Physics
Electrostatics: Electric Field Diagrams

Science and Mathematics Education Research Group

Representations of Electric Fields
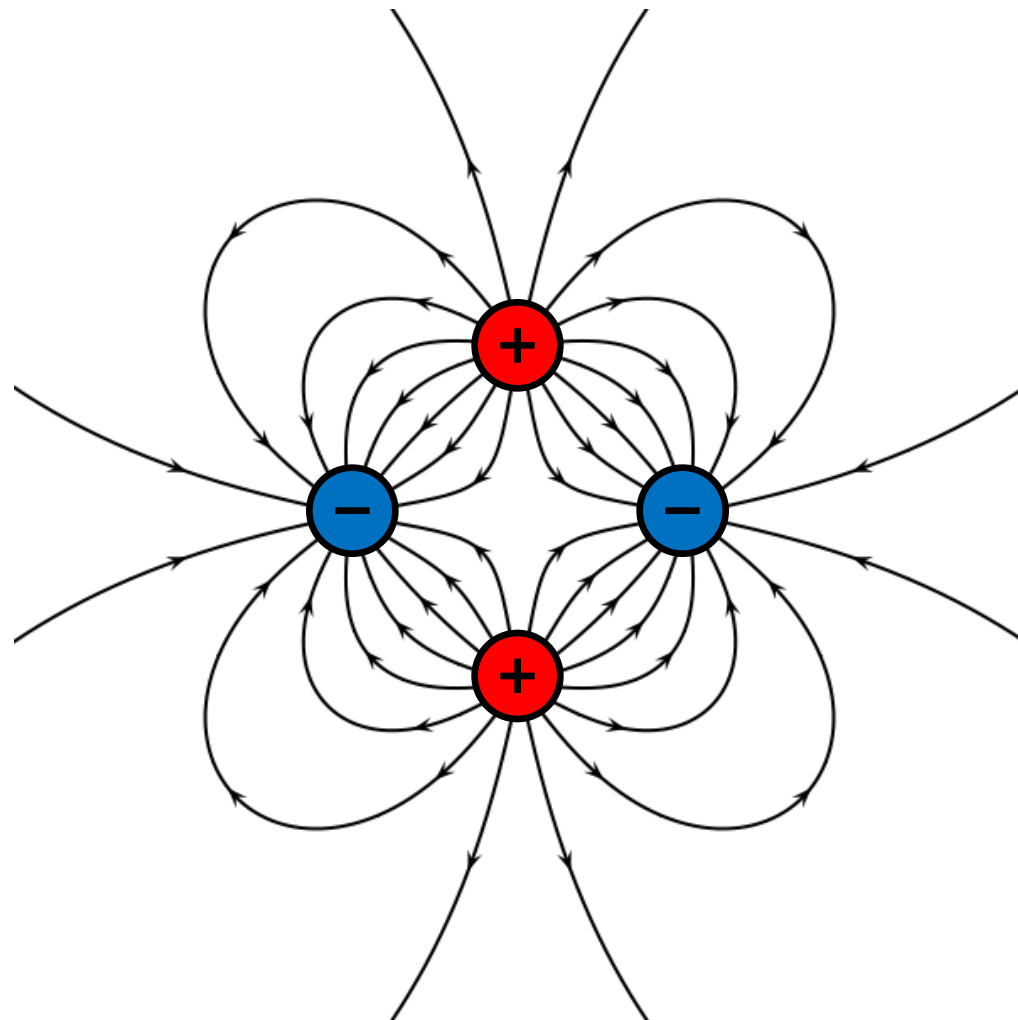
Electric Fields

The electric field is defined as the force per unit charge experienced by a positive test charge q:

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

(A positive test charge is used by convention, instead of a negative charge)

The electric field is a vector quantity with units newtons per coulomb (N/C). It is directed in the same direction as the force experienced by the small positive test charge inside the electric field.

The magnitude of the electric field created by a single charge Q at a distance r is:

$$E = \frac{1}{q}\frac{kQq}{r^2} = \frac{kQ}{r^2}$$

Electric Field Diagrams I

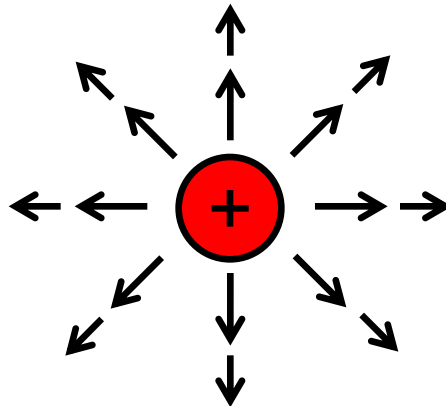Which diagram best represents the electric field lines around a positive charge Q?

A.

B.

C.

D.
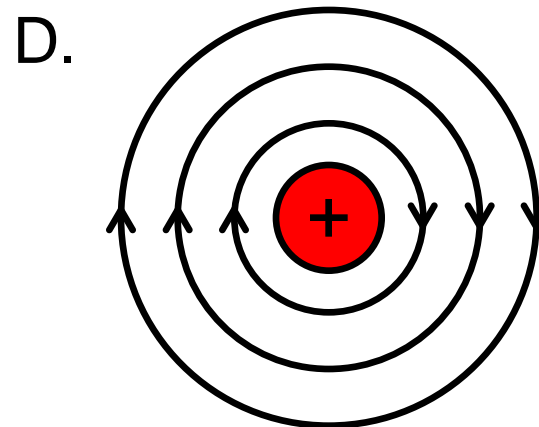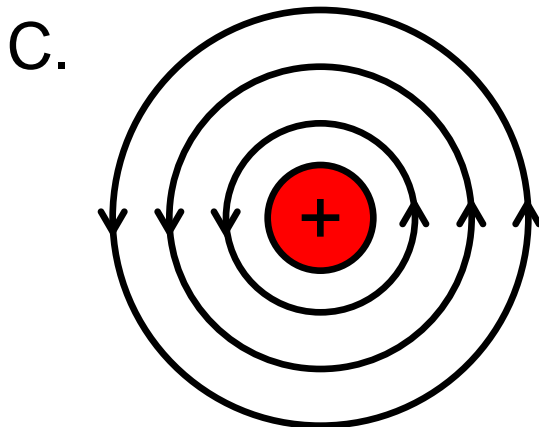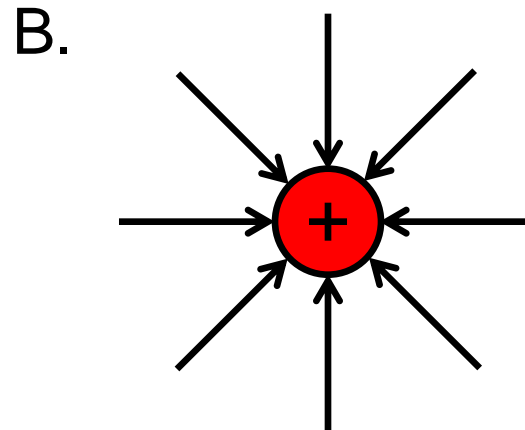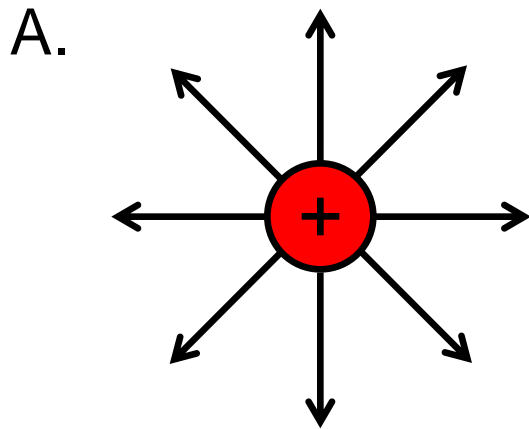
Solution

Answer: A

Justification: A positive charge repels positive test charges, pushing them away. Since electric field lines are in the same direction as the force experienced by a positive test charge, the electric field lines will point away from the positive charge.

The magnitude of each electric field is given by: $E = \dfrac{F}{q} = \dfrac{kQ}{r^2}$

The farther away from the charge Q, the weaker the electric field. Therefore, the vectors describing the electric field should be longer closer to Q, and shorter farther away from Q.
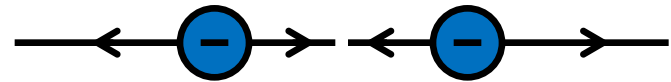
Electric Field Diagrams II

Which diagram represents the electric field created by two equal negative charges along the line connecting the two charges?
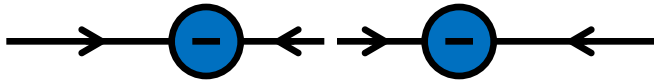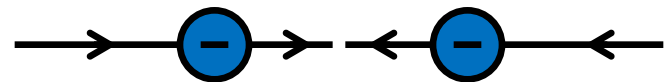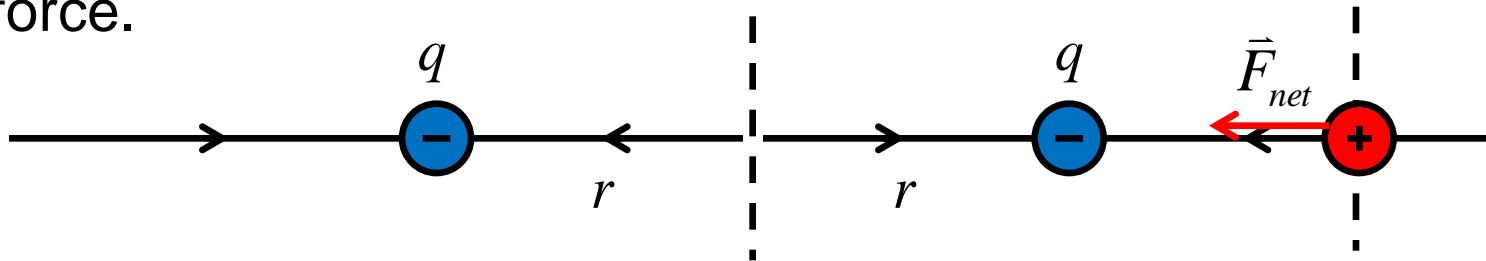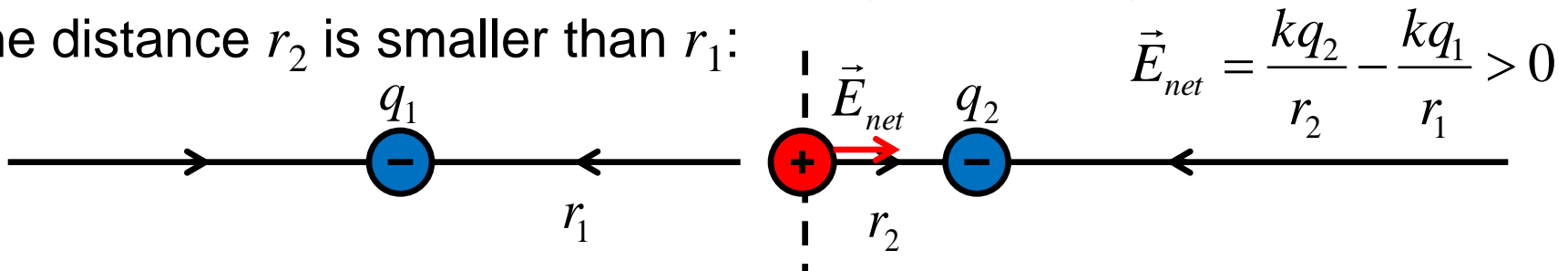
Solution

Answer: A

Justification: When a small positive test charge is on the outsides of the two charges, it will experience an attractive force pointing towards the two negative charges. The electric field points in the direction of the force.

q q $\vec{F}_{net}$

r r

Slightly off the center, a small positive test charge will experience a net electric field towards the closer negative charge. This is because the distance r_2 is smaller than r_1:

$$\vec{E}_{net} = \frac{kq_2}{r_2} - \frac{kq_1}{r_1} > 0$$

q_1 $\vec{E}_{net}$ q_2

r_1 r_2

Solution Continued

Answer: A

Justification: At the midpoint of the two negative charges, there is no electric field. A charge located at this point will not experience a net force.

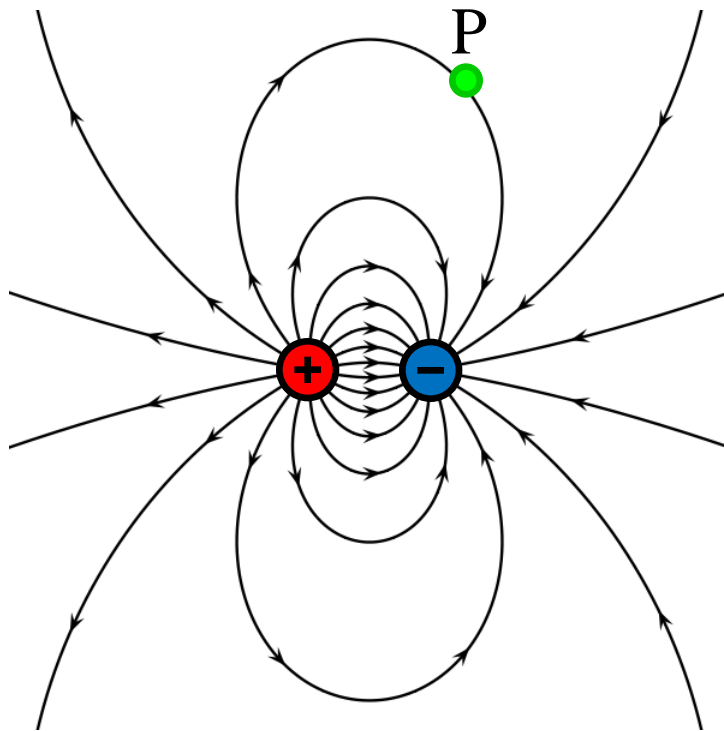$$\vec{E}_{net} = \frac{kq}{r} + \left(\frac{-kq}{r} \right) = 0 \text{ N/C}$$
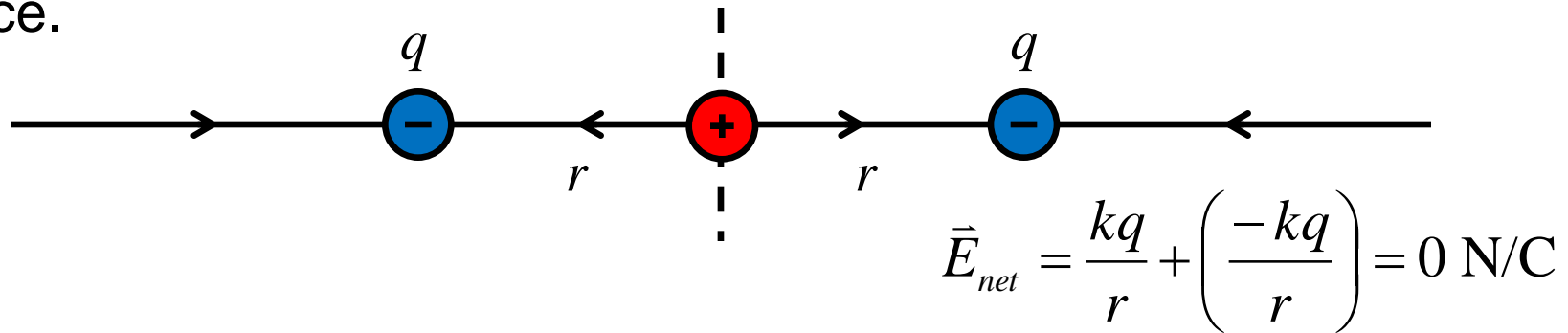
Electric field lines should point towards the closest negative charge. This is the charge that a positive test charge will be attracted towards.
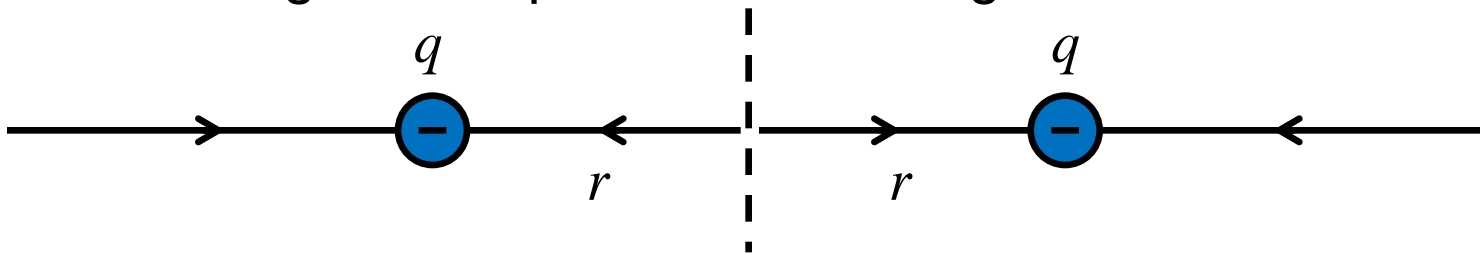
Electric Field Diagrams III

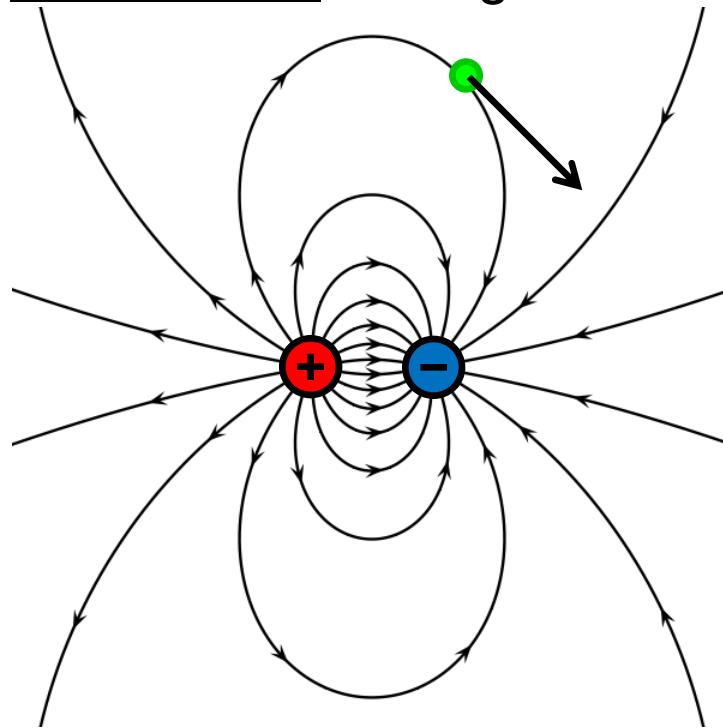What is the direction of the electric field at the point P?

P

(Electric field lines of a positive and negative charge)

A. →

B. ↓

C. ↘

D. ↗

E. ↘

Solution

Answer: C

Justification: The <u>electric field</u> is tangent to the <u>electric field line</u> at the point P.
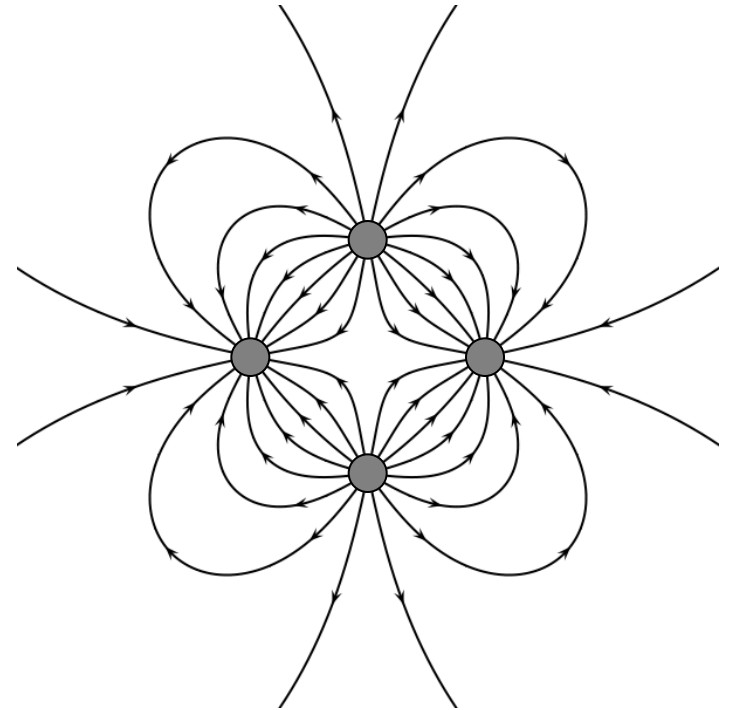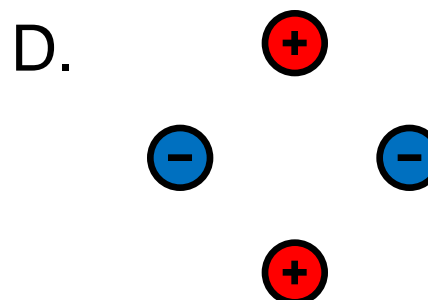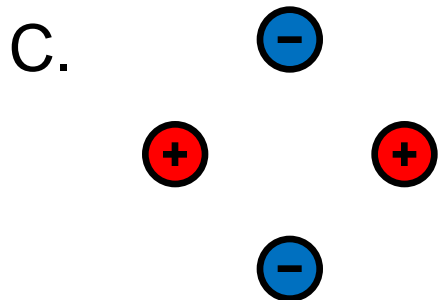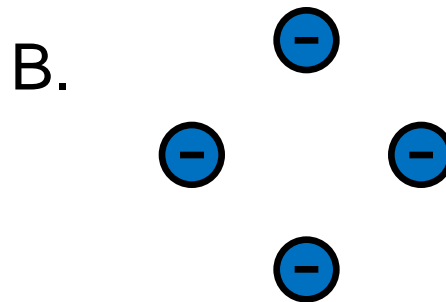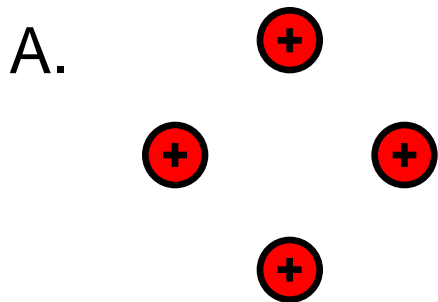

The electric field is a vector, and cannot be a curved line. Only electric field lines are curved. This eliminates answer E.

Electric Field Diagrams IV

The electric field lines of four charges are shown to the right.

What are the signs of the four charges?

A.

B.

C.

D.

Solution

Answer: D

Justification: Recall that we used a positive test charge by convention to determine the direction of electric field lines. Electric field lines flow out of positive charges and into negative charges. This is because positive charges will repel a positive test charge, while negative charges will attract them.

Note: The four charges are also equal in magnitude. We know this because they have the same number of lines flowing in or out of them.
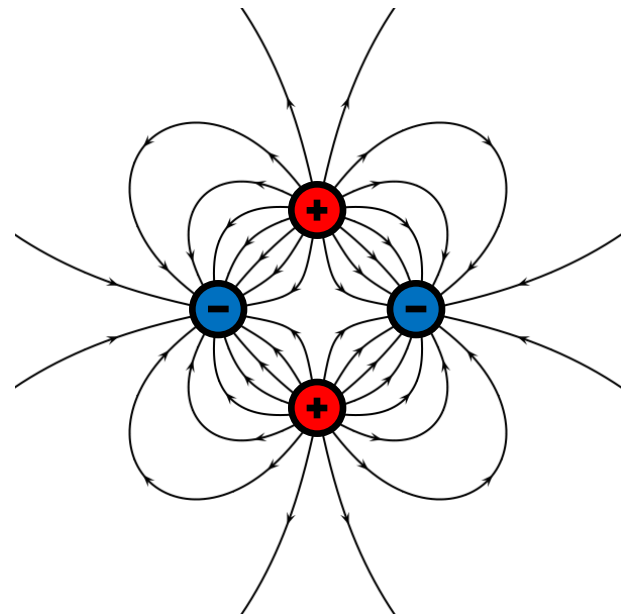
Electric Field Diagrams V

Which arrangements of four equal charges will generate zero net electric field at their center?

1.

2.
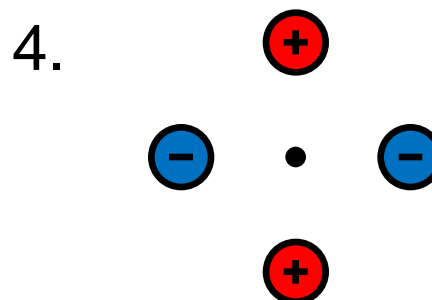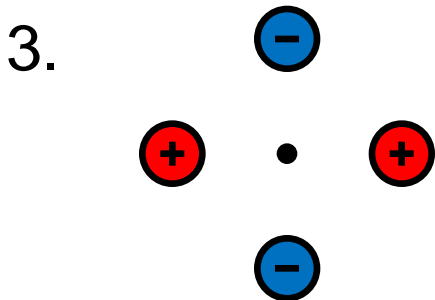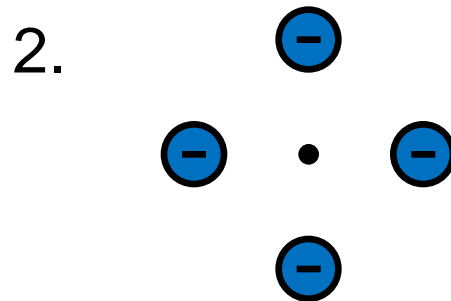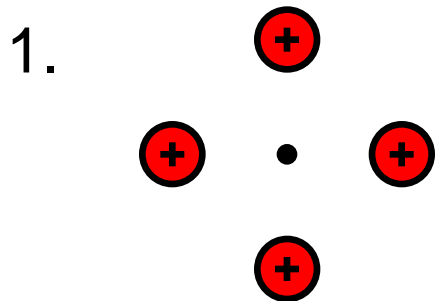
A. 1 only

B. 1 and 2

C. 3 and 4

D. None of the arrangements

3.

4.

E. All of the arrangements

Solution
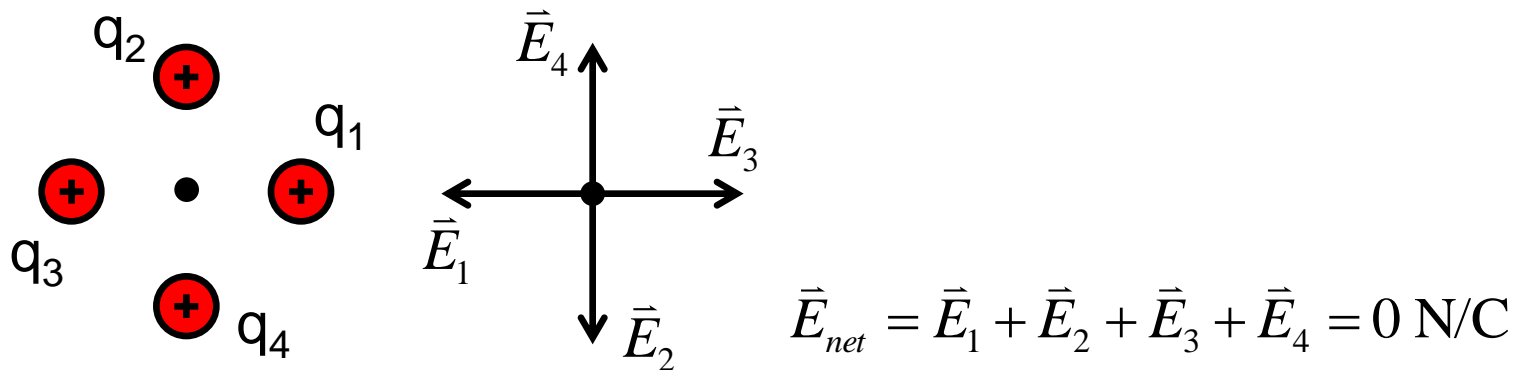
Answer: E

Justification: Determine the electric field at the midpoint caused by each charge separately. Adding the electric field vectors will give the net electric field. For example, adding the electric fields vectors from option A give:

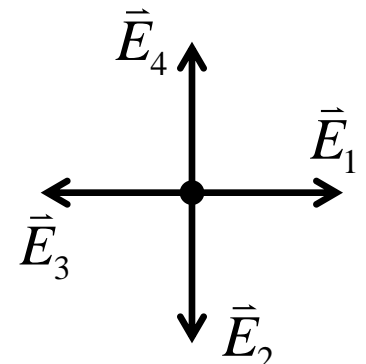$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4 = 0 \text{ N/C}$$

Drawing similar diagrams for each arrangement will show that the net electric field is zero at the midpoint in each situation. The answer diagrams are shown in the next slide.

Solution Cont'd

Answer: E

Justification: $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4 = 0 \text{ N/C}$
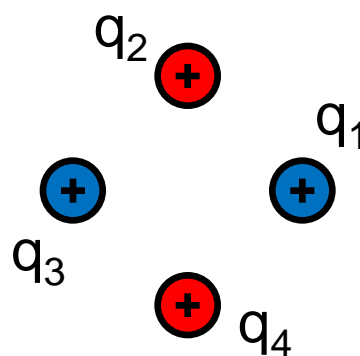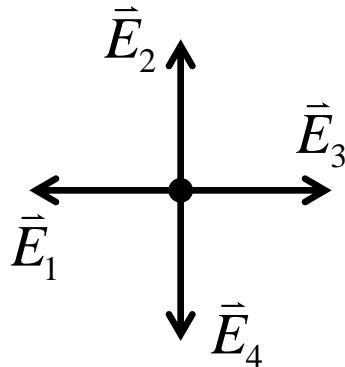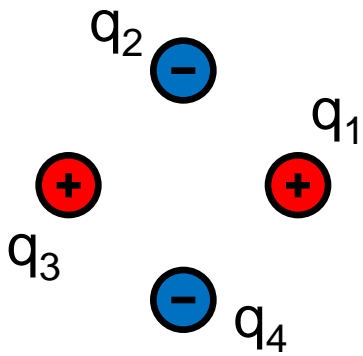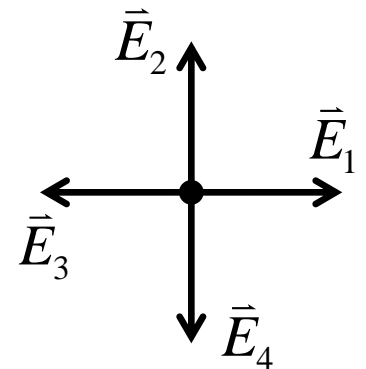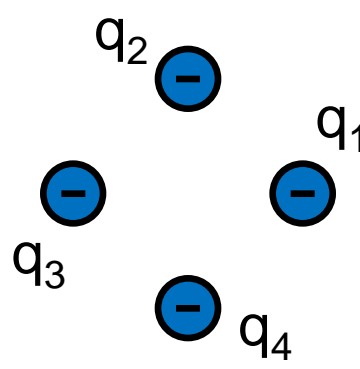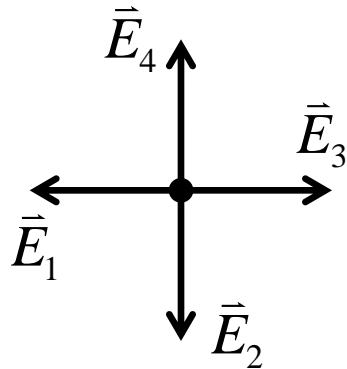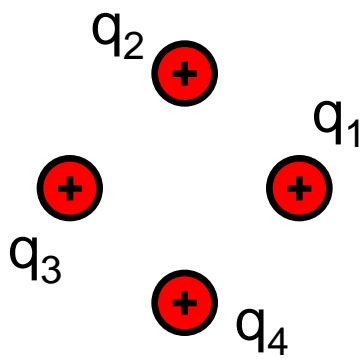
Electric Field Diagrams VI

A proton enters an electric field with the initial velocity shown.

Which illustrated electric field is responsible for the trajectory of the proton?

$\vec{v}_i$

Parabolic
trajectory
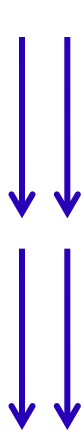
A.   B.   C.   D.   E.
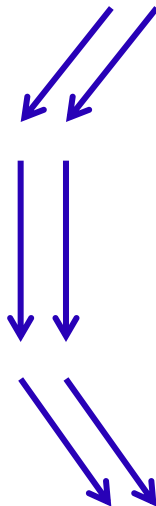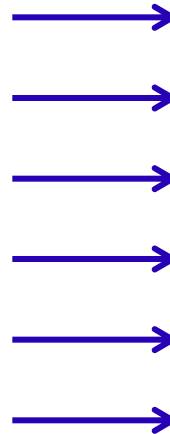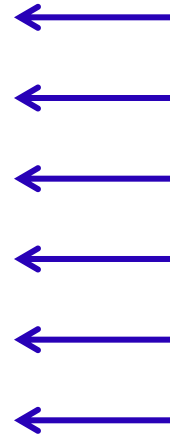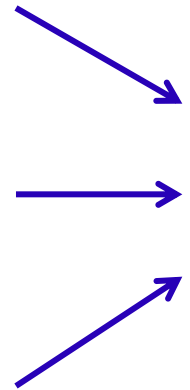
Solution

Answer: C

Justification: Recall from projectile motion that a uniform gravitational field causes a mass with an initial horizontal component of velocity to move in a parabola (left diagram).

$$\vec{g} = \frac{\vec{F}}{m}$$

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

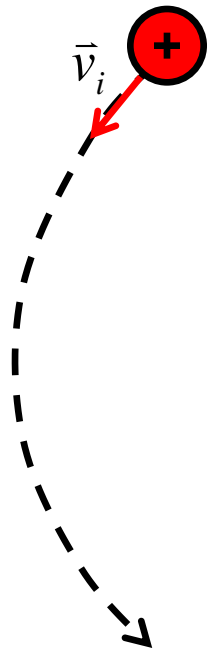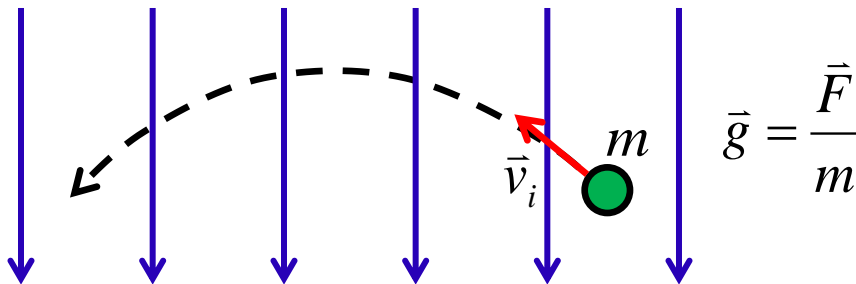A proton travelling in an electric field will also experience a parabolic trajectory (right).
Notice the similarity between the direction and magnitude of the gravitational and electric field, and their impact on the trajectory.
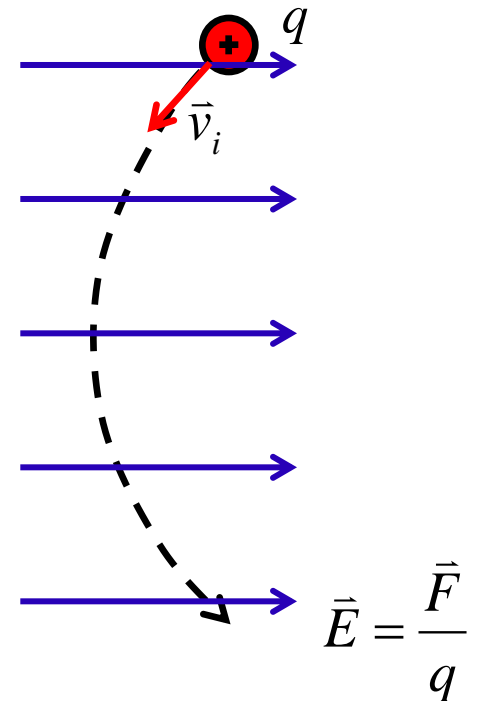
Electric Field Diagrams VII

The electric field between two charged parallel plates is uniform and directed as shown. An electron (with charge e and mass m) is placed at the midpoint of the two plates.

What is the acceleration of the electron?
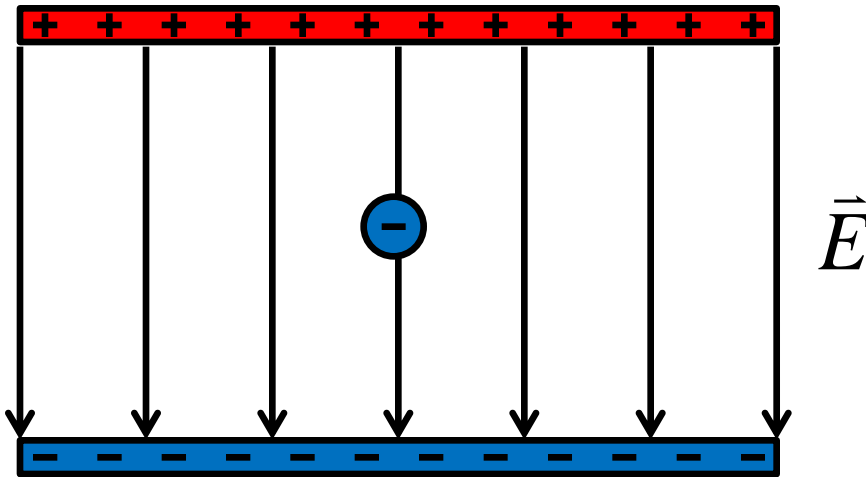
A. $\vec{a} = \dfrac{eE}{m}$ ↑

B. $\vec{a} = \dfrac{eE}{m}$ ↓

C. $\vec{a} = \dfrac{E}{m}$ ↑

D. $\vec{a} = \dfrac{E}{m}$ ↓

E. None of the above

$\vec{E}$

Solution

Answer: A

Justification: The force on the negatively charged electron is in the opposite direction of the electric field lines, so the acceleration should be directed upwards.

The force experienced by the electron can be found from the electric field (the force per unit charge):

$$E = \frac{F}{q} \quad \Rightarrow \quad F = qE = eE, \quad q = e$$

The acceleration is therefore $\vec{a} = \dfrac{\vec{F}}{m} = \dfrac{e\vec{E}}{m} \uparrow$

Think: If a proton were put into the electric field instead of the electron, which direction would it accelerate? Will a proton or electron have greater acceleration?

Electric Field Diagrams VIII

Four electrons are placed in between two charged plates. Two electrons are initially at rest (1 and 2), while two have an initial velocity v_0 in the directions shown (3 and 4). Assume that the four electrons do not interact with each other.

Which electron will experienced the largest initial acceleration?
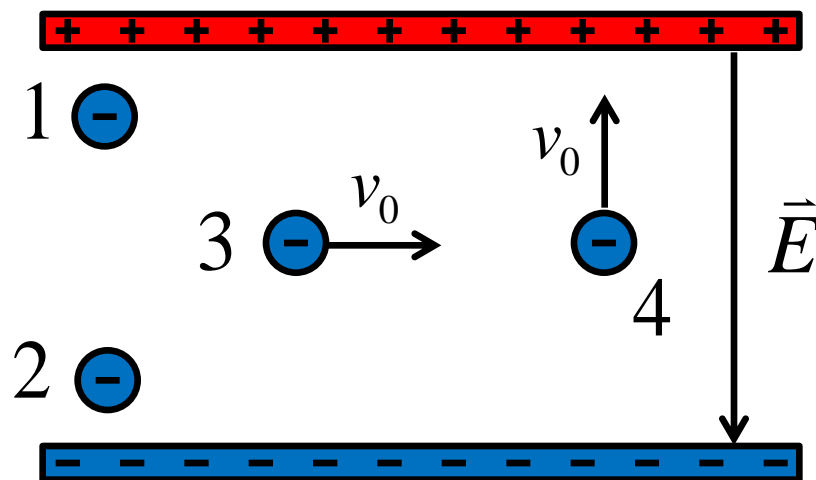
A. Electron 1

B. Electron 2

C. Electron 3

D. Electron 4

E. All experience the same initial acceleration

Solution

Answer: E

Justification: The acceleration (calculated in the previous question) depends only on the charge of the electron, the mass of the electron, and the electric field. Each electron in the situation has the same mass and charge. As well, the electric field is the same at all points in between the two plates, so the acceleration and force is constant.

$$\vec{a} = \frac{e\vec{E}}{m} \quad \uparrow$$

The position of the electron between the charged plate and the electron's initial velocity does not change the acceleration.

Think: How will different initial positions and velocities change the trajectory of the electron?

Electric Field Diagrams IX

If an electron is fired horizontally between the two charged plates, what is the trajectory of the electron?
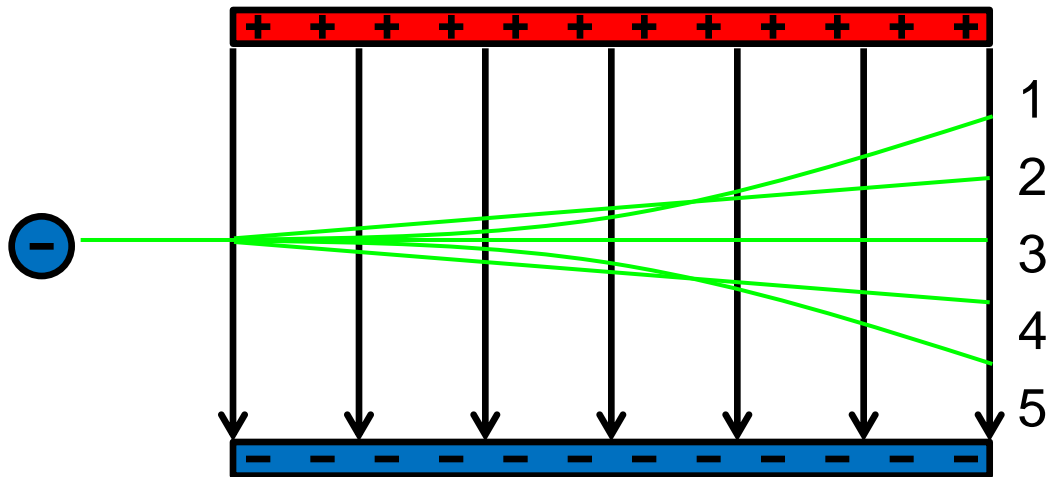
A.   1

B.   2

C.   3

D.   4

E.   5

Solution

Answer: A

Justification: From the previous questions, we saw that the electron experienced constant upwards acceleration. This eliminates answers 3, 4, and 5.

The electron will move in a parabola since it is in a uniform electric field (see question 6). Since an electron is moving in the field instead of a proton, the trajectory curves upwards rather than downwards.