Lecture 05: 01/30/2024

- Announcements
  Written HW#2 due midnight tonight
  Written HW#2 due Friday
  Special zoom review session at 7 pm tonight

- Last Time
  - Coulomb's Law
  - Solving problems by adding vectors geometrically
  - Introduction to r-hat

- Today
  - Coulomb's Law
    Coulomb vector form and r-hat
    Electric field
    Electric field lines

SCHEDULE

#	Dates	Reading	Topic	Lab.
1	Jan 16	B1Ch16	Intro, Waves ($v = f\lambda$, $v = \sqrt{T/\mu}$)	no lab
2	Jan 18		Superposition, Standing Waves	
3	Jan 23	B2Ch5	$F = q_1 q_2 / r^2 \hat{r}$, conductors/insulators	Wave Superposition
4	Jan 25		$\vec{E}$-field concept and multi-Q	
5	Jan 30	Ch 5	Field lines and dipoles	Oscilloscope
6	Feb 1	Ch 5	Flux concept and Gauss Law	
7	Feb 6	Ch 6	Field of line, point, plane	Coulomb's Law
8	Feb 8	Ch 6	Gaussian tricks!	
9	Feb 13	Ch 7	PE and Electric Potential	E-field and Superposition
10	Feb 15	Ch 7	$V = \int \vec{E} \cdot d\vec{s}$	
11	Feb 20		V for multi charges	Electric Field Mapping
12	Feb 22		Test 1	
13	Feb 27	Ch 8	Capacitance	Capacitors and Delectrics
14	Feb 29	Ch 8	Capacitance	
15	Mar 5	Ch 9	Current and Resistance	Ohm's Law
16	Mar 7	Ch 9	Current and Resistance	
17	Mar 12	Ch 10	DC Circuits	Kirchoff's Laws
18	Mar 14	Ch 10	Magnetic Forces & Fields	
	Mar 19/21		Spring Break	

Coulomb's Law

$$F = k\frac{q_1 q_2}{r^2}$$

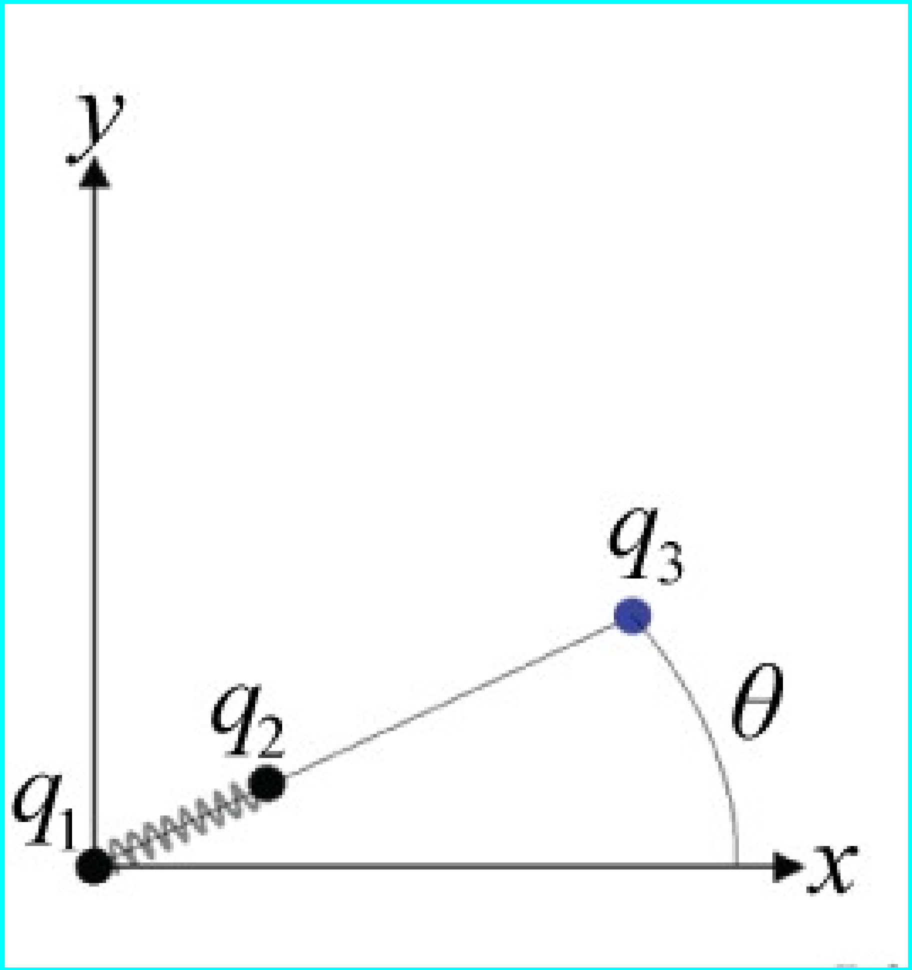
$$k = 8.99 \times 10^9 \frac{N\,m^2}{C^2}$$

Online Problem 2-9

$q_1 = q_2 = q \quad q_3 = -q$

Force on q_2?

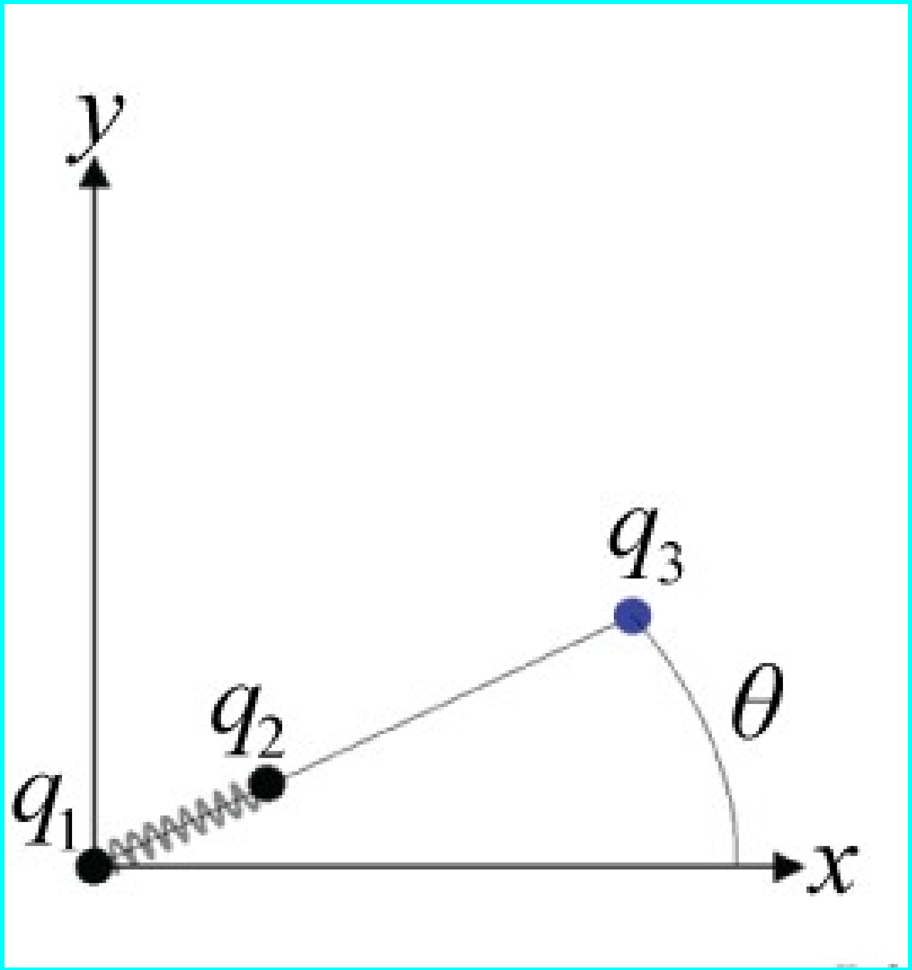
$L\cos\theta\,\hat{i} + L\sin\theta\,\hat{j}$



Online Problem 2-9

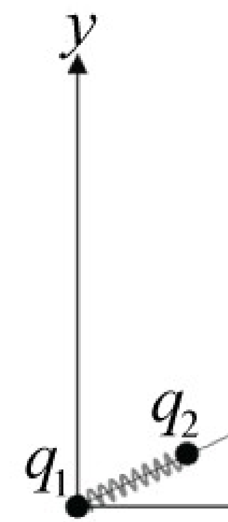
$q_1 = q_2 = q \quad q_3 = -q$

Force on q_2?



Problem 9: Three charged particles lie in the xy plane at an angle of θ relative to the x-axis. Charge q_1 is located at the origin, q_2 is a distance r from q_1, and q_3 is a distance $3r$ from q_1. The charges each have magnitude of q, but $q_1 = q_2 = +q$, and $q_3 = -q$. Charges q_1 and q_3 are fixed, and q_2 can move. However, q_1 and q_2 are connected by an ideal, neutral spring of spring constant k_s. The spring is initially not stretched. Let Coulomb's constant be k_e. q_1 and q_2 are positive and q_3 is negative.

richard.sonnenfeld@nmt.edu



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Part (a) Choose the best expression for the net electrostatic force on q_2, in terms of the given variables.

Expression :

F = ____

Select from the variables below to write your expression. Note that all variables may not be required.

cos(α), cos(φ), cos(θ), sin(α), sin(φ), sin(θ), γ, (,), i, j, $\mathbf{k_e}$, n, q, r

Part (b) Because the force on q_2 is nonzero, it will begin to move from rest. In which direction will it move?

MultipleChoice :

1) It will move toward q_3.
2) It will not move.
3) There is not enough information.
4) It will move out of the xy plane.
5) It will move toward q_1.
6) It will move along the $+x$ direction.
7) It will move along the $+y$ direction.

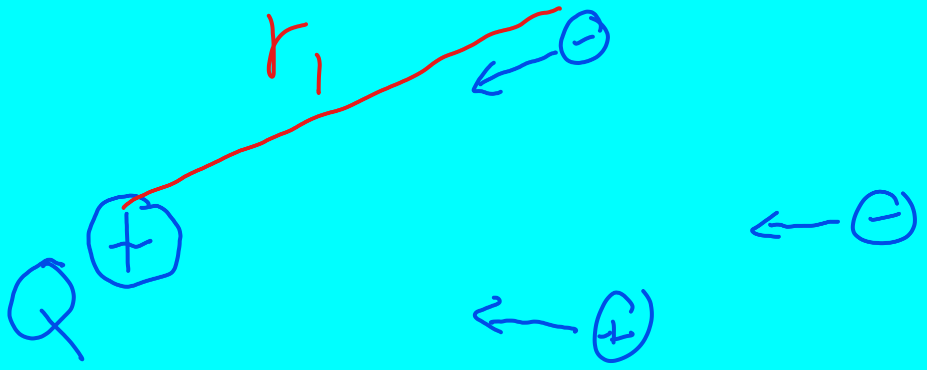
Part (c) When q_2 begins to move, it will stretch the spring. Choose the equation for the force vector from the spring, $\mathbf{F}_s$, due to stretching the spring a dis

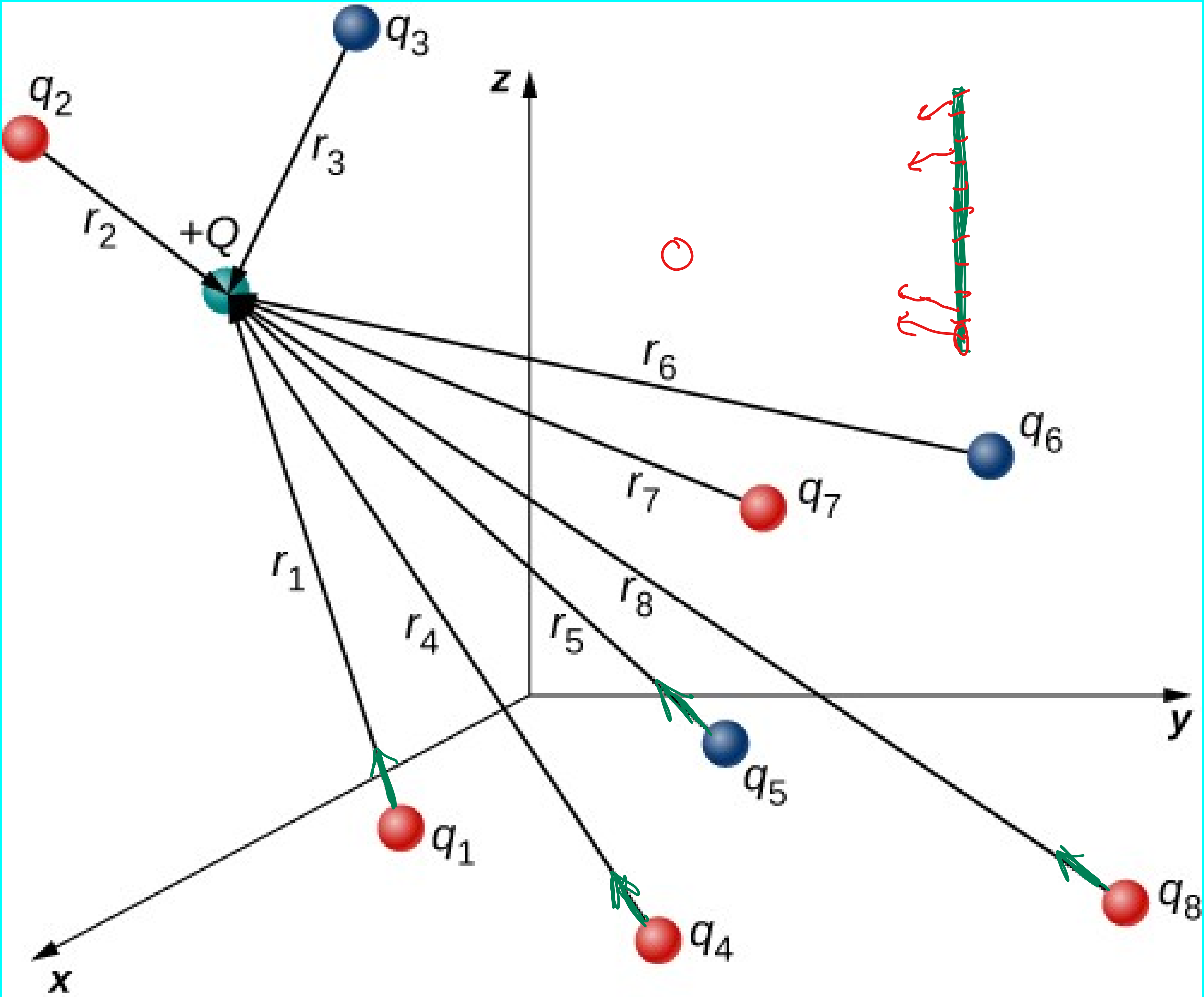
Coulomb's Law, Vector Form

$$\vec{F}_{12} = k\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12}$$

$$\cancel{\vec{F}_{net} = \sum_{n=1}^{N} k\frac{q_1 q_n}{r_{1n}^2}\hat{r}_{1n}}$$

$$\vec{F}_{net} = Q\sum_{n=1}^{N} k\frac{q_n}{r_n^2}\hat{r}_n$$

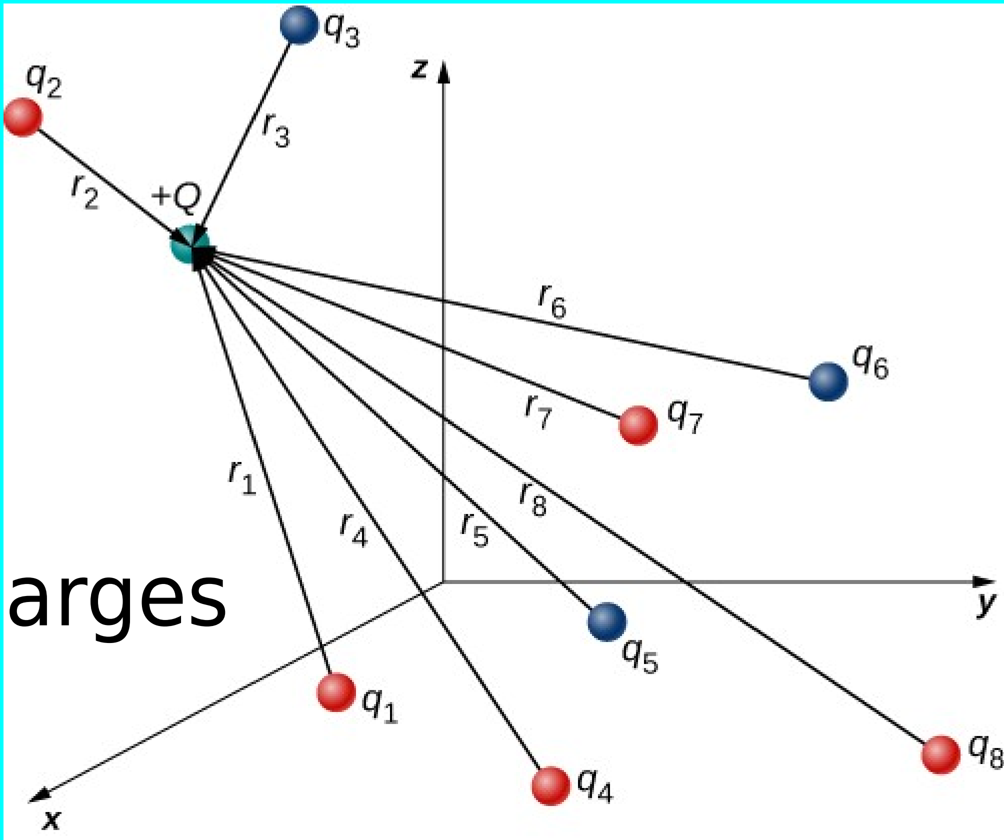




$\hat{r}$

Making friends with “r-hat”

$$\hat{r}$$

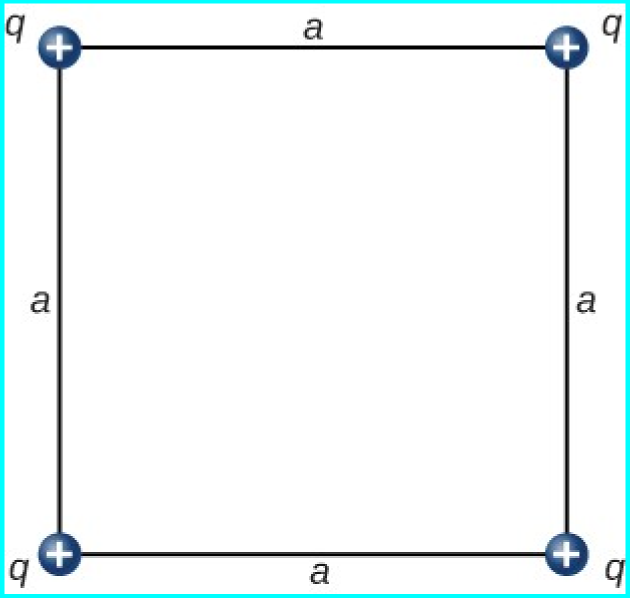


r-hat points from other charges to 'your' charge.

$\hat{r}$ is a unit vector like $\hat{i}$, $\hat{j}$, and $\hat{k}$

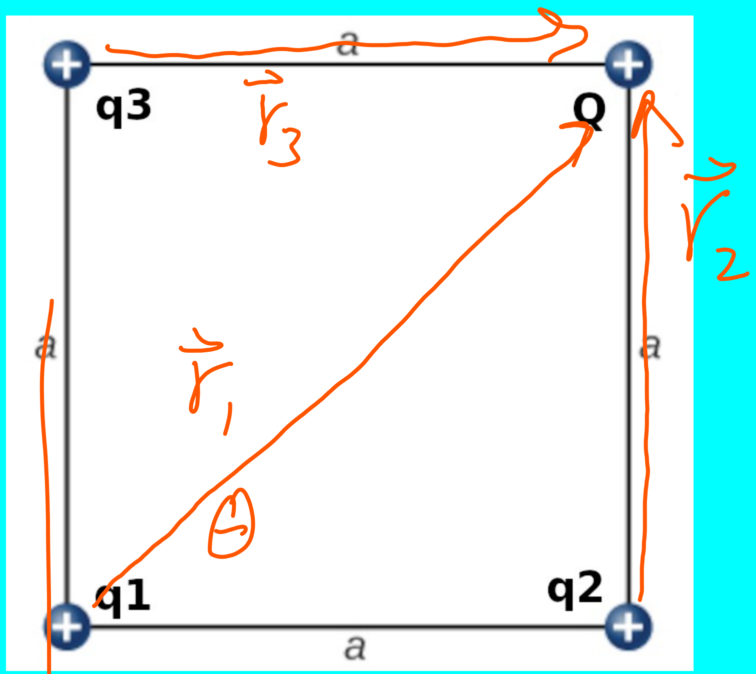
$\hat{r}$ points in different directions for different charges

Homework 5-63-ish



Find force on the q on top right corner

$$\overrightarrow{F_{net}} = Q \sum_{n=1}^{N} k \frac{q_n}{r_n^2} \hat{r}_n$$



$$\vec{F}_{net} = Q\sum_{n=1}^{N} k\frac{q_n}{r_n^2}\hat{r}_n$$

$$F_{Net} = Qk\left[\frac{q_1}{r_1^2}\hat{r}_1 + \frac{q_2}{r_2^2}\hat{r}_2 + \frac{q_3}{r_3^2}\hat{r}_3\right]$$

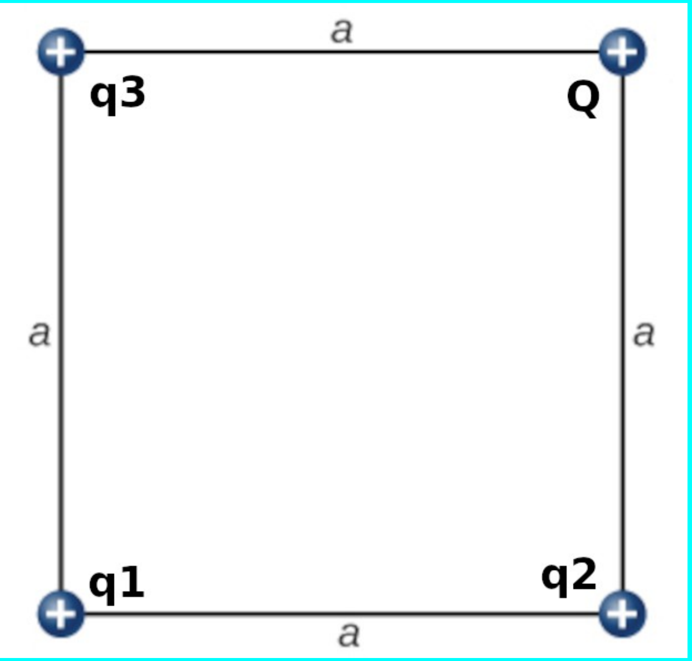
$$F_{Net} = Qqk\left[\frac{\hat{r}_1}{r_1^2} + \frac{\hat{r}_2}{r_2^2} + \frac{\hat{r}_3}{r_3^2}\right]$$

$r_2^2 = a^2$ $\quad$ $\hat{r}_2 = \hat{j}$

$r_3^2 = a^2$ $\quad$ $\hat{r}_3 = \hat{i}$

$r_1^2 = 2a^2$

$$F_1 = qQk\frac{\hat{r}_1}{r_1^2} \rightarrow \frac{qQk}{2a^2}(\cos\theta\,\hat{i} + \sin\theta\,\hat{j})$$



$$\overrightarrow{F_{net}} = Q \sum_{n=1}^{N} k \frac{q_n}{r_n^2} \hat{r}_n$$

What is r_1^2?

$\frac{\sqrt{2}}{2}$

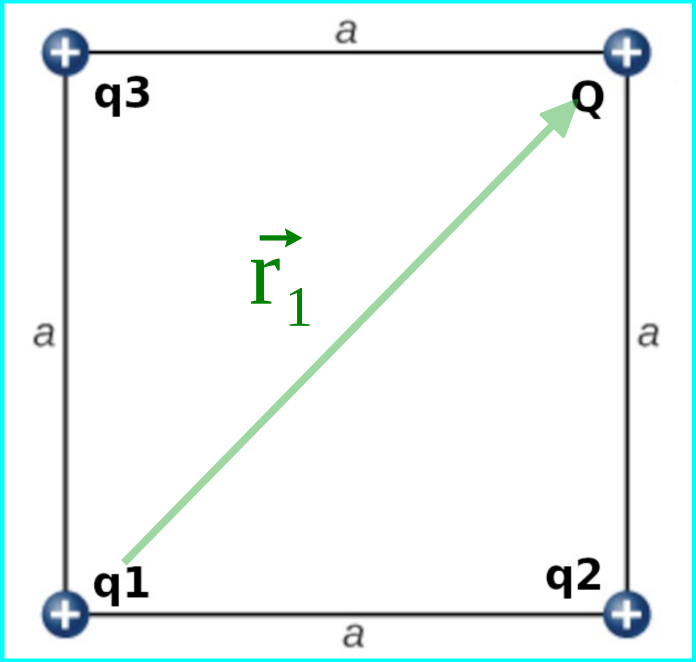
(A) $\frac{\sqrt{2}}{2}a$

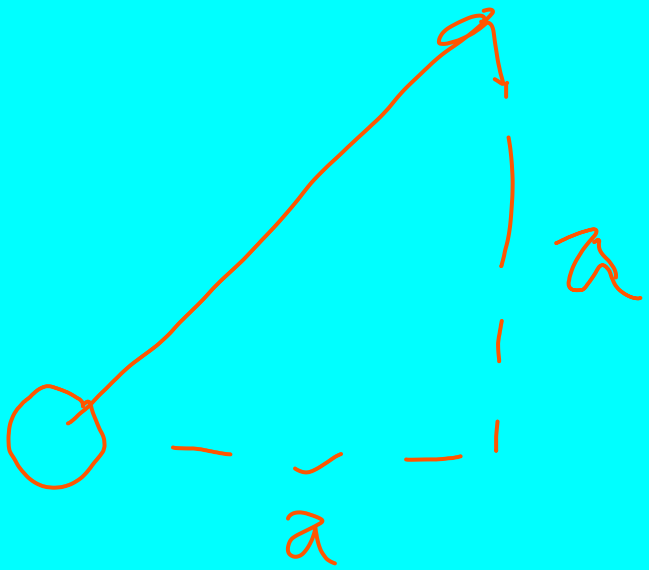
(B) $\sqrt{2}\,a$

(C) $\sqrt{2}\,a^2$

(D) $2a$

(E) $2a^2$

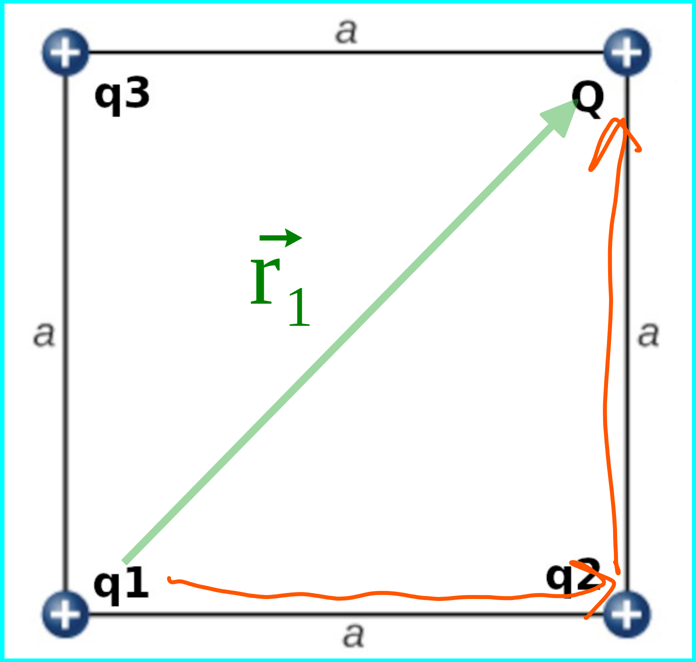




What is $\vec{r}_1$?

$(a\hat{i}+a\hat{j})\cdot(a\hat{i}+a\hat{j})$

$a^2\hat{i}\cdot\hat{i}+a^2\hat{j}\cdot\hat{i}+a^2\hat{i}\cdot\hat{j}+a^2\hat{j}\cdot\hat{j}$



(A) a

(B) $a\hat{i}$

$\boxed{\text{(C)}\ a\hat{i}+a\hat{j}}$

(D) $\sqrt{2}a\hat{i}+\sqrt{2}a\hat{j}$

(E) $\frac{\sqrt{2}}{2}a\hat{i}+\frac{\sqrt{2}}{2}a\hat{j}$

$\vec{r}_1 = a\hat{i}+a\hat{j}$

$\frac{\cancel{a}\hat{i}+\cancel{a}\hat{j}}{\sqrt{2}\cancel{a}}$

$\hat{r}_1 = \frac{\vec{r}_1}{|r_1|}$

$(\hat{i}+\hat{j})\frac{\sqrt{2}}{2}$

$|r_1| = \sqrt{2a^2} = \sqrt{2}a$

What is $\hat{r}_1$?

$\vec{r}_1 = a\hat{i} + a\hat{j}$

(A) a

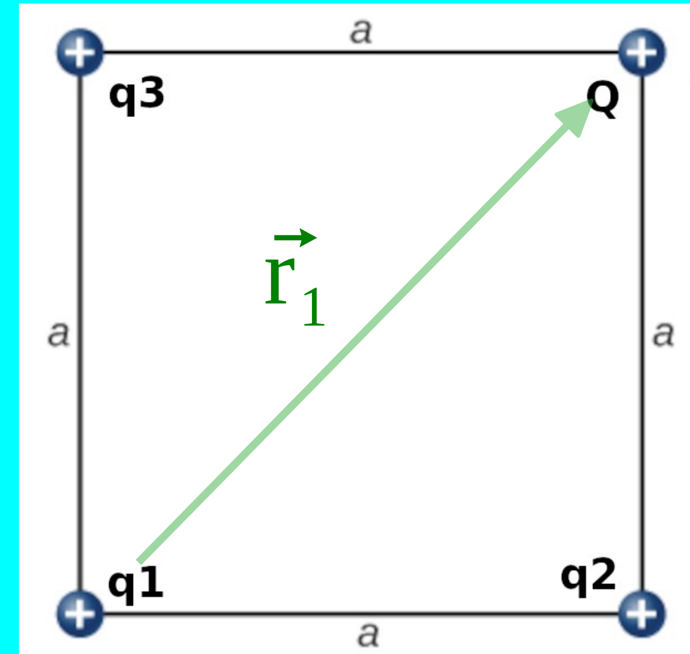
$\vec{r}_1^{\,2} = 2a^2$

(B) $\hat{i}$

(C) $\hat{i} + \hat{j}$

(D) $\sqrt{2}\,\hat{i} + \sqrt{2}\,\hat{j}$

(E) $\frac{\sqrt{2}}{2}\hat{i} + \frac{\sqrt{2}}{2}\hat{j}$



$\hat{r}_1 = \frac{\vec{r}_1}{|\vec{r}_1|}$

$\left(\frac{\sqrt{2}}{2}\right)^2 + \left(\frac{\sqrt{2}}{2}\right)^2$

$\frac{1}{2} + \frac{1}{2} = 1$

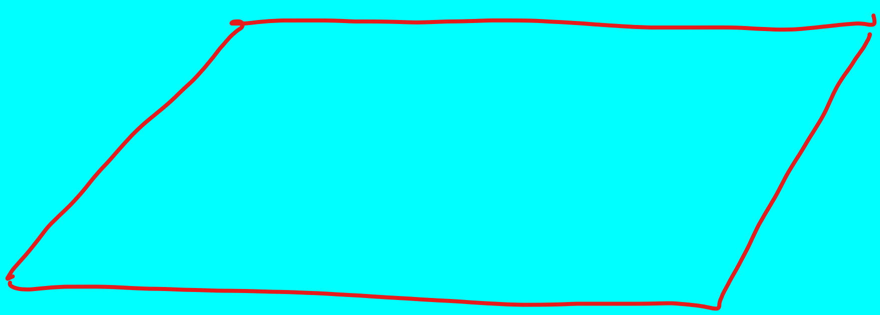
From Coulomb's Law to Electric field

$$\overrightarrow{F_{net}} = Q \sum_{n=1}^{N} k \frac{q_n}{r_n^2} \hat{r}_n$$

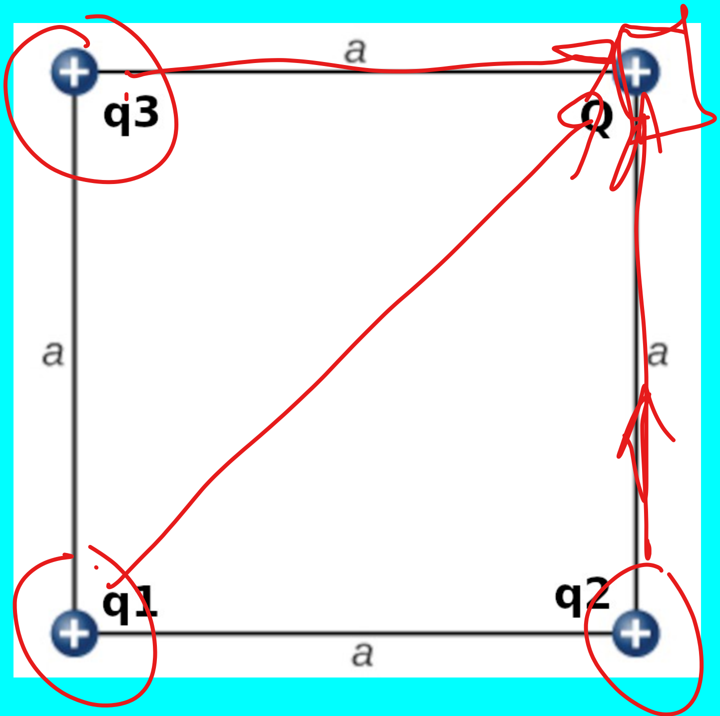
$$\vec{E} = \sum_{n=1}^{N} k \frac{q_n}{r_n^2} \hat{r}_n$$

$$\vec{E} = \frac{Q}{A} \epsilon_0$$

$$\overrightarrow{F_{net}} = Q \vec{E}$$



Homework 5-63-ish with field



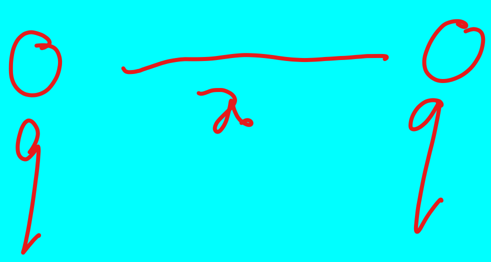
Find $\vec{E}$-field at top right corner in absence of Q

$$\vec{E} = k \sum_n \frac{\hat{r}_n q_n}{r_n^2}$$

$\vec{E}$

$$\vec{E}_P = k \sum_n \frac{q_n \hat{r}_n}{r_n^2}$$

$$\vec{E} = kq\left(\frac{\hat{i}}{a^2} + \frac{\hat{j}}{a^2} + \frac{\sqrt{2}}{2}\frac{\hat{i}}{2a^2} + \frac{\sqrt{2}}{2}\frac{\hat{j}}{2a^2}\right)$$



$$\vec{F} = \cancel{Q}\vec{E}$$

Superposition (Force)

The net force on $-Q$ is

A. Up.
B. Down.
C. Left.
D. Right.
E. The force on $-q$ is zero.

Superposition (Field)

The net field at the position "P" is

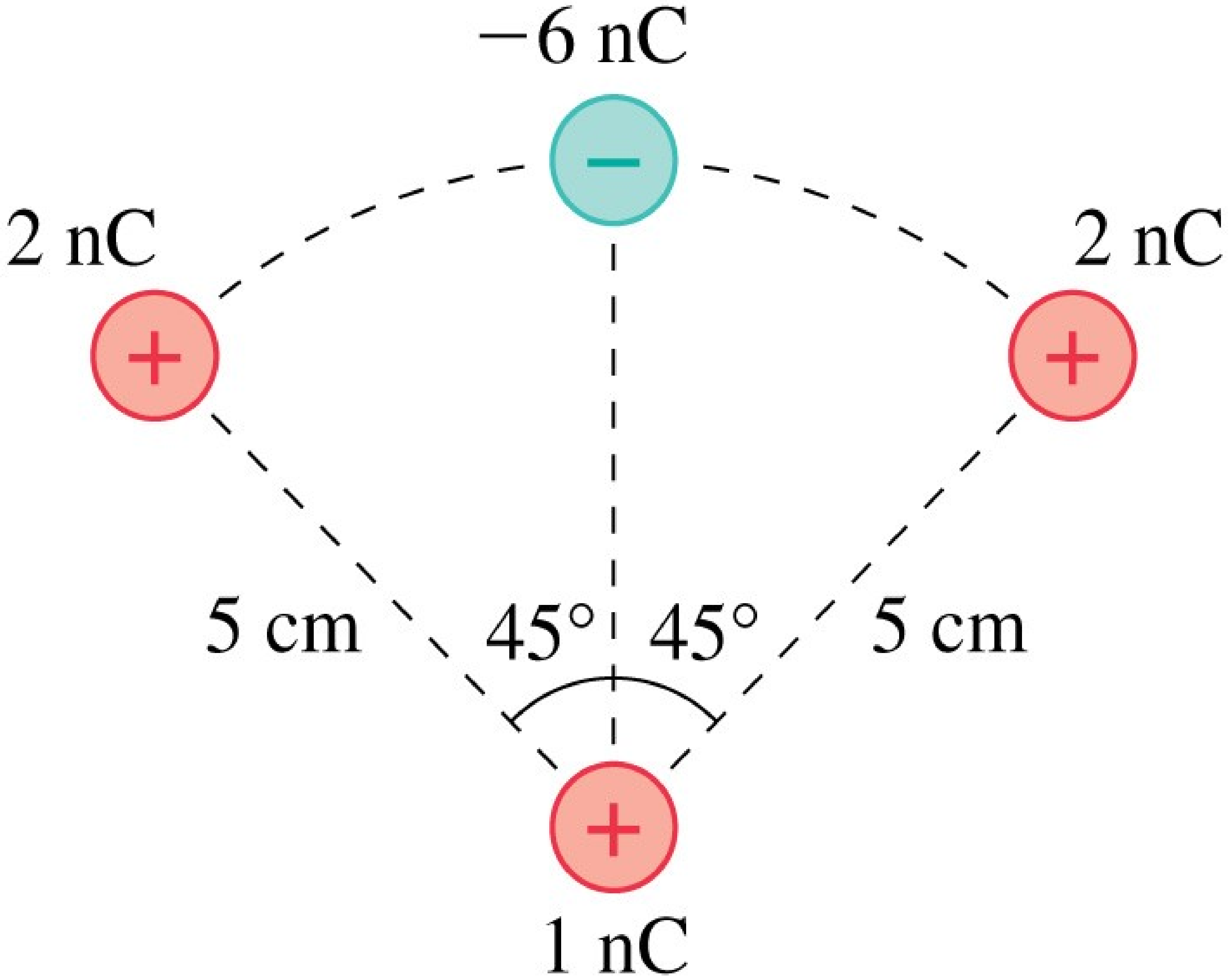
A. Up.

B. Down.

C. Left.

D. Right.

E. The force on $-q$ is zero.



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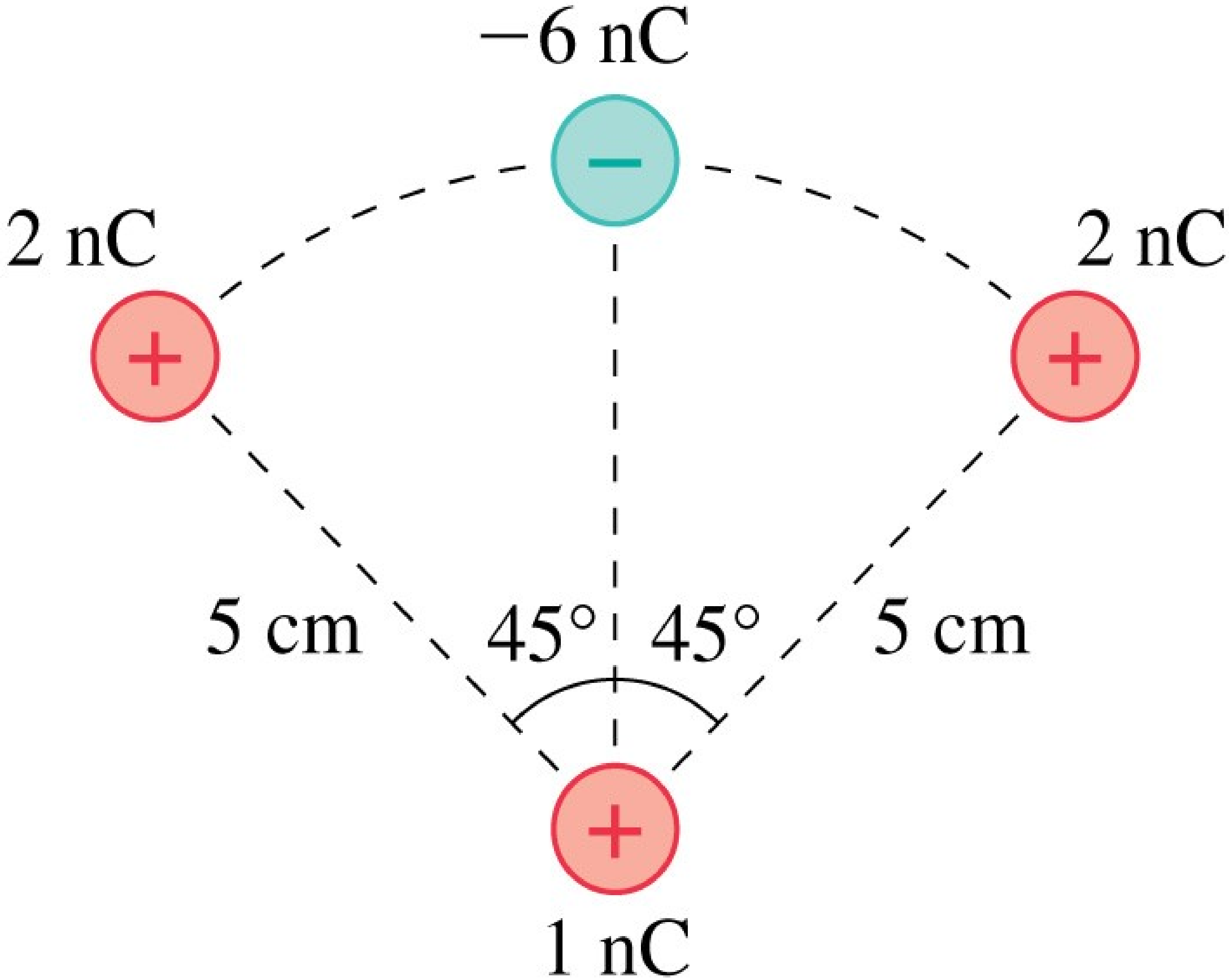
What is the direction of the field at the 1 nC charge?

Is it
(A) Up
(B) Down
(C) Zero
(D) Left
(E) Right



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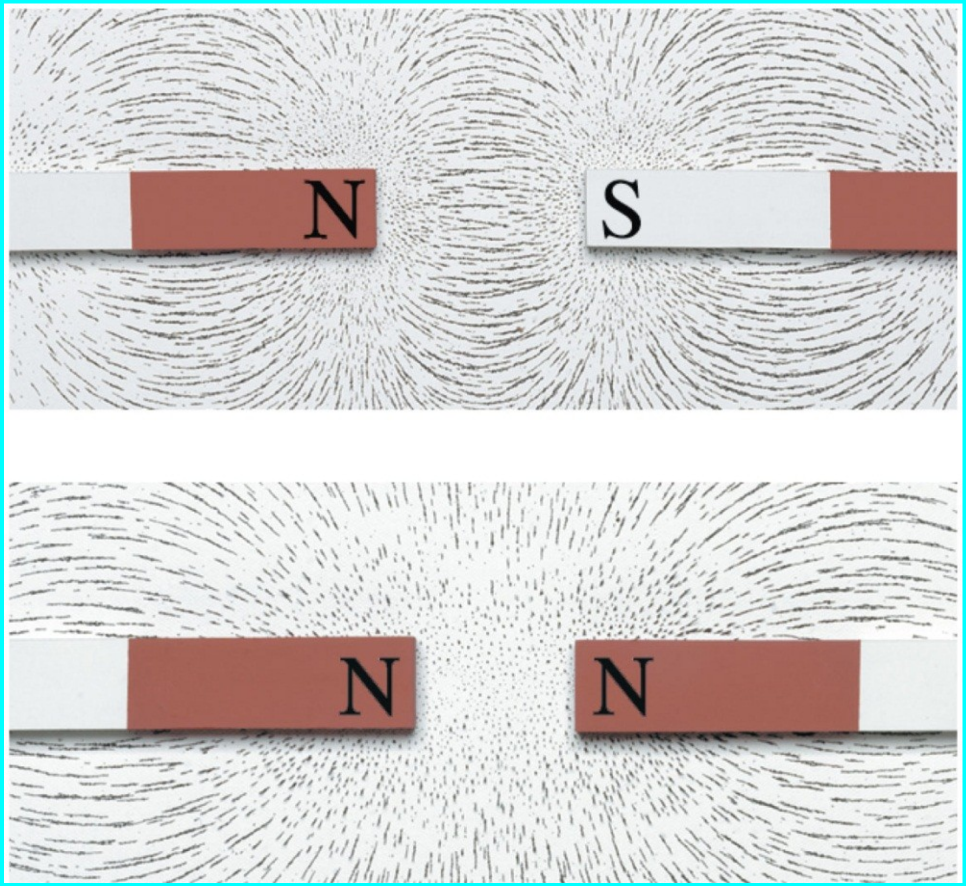
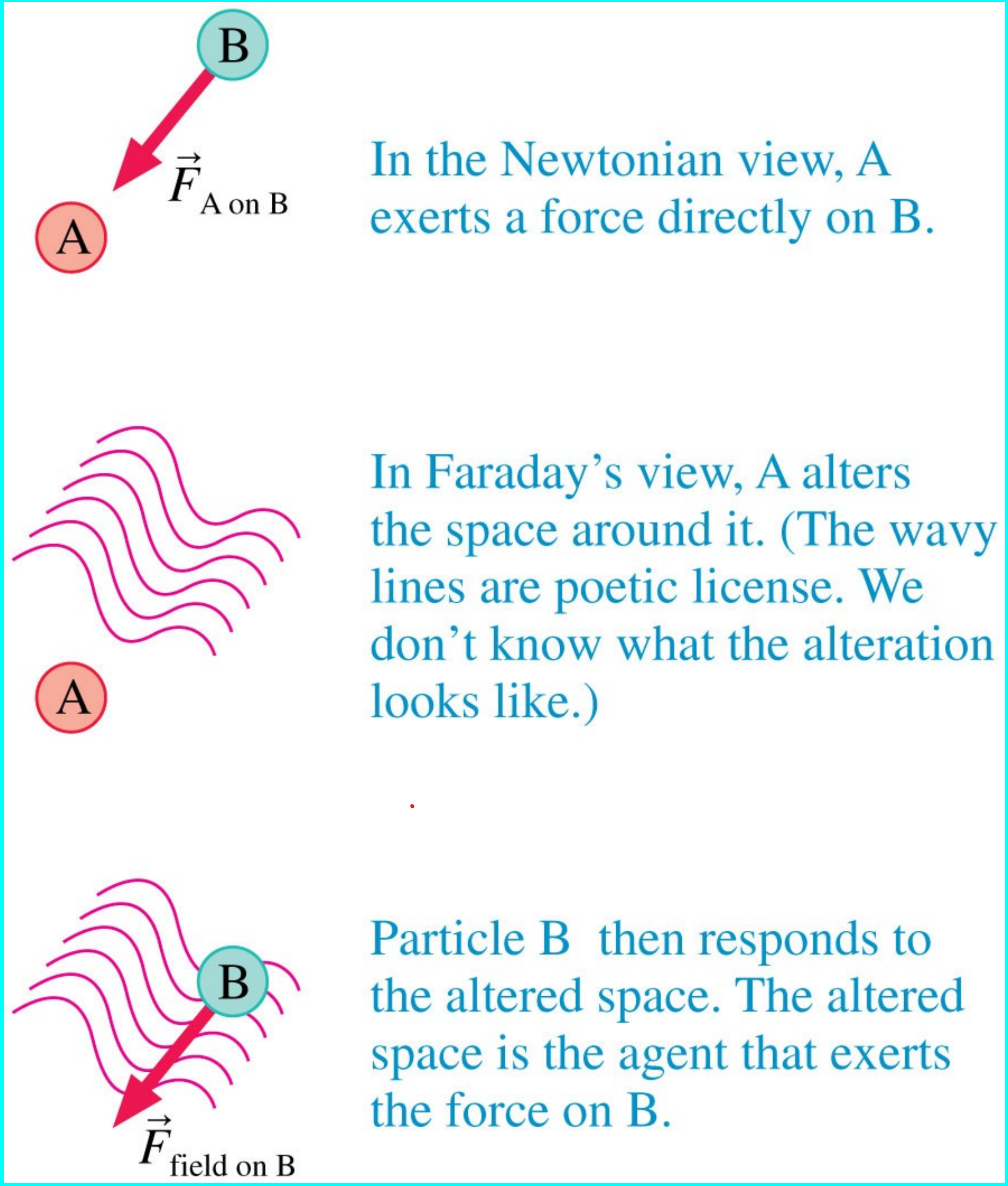
The Field Model



- The photos show the patterns that iron filings make when sprinkled around a magnet.
- These patterns suggest that *space itself* around the magnet is filled with magnetic influence.
- This is called the **magnetic field**.
- The concept of such a “field” was first introduced by Michael Faraday in 1821.

The Field Model

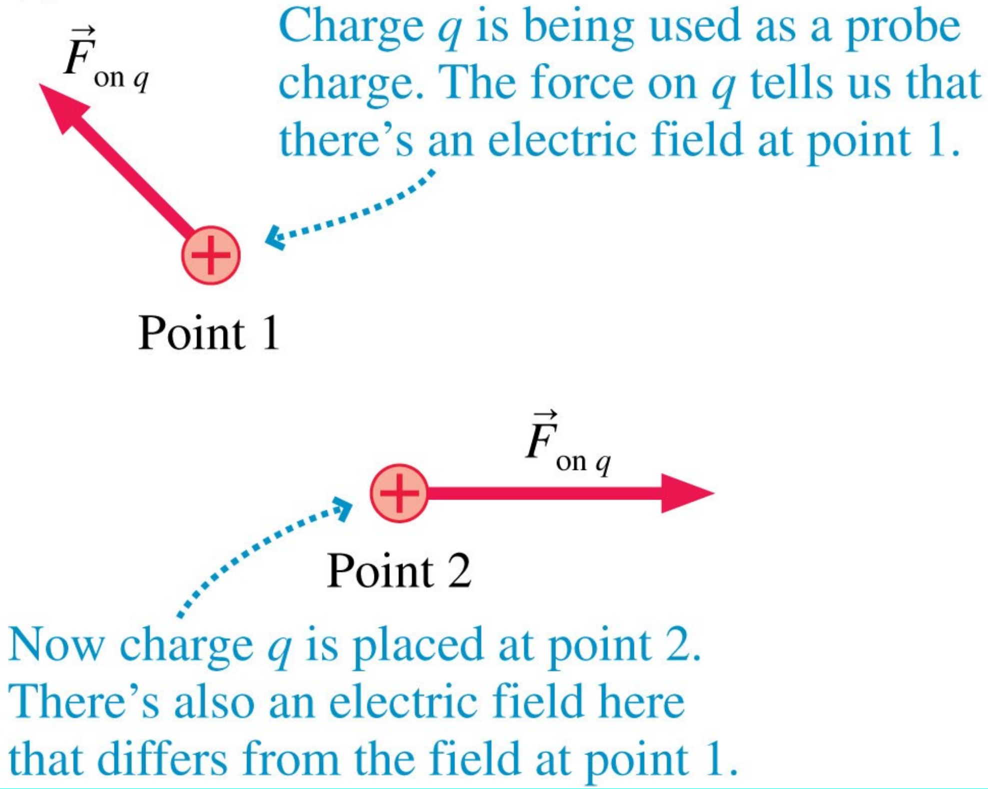
- A *field* is a function that assigns a vector to every point in space.
- The alteration of space around a mass is called the *gravitational field*.
- Similarly, the space around a charge is altered to create the **electric field**.



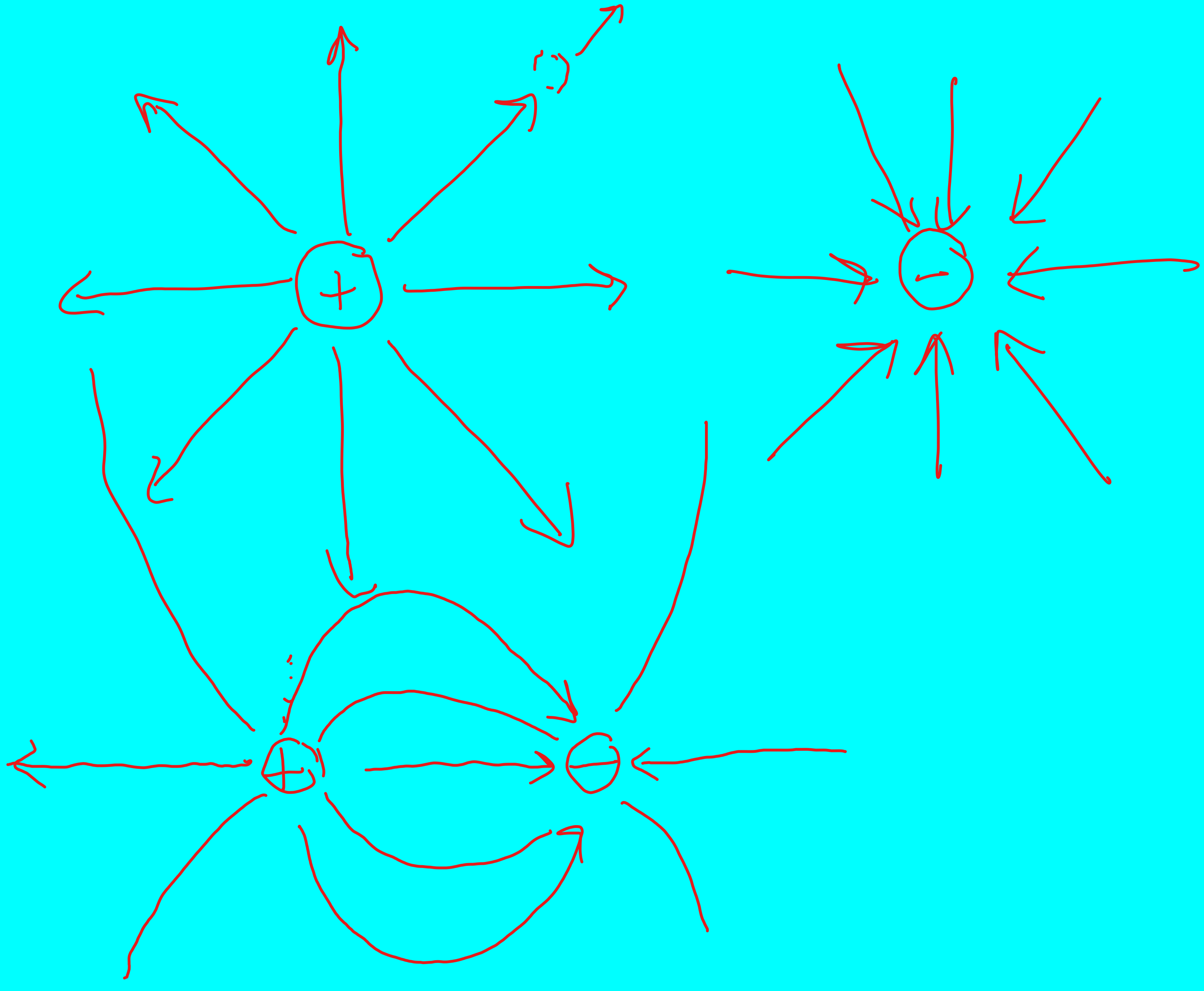
The Electric Field

- If a probe charge (or test charge) "q" experiences an electric force at a point in space, we say that there is an electric field $\vec{E}$ at that point causing the force.

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



The units of the electric field are N/C. The magnitude E of the electric field is called the **electric field strength.**

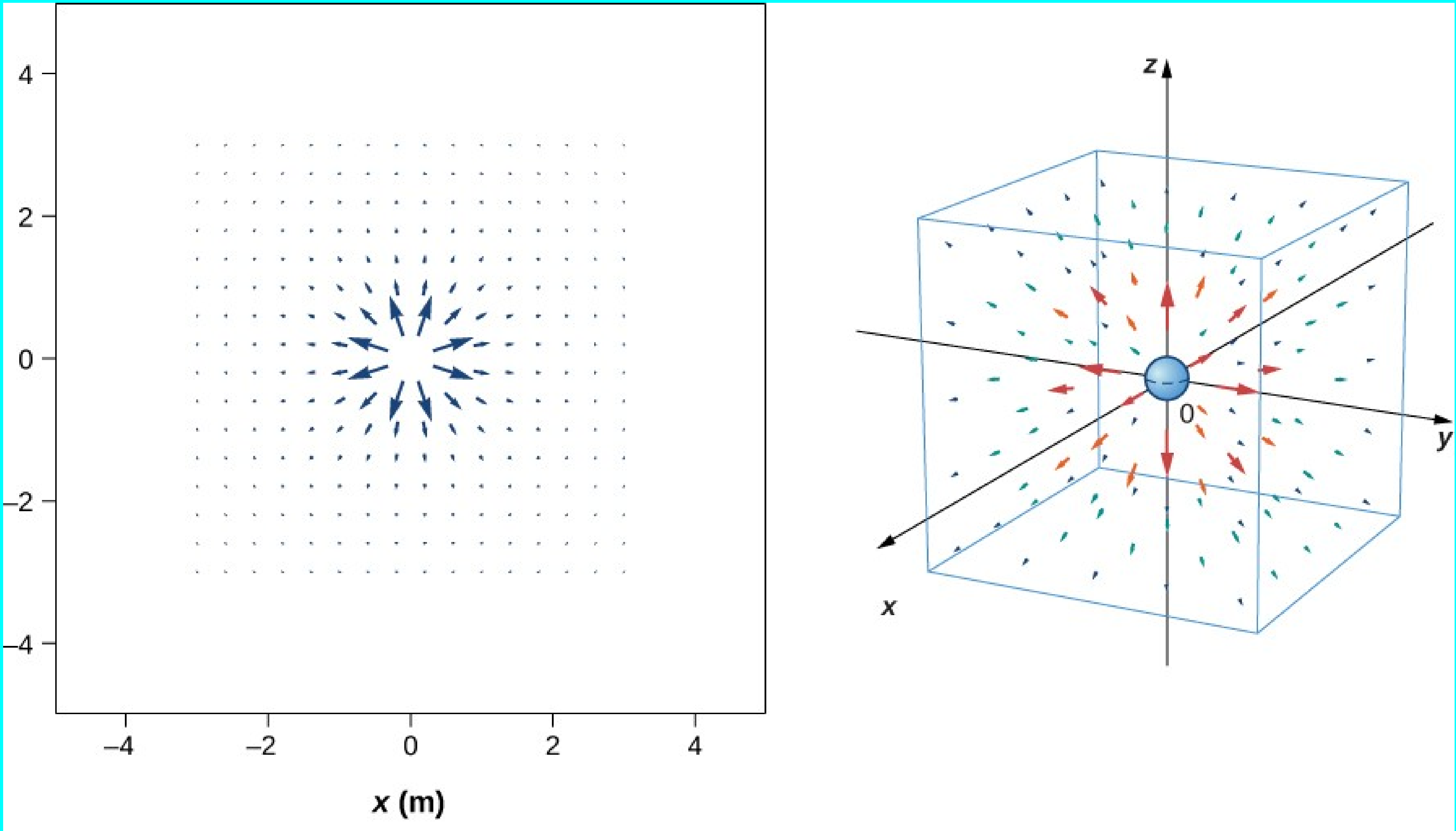


Electric Field Lines

- A way of getting intuition for the fields caused by a few charges (without calculating)

- Positive charges "emit" field lines.
- Negative charges "absorb" field lines.
- Field lines begin at + charge and end at infinity or negative charge.
- The tangent to an electric field line gives direction of force
- Electric field lines do not cross

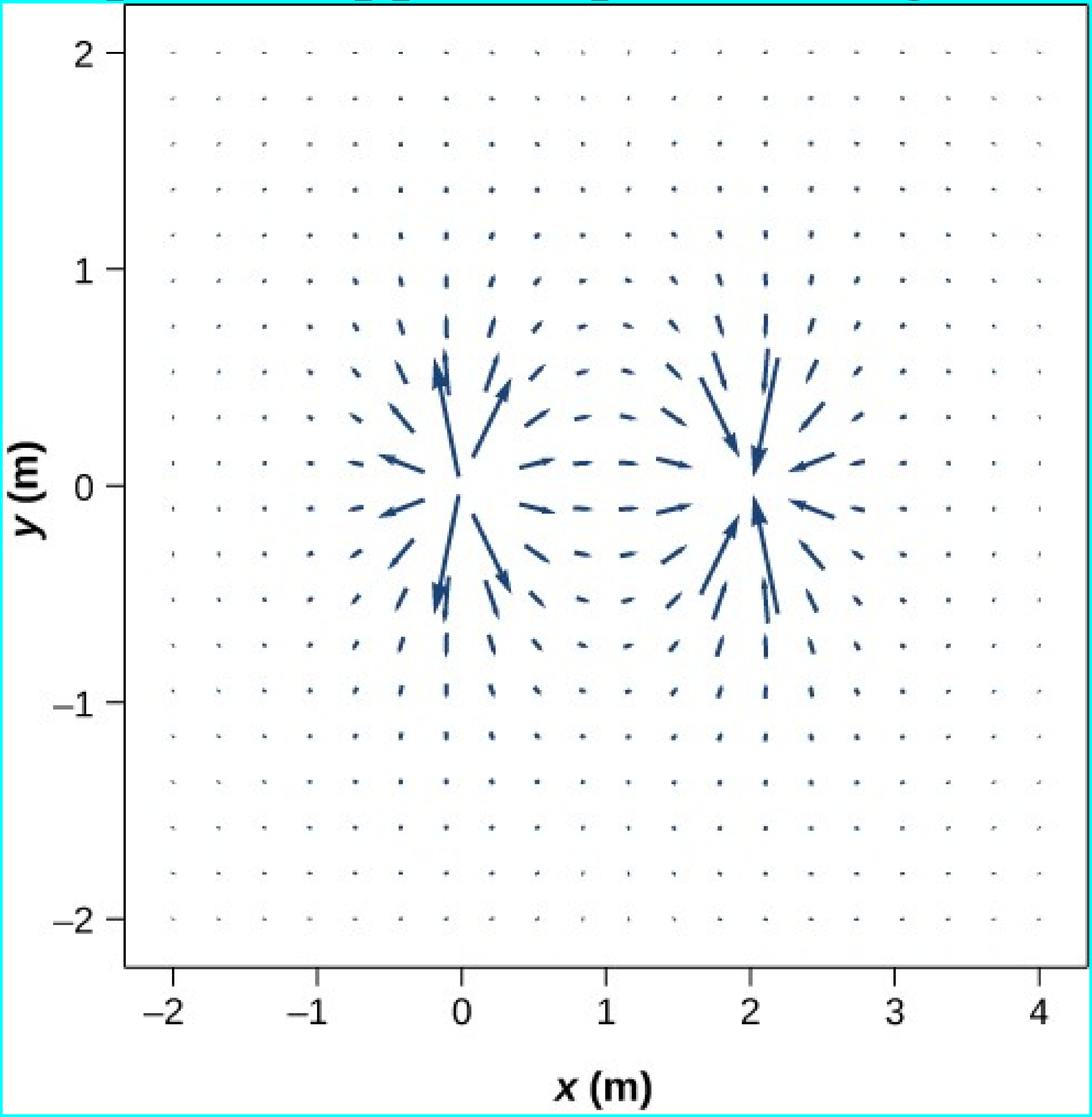
E-field of a + point charge

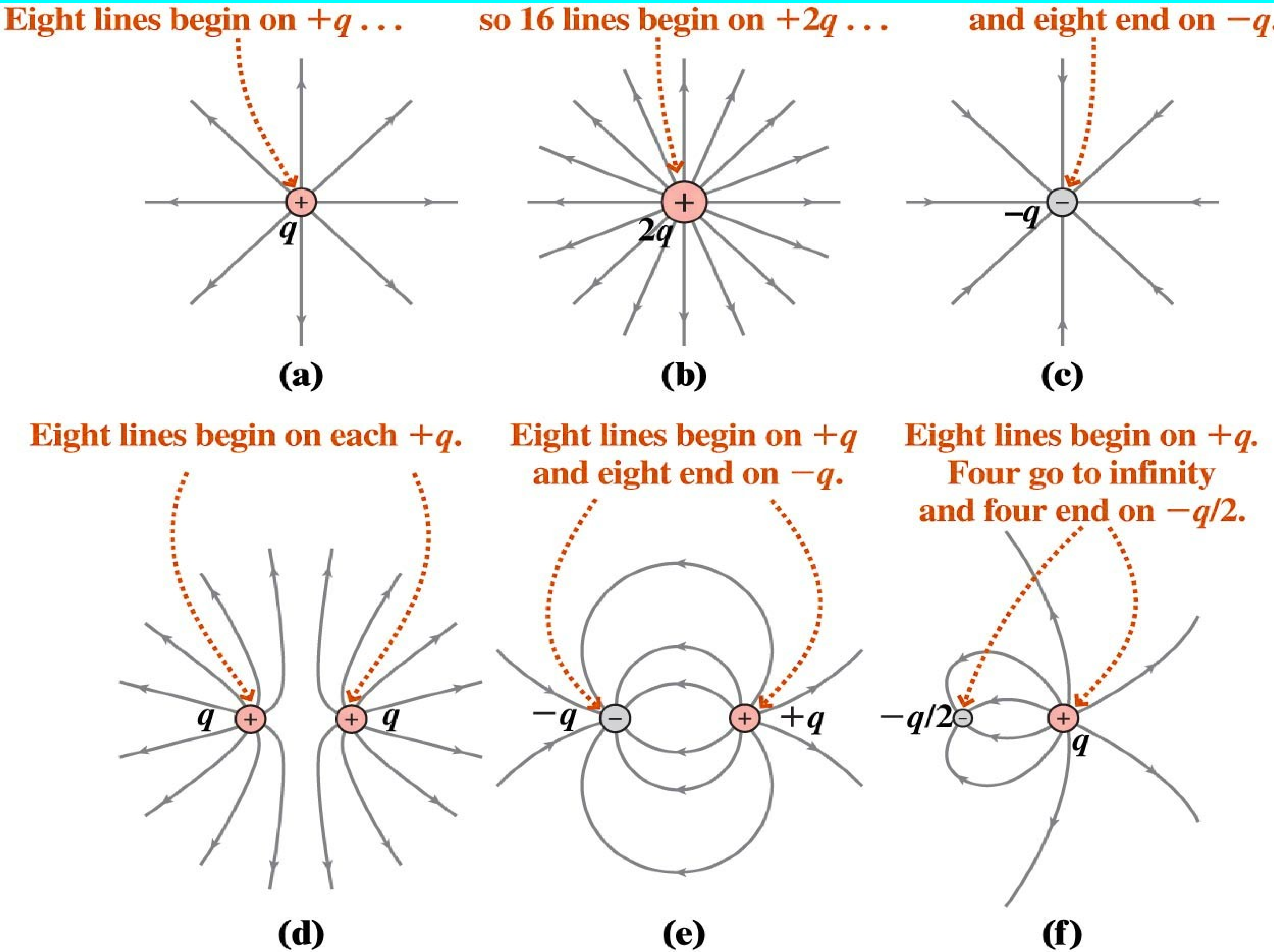


(a)

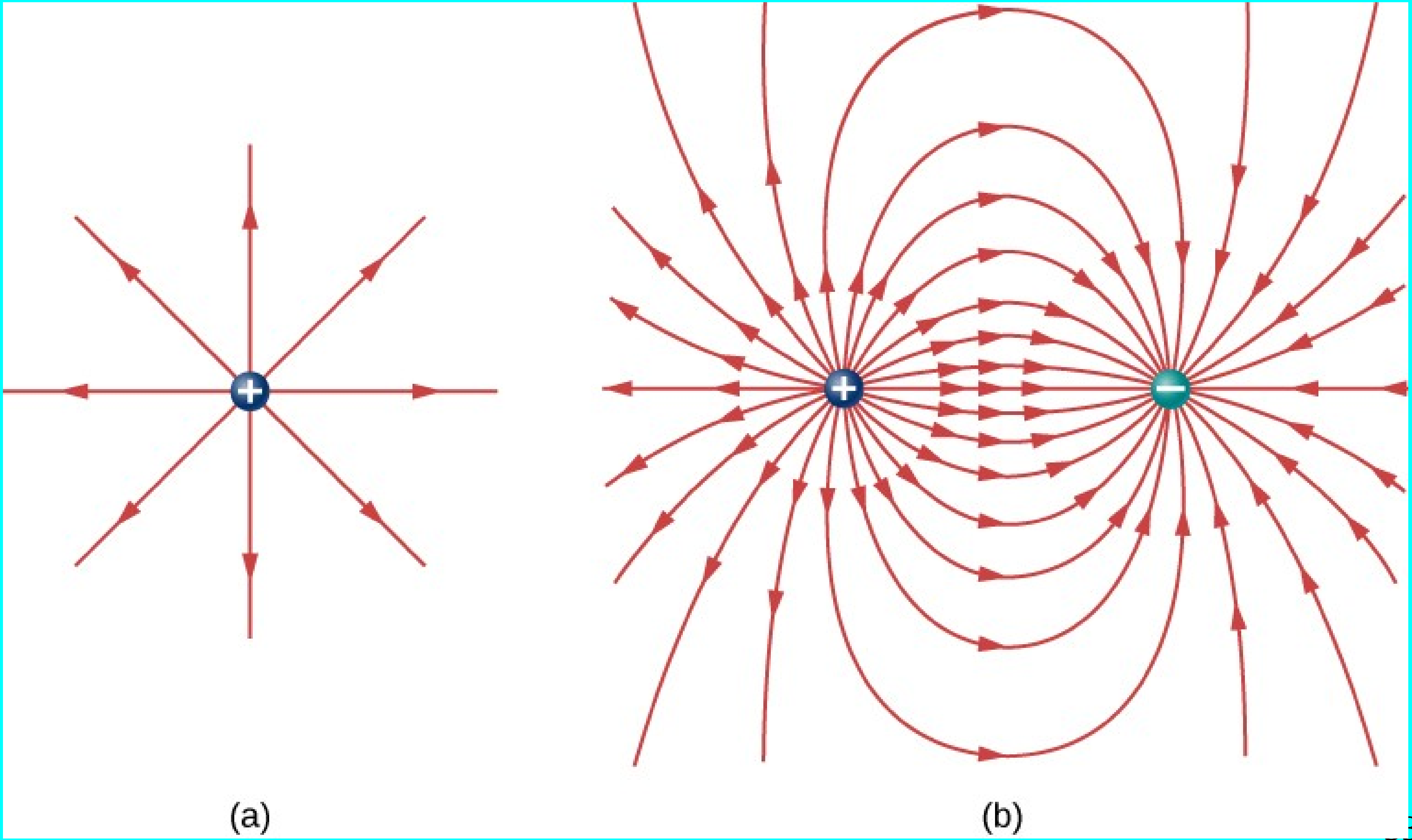
(b)

E-field of a pair of opposite point charges

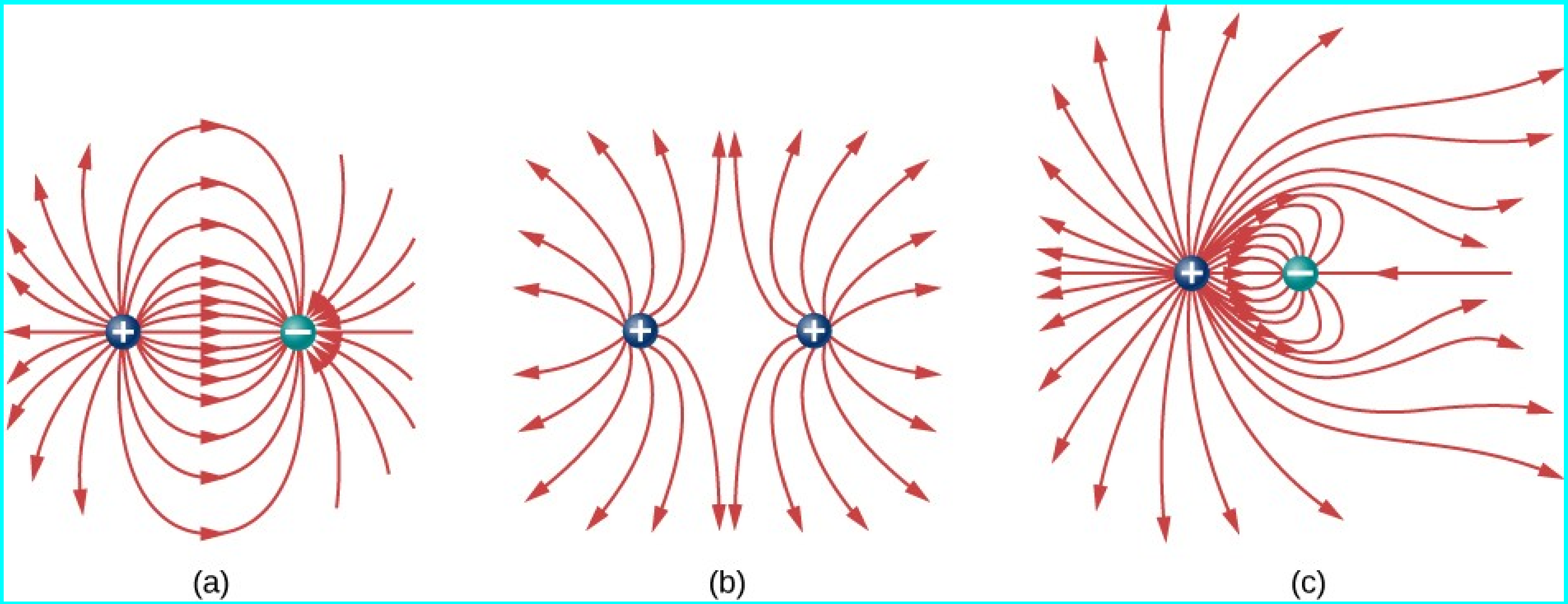



Eight lines begin on +q . . .
so 16 lines begin on +2q . . .
and eight end on −q.
q
2q
−q
(a)
(b)
(c)
Eight lines begin on each +q.
Eight lines begin on +q and eight end on −q.
Eight lines begin on +q. Four go to infinity and four end on −q/2.
q
q
−q
+q
−q/2
q
(d)
(e)
(f)

Field line views

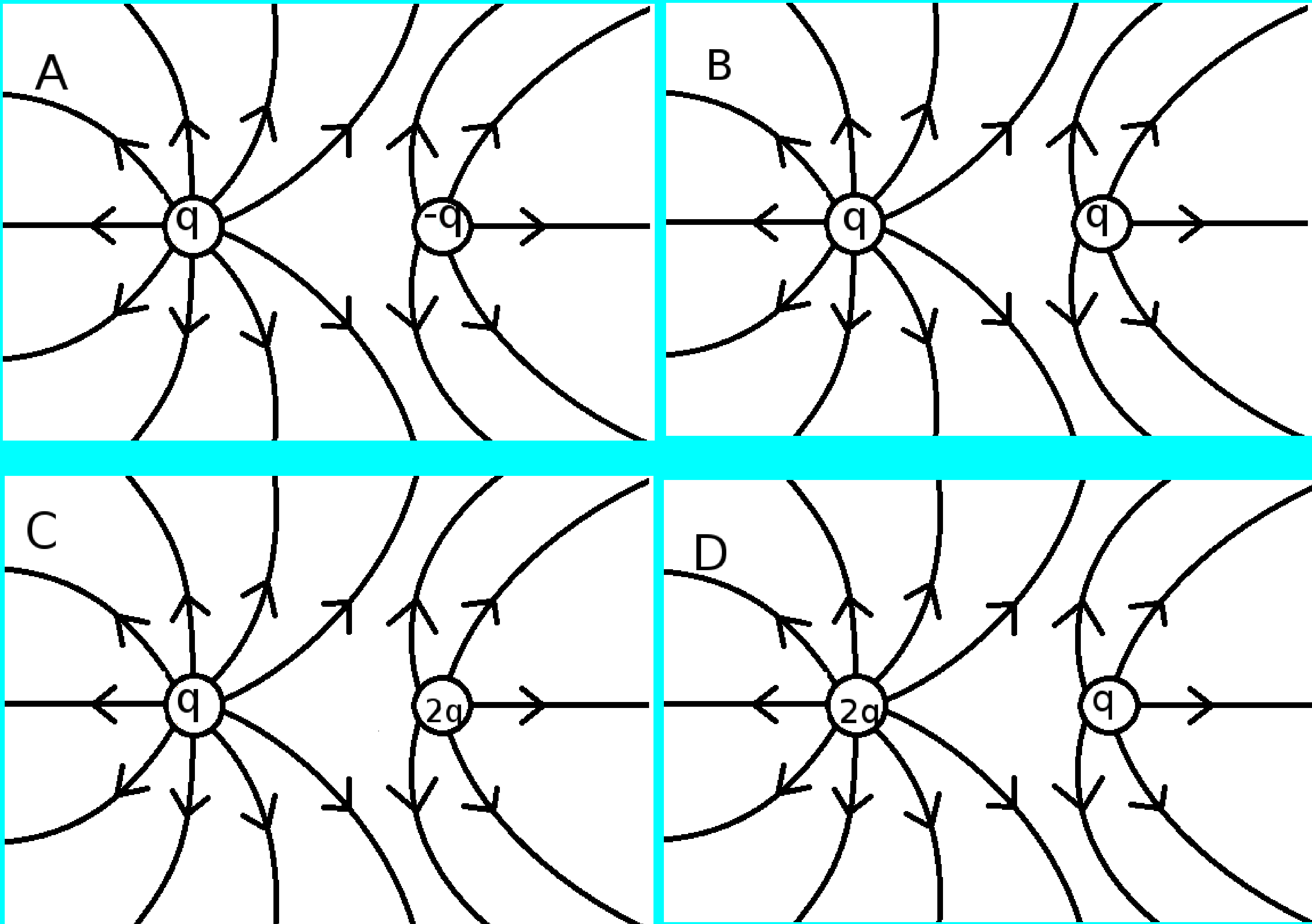


More field line views



PheT …
Charges and fields
Electric field of dreams

Which set of field lines matches the charges shown?



Key Equations

Coulomb's law	$\vec{\mathbf{F}}_{12}(r) = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{\mathbf{r}}_{12}$
Superposition of electric forces	$\vec{\mathbf{F}}(r) = \frac{1}{4\pi\varepsilon_0} Q \sum_{i=1}^{N} \frac{q_i}{r_i^2}\hat{\mathbf{r}}_i$
Electric force due to an electric field	$\vec{\mathbf{F}} = Q\vec{\mathbf{E}}$
Electric field at point P	$\vec{\mathbf{E}}(P) \equiv \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{N} \frac{q_i}{r_i^2}\hat{\mathbf{r}}_i$
Field of an infinite wire	$\vec{\mathbf{E}}(z) = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{z}\hat{\mathbf{k}}$
Field of an infinite plane	$\vec{\mathbf{E}} = \frac{\sigma}{2\varepsilon_0}\hat{\mathbf{k}}$
Dipole moment	$\vec{\mathbf{p}} = q\vec{\mathbf{d}}$

Coulomb's Law and Gravitation

$$F_E = k\frac{q_1 q_2}{r^2}$$

$$F_G = G\frac{m_1 m_2}{r^2}$$

$$k = 8.99\times 10^9 \frac{\mathrm{N\,m^2}}{\mathrm{C^2}}$$

$$G = 6.674\times 10^{-11}\ \mathrm{N\,m^2/kg^2}$$

Why do masses attract?

Why do charges attract/repel?

Next Class:

Electric field and flux