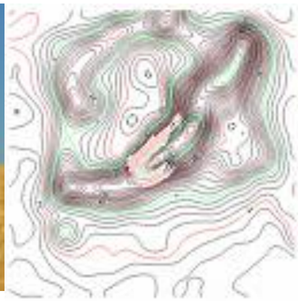
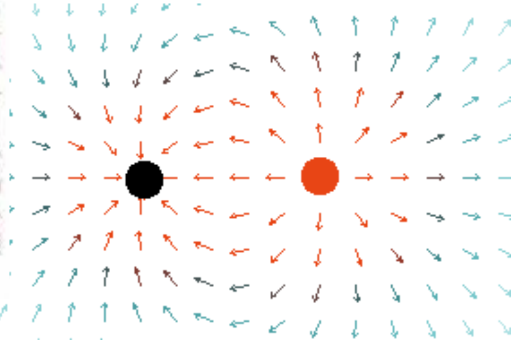
22.1-22.3, 22.7

#6: Fields





Loosely defined, a field is a map of any quantity throughout a region of space.

A ***scalar field*** is a map of a single (directionless) quantity:

A topographical map of the height of the land vs. position

A map of the temperature at all points in this room

A ***vector field*** is a map of a quantity that has both magnitude and direction:

A map of winds in Baton Rouge during Gustav

The electric field caused by a charged object

You can think of the electric field as a hypothetical force. What would the force be on a positive charge q_0 if you placed it at a given location:

$$\vec{F} = q_0 \vec{E} \qquad \textbf{OR} \qquad \vec{E} = \frac{\vec{F}}{q_0}$$

Think of it this way:

Force: Acts upon an object

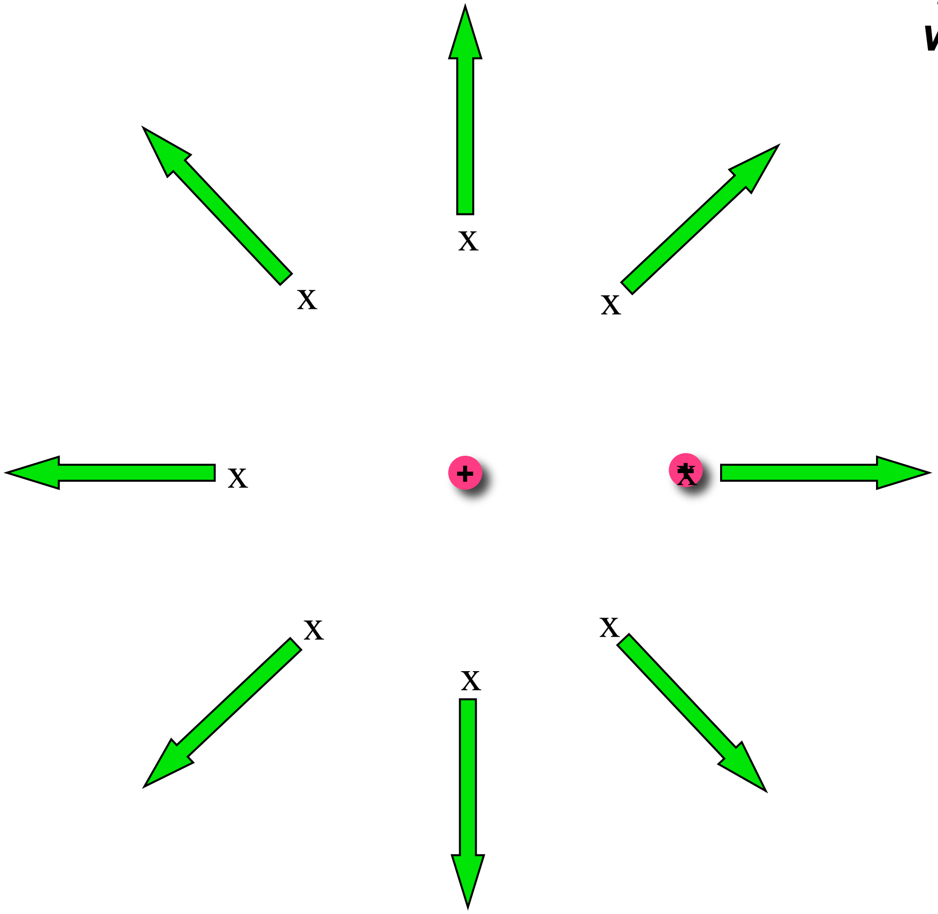
Can cause an acceleration

What object?

Which way will it move?

Field: Hypothetical force

If I placed an object there, what would the force on it be?



Electric field points radially outward from a positive point charge

$$\vec{E}_q = k\frac{|q|}{r^2}$$

Away from a + charge
Towards a - charge

Remember the electric force and the electric field are both ***vectors***

Is the Electric Field “real”?

How does one object exert a force on another object some distance away?

How does one object “know” that another object even exists?

In a fundamental sense, it is the field that produces the force.

Quantum Electrodynamics is the gauge field theory from which classical electrodynamics can be derived.

The electric force results from the exchange of ***photons*** between two particles.

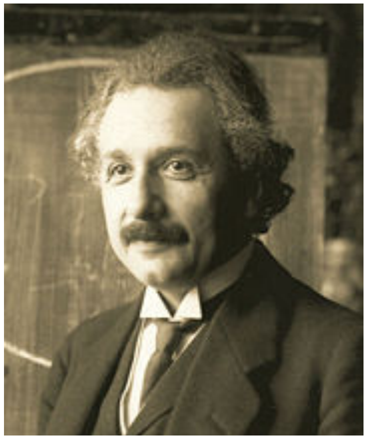
Photon- the basic building block of light - a localized “wavepacket”

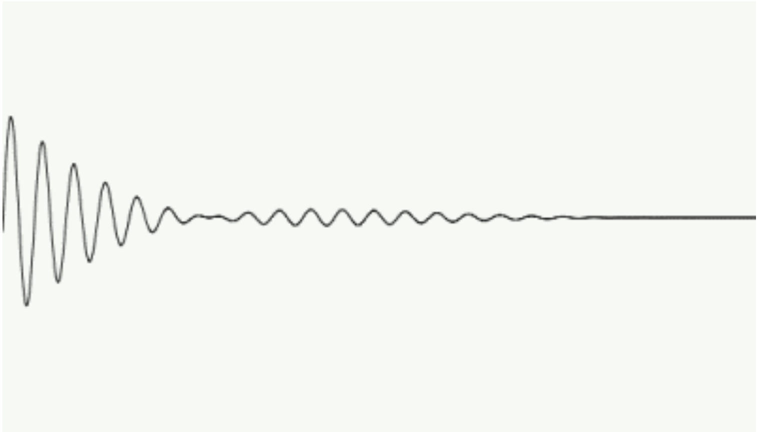
A charged particle produces a field of short-lived photons and e^-e^+ pairs

It is the interaction of a particle with these field particles that produces the force.

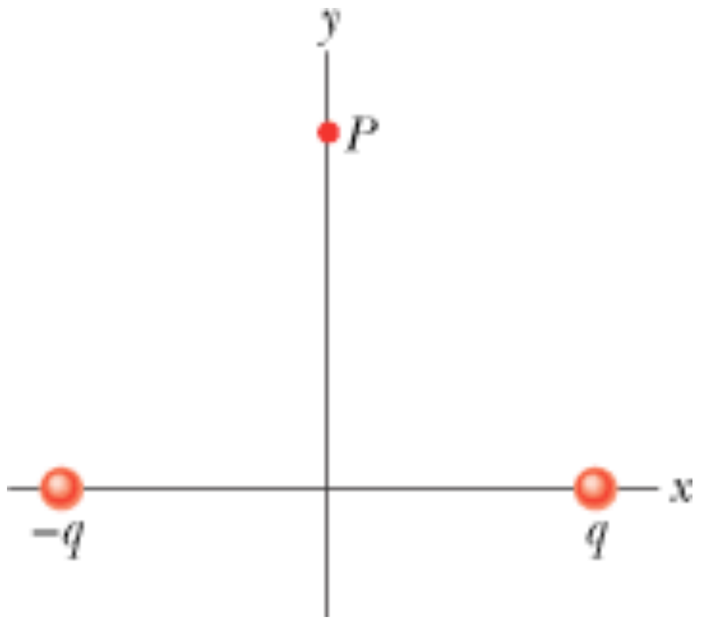
Momentum and energy are naturally conserved

Einstein introduced the photon in 1905 to explain the photoelectric effect
1921 Nobel Prize





Problem: The figure shows two charged particles on an x axis: $-q = -3.2 \times 10^{-19}$ C at $x = -3.0$ m and $q = 3.2 \times 10^{-19}$ C at $x = +3.0$ m. What are the (a) magnitude and (b) direction (relative to the positive direction of the x axis) of the net electric field produced at point P at $y = 4.0$ m?



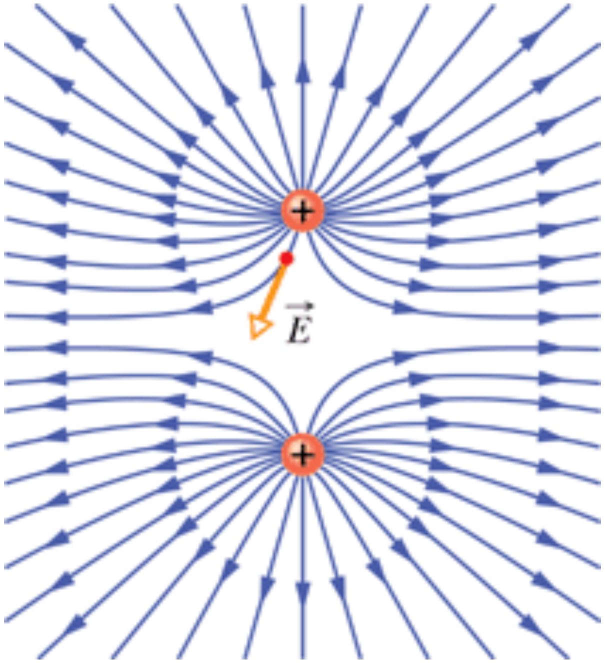
Electric field lines

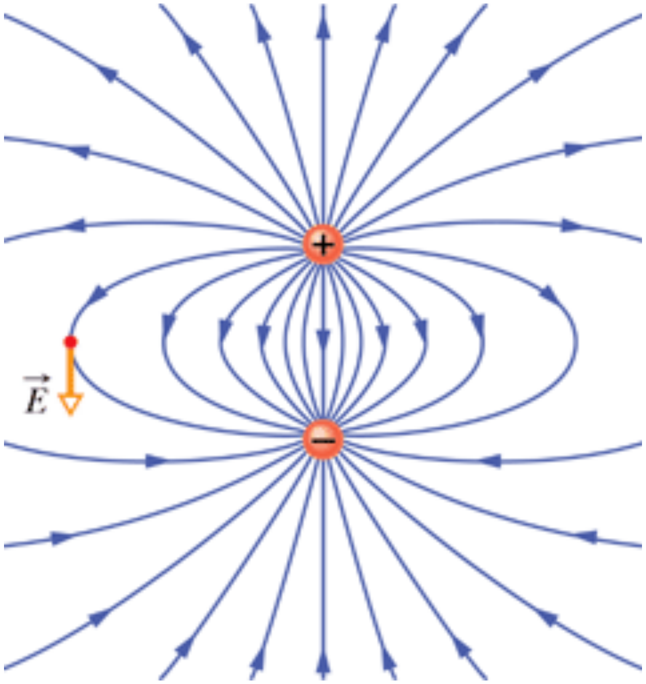
Electric field lines are a map of the electric field

Start at positive charges and move outward

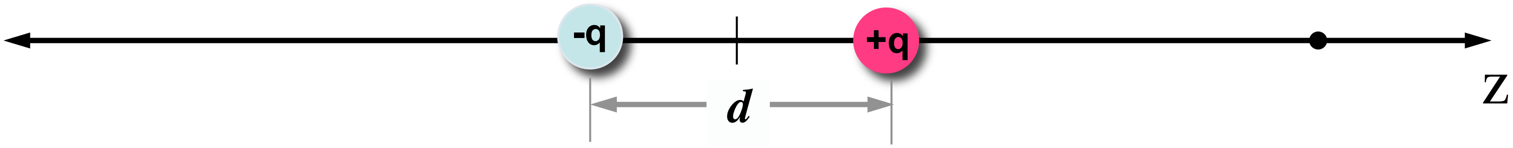
Strength of the field → the density of lines

Number of lines → the electric charge





Electric Dipole



$$E_z = \frac{1}{4\pi\varepsilon_0}\frac{q}{\left(z-\frac{d}{2}\right)^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{\left(z+\frac{d}{2}\right)^2} \qquad = \frac{qd}{2\pi\varepsilon_0 z^3}\frac{1}{\left(1-\left(\frac{d}{2z}\right)^2\right)^2}$$

$$\boxed{E_z \approx \frac{1}{2\pi\varepsilon_0}\frac{qd}{z^3}}$$

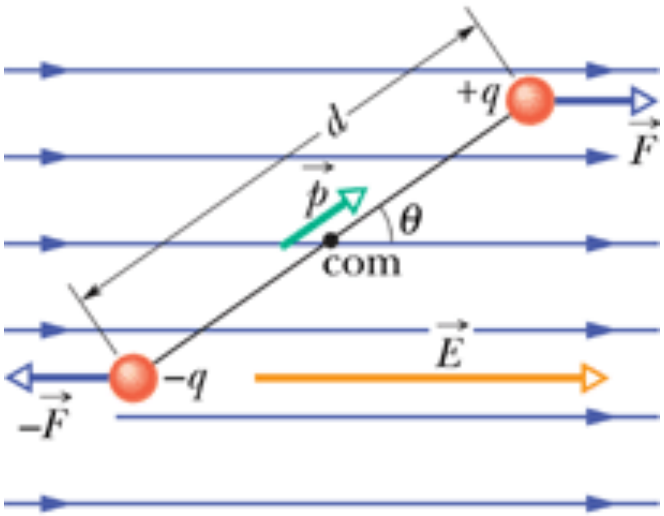
For $d << z$

$\vec{p} \equiv q\vec{d}$ ***Electric dipole moment*** - points along axis from negative to postive

We can measure the product qd accurately, but not q or d individually

The field strength falls off as z^{-3} for all points, not just along the z axis

Dipole in an E field



A uniform E field can exert a torque,
but no net force on a dipole.

$$|\tau| = Fd\sin\theta = qEd\sin\theta = pE\sin\theta$$

Can be generalized to:

$$\vec{\tau} = \vec{p} \times \vec{E}$$

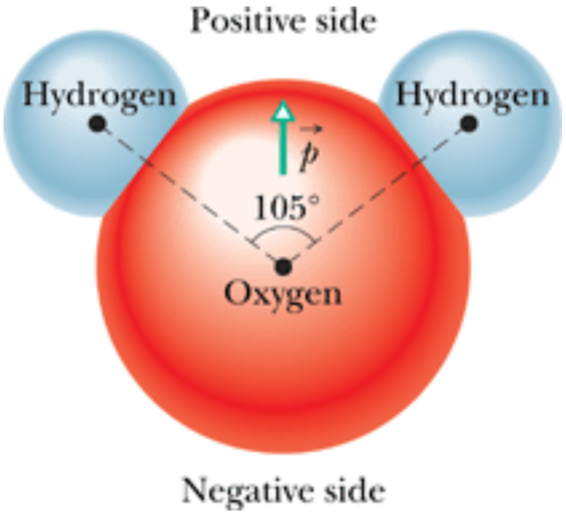
Work is done in rotating the dipole:

$$W = \int \tau \cdot d\theta = pE\left(\cos\theta_f - \cos\theta_i\right)$$

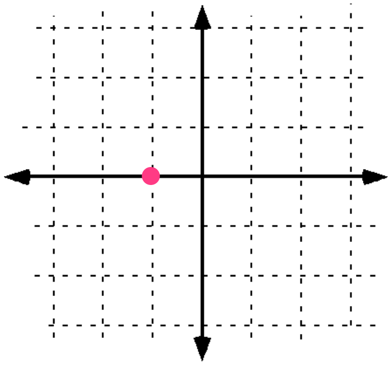
This is the basic principle
behind a microwave oven

Water molecules behaves like electric dipoles

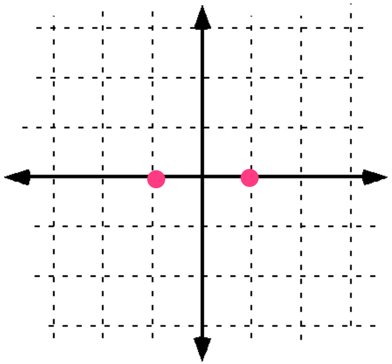
Oscillating field (EM waves) causes the water
molecules to oscillate back and forth → heat



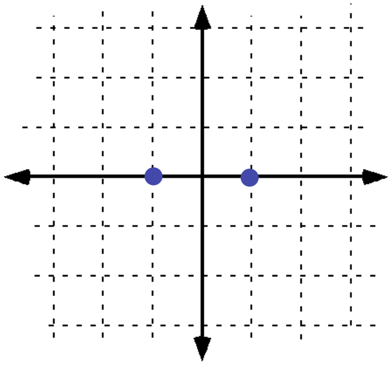
In the scenarios below, red dots represent positive charges and purple dots represent negative charges with the same magnitude. In which case is the magnitude of the electric field at the origin greatest?



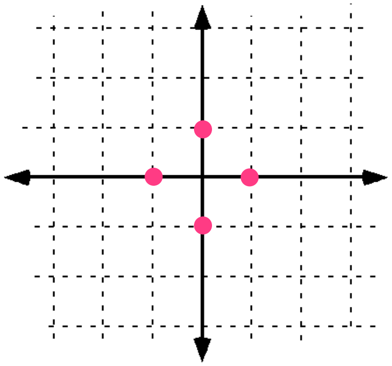
1. Scenario A



2. Scenario B

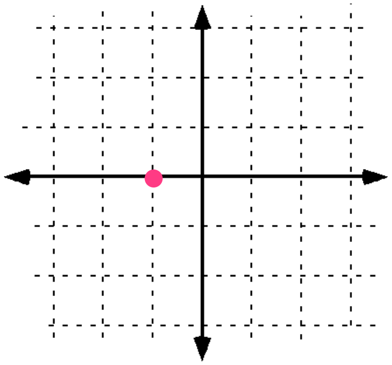


3. Scenario C

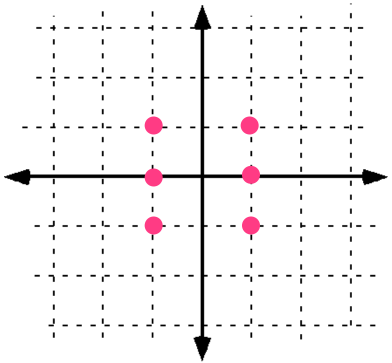


4. Scenario D

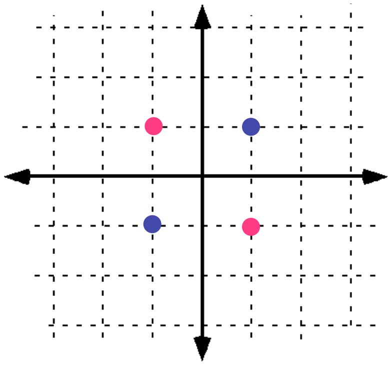
In the scenarios below, red dots represent positive charges and purple dots represent negative charges with the same magnitude. In which case is the magnitude of the electric field at the origin greatest?



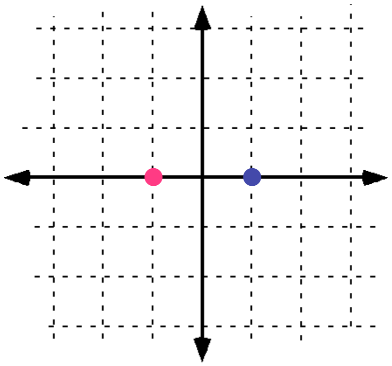
1. Scenario A



2. Scenario B

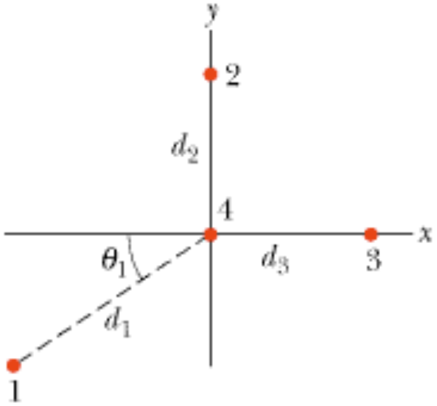


3. Scenario C



4. Scenario D

In the figure, what are the (a) magnitude and (b) direction of the net electrostatic force on particle 4 due to the other three particles? All four particles are fixed in the xy plane, and $q_1 = -9.60 \times 10^{-19}$ C, $q_2 = +4.80 \times 10^{-19}$ C, $q_3 = +9.60 \times 10^{-19}$ C, $q_4 = +3.20 \times 10^{-19}$ C, $\theta_1 = 25.0°$, $d_1 = 3.00$ cm, and $d_2 = d_3 = 2.00$ cm



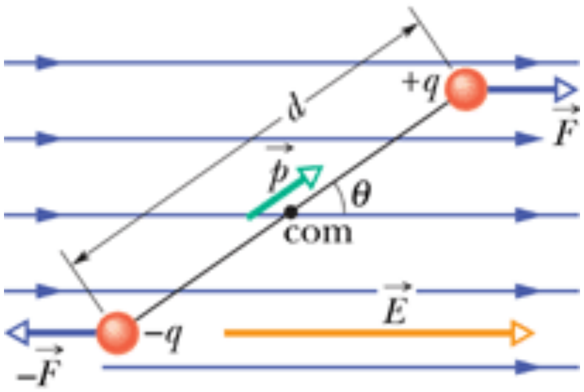
(a) magnitude:

N

(b) direction (angle measured counter-clockwise with respect to x-axis):

°

How much work is required to turn an electric dipole 180° in a uniform electric field of magnitude 46 N/C if the dipole moment has a magnitude of 3.0×10^{-25} C•m and the initial angle is 60°?



$$\vec{\tau} = \vec{p} \times \vec{E}$$

$$W = \vec{p}_f \cdot \vec{E} - \vec{p}_i \cdot \vec{E}$$