Rice University
PHYS 112

Charges and Fields

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In this qualitative lab, a computer simulation was used to observe the properties of electric fields and potentials around charges and conductors.

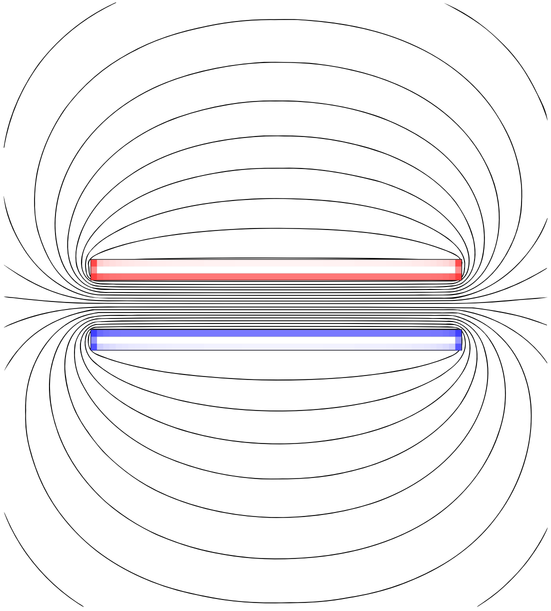
1 Procedure

The electrostatics simulation used was the 2-D Electrostatics Applet, a Java applet written by programmer Paul Falstad in 2001. This applet allows visualization of various configurations of charges and conductors. A selection of configurations were qualitatively analyzed in this lab.

2 Parallel Plates

A pair of conducting plates was simulated. Each plate was given an equal and opposite charge. In the following diagram, charge is indicated with red representing positive charge and blue representing negative, with saturation corresponding to charge density. Equipotential lines are drawn.

Figure 1: Parallel plates with equipotentials

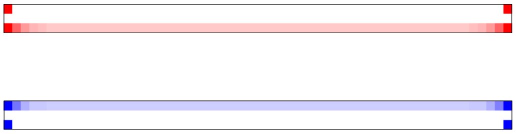


In the region between the plates, the electric field points downward, from positive to negative charge. In the center and away from the ends of the plate, the electric field points directly downward with little horizontal deviation. Furthermore the equipotential lines are about equally spaced in the middle region, suggesting that the electric field has roughly the same magnitude regardless of closeness to either plate, at least with distances not too excessively close to either plate.

While it can be reasoned that the region in between the plates is not *exactly* uniform, it does seem to be rather uniform in nature, especially in the space that is not close to the ends of the plates and is not too close to either individual plate.

Importantly, these plates were conductors, meaning that the net charge of the plates was free to distribute itself into an equilibrium. The applet used simulated charge in discreet blocks with each block having a specific charge density. Here is a close up of the charge distribution of the plates at equilibrium, with the blocks clearly visible. The brightness and contrast of this image were changed to emphasize the different charge levels at the inner surfaces of the plates, which is where more charge resided; this adjustment had the effect of completely washing out the charge on the outer surfaces.

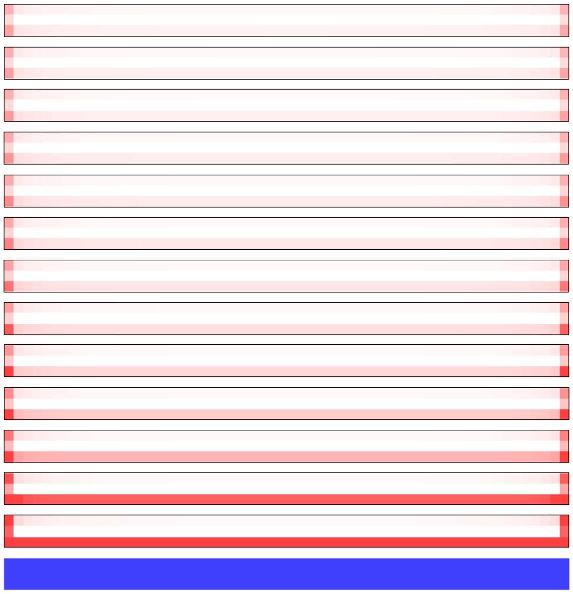
Figure 2: Parallel plates charge distribution



It is seen that the charges are not uniformly distributed along the plates. There is a lot of charge concentrated at the corners, and more charge is on the inner surfaces than the outer surfaces. Furthermore, along the inner surfaces, there is more charge concentrated at the ends than in the middle.

The exact distribution of charge changed depending on the separation between the plates. In the following diagram, the negatively charged plate is drawn in blue, while the charge distribution of the positively charged plate is shown for varying distances away from the negative plate. The diagram is to scale.

Figure 3: Parallel plates charge distributions for various separation distances



For any separation distance, the negative plate simply mirrored the distribution of the positive plate, with negative charge of course.

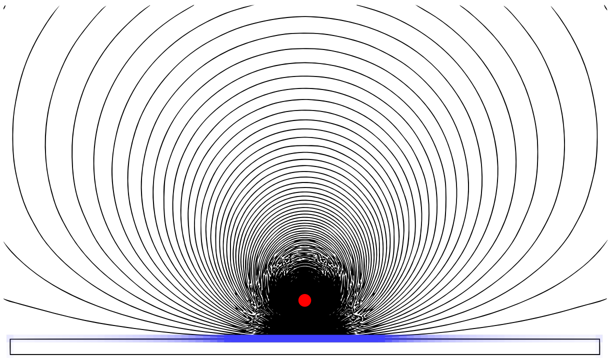
As the plates became closer together, the charge on them became more concentrated on their inner surfaces. At adequately separate distances, the plates showed distributions close to those exhibited had they been isolated entirely.

3 Induced Charge and Shielding

3.1 Point Charge and a Plate

The next configuration of interest was a point charge next to a conducting plate.

Figure 4: Point charge by a grounded plate

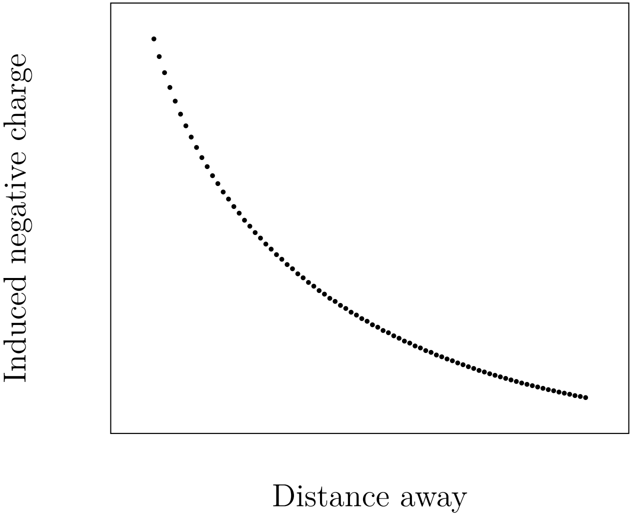


The increment between equipotential lines was shrunk in order to make clear that the equipotential lines in fact flatten out as they approach the surface of the plate. This flattening indicates that the electric field runs perpendicular to the surface of the plate as it approaches it.

The image is not cropped; the electric field is almost immeasurably weak on the opposite size of the plate from the point charge. The plate possesses just enough negative charge to perfectly cancel the field. This exact amount of negative charge comes from the fact that in this example, the plate was in fact *grounded*, allowing it to draw an arbitrary amount of charge from a never-ending neutral source.

The amount of negative charge drawn by the plate from the ground was seen to depend on the distance away from the point charge. The following graph was created by painstakingly moving the plate in the simulator and recording the charge displayed. The units are arbitrary; the simulation does not provide a way to relate the units shown to physical measurements. It is only known that the units are proportional to their physical counterparts.

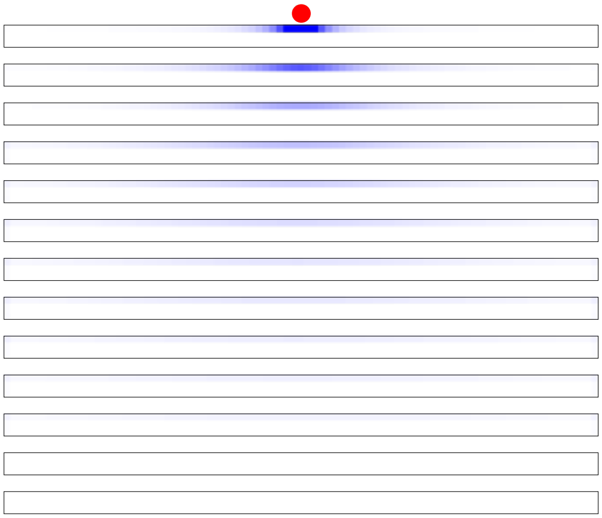
Figure 5: Induced charge / varying distance



When the plate is closer, the effects of the point charge's electric field are stronger, inducing more charge in the grounded plate, for the grounded plate can draw any amount of charge necessary to cancel out the effects of the point charge. This field canceling resulted in little to no electric field on opposite side of the plate for any distance.

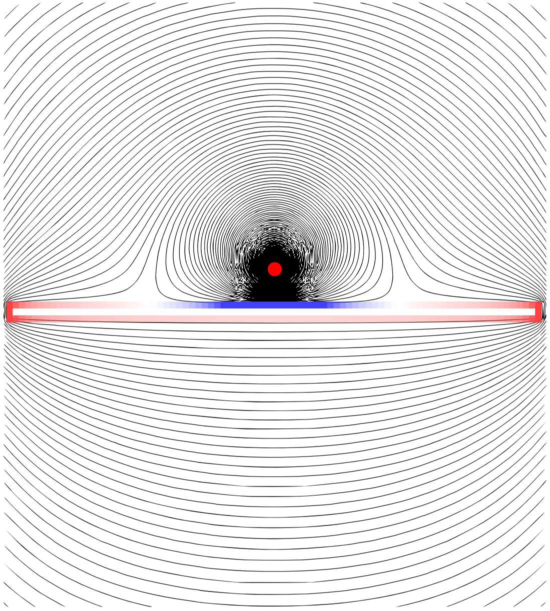
The induced charge was shown to concentrate around the part of the plate closest to the point charge. In the following diagram, the red-colored positive point charge sits fixed whilst the plate is moved away by increments shown visually. The plate's negative charge is shown in blue.

Figure 6: Point charge at varying distances away from grounded plate



The plate in this case was grounded, allowing it to pull any charge to cancel the point charge's electric field. This contrasts the situation where the plate is floating, meaning it has a net charge of 0 and can only redistribute its possessed charge differently to reach an equilibrium. In the following diagram, positive charge is red, negative charge is blue, and the same threshold between equipotential surfaces was chosen as from figure 4.

Figure 7: Point charge next to a floating plate

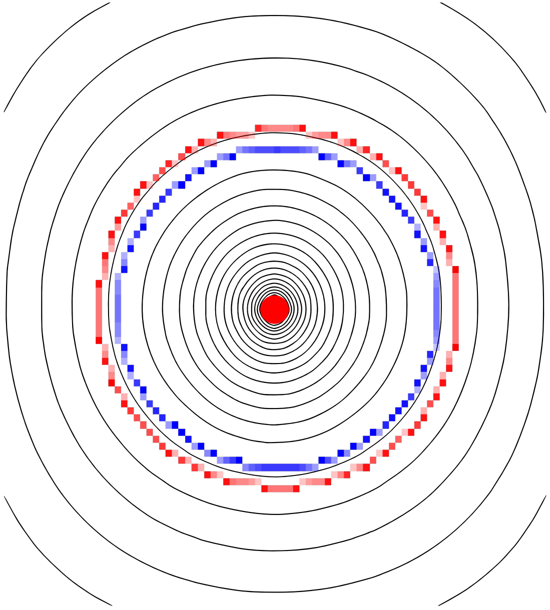


It is seen that the plate's inability to counteract the field of the point charge results in a positive electric field on the opposite side of the plate, not identical but similar to the field that would've been there had the plate not been present. Negative charge still accumulates by the point closest to the point charge, but with a floating plate, the depletion of negative charge from every other point on the plate results in the remainder of the plate being positively charged. The fact that positive charge accumulates on the ends of the plate could possibly be explained by a combination of the ends being the farthest points away from the point charge, and the fact that — as shown in the parallel plates experiment — charges in convex conductors generally concentrate more at sharp corners.

3.2 Floating Hollow Cylinder

Another scenario looked at to analyze induced charges was a hollow cylinder with a point charge inside.

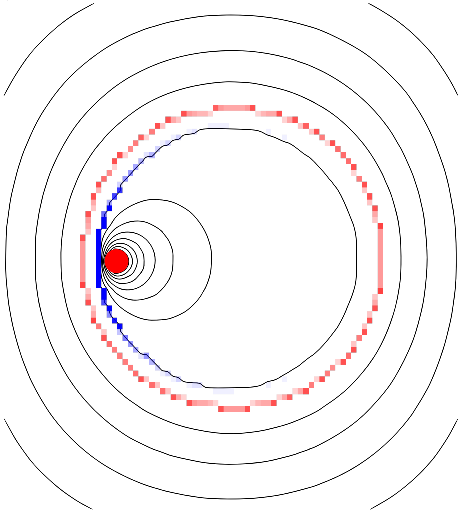
Figure 8: Hollow cylinder with point charge



As shown, the electric field sort of "bleeds through" the cylinder. The cylinder is not grounded, so it cannot produce the negative charge required to cancel out the point charge's electric field. The positive point charge induces the net neutral charge of the cylinder to spread out unevenly, attracting negative charge to the inner boundary and pushing positive charge to the outer boundary.

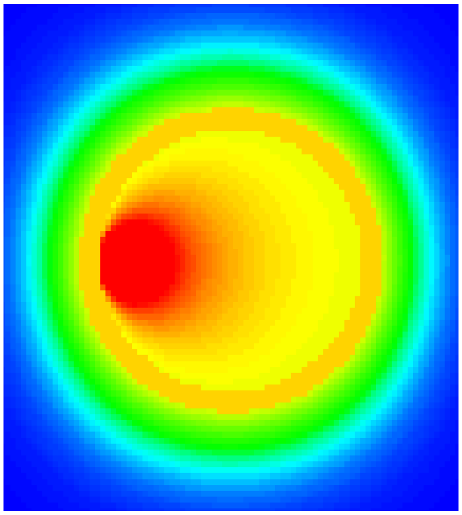
This effect occurs no matter where the point charge is inside the cylinder, although the position does change the distribution of the induced charges within their boundaries.

Figure 9: Hollow cylinder with point charge inside, off-center



It is not clear from the equipotential diagrams that there is 0 electric field inside the conductive regions. This is made apparent by the constant electric potential inside the conductor, with no gradient visible. The constant potential of the conductor in this diagram is the orange beige color.

Figure 10: Potential energy of cylinder configuration



The electric field is 0 inside the conductor for a combination of reasons. The point charge itself creates an outward electric field that would penetrate the conductor if it had no charges to move in response to it. The charges inside the conductor do move, specifically until they reach an equilibrium state. The equilibrium state implies that no charges inside the conductor are moving, and thus no charges inside the conductor experience a net electric field. Because this is ultimately what dictates an equilibrium state, the charges redistribute to create an opposing electric field whenever possible, making the field inside the conductive region 0.

Intuitively, this 0 electric field is observed because the positive charge pulls negative charges inward and pushes positive charges outward. Because electric fields point from positive charges to negative charges, the induced charge creates an inward electric field, counteracting and perfectly canceling out the field from the point charge.

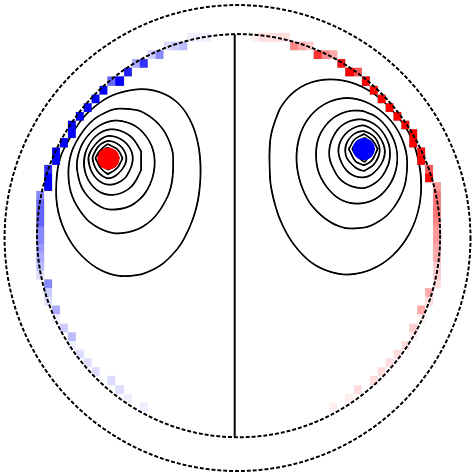
Because positive charges are pushed to the outer surface, the cylinder creates an outward electric field on its external boundary. This also complies with Gauss's Law; the point charge is positive, but the cylinder overall has no net charge. Thus, any surface fully encompassing the configuration would experience an electric field similar to that of the point charge alone.

Gauss's Law can be used to easily calculate the electric field in symmetric situations, similar to the point charge being centered as in figure 8. However, figure 9 demonstrates that even though the conductor has no net charge, it does create an electric field that differs from that of the point charge alone.

In fact, it was found that moving the point charge within the cylinder did not significantly affect the electric field outside of the cylinder.

A negative charge was added beside the positive charge.

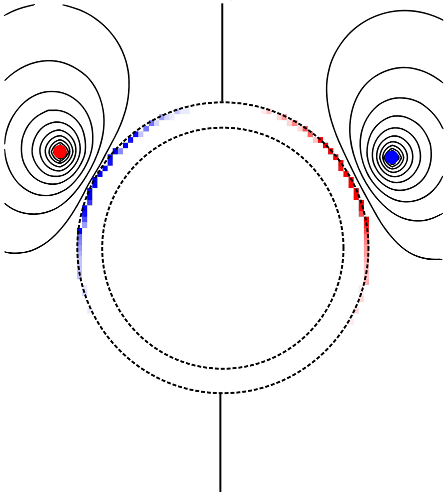
Figure 11: Grounded cylinder, dipole inside



With the two charges inside the cylinder, it also is in line with Gauss's Law that there was no electric field outside the cylinder.

The charges were then moved outside the cylinder.

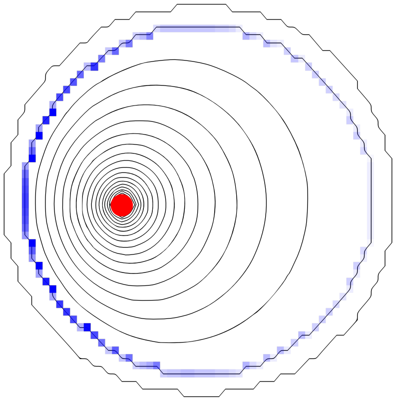
Figure 12: Grounded cylinder, dipole outside



When both charges were moved outside of the cylinder, there resulted no electric field inside the cylinder. This is explainable by the fact that inside any conducting region, there is no net electric field, for any non-zero field would cause charges to move until one was created. Thus, the hollow cavity inside the cylinder also has no electric field because nothing inside it can create an electric field and the conductor completely surrounding it must not have any electric field either. This effect is known as shielding.

It is worth noting that the cylinder in these situations was floating. The case where the cylinder was grounded was also looked at.

Figure 13: Grounded cylinder, point charge

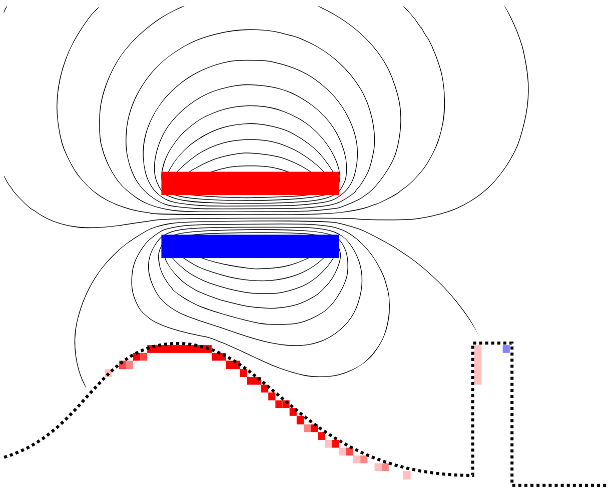


The cylinder when grounded was able to draw the negative charge needed to cancel out the effects of the positive point charge. Thus, virtually no electric field was recorded outside of the cylinder. Similarly, when the point charge was moved outside the grounded cylinder, the inside had no electric field.

4 Lightning

A model was created within the simulation to give rough insight into the phenomenon of lightning. To emulate a cloud above a terrain, an opposing set of charged plates was put above a grounded conductive surface.

Figure 14: Emulated cloud and terrain

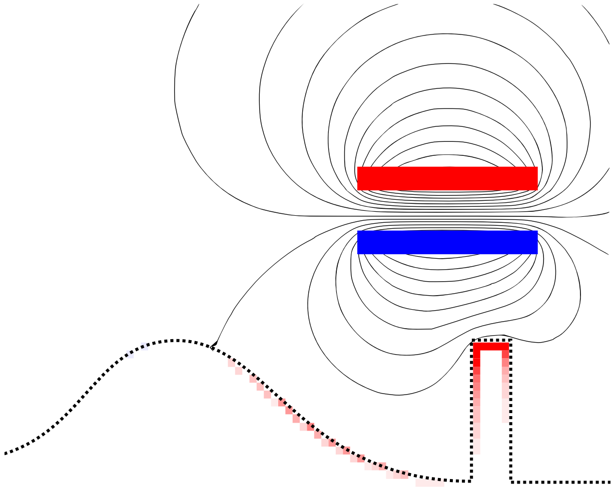


The hill in this model that is near the cloud becomes charged, and a strong electric field between the hill and the cloud is present as represented by the closely packed equipotential lines.

The lines are most closely packed at the top of the hill, suggesting that the top of the hill experiences the greatest electric field. Thus, it can be reasoned that the higher part of the hill would be more commonly struck by lightning than the lower parts.

The cloud was moved closer to the column in the scene.

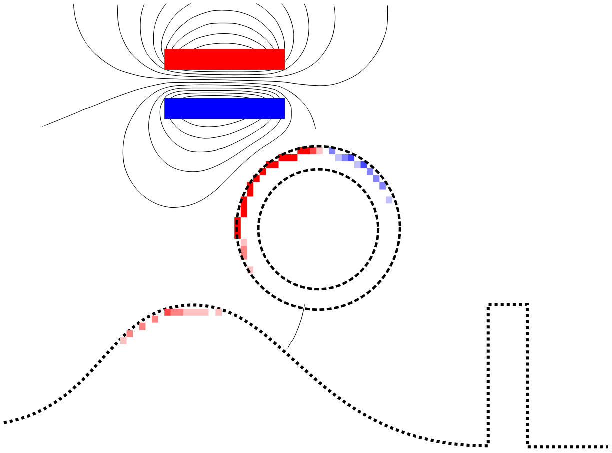
Figure 15: Emulated cloud and terrain, cloud next to column



Now the electric field is strongest above the column, as shown by the equipotential lines "bunching up" above the column to make room for it. The top of the column also has a lot of induced charge. Thus, it is reasonable to assume that the top of the column is very likely to be struck by lightning in this situation.

Next, a ungrounded hollow cylinder was introduced to the scene. The cylinder is comparable with a plane flying through the storm.

Figure 16: Emulated cloud and terrain, cloud next to column



It is seen that the hollow cylinder shields the inside space from the electric field of the cloud. Since airplanes are also large metal containers, it can be reasoned that airplanes also have a shielding effect to the passengers inside when flying through a lightning storm. Thus, with lightning strikes that aren't large enough to disable or destroy the airplane itself, passengers within a plane should be reasonably safe from lightning while inside the plane.

5 Conclusion

Several configurations involving charges and conductors were created and analyzed within the abilities of the simulation used. Phenomena such as induced charge and shielding were demonstrated while occurring in both floating and grounded conductors with charges in or nearby them.

Ultimately the simulator used has limited abilities. The simulator, while simulating 3D interactions, can only move objects in 2-dimensional space. Furthermore, the simulator uses a fixed resolution that displays artifacts in the results. However, despite these limitations the simulator is still capable of demonstrating the electric phenomena of interest.