Physics 115
General Physics II

Session 16

Electric Fields
Charging by Induction

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Lecture Schedule
(up to exam 2)

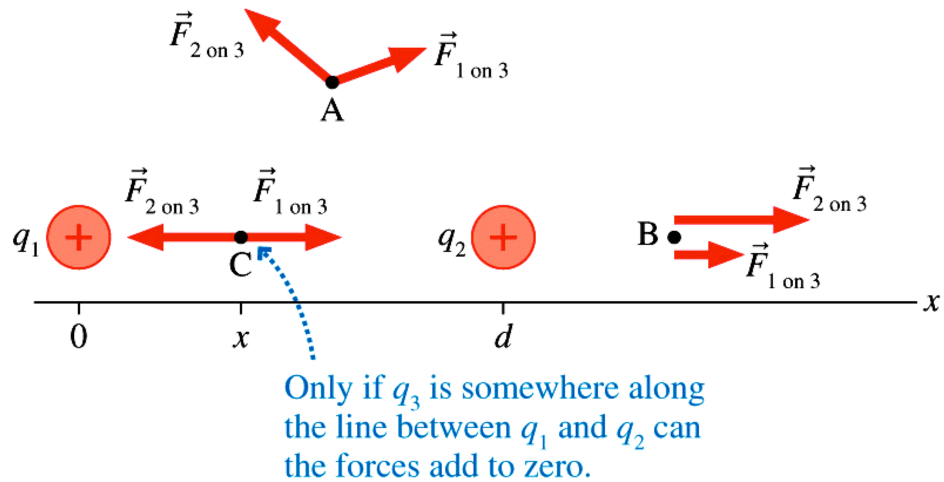
21-Apr	Mon	12	Specific Heats	18.4-18.6
22-Apr	Tues	13	Second Law	18.7-18.10
24-Apr	Thurs	14	Entropy	18.8-18.10
25-Apr	Fri	15	Charges	19.1-19.4
28-Apr	Mon	16	E field	19.5-19.66
29-Apr	Tues	17	Gauss law	19.7
1-May	Thurs	18	Electrical potential	20.1-20.3
2-May	Fri	19	Potential, conductors	20.4
5-May	Mon	20	Capacitors	20.5-20.6
6-May	Tues	21	Current	21.1-21.2
8-May	Thurs	22	Power, Series & Parallel Circuits	21.3-21.4
9-May	**Fri**		**EXAM 2 - Ch. 18,19,20**	

Today

Minor revisions to calendar – almost caught up...

Example: Point of Zero Force

Two positively charged particles q_1 and q_2=**3**q_1 are placed 10. 0 cm apart. Where could another charge q_3 be placed so it experiences no net force? (other than at infinity...)



1. Need force vectors to be co-linear, so location must be on x axis.
2. Need force vectors to be in opposite directions, so location must be between 0 and d.
3. Need force vectors equal in magnitude

$\mathbf{r_1 = x}$, $\mathbf{r_2 = d\text{-}x}$ $\mathbf{q_2 = 3q_1}$

so $\mathbf{F = Kq_1q_3/x^2 = Kq_2q_3/(d\text{-}x)^2}$.

Therefore, $\mathbf{(d\text{-}x)^2 = 3x^2}$ or $\mathbf{x = d/(1 \pm \sqrt{3})}$ = 10 cm/(1±1.732) – 2 solutions:

$x_- = 10.0$ cm/-0.732=−13.66 cm, ...this does not satisfy requirement #2.

$x_+ = 10.0$ cm/2.732 = 3.66 cm **OK**

What's a "field"?

According to physicists*, a field is:

An association between some physical quantity and each point in some region of space.

Examples:

*mathematicians have a more abstract description

1. Temperature in this room

   Every point in the room has a temperature (scalar quantity)

   The temperature "varies smoothly" from point to point

   → describe T with real numbers

   T(***x***) is a scalar field

2. Gravitational field

   Every point in the room has some ***g*** vector

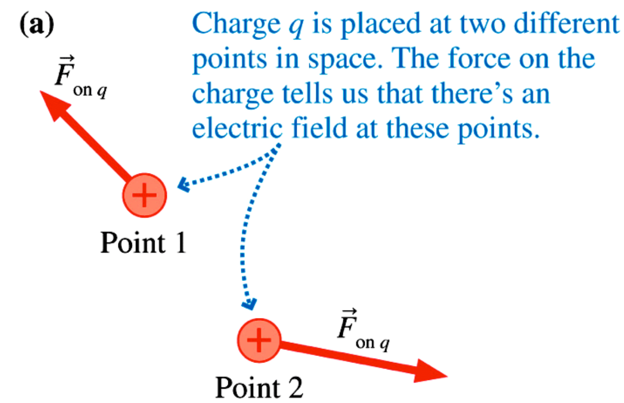
   Value and direction of ***g*** "varies smoothly" from point to point.

   g(x) is a vector field

The Field Model

Field Model:

1. Some charges(“***source charges***”), alter the space around them by creating an electric field $\boldsymbol{E}$.
2. A separate “***test charge”*** *in* this electric field experiences a force $\boldsymbol{F}$ exerted *by the field*.



$$\boxed{\vec{E}(x,y,z) = \frac{\vec{F}_{\text{on q at (x,y,z)}}}{q}}$$

Units for electric field: force/charge = N/C

3. This equation assigns a field vector to *every point in space*.
4. If $\boldsymbol{q}$ is positive, the electric field vector points in the same direction as the force vector.
5. Does $\boldsymbol{E}$ depend on $\boldsymbol{q}$ (the charge that detects it)? No, because the force is proportional to $\boldsymbol{q}$.

$$\boxed{\vec{F} = q\vec{E}}$$

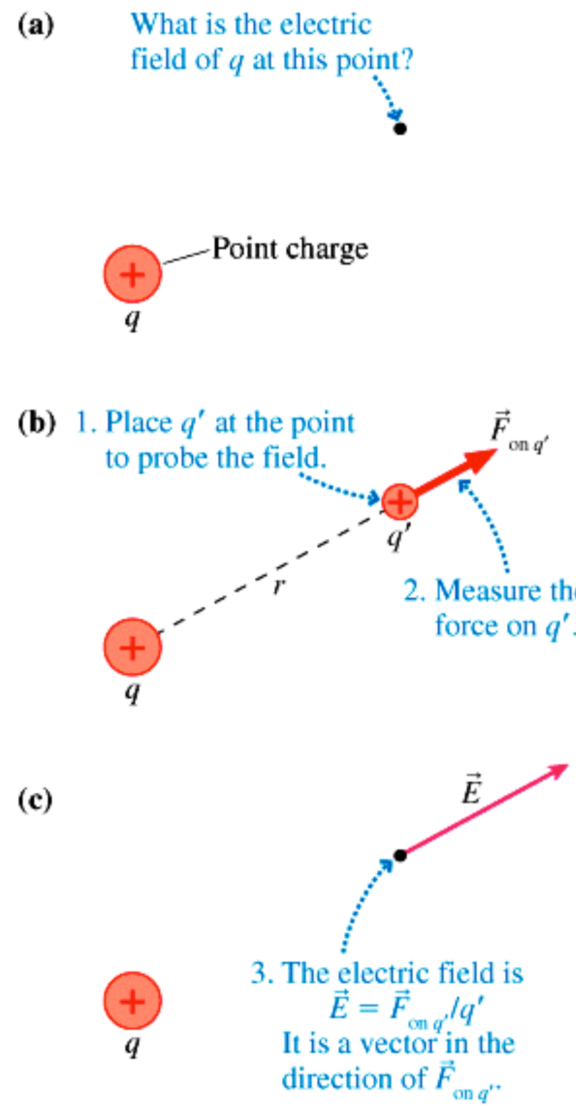
The Electric Field of a Point Charge

To measure an electric field, insert a small test charge *q'* and measure the force on it. We assume the test charge does not affect the field pattern set up by other charges.

$$\vec{F}_{\text{on q'}} = \left(\frac{1}{4\pi\varepsilon_0} \frac{qq'}{r^2}, \text{ away from q} \right)$$

$$\vec{E} = \frac{\vec{F}_{\text{on q'}}}{q'}$$

$$= \left(\frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}, \text{ away from q} \right)$$



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Typical Electric Field Strengths

Field location	Field strength (N/C)
Inside a current-carrying wire	10^{-2}
Near the earth's surface	10^2–10^4
Near objects charged by rubbing	10^3–10^6
Electric breakdown in air, causing a spark	3×10^6
Inside an atom	10^{11}

Table 21-2 Some Electric Fields in Nature

	E, N/C
In household wires	10^{-2}
In radio waves	10^{-1}
In the atmosphere	10^2
In sunlight	10^3
Under a thundercloud	10^4
In a lightning bolt	10^4
In an X-ray tube	10^6
At the electron in a hydrogen atom	6×10^{11}
At the surface of a uranium nucleus	2×10^{21}

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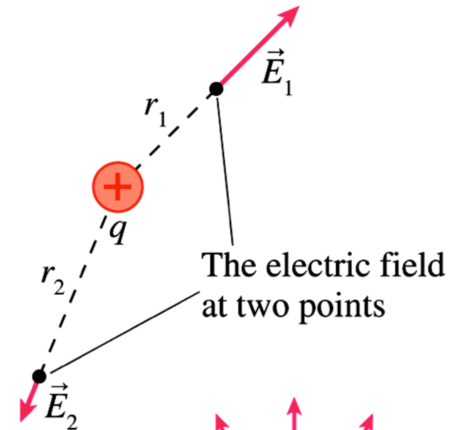
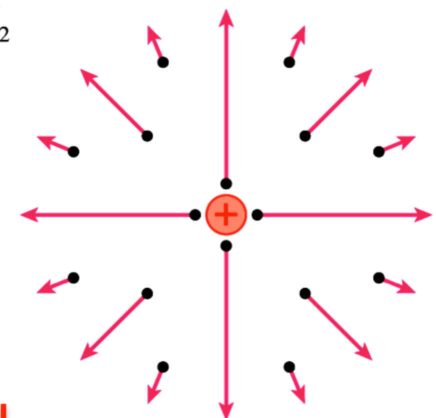
Electric Field Diagrams

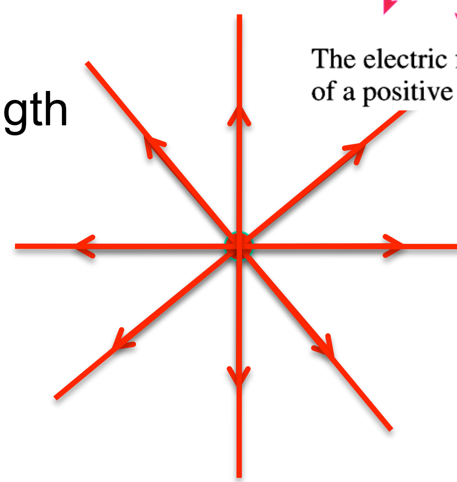
Things to remember about field diagrams:

1. The field diagram shows only a sample of the electric field. The field exists at *all points in space*.
2. The electric field is not a quantity that stretches from one point to another. Each vector represents the field at *one point* in space.
3. The arrow indicates the direction and strength of the field at *the point to which the vector **tail** is attached*. The length of the vector is a relative measure of the field strength.
4. Some diagrams instead show continuous lines with embedded arrows. In this format, the strength of the field at any point is proportional to the **density** of lines: denser = stronger field



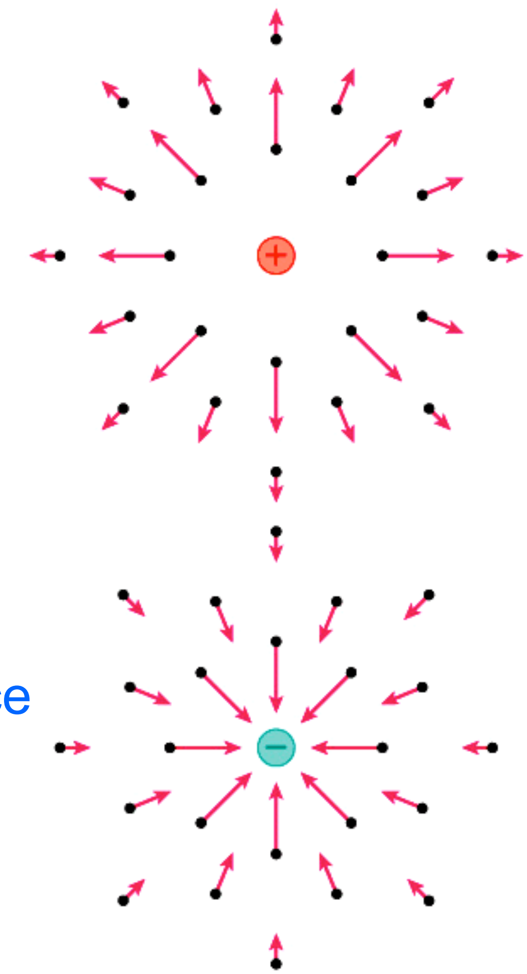


The electric field diagram of a positive point charge



Field patterns for + and - point charges

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$



Positive

Negative

Field vector points

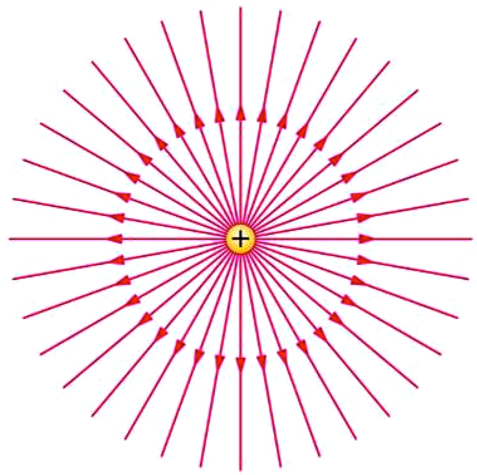
away from a + charge,

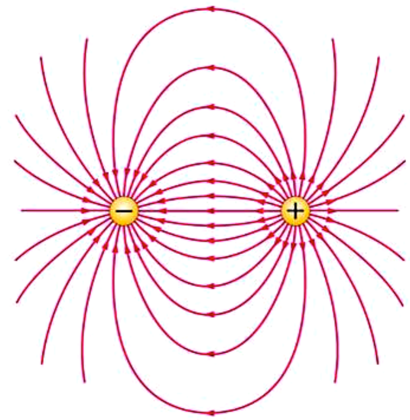
toward a – charge

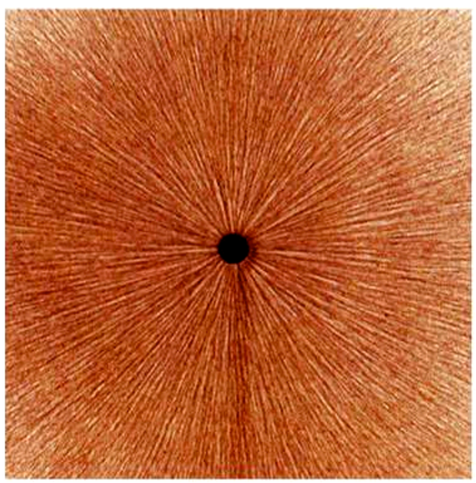
Its direction is that of the force

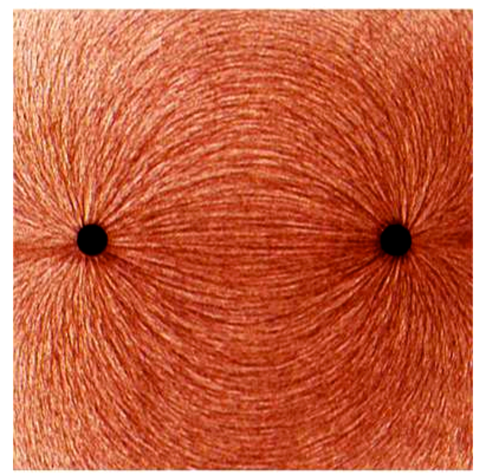
on a + test charge

Grass Seeds & Field Patterns

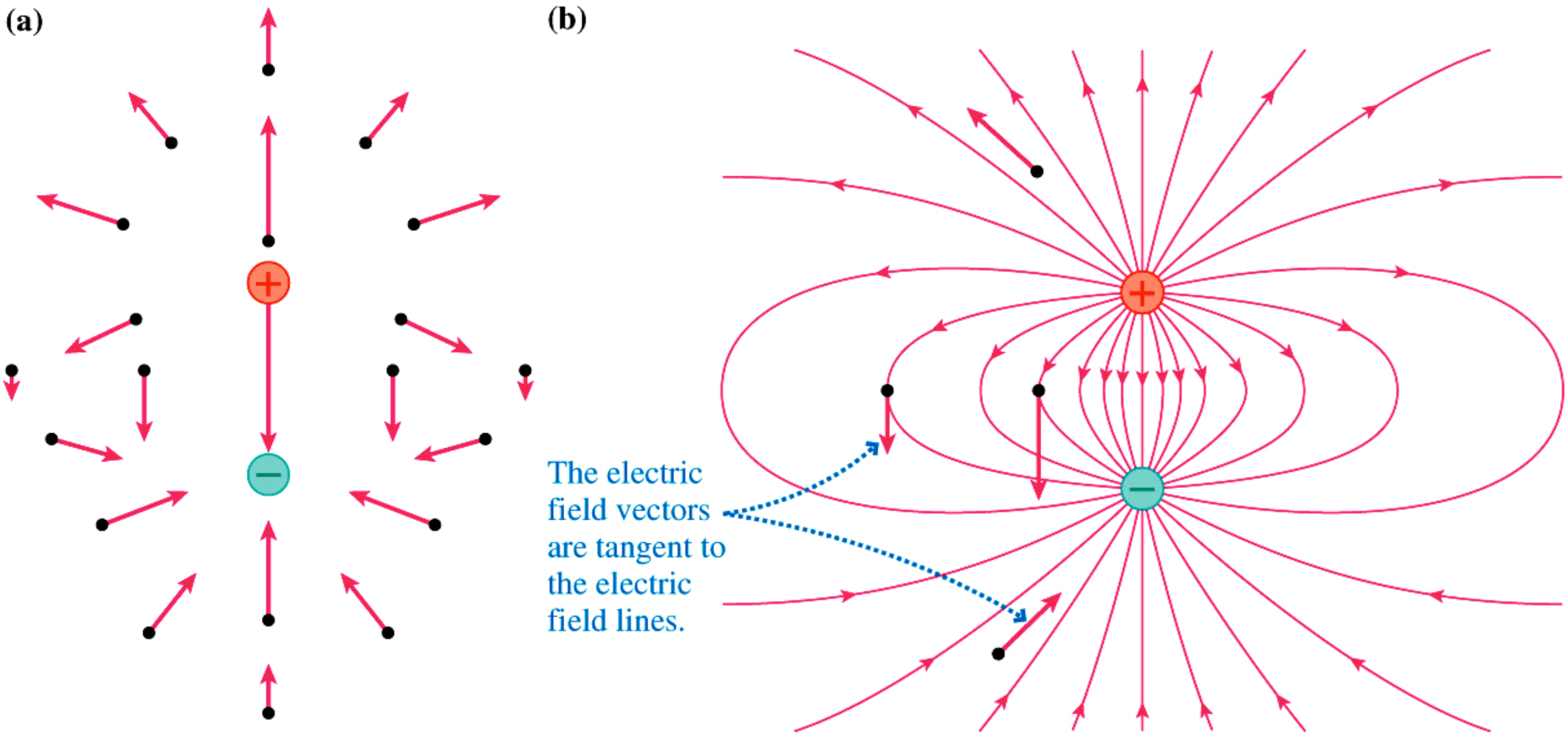




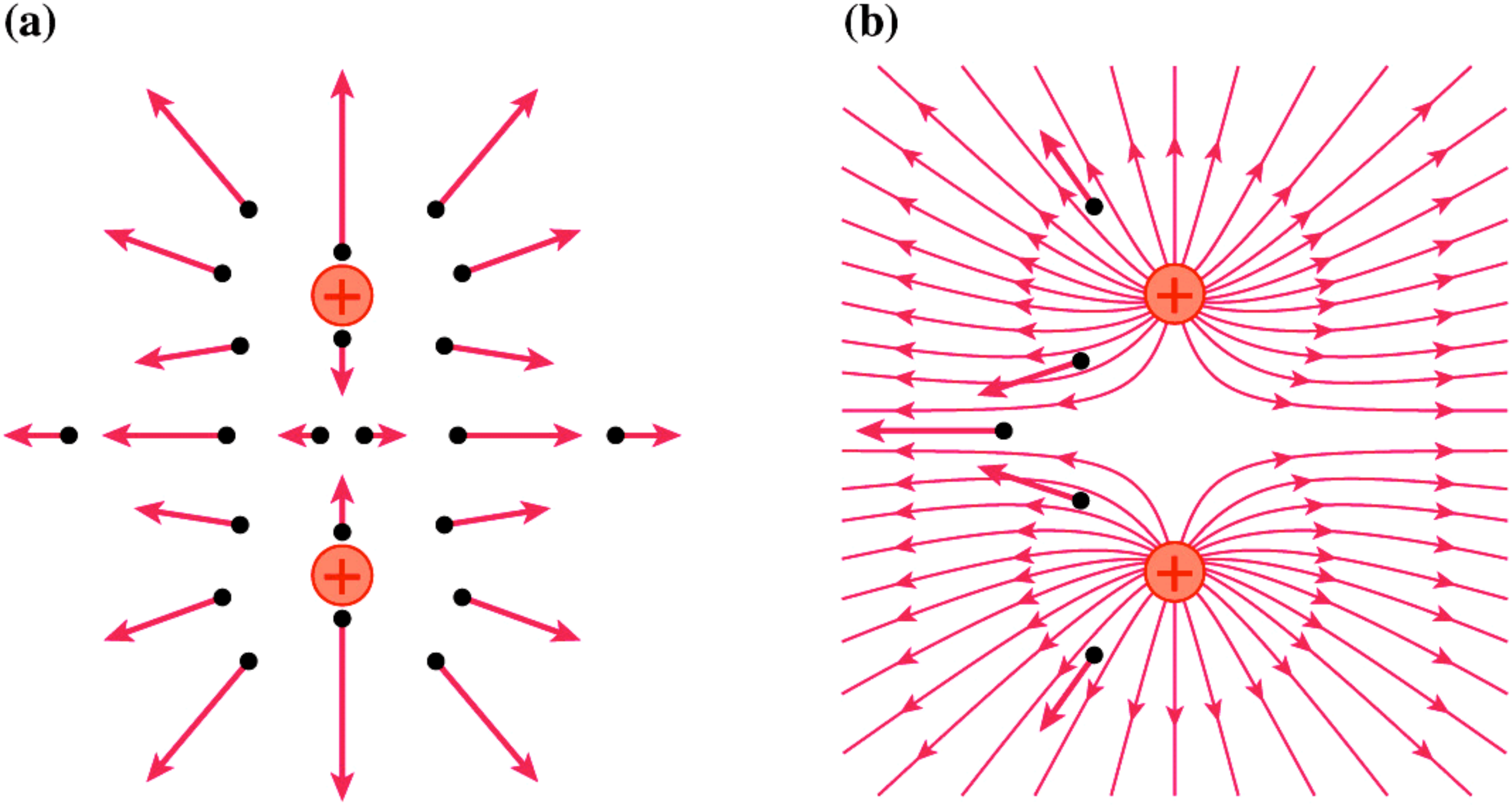




The Dipole Field



Two Positive Charges



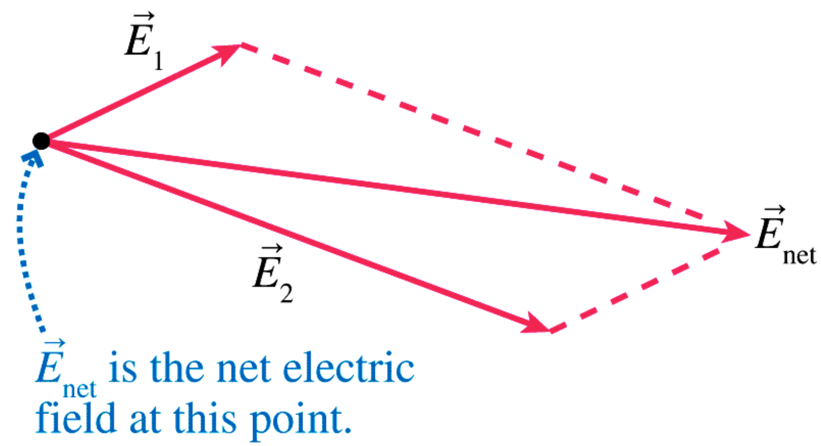
Electric Field Superposition

Superposition principle: forces from individual sources can be added vectorially to find the net force.

F = *q**E*** → we can add field contributions from individual charges to find the net E field

Field value gives us the net force on any test charge q' at that location

$$\vec{F}_{\text{on q}} = q'\vec{E}$$



$$\vec{F}_{\text{net}} = \vec{F}_{\text{1 on q'}} + \vec{F}_{\text{2 on q'}} + \cdots$$

$$\vec{E}_{\text{net}} = \frac{\vec{F}_{\text{on q'}}}{q'} = \frac{\vec{F}_{\text{1 on q'}}}{q'} + \frac{\vec{F}_{\text{2 on q'}}}{q'} + \cdots = \vec{E}_1 + \vec{E}_2 + \cdots = \sum_i \vec{E}_i$$

Simple superposition works for discrete (individual) point charges.
(For a continuous charge distribution, calculus is required to do the summation.)

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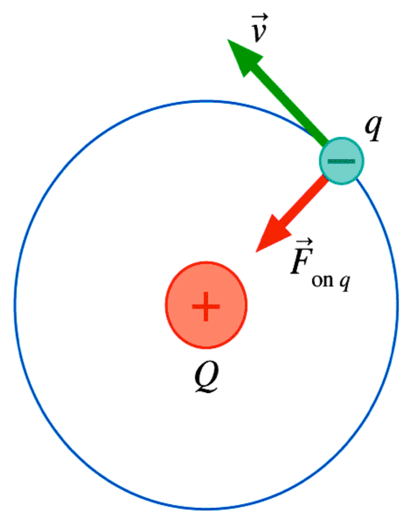
Example:
The Electric Field of a Proton

In a hydrogen atom, the electron orbits the proton at a radius of 0.053 nm. Both have charges of magnitude e = 1.60 x 10^{-19} C.

(a) What is the proton's electric field strength at the position of the electron?

(b) What is the magnitude of the electric force on the electron?



$$E = \frac{1}{4\pi\varepsilon_0}\frac{e}{r^2} = \frac{(8.99\times10^{9}\ \text{Nm}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})}{(5.3\times10^{-11}\ \text{m})^2} = 5.12\times10^{11}\ \text{N/C}$$

$$F = eE = (1.60\times10^{-19}\ \text{C})(5.12\times10^{11}\ \text{N/C}) = 8.20\times10^{-8}\ \text{N}$$

Clicker Question 9

Which charge has the **largest** electric field at the location of the numbered point?

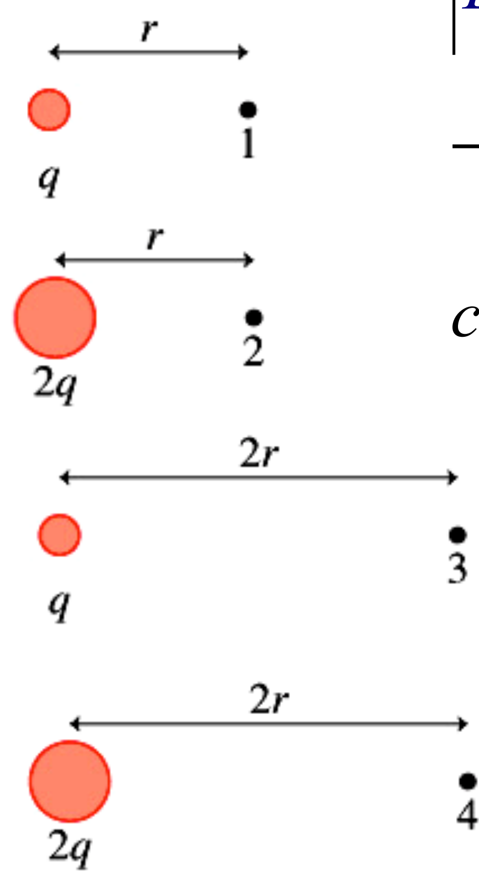
$$\left|\vec{E}\right| = k\frac{q}{r^2}$$

A) q=1 unit, r=1 unit

B) q=2, r=1

C) q=1, r=2

D) q=2, r=2

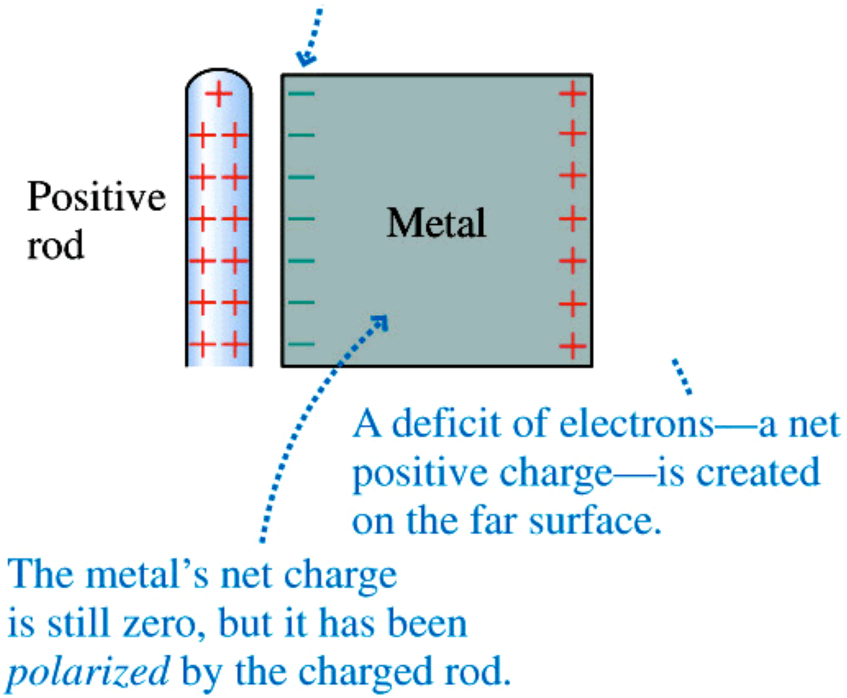


$$\rightarrow a:\frac{1}{1}, \quad b:\frac{2}{1},$$

$$c:\frac{1}{4}, \quad d:\frac{2}{4}=\frac{1}{2}$$

Charge Polarization

Another consequence of charge mobility:
- Hold charged rod near metal object
(not in contact – no direct transfer of Q)
- rod attracts opposite charge within conductor
- same-sign charge is repelled / left behind



Charging by Induction

Using charge polarization, we can induce charge on an electrically neutral object.

Example: Bring a charged rod near (but not touching) an electroscope and observe the effect on the leaves.