Chapter 19
Electric Charges, Forces, and Fields

Outline
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19-2 Insulators and Conductors
19-3 Coulomb’s Law
19-4 The Electric Field
19-5 Electric Field Lines
19-6 Shield and Charging by Induction
19-7 Electric Flux (and Gauss’s Law)
19-4 The Electric Field

Since an electric charge apply a “force field” every around it (see Fig 19-9), it is very natural to define a Electric Field.

Figure 19-9. A Electric Field
Definition of Electric Field, \( \vec{E} \)

If a test charge \( q_0 \) experiences a force \( \vec{F} \) at a given location, the electric field at that location is

\[
\vec{E} = \frac{\vec{F}}{q_0}, \quad (19-8)
\]

SI unit: N/C

Note:

1) The electric field is the force per charge at a given location.

2) The electric field is a vector.

3) A positive charge experiences a force in the direction of \( \vec{E} \).

4) A negative charge experiences a force in the opposite direction of \( \vec{E} \).

5) The magnitude of the force acting on the charge \( q \) is \( F = |q|E \).
From the definition, one also has

\[ \vec{F} = q \vec{E} \]  

(19–9),

where \( q \) is the charge, and \( \vec{F} \) is the force applied on the charge.
**Example 19-33: Force Field**

A + 5.0 uC charge experiences a 0.44 N force in the positive y direction. If this charge is replaced with a -2.7 uC charge, what force it will experience?

*Picture the Problem (force directions)*
Solution:

1. Find $\vec{E}$ using equation 19-8:

$$\vec{E} = \frac{\vec{F}}{q} = \frac{0.44 \text{ N} \hat{y}}{5.0 \times 10^{-6} \text{ C}} = (8.8 \times 10^4 \text{ N/C}) \hat{y}$$

2. Use equation 19-9 to find the new force:

$$\vec{F} = q\vec{E} = (-2.7 \times 10^{-6} \text{ C})(8.8 \times 10^4 \text{ N/C}) \hat{y} = (-0.24 \text{ N}) \hat{y}$$
The Electric Field of a Point Force

The simplest case is that electric field is created by a Point Charge, as shown in Fig. 19-10.

Figure 19-10. The Electric Field of a Point.
Suppose a positive point charge \( q \) is at the origin. A positive test charge \( q_0 \) is placed a distance \( r \) from the original, then the magnitude of the force it experiences is

\[
F = k \frac{|q||q_0|}{r^2}
\]

Applying the definition of the electric field, the magnitude of the field is

\[
E = \frac{F}{q_0} = \frac{(k \frac{|q||q_0|}{r^2})}{q_0} = k \frac{|q|}{r^2}
\]

The electric field direction is radially outward.
Magnitude of the Electric Field due to a Point Force

A simplest case is that electric field is created by a Point Charge, as shown in Fig. 19-10.

\[ E = k \frac{|q|}{r^2} \]  \hspace{1cm} (19–10)

- If q is positive, the electric field points radially outward;
- If q is negative, the electric field points radially inward;
Superposition

For case of more than two charges, the net electric field vector is

\[ \vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots \]

The X and Y components of the net electric field are

\[ E_{net,x} = E_{1,x} + E_{2,x} + E_{3,x} + \ldots \]
\[ E_{net,y} = E_{1,y} + E_{2,y} + E_{3,y} + \ldots \]

The magnitude and direction of the net electric field are

\[ E_{net} = \sqrt{E_{net,x}^2 + E_{net,y}^2} \]
\[ \theta = \tan^{-1} \left( \frac{E_{net,y}}{E_{net,x}} \right) \]
Example 19-5: Superposition in the Electric Field

Two charges, each equal to +2.90 uC, are placed at two corners of a square 0.500 on side, as shown in the figure. Find the magnitude and direction of the net electric field at a third of the square.
**Solution**

1) Find the magnitude of the $\vec{E}_1$

$$E_1 = k \frac{|q|}{(\sqrt{2}r)^2}$$

$$= (8.99 \times 10^9 \text{ N.m}^2 / \text{C}) \frac{(2.90 \times 10^{-6} \text{ C})}{2(0.500 \text{ m})^2}$$

$$= 5.21 \times 10^4 \text{ N/C}$$

2) Find the magnitude of the $\vec{E}_2$

$$E_2 = k \frac{|q|}{(r)^2}$$

$$= (8.99 \times 10^9 \text{ N.m}^2 / \text{C}) \frac{(2.90 \times 10^{-6} \text{ C})}{(0.500 \text{ m})^2}$$

$$= 1.04 \times 10^5 \text{ N/C}$$
3) Calculate the components of $\vec{E}_1$ and $\vec{E}_2$

$$\vec{E}_{1,x} = E_1 \cos(45.0^\circ)$$
$$= 3.68 \times 10^4 \ N / C$$

$$\vec{E}_{1,y} = E_1 \sin(45.0^\circ)$$
$$= 3.68 \times 10^4 \ N / C$$

$$\vec{E}_{2,x} = E_2 \cos(0^\circ)$$
$$= 1.04 \times 10^5 \ N / C$$

$$\vec{E}_{2,y} = E_2 \sin(0^\circ)$$
$$= 0 \ N / C$$
4) Calculate the components of \( \overrightarrow{E}_{\text{net}} \)

\[
E_{\text{net},x} = E_{1,x} + E_{2,x} \\
= 3.68 \times 10^5 + 1.04 \times 10^5 \\
= 1.41 \times 10^5 \ \text{N} / \text{C}
\]

\[
E_{\text{net},y} = E_{1,y} + E_{2,y} \\
= 3.68 \times 10^4 + 0 = 3.68 \times 10^4 \ \text{N} / \text{C}
\]

5) The magnitude and the direction of the net field \( \overrightarrow{E}_{\text{net}} \) are

\[
E_{\text{net}} = \sqrt{E_{\text{net},x}^2 + E_{\text{net},y}^2} = \sqrt{(1.41 \times 10^5)^2 + (3.68 \times 10^4)^2} = 1.46 \times 10^5 \ \text{N} / \text{C}
\]

\[
\theta = \tan^{-1} \left( \frac{E_{\text{net},y}}{E_{\text{net},x}} \right) = \tan^{-1} \left( \frac{3.68 \times 10^4}{1.41 \times 10^5} \right) = 14.6^\circ
\]
19-5 Electric Field Lines

Figure 19-14
Electric Field Lines for a Point Charge
Rules for Drawing Electric Field Lines

1. Point in the direction of the electric field vector $\vec{E}$ at every point;

2. Start at positive (+) charges or at infinity;

3. End at negative (-) charge or at infinite;

4. The number of lines (density) is proportional to the magnitude of the field $\vec{E}$. 
CONCEPTUAL CHECKPOINT 19–5

Which of the following statements is correct: Electric field lines (a) can or (b) cannot intersect?
CONCEPTUAL CHECKPOINT 19–5
Which of the following statements is correct: Electric field lines (a) can or (b) cannot intersect?

Reasoning and Discussion
By definition, electric field lines are always tangent to the electric field. Since the electric force, and hence the electric field, can point in only one direction at any given location, it follows that field lines cannot intersect. If they did, the field at the intersection point would have two conflicting directions.

Answer
(b) Electric field lines cannot intersect.
Examples of Electric Field of Two charges
Figure 19-15a
Electric Field Lines for Systems of Charges

(a) (+q and −q)
Figure 19-15bc
Electric Field Lines for Systems of Charges

(2q and −q)

(+q and +q)
Figure 19-17
A parallel-plate capacitor (Electric Capacitor)
Example 19-35:

An object with a charge of -3.6 uC and a mass of 0.012 kg experience an upward electric force that is equal in magnitude to its weight, due to the uniform electric field created by the parallel-plate capacitor. Find the direction and magnitude of the electric field.

Picture the Problem: An electric charge experiences an upward force due to the presence of an electric field.

The negative charge experiences an upward electric force, so we can conclude the electric field points downward.
Solution:

1. (a) Set $\vec{F}_E = mg$ and solve for $\vec{E}$

$$|q| E = mg \quad \Rightarrow \quad E = \frac{mg}{|q|} = \frac{(0.012 \text{ kg}) \left(9.81 \text{ m/s}^2\right)}{3.6 \times 10^{-6} \text{ C}} = 3.3 \times 10^4 \text{ N/C}$$

$$\vec{E} = E \left(-\hat{y}\right) = \left(-3.3 \times 10^4 \text{ N/C}\right)\hat{y}$$
Summary

1) Electric Field

\[ \vec{E} = \frac{\vec{F}}{q_0}, \quad (19-8) \]

For point charge

\[ E = k \frac{|q|}{r^2}, \quad (19-10) \]

2) Superposition of the Electric Field: vector calculation.

3) Electric Field Lines