Physics II: 1702
Gravity, Electricity, & Magnetism

Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

Electric Field

- Coulomb's law tells us that the electrostatic force between two charged particles is
  - $F = kq_1q_2/r^2 = q_1q_2/(4\pi\varepsilon_0 r^2)$
- The total force on any charged particle is the sum of such forces exerted by a distribution of charge
- We will now introduce the electric field, which is the electrostatic force per unit charge exerted on a charged particle by a distribution of charge

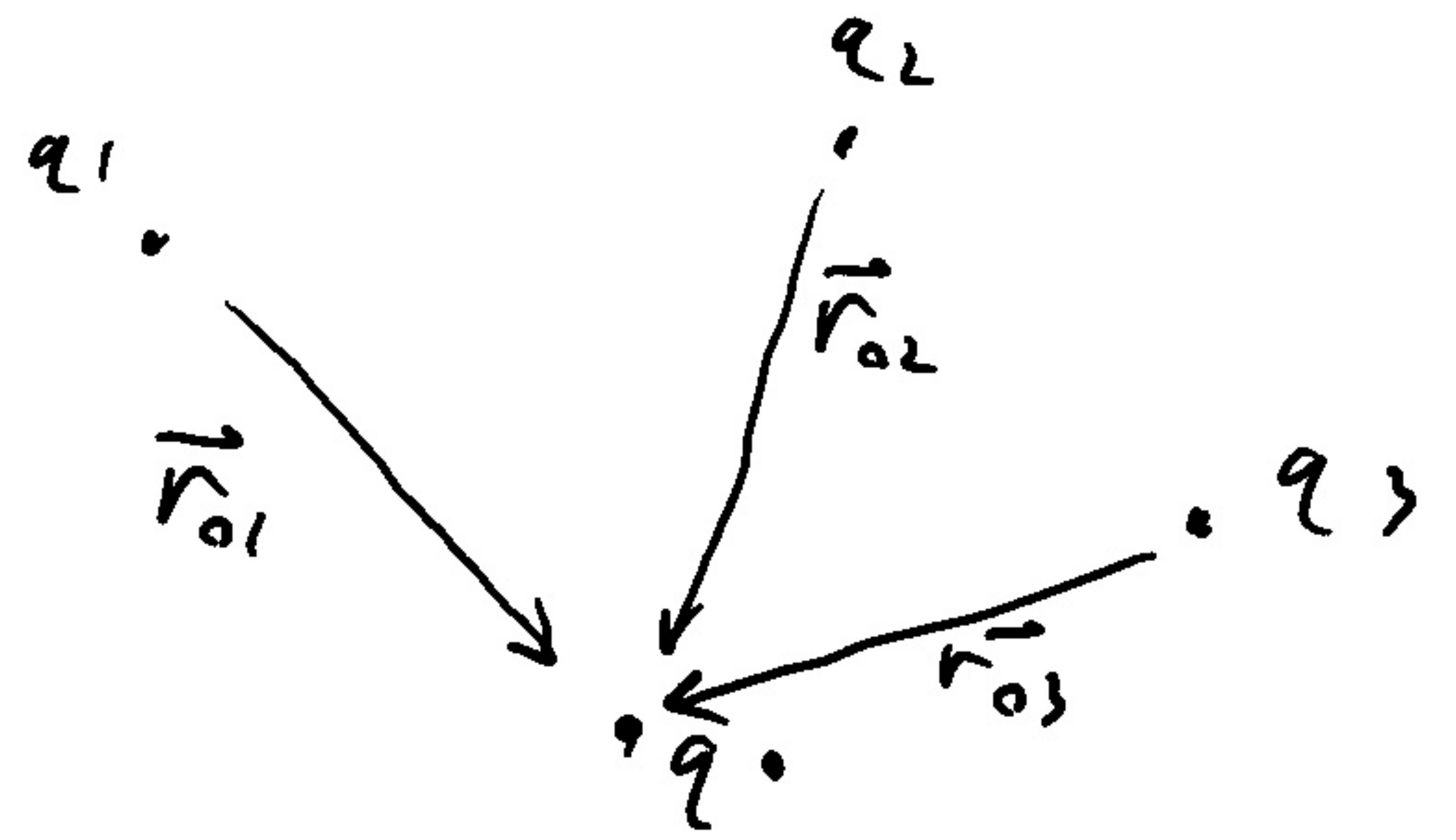
Electric Fields

Look at the force on a test charge q_0 from a group of charges q_1, q_2, q_3 ---

$\vec{F}_0$ on q_0 =

$$\vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} \text{ ---}$$

$$= \frac{k q_0 q_1 \hat{r}_{01}}{|\vec{r}_{01}|^2} + \frac{k q_0 q_2 \hat{r}_{02}}{|\vec{r}_{02}|^2} + \frac{k q_0 q_3 \hat{r}_{03}}{|\vec{r}_{03}|^2} \text{ ---}$$



$$\vec{r}_{ij} = \vec{r}_i - \vec{r}_j$$

Factor out q_0 to get:

$$\vec{F}_0 = q_0 \left[\frac{k q_1 \hat{r}_{01}}{|\vec{r}_{01}|^2} + \frac{k q_2 \hat{r}_{02}}{|\vec{r}_{02}|^2} + \frac{k q_3 \hat{r}_{03}}{|\vec{r}_{03}|^2} \text{ ---} \right]$$

$$= q_0 \vec{E}$$

where $\vec{E}$ = Electric Field

- Note that $\vec{r}_0$, the position of q_0, is in our formula. However, we can make this fully general by changing $\vec{r}_0$ to an arbitrary coordinate $\vec{r}$

$$\vec{E}(\vec{r}) = \frac{kq_1(\vec{r}-\vec{r}_1)}{|\vec{r}-\vec{r}_1|^3} + \frac{kq_2(\vec{r}-\vec{r}_2)}{|\vec{r}-\vec{r}_2|^3} + \frac{kq_1(\vec{r}-\vec{r}_3)}{|\vec{r}-\vec{r}_3|^3} ----$$

Direction of $\vec{E}$ depends on charge causing it:

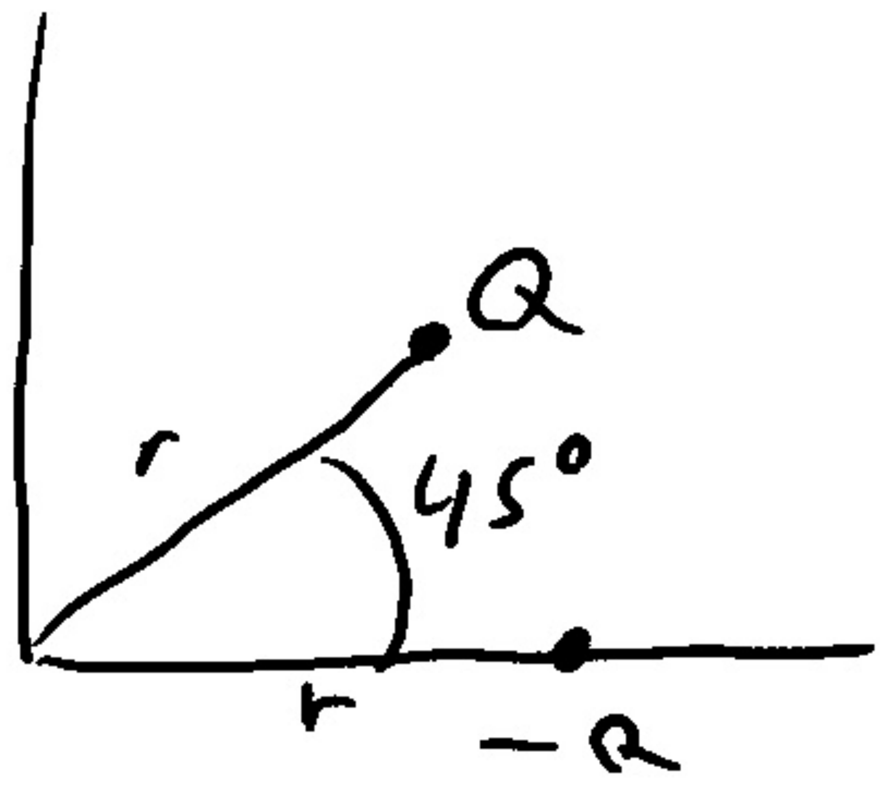
if $q_i > 0$

$\vec{E}_i \parallel \vec{r}-\vec{r}_i$
outward from $\vec{r}_i$

if $q_i < 0$

$\vec{E}_i \parallel -(\vec{r}-\vec{r}_i)$
inward toward $\vec{r}_i$

Example:



what is $\vec{E}(0,0,0)$?

$\vec{E}$ from $+Q$

$$= \frac{K \cdot Q \cdot (0 - \vec{r}_1)}{|0 - \vec{r}_1|^3}$$

with $\vec{r}_1 = \frac{1}{\sqrt{2}} r \hat{i} + \frac{1}{\sqrt{2}} r \hat{j}$

$$= \frac{KQ \left(-\frac{1}{\sqrt{2}} r \hat{i} - \frac{1}{\sqrt{2}} r \hat{j}\right)}{r^3}$$

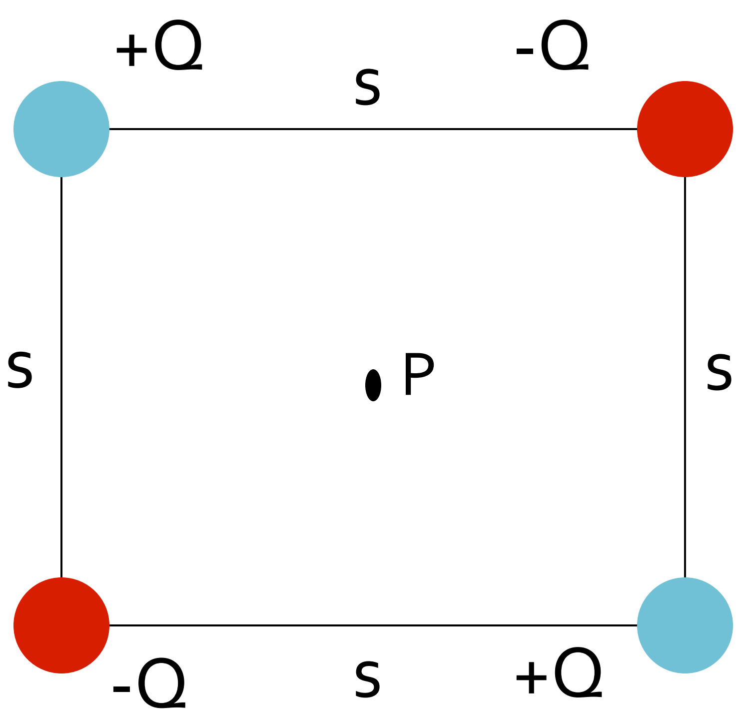
$$= -KQ \left(\frac{1}{\sqrt{2}} \hat{i} + \frac{1}{\sqrt{2}} \hat{j}\right) / r^2$$

$\vec{E}$ from $-Q$

$$= \frac{-KQ (0 - r\hat{i})}{|0 - r\hat{i}|^3} = \frac{KQ}{r^2} \hat{i}$$

$$\boxed{\vec{E}_{total}(0,0,0) = \frac{KQ}{r^2} \left[1 - \frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}}, 0\right]}$$

Electric Field Concept Check



What is the E-field at point P?

A) $|E| = 2kQ / s^2$

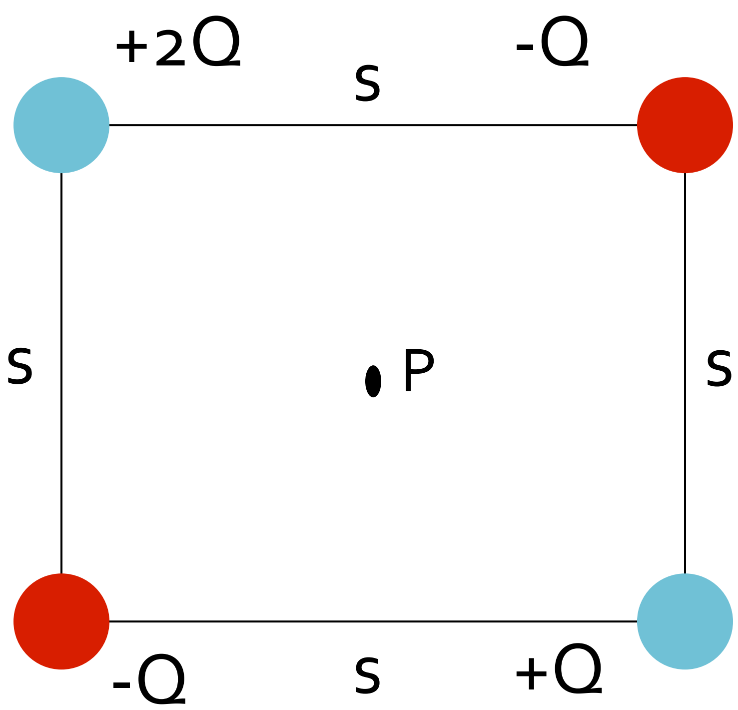
B) $|E| = \mathrm{sqrt}(2)\ kQ / s^2$

C) $|E| = kQ / (\ \mathrm{sqrt}(2)\ s)^2$

D) zero

E) none of the above

Electric Field Concept Check



What is the E-field at point P?

A) $|E| = 2kQ / s^2$

B) $|E| = \text{sqrt}(2)\, kQ / s^2$

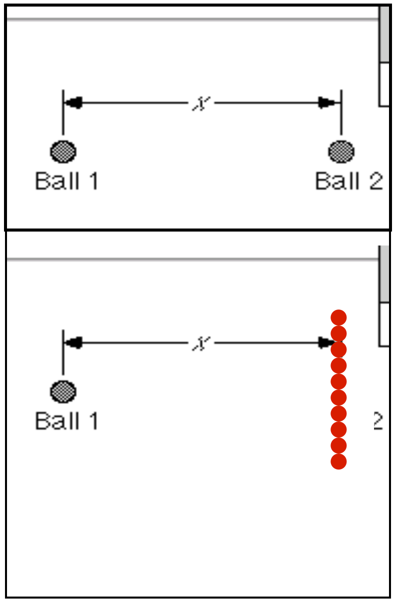
C) $|E| = kQ / (\text{sqrt}(2)\, s)^2$

D) zero

E) none of the above

Electric Field: Distribution of Charge

Ball 2 has charge Q. Ball 2 is torn apart into a rod of 10 smaller balls each with charge Q/10.



Compare the electric force on ball 1 from ball 2 and the rod.

A) The rod exerts a larger magnitude force.

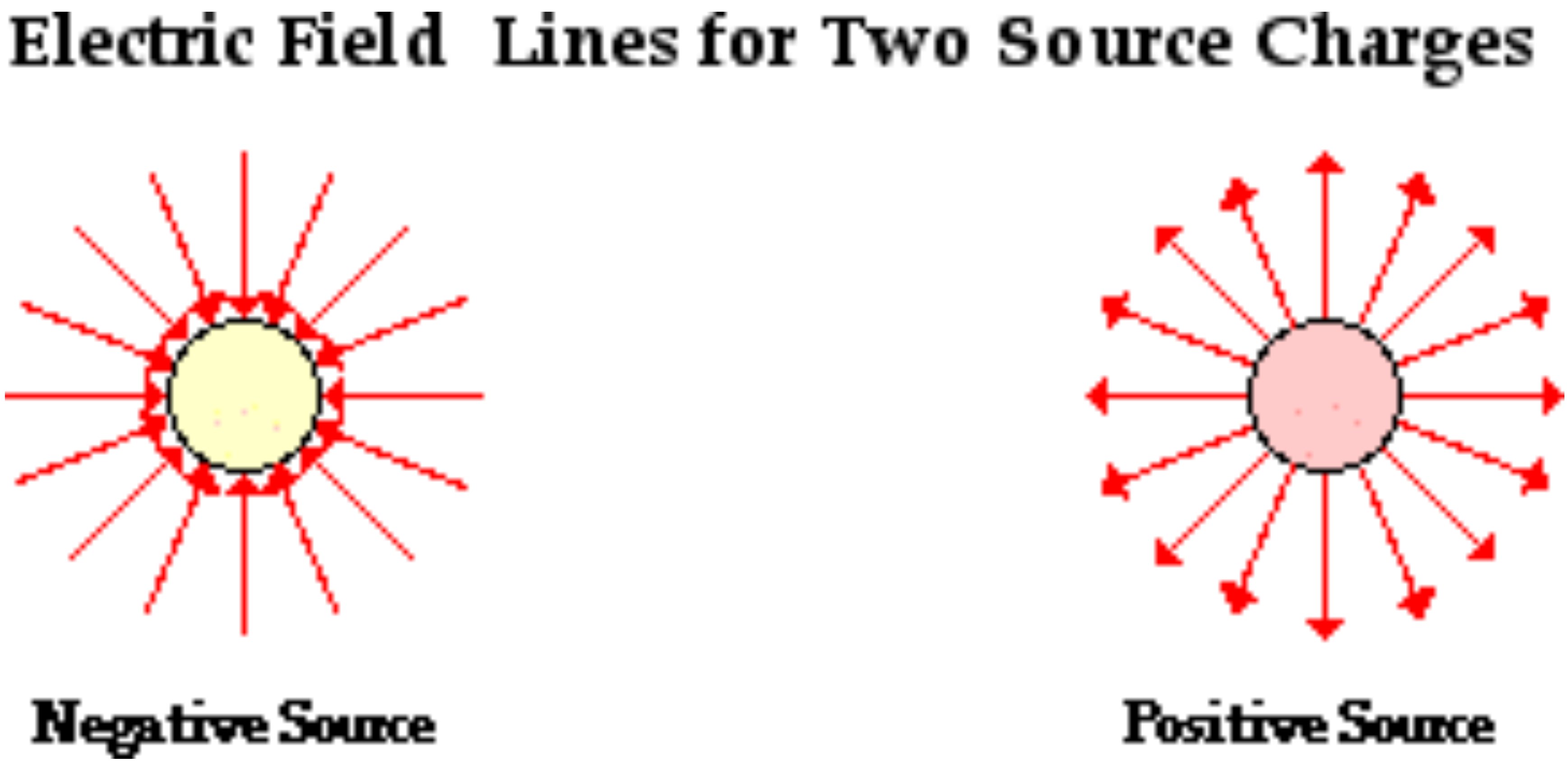
B) The ball 2 exerts a larger magnitude force.

C) The rod and ball 2 exert the same magnitude force.

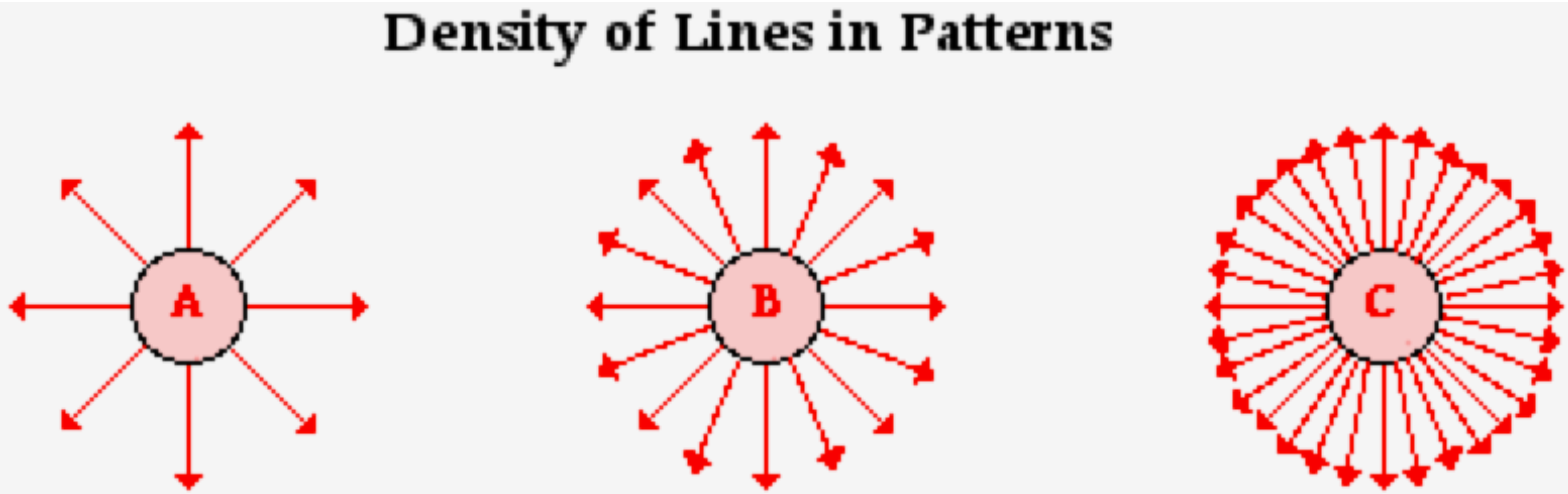
Electric Field Lines

- Are precisely mathematically defined, but have no physical reality
  - There is no "line" that is moving around
- Are a very useful way of representing the electric field graphically
  - Draw lines going out from positive charge, in to negative charge
    - All field lines must terminate on a charge
  - Field lines should everywhere be tangent to electric field vector
  - Field line density is proportional to electric field strength

Examples: Point Charges

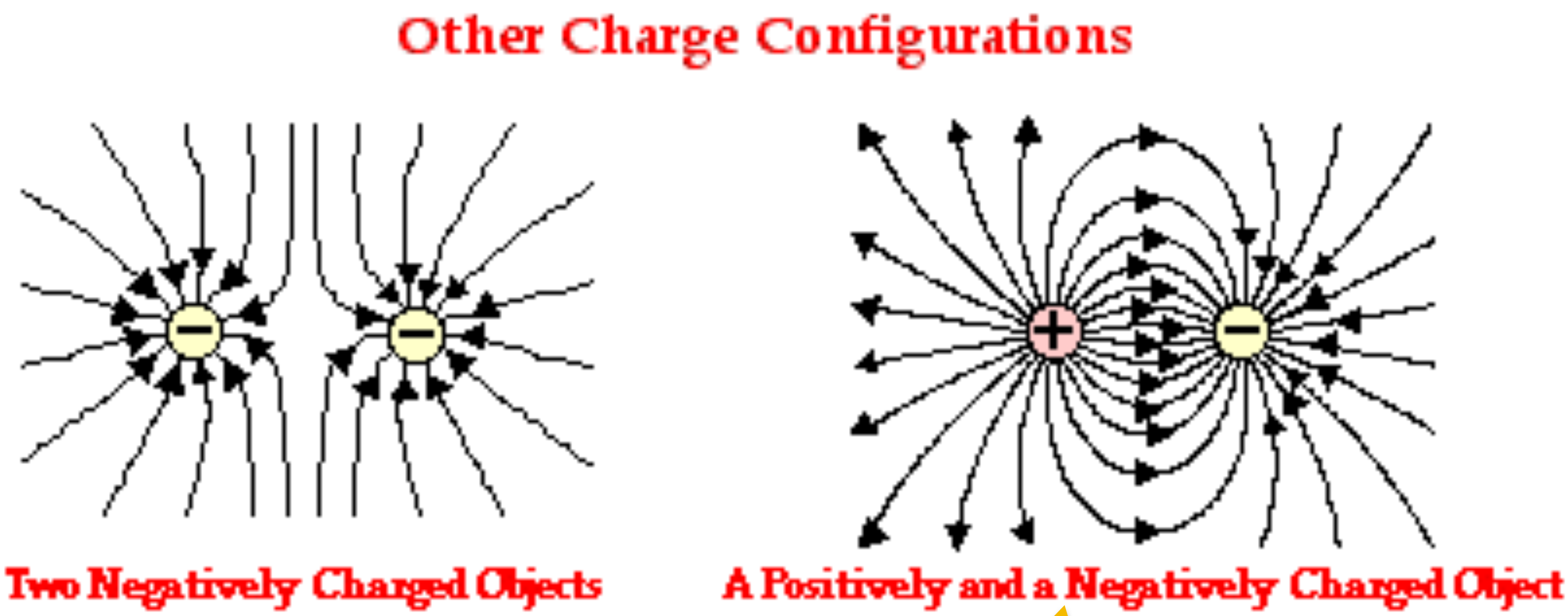


Examples: Point Charges



The density of electric field lines around these three objects reveals that the quantity of charge on C is greater than that on B which is greater than that on A.

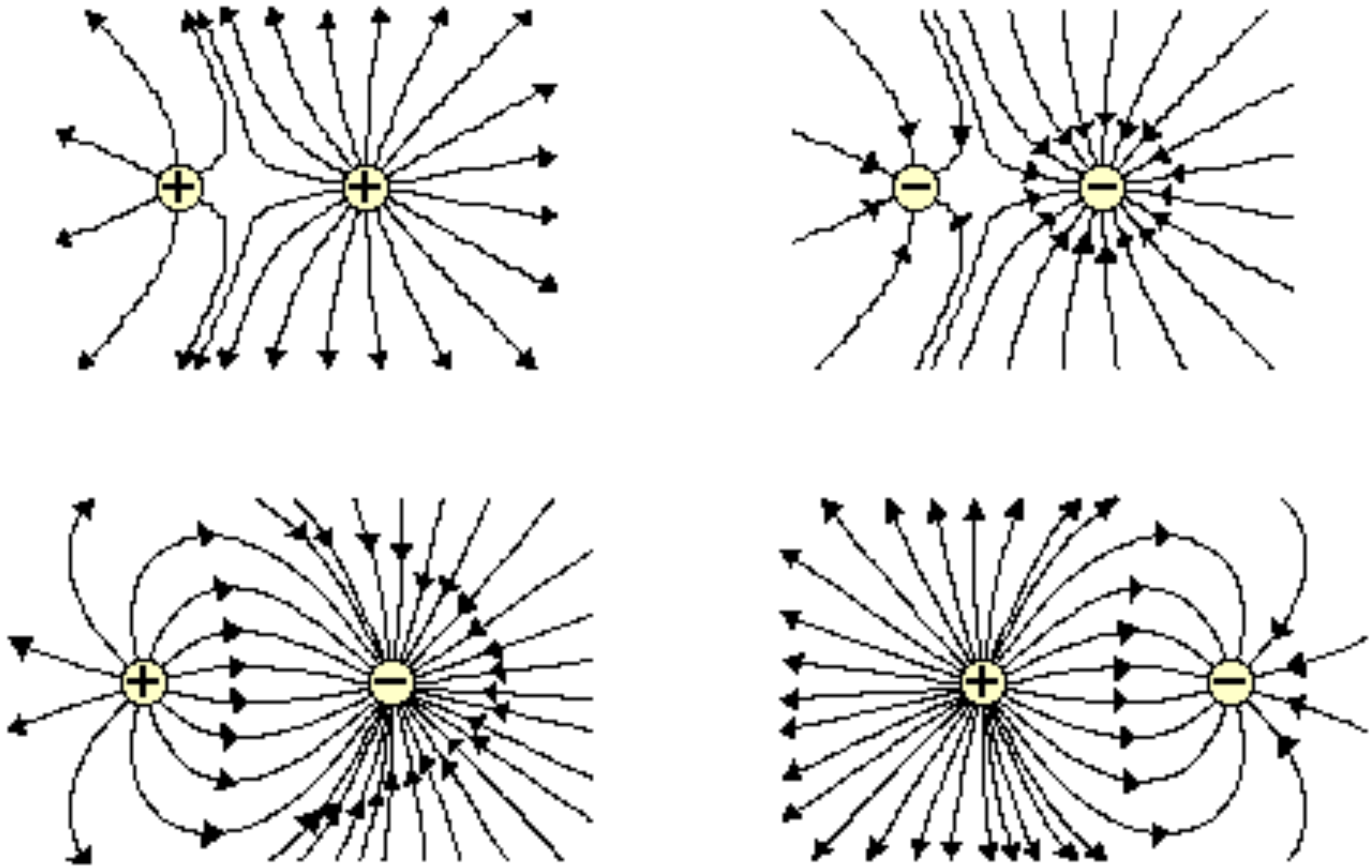
Examples: Multiple Charges



This is a Dipole

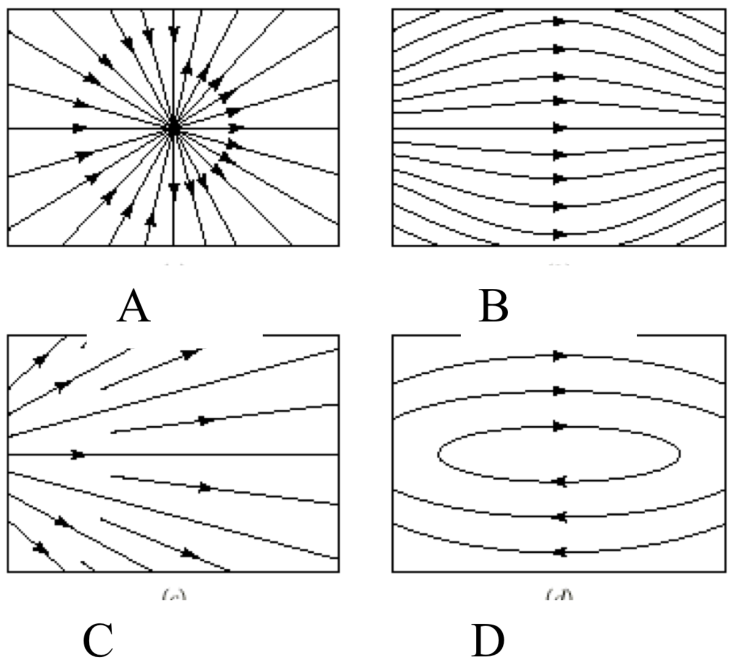
Examples: Multiple Charges

Electric Field Line Patterns for Objects with Unequal Amounts of Charge



Electric Field Line Concept Check

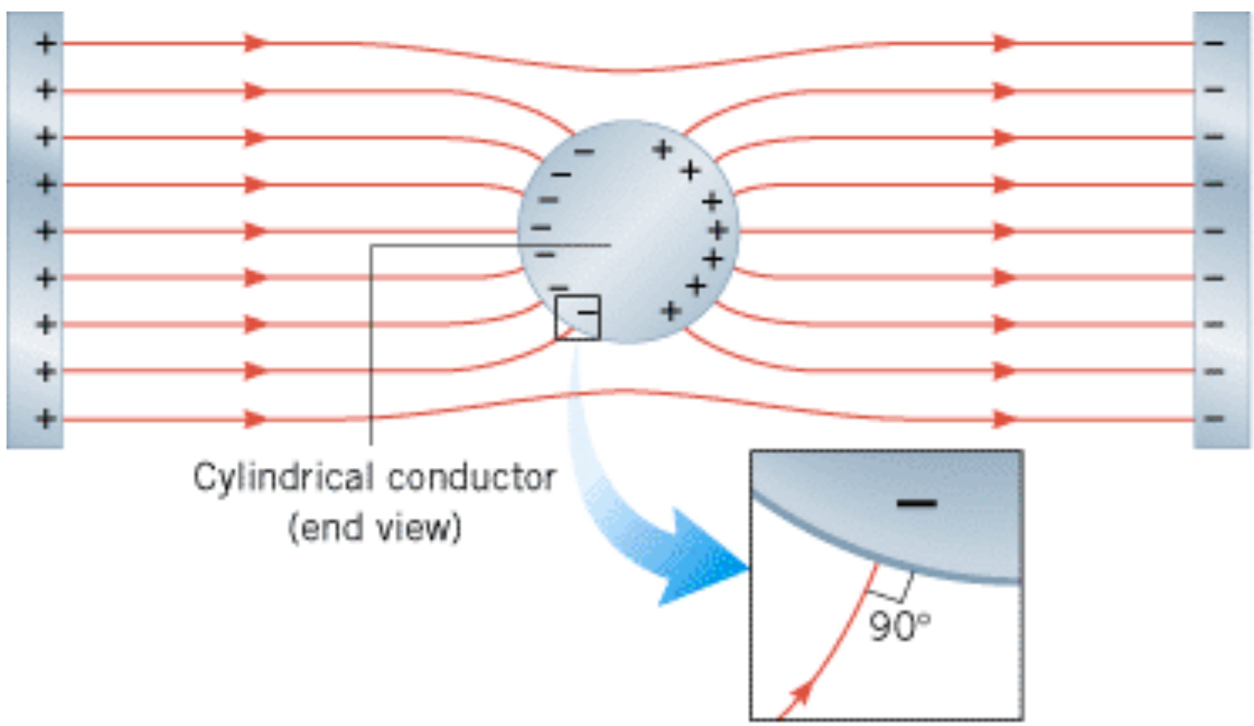
There are no charges in the regions shown. Which of the following are physically possible electrostatic field line configurations?



E: More than one of the above is o.k.

Electric Fields in a Conductor

- None!
  - Any electric field in a conductor causes charge to move in such a way that it shorts out that field
  - Also, electric fields must be perpendicular to the surface (or else they would move charge along the surface)



(a)

Electric Fields in a Conductor