Electric Field and Potential
PHY-222-AC01

Jasper Runco

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1 Theory

Electric Field of the Point Charge: In the previous lab, the interaction of charged objects at a distance was studied and we concluded that the phenomenon of an electric force pair exists along the path connecting the charged objects with opposite direction depending on parity of the charge carriers (opposites attract). The magnitude of the electric force is defined by Coulomb's law.

When studying the electric force generated by a given localized charge, it is very useful to construct a vector field at all posible points in space around the localized charge. The fact that our localized charge may be continuous distributions of charge across surfaces or volumes is problematic. The resulting vector field should not be ambiguous. To avoid this wherever possible, we can use Coulomb's equation to derive an equation that generates a vector field around a point charge, a hypothetical e_- or e_+, and use calculus to extrapolate this vector field to the entire charged region

Given the similarities between Coulomb's law and Newton's law of gravitation, calling this calculation an electric field is likely a poor choice of wording. We should be careful not to exagerate what this "electric field" describes. We have already seen that Newton's gravity gave rise to relativity, in which gravity went from being a force to a field that affects the geometric proporties of space-time. A vector field calculation gives a good insight for possible electric forces, but these are labels, not nesecarily properties.

2 Objectives

First Objective

Verify the formula for the electric field of the point charge.

Second Objective

Explore the electric field lines of various charge configurations and the superposition principle.

Third Objective

Explore the relationship between the electric field and electric potential.

3 Experimental Data

3.1 Part I

3.1.1 Qualitative Data

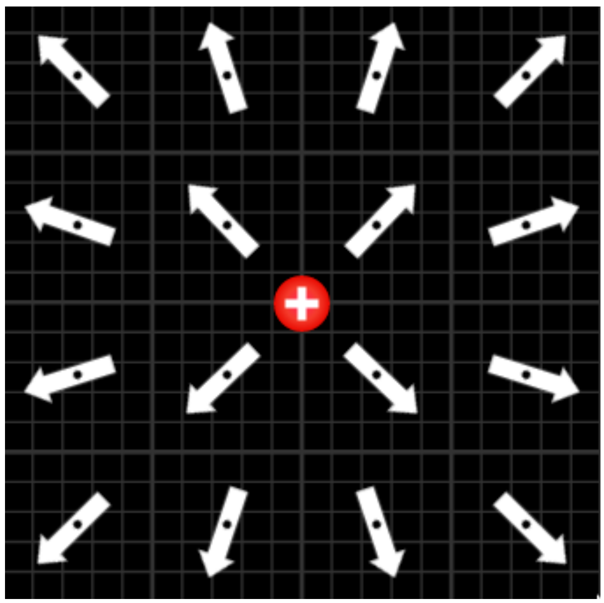

Figure 1: Part 1.1 Simulation

3.1.2 Quantitative Data

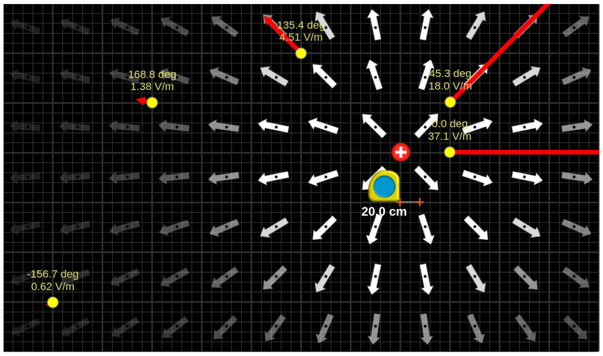

Figure 2: Part 1.2 Simulation

Table 1: Part 1.2

Sensor #	x (cm)	y (cm)	$r = \sqrt{x^2 + y^2}$ (cm)	$\theta = \arctan \frac{y}{x}$ (rad)	$\left\|\overline{E}\right\|$ (V/m)	Electric Field angle (degrees)
1	50.0	0.0	50.0	0.0	37.1	0.0
2	50.0	50.0	70.7	0.785	18.0	45.3
3	-100.0	100.0	141.4	2.356	4.51	135.4
4	-250.0	50.0	255.0	2.94	1.38	168.8
5	-350.0	-150.0	380.8	-2.737	0.62	-156.7

3.2 Part II

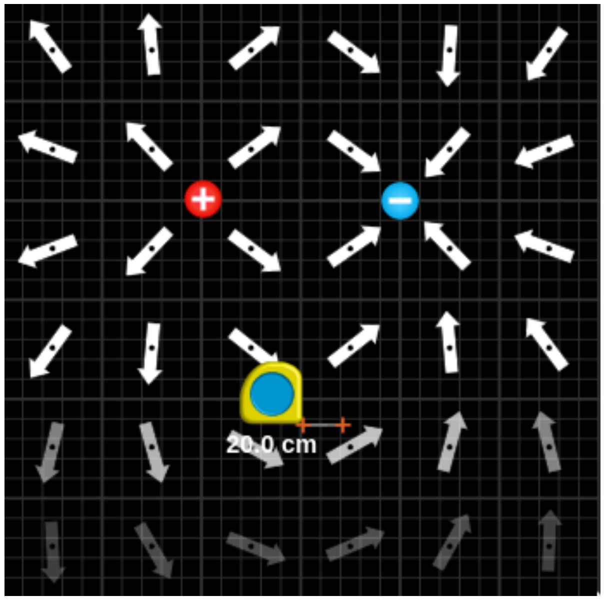

Figure 3: Part 2.1-2.3 Simulation

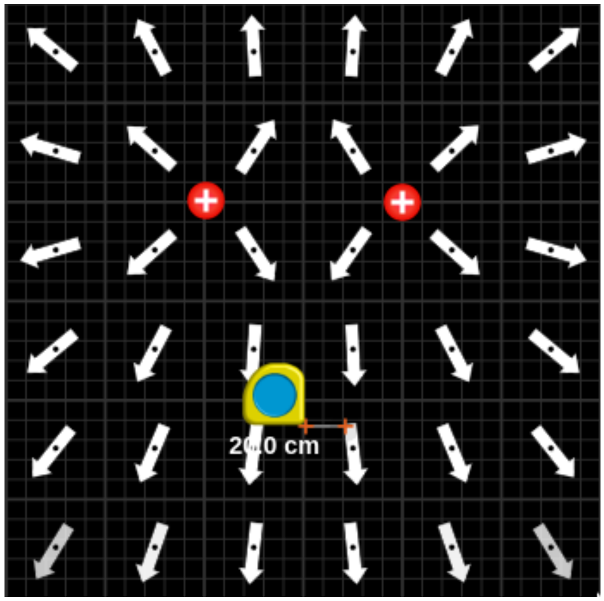

Figure 4: part 2.4-2.5 simulation

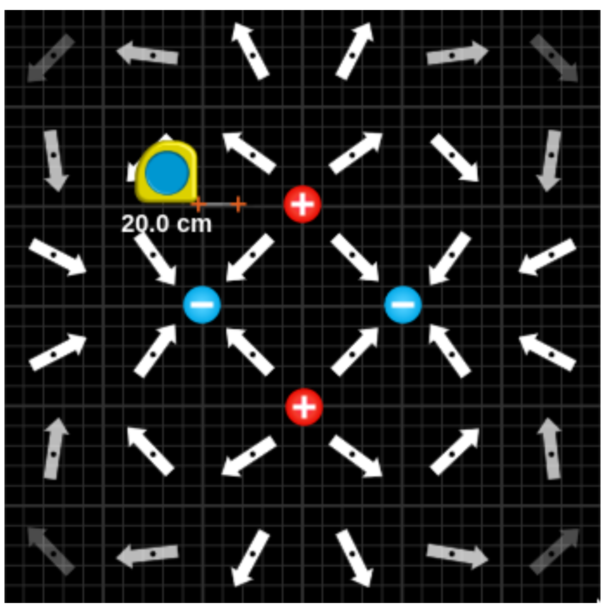

Figure 5: part 2.6 simulation

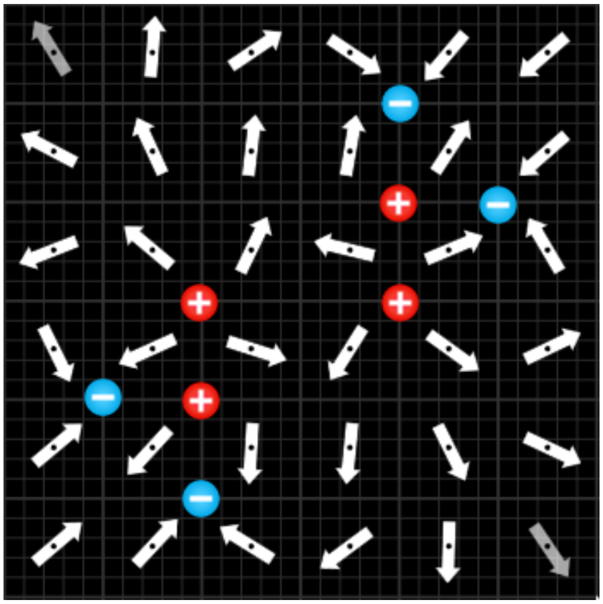

Figure 6: part 2.7 simulation

3.3 Part III

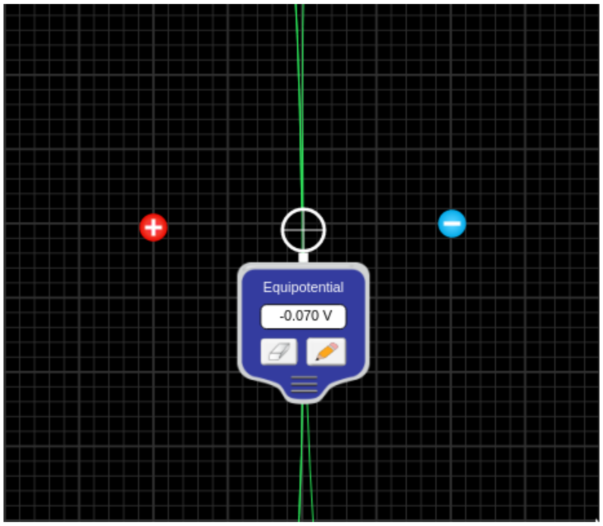

Figure 7: part 3.2 simulation

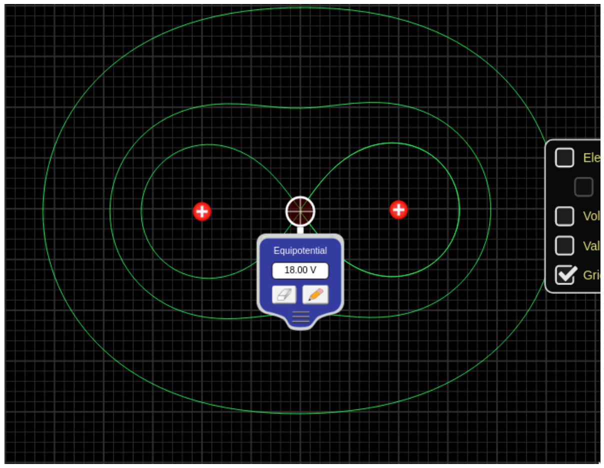

Figure 8: part 3.3 simulation

3.4 Part IV

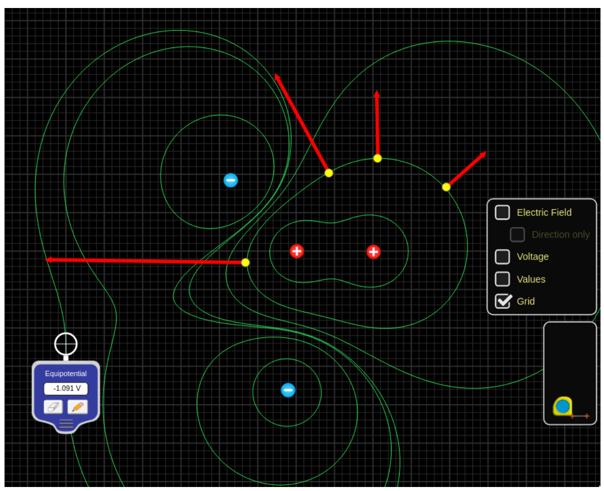

Figure 9: part 4.1 simulation

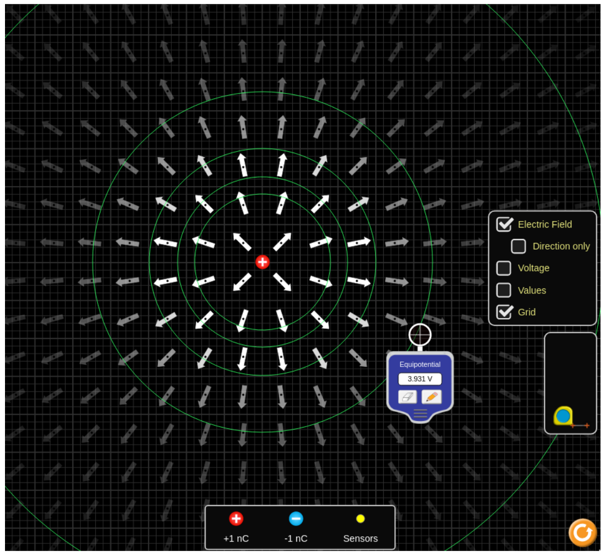

Figure 10: part 4.2 simulation

4 Data Analysis

4.1 Part I

4.1.1 Can the arrows that the program uses to visualize the electric field be called field lines? How are they similar and different from the field lines?

The arrows could be used to visualize the electric field lines, but they are not lines. Like electric field lines, the arrows indicate the direction and strength of the electric field. The lines indicate the relative strength of the field in a different way. The opacity of the arrows describes the field strength while field lines show field strength with their proximity to adjacent field lines.

4.1.2 Section 2

a) The angle of the position vector of the test charges is equal to the angle of the electric field in every test charge in this experiment. This suggests a theory that the electric field is directed radially. To prove that the electric field of the point charge is radial by statistical proof would warrant more data.
b) See Table 2. The fourth column, $\overline{E} \times r^2$ (Vm), does show that the magnitude of the electric field is inversely proportional to the distance squared because their product is constant. Sensor 1 is an outlier, and the median is sensor 2 at 9.00 Vm. Sensor 2 will be used to calculate k.

$$
\begin{aligned}
\left|\overline{E}\right| &= \frac{kq}{r^2} \implies \\
k &= \frac{\left|\overline{E}\right| r^2}{q} \\
k &= \frac{18.0\frac{V}{m} \cdot (70.7cm)^2}{1nC} \\
k &= \frac{18.0\frac{N}{C} \cdot (0.707m)^2}{10^{-9}C} \\
k &= \boxed{9.00 \times 10^9 \frac{Nm^2}{C^2}}
\end{aligned}
$$

Table 2: Part 1.2

Sensor #	$r = \sqrt{x^2 + y^2}$ (cm)	$\left|\overline{E}\right|$ (V/m)	$\left|\overline{E}\right| \times r^2$ (Vm)
1	50.0	37.1	9.27
2	70.7	18.0	9.00
3	141.4	4.51	9.02
4	255.0	1.38	8.97
5	380.8	0.62	8.99

Question: Using a negative point charge, the electric field angle measurements would be anti-parallel to the values for a positive point charge ($\pm\pi$ rad). All other values would be the same.

4.2 Part II

4.2.1 Section 2: Field Line Description

- On the horizontal axis to the right of the dipole, the field is pointing left because the charges superimpose in line, negating each other but the negative charge has a greater effect because it is closer.

- On the horizontal axis between charges, the field is in the positive-x direction because the charges superimpose in line but from opposite directions, creating a cumulative effect.

- On the horizontal axis to the left of the dipole, the field is pointing left because the charges superimpose in line, negating each other but the positive charge has a greater effect because it is closer.

- Along the vertical bisector above the dipole, the field is to the right because the vertical components of the superimposed fields are equal in magnitude and opposite in direction and the horizontal components of the two charges combine in the positive x direction. The field strength diminishes farther in the positive-y direction.

- Along the vertical bisector below the dipole, the field behaves the same as above the dipole for the same reasons, except the field strength diminishes farther in the negative-y direction.

4.2.2 Section 3: Is there a location where the electric field is exactly zero?

In the case of an electric dipole, at no position do the electric fields of the two charges cancel.

4.2.3 Section 4: Field Line Description

- On the horizontal axis to the right of the dipole, the field is pointing right because the charges superimpose in line, reinforcing each other.
- On the horizontal axis between charges, the field points away from whichever charge is closer because the charges superimpose in line but in opposite directions. Field strength increases closer to either positive charge.
- On the horizontal axis to the left of the dipole, the field is pointing left because the charges superimpose in line, reinforcing each other.
- Along the vertical bisector above the dipole, the field in the positive-y direction because the horizontal components of the superimposed fields are equal in magnitude and opposite in direction and the vertical components of the two charges combine in the positive y direction. Field strength diminishes farther from the charges.
- Along the vertical bisector below the dipole, the field behaves the same as above the dipole for the same reasons, except field strength diminishes farther in the negative-y direction.

4.2.4 Section 5: Is there a location where the electric field is exactly zero?

Yes, the only location where the field strength is zero is along the x-axis at the bisector of the two charges.

4.2.5 Section 6: See Figure 5

4.2.6 Section 7: See Figure 6

4.3 Part III

See Figure 7 and Figure 8
Based on these observations, electric field superposition with opposite charges behaves like the potential superposition with like charges. In other words, a pair

of positive charges or a pair of negative charges will have a cumulative effect of electrical potential, but a diminishing effect on electric field.

4.4 Part IV

4.5 Section 1

See Figure 9. The voltage sensor reads the same at every point on these lines, indicating that these are equipotential lines over this charged surface. The electric field at every point on the line is always perpendicular to the line itself. The field magnitude increases with proximity to the point charges, where the exhibit closer proximity to each other.

4.6 Section 2

See Figure 10. The lines that are closer to each other occur in the regions where the strength of the electric field is greater.

5 Conclusion

These experiments demonstrate several relationships between electric field lines and electrical potential. First, the two are mutually perpendicular. Second, movement in the direction of an electric field results in a decrease in the electrical potential. Because work has an inverse relationship with potential energy, it is comparable to say work is done by the electric field to a particle that moves through the electric field. Finally, if a field is mapped with equipotential lines where the difference in potential between neighboring lines is the same, then the field strength is going to be greater in regions where the equipotential lines are closer. In a two-dimensional field, the field is like a topographical map with the equipotential lines being elevation and the gradient being field strength.

6 Discussion of Experimental Uncertainty

The is a virtual experiment and so there is no source of uncertainty other than the precision of the programs calculations.