the blunt tab tape. Press the tapes together, then, grasping them by their tabs, peel them apart as in Figure 8.11a.



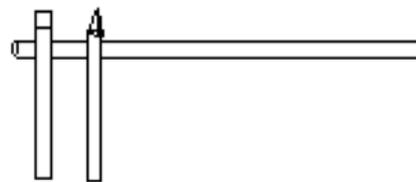
'Blunt' tab tape



'Pointy' tab tape



Figure 8.11a



**BLUNT & POINTY
TAPES**

**POINTY AND BLUNT
SEPARATION**

**TAPES STUCK
ON STRAW**

4. Hold the tapes with their slick sides towards each other and bring them close to each other. What happens?

5. Make a second set of pointy and blunt tabs in exactly the same way, and try bringing pointy near pointy, blunt near blunt, and pointy near blunt. Record your results.

6. Do you have evidence that peeling the tapes apart has separated charge? What evidence?

7. Now bring the pointy and blunt tapes near a positively charged acrylic plate. (If necessary repeat the sticking together and separation of the pointy and blunt tape sandwich first. Remember, pointy on top, blunt on bottom.) You may stick both tapes on a plastic drinking straw (Figure 8.11a) to handle them easily.



What do you observe?

Bring the pointy and blunt tapes near a negatively charged foam plate. What do you observe?

8. From your observations state the sign of the charge on pointy and blunt tapes, and your evidence for your statement.

The pointy and blunt tapes are a convenient way to make small charged objects, and to see the effect of bringing those objects into the halo of a charged (+) or (-) plate.

9. When you bring small positively and negatively charged objects near a positively charged (high pressure or potential) object, such as the acrylic plate, which object is pushed from high to lower potential pressure? Which from lower to higher potential?

10. When you bring small charged objects near a negatively charged (low pressure or potential) object, which object is pushed from higher potential towards low potential? Which is pushed from lower potential towards higher potential?

11. On the diagrams in Figures 8.11b and 8.11c, draw arrows to show the directions that the (+) and (-) particles (or charged tapes represented by small circles) are being pushed by the charged capacitor plates.

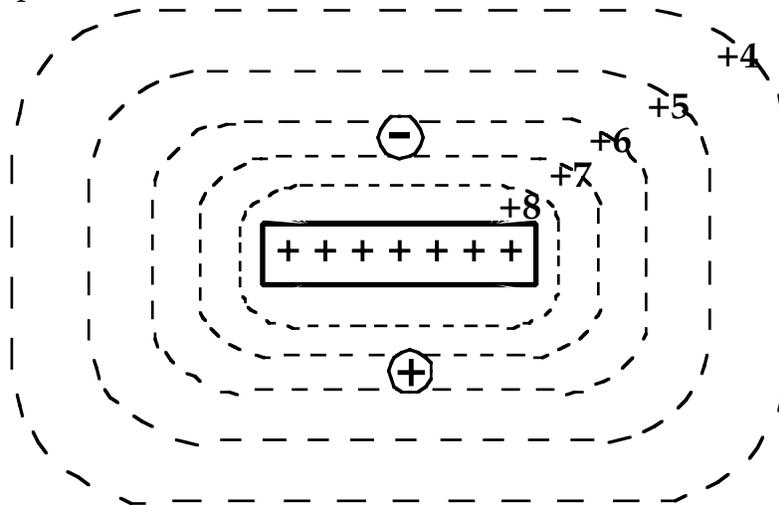


Figure 8.11b

(+) AND (-) PARTICLES IN THE HALO OF A (+) CAPACITOR PLATE

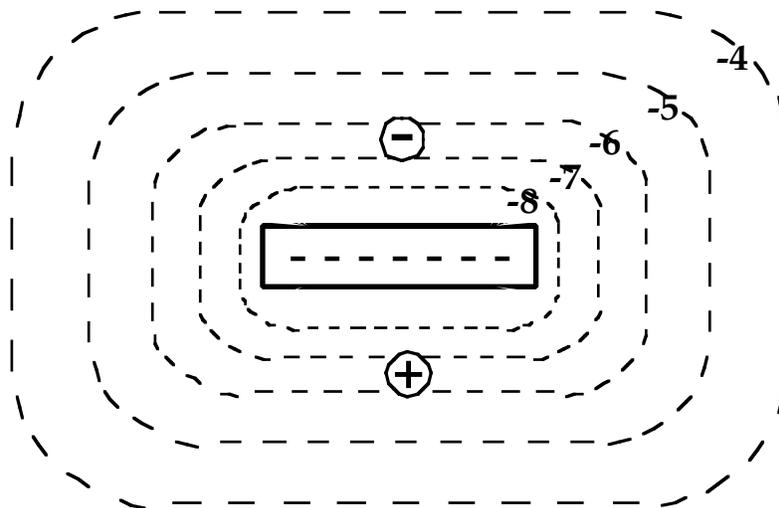


Figure 8.11c

(+) AND (-) PARTICLES IN THE HALO OF A (-) CAPACITOR PLATE

12. Is the above description of how charges act on each other equivalent to pressure halos pushing (+) particles from HIGH to LOW potential and pushing (-) particles from LOW to HIGH potential? Explain.

Two ways to describe electrical pushing

The arrows you placed in the halos in Figures 8.11a and 8.11b show that repulsion of like charges and attraction of unlike charges provide a different description of halos pushing (+) charge HIGH—>LOW and pushing (-) charge LOW—>HIGH.

These two descriptions are completely equivalent, but sometimes one is more useful than the other. The only criterion for which one you should choose is usefulness.

8.12 Activity: Electrical pushing and “polarization”

To test the idea of electrical pushing, set up the components of Figure 8.12. A metal pie plate is supported on a foam cup to insulate it electrically from the table. Individual pieces of conducting tinsel are taped in contact with the metal pie plate.

Predict what you will observe when you bring a charged acrylic plate near the pie plate on the opposite side from the tinsel.

Prediction:

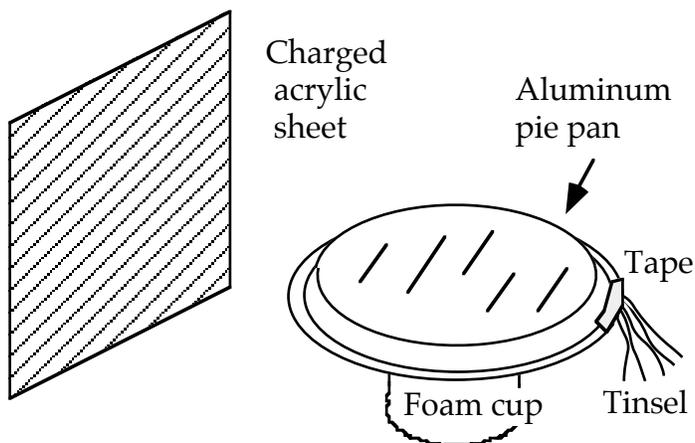


Figure 8.12
TINSEL ATTACHED TO PIE PLATE

1. Charge the acrylic sheet by rubbing it with a foam pie plate. Bring the acrylic sheet near the aluminum pie pan. What do you observe?
2. Explain your observations in terms of
 - a) attraction and repulsion of charges:
 - b) pushing as a result of an electric pressure halo:

3. Generally, the tinsel will spread out and stand away from the metal pie pan. Why does this occur?

4. On Figure 8.12, draw the concentrations of (+) and (-) charge.

Cutting each strip of tinsel into narrower strips would show that the smaller amounts of charge on these also repel each other. This suggests that the effects we have just observed exist even for extremely small amounts of charge in bits of matter too small to see. So it seems reasonable to assume that all carriers of like charge repel each other — even particles as tiny as those in atoms.

Do all carriers of unlike charge also attract each other — even the tiny particles in atoms? Evidence for the answer “Yes” is provided by the fact that matter does not fly apart due to repulsion by the like-charged particles in it. Evidently, attractive forces by unlike charges are able to hold the positive and negative charge together. The result is complete cancellation of powerful repulsions and attractions — with matter under normal circumstances showing no net electrical effects at all.

5. The noun “polarization” is used to describe a condition in matter where there is a spatial separation of (+) and (-) charges. The verb “to polarize” is used to describe an action that causes polarization. Is there polarization in the pie plate in Figure 8.12? Does the excess (+) charge on the acrylic polarize the pie plate? Explain.



8.13 Activity: Experiments with a versorium

A simple device known historically as a versorium can provide insight into the interaction between an uncharged and a charged object.

To make your own versorium, cut a rectangular piece of aluminum foil about 2 cm by 8 cm. Fold the rectangle in half along its long axis, and again along its short axis. Then open it into a “tent” shape, as shown at the top of Figure 8.13.

Take a foam cup, stick a sharp pencil outward through its bottom, and set the cup down on its rim with the pencil point up in the air. Balance the creased foil tent on the pencil point, as shown in Figure 8.13.

1. You will bring a charged plate near the versorium. Predict what you will observe.

Prediction:

2. Rub an acrylic plate with a foam plate, and bring the acrylic plate near the foil level with the top of the versorium. Then move the acrylic in a horizontal arc around the foil. What do you observe?

3. An uncharged object with its (+) and (-) charges separated is said to be polarized. Does the aluminum foil become polarized? Explain.

4. Predict how the movement of the aluminum foil will be similar or different if you bring the foam plate near the versorium, instead of the acrylic plate. Then try it. What do you observe?

Prediction:

5. Is the piece of aluminum again polarized when you bring the foam plate near the versorium? Is there be any difference in the polarization? Explain.

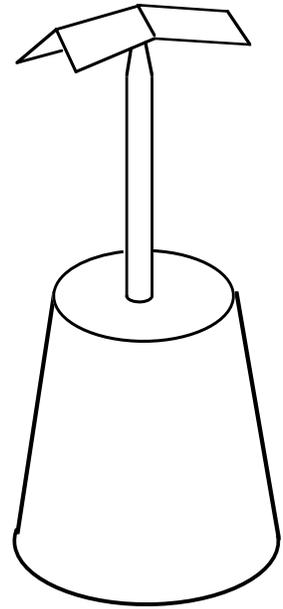


Figure 8.13
THE VERSORIUM

6. Next, replace the metal foil “tent” with a paper “tent” resting on the pencil point. Predict what you think will happen when you bring the charged acrylic near the “tent”.

Prediction:

7. Observe what happens when you bring the (+) acrylic plate, and then the (-) foam plate near the “tent”. Why does this occur? Write a hypothesis consistent with your observations.

8.14 Commentary: Polarization of atoms

In the experiment you have just done, you may have been surprised to observe the rectangle of paper (an insulator) rotate and “point” toward the charged acrylic or foam, just like the rectangle of conducting foil did. What is going on in the paper – which is supposed to prevent charge from moving?

Certainly, charge can’t be pushed all the way through the paper to collect at one end or another. But what if an atom is a system with a (+) ion and (-) electrons that are held together by the attraction of opposite charges? What if the halos around acrylic and foam can polarize the atoms in the paper? You would then have electrons being pushed to one side of an atom – a much shorter distance than through a piece of paper.

If atoms in the paper rectangle become polarized, then attractions and repulsions of the (+) and (-) parts of the atoms could be what’s causing the paper rectangle to rotate and “point”. The forces causing rotation may be weaker for each atom than for the metal rectangle that you used earlier in the versorium – but there are a lot of polarized atoms in the paper, compared to only one polarized metal rectangle.

The versorium experiment with the paper rectangle provides evidence that atoms are not rigid structures. The evidence is that electrons are able to move around in atoms – which provides a basis for external influences being able to polarize the atoms.



SUMMARY EXERCISE

1. Using the circuit in Activity 8.1, explain why the idea that electric pressure behaves exactly like air pressure fails to correctly predict what happens in these circuits.
2. What are the essential features of the “pressure halo” or “electric potential halo” idea?
3. Describe the evidence in this section that can be cited to support the existence of two kinds of charge.
4. What is the evidence for different pushing effects of a pressure halo on small positively and negatively charged objects?
5. Explain why this section is titled “Distant Action”?
6. Use the versorium activity to describe similarities and differences between conductors and insulators.