# Electricity and Magnetism
# Electric Fields


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De Anza College


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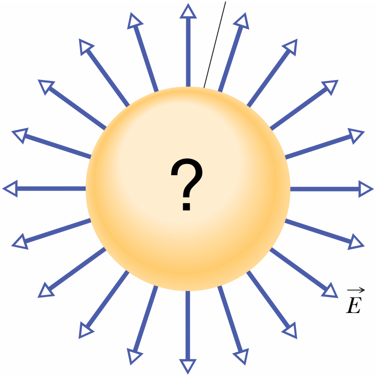
# Last time

- Forces at a fundamental level
- Electric field
- net electric field
- electric field lines

# Warm Up Questions

Which of the following could be the charge on the particle hidden by the question mark?




**(A)** 0 C

**(B)** $-1$ C

**(C)** $-1.6 \times 10^{-19}$ C

**(D)** $+1$ μC

[1]Figure from Halliday, Resnick, Walker

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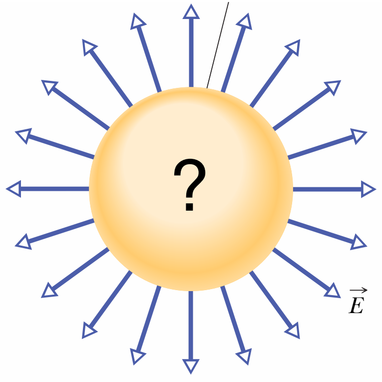


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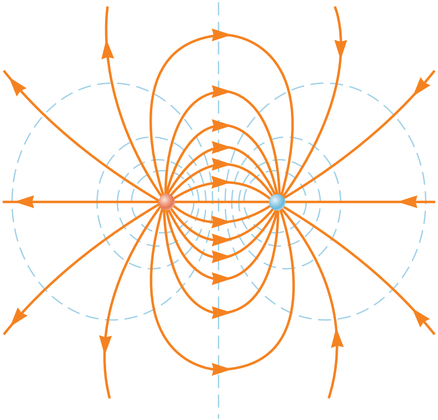
# Overview

- Electric field lines
- Net electric field
- the effect of fields on charges
- the electric dipole

# Field Lines

The electrostatic field caused by an electric dipole system looks something like:



Notice that the lines point **outward** from a positive charge and **inward** toward a negative charge.

[1]Figure from Serway & Jewett

## Field Lines

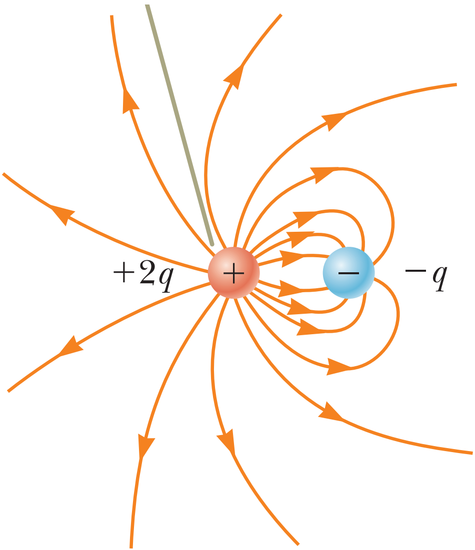
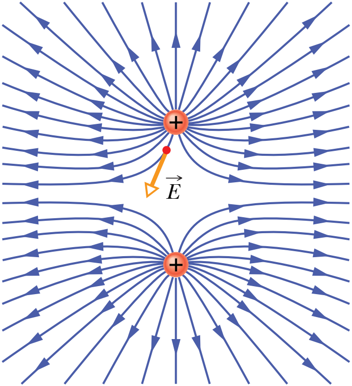
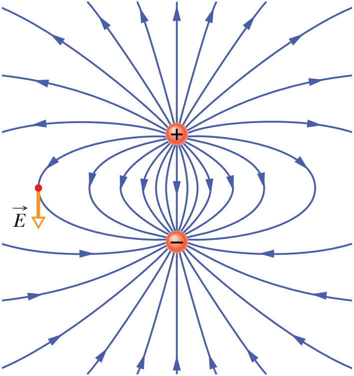



Figure from Serway & Jewett[1]

# Field Lines

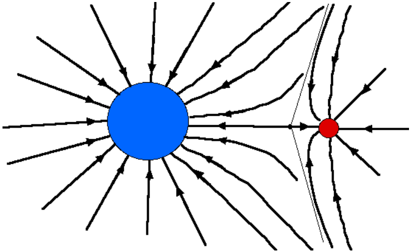
Compare the electrostatic fields for two like charges and two opposite charges:

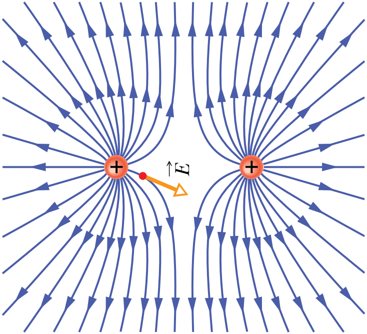


# Field Lines

Compare the fields for gravity in an Earth-Sun system and electrostatic repulsion of two charges:

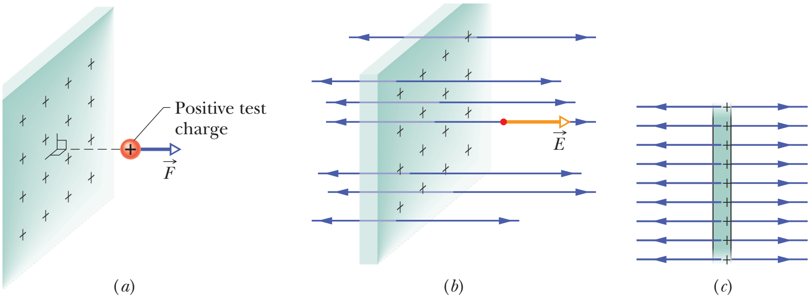





[1]Gravity figure from http://www.launc.tased.edu.au ; Charge from Halliday, Resnick, Walker

# Field Lines: Uniform Field

Imagine an infinite sheet of charge. The lines point **outward** from the positively charged sheet.



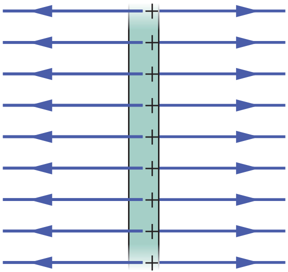

[1]Figure from Halliday, Resnick, Walker.

# Electric field due to an Infinite Sheet of Charge

Suppose the sheet is in air (or vacuum) and the charge density on the sheet is $\sigma$ (charge per unit area):

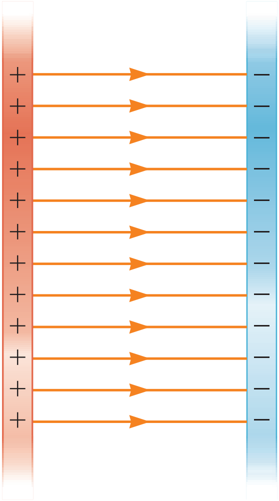
$$E = \frac{\sigma}{2\epsilon_0}$$

It is uniform! It does not matter how far a point $P$ is from the sheet, the field is the same.



# Field Lines: Uniform Field

The field from two infinite charged plates is the sum of each field.



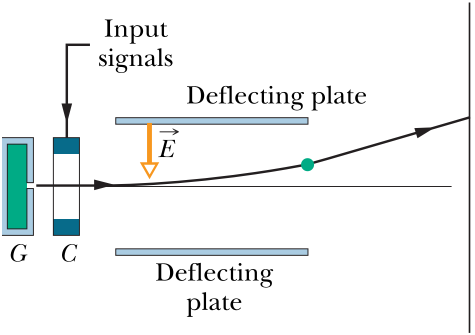
The field in the center of a parallel plate **capacitor** is nearly uniform.

# Free charges in an E-field

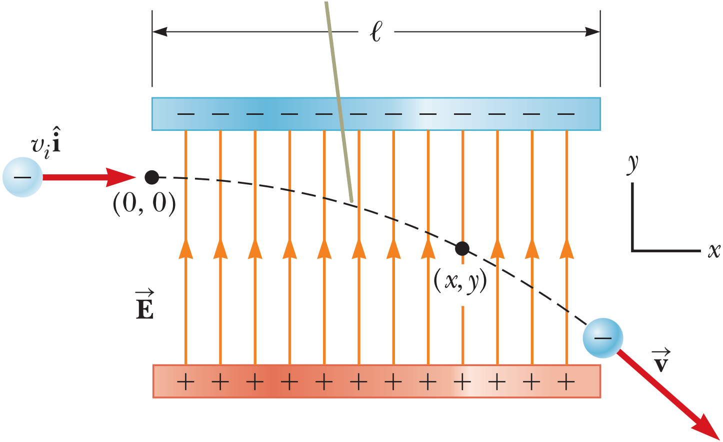
The force on a charged particle is given by $\mathbf{F} = q\mathbf{E}$.

If the charge is free to move, it will accelerate in the direction of the force.

Example: Ink-jet printing



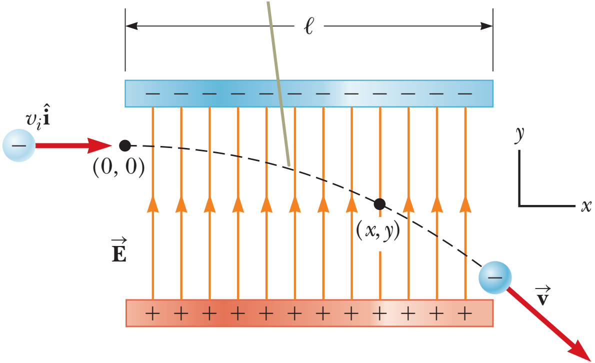
# Motion of a Charged Particle in an E-field




Trajectory is a parabola: similar to projectile motion.

# Motion of a Charged Particle in an E-field

(a) What is the acceleration of an electron in the field of strength $E$?




(b) The charge leaves the field at the point $(\ell, y_f)$. What is $y_f$ in terms of $\ell$, $v_i$, $E$, $e$, and $m_e$?

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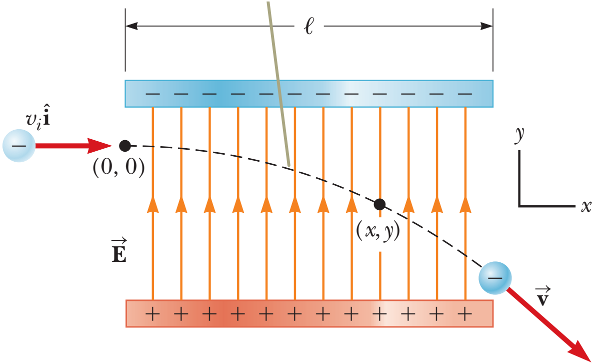



(b) The charge leaves the field at the point $(\ell, y_f)$. What is $y_f$ in terms of $\ell$, $v_i$, $E$, $e$, and $m_e$?

$$y_f = -\frac{eE\ell^2}{2m_e v_i^2}$$

# Trick for working out Net field

**Look for symmetry in the problem.**

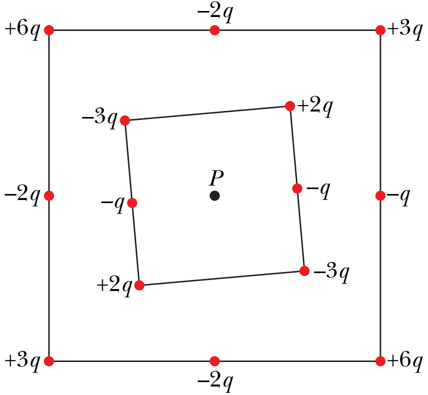
To find the E-field, usually several components ($E_x$, $E_y$, $E_x$) must be found independently.

If the effects of charges will cancel out, you can neglect those charges.

If the effects of charges cancel out in one component, just worry about the other component(s).

# Question about net field

**2** Figure 22-21 shows two square arrays of charged particles. The squares, which are centered on point $P$, are misaligned. The particles are separated by either $d$ or $d/2$ along the perimeters of the squares. What are the magnitude and direction of the net electric field at $P$?




[1]Figure from Halliday, Resnick, Walker, page 597, problem 2.

# Electric Dipole

**electric dipole**

A pair of charges of equal magnitude $q$ but opposite sign, separated by a distance, $d$.

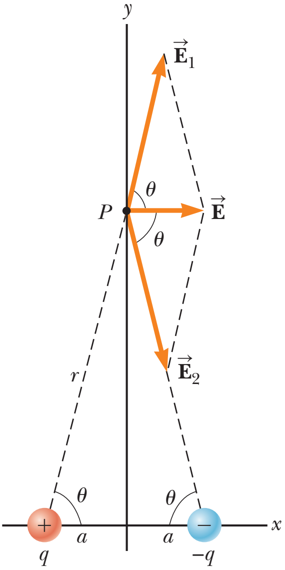
**dipole moment**:

$$\mathbf{p} = qd\,\hat{\mathbf{r}}$$

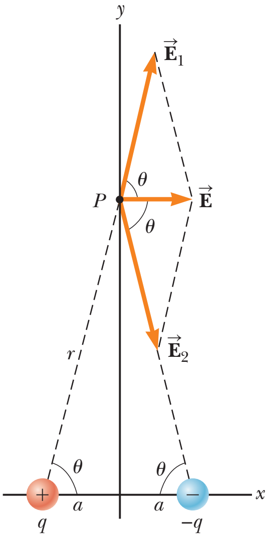
where $\hat{\mathbf{r}}$ is a unit vector pointing from the negative charge to the positive charge.

# Electric Dipole (Example 23.6, B)

Evaluate the electric field from the dipole at point $P$, which is at position $(0, y)$.



# Electric Dipole (Example 23.7)




The $y$-components of the electric field cancel out, $E_y = 0$.

$x$-components:

$$E_x = E_{1,x} + E_{2,x}$$

Also $E_{1,x} = E_{2,x}$

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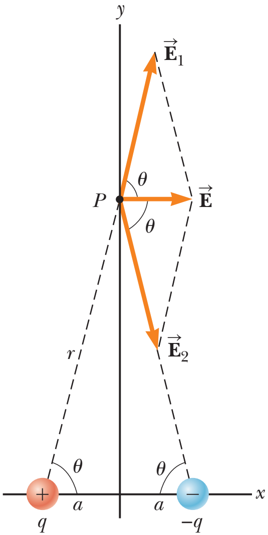


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$$\begin{aligned} E_x &= 2\left(\frac{k_e\, q}{r^2}\cos\theta\right) \\ &= \frac{2k_e\, q}{(a^2+y^2)}\left(\frac{a}{\sqrt{a^2+y^2}}\right) \\ &= \frac{2k_e\, a\, q}{(a^2+y^2)^{3/2}} \end{aligned}$$

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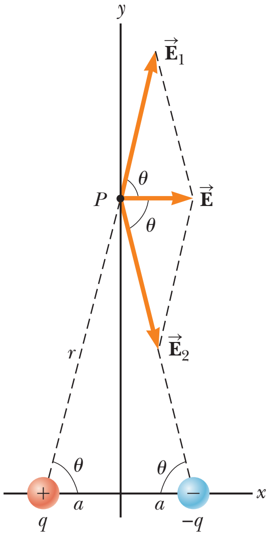


What happens as we move infinitely far from the dipole? ($y >> a$)

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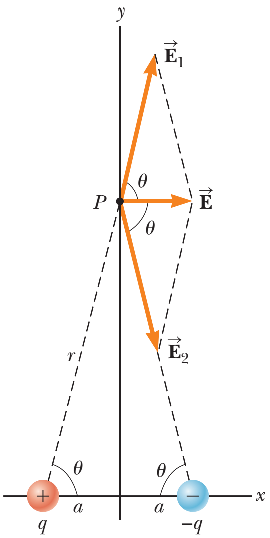


What happens as we move infinitely far from the dipole? ($y >> a$)

The constant $a$ in the denominator has less and less affect on the function. We can see that the field function approaches $E_{\text{far}} = \frac{2k_e\, a\, q}{y^3}$

$$
\begin{aligned}
\lim_{y\to\infty}\left[\frac{E}{E_{\text{far}}}\right] &= \lim_{y\to\infty}\left[\frac{\frac{2k_e\, a\, q}{(a^2+y^2)^{3/2}}}{\frac{2k_e\, a\, q}{y^3}}\right] \\
&= \lim_{y\to\infty}\left[\frac{\frac{2k_e\, a\, q}{y^3\left(\left(\frac{a}{y}\right)^2+1\right)^{3/2}}}{\frac{2k_e\, a\, q}{y^3}}\right] \\
&= 1
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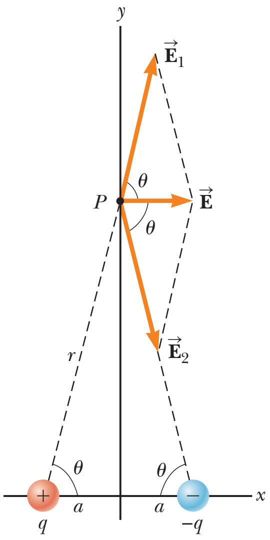


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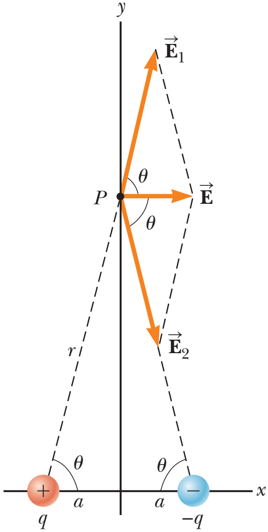
# Big-O Notation (Example 23.7)




$y >> a$

Recall that $f(x) = O(g(x))$ if $\left|\frac{f(x)}{g(x)}\right| \leqslant C$ $\forall\ x > k$.

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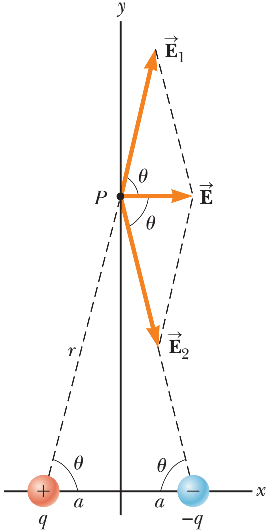


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Recall that $f(x) = O(g(x))$ if $\left|\frac{f(x)}{g(x)}\right| \leqslant C$ $\forall\ x > k$.

$$\left|\frac{E}{E_{\text{far}}}\right| = \left|\frac{\frac{2k_e\, a\, q}{(a^2+y^2)^{3/2}}}{\frac{2k_e\, a\, q}{y^3}}\right|$$

$$= \left|\left(\left(\frac{a}{y}\right)^2 + 1\right)^{-3/2}\right|$$

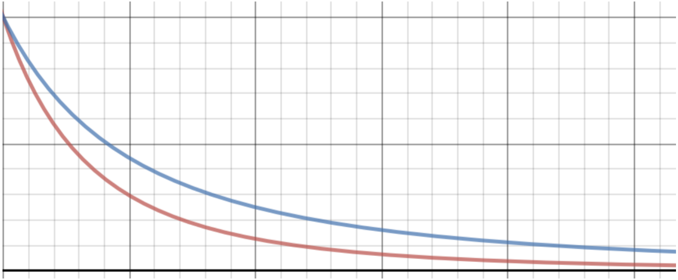
Choosing $k = a$ we can see:

$$\left|\frac{E}{E_{\text{far}}}\right| \leqslant \frac{1}{2\sqrt{2}} \quad \forall\ y > a$$

Therefore, $E = O\left(\frac{2k_e\, a\, q}{y^3}\right)$ or simply $O(y^{-3})$.

# Electric Dipole (Example 23.7)

As we move away from the dipole (red line, $r^{-3}$) the E-field falls off faster than it does for a point charge (blue line, $r^{-2}$).



The negative charge partially shields the effect of the positive charge and vice versa.

# Summary

- electric field lines
- the effect of fields on charges
- the electric dipole

## Homework

- Collected homework 1, posted online, due on Monday, Jan 22.

Serway & Jewett:

- NEW: Ch 23, onward from page 716. Probs: 36, 51, 61, 79
- Understand examples 23.8 and 23.9.