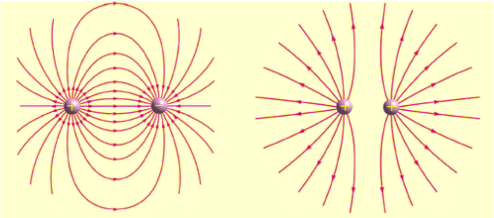
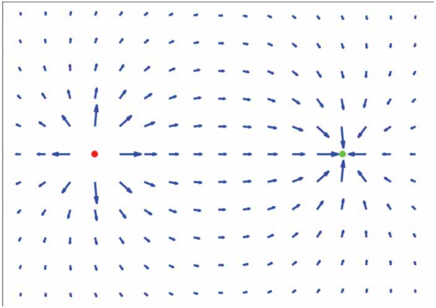
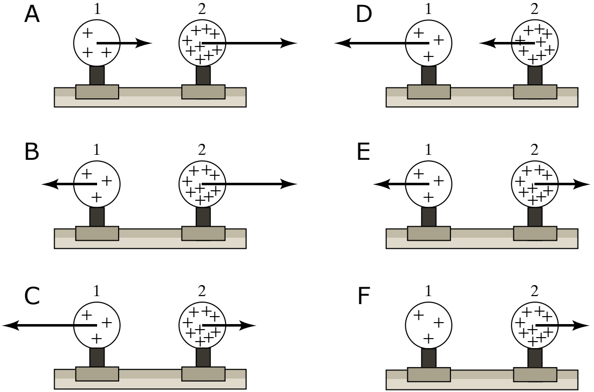
Electric and Gravitational Fields





Two uniformly charged spheres are firmly fastened to and electrically insulated from frictionless pucks on an air table. The charge on sphere 2 is three times the charge on sphere 1. Which force diagram correctly shows the magnitude and direction of the electrostatic forces:



ANS: Diagram **E** is correct.

The forces that the two spheres will be equal and opposite, according to Newton's third law. In this case, because the spheres have the same sign of charge, the forces will be repulsive and equal in magnitude, regardless of the relative amounts of charge.

In fact, this really isn't a question about electric force at all. No matter what the nature of the force between the two objects, the answer would be the same. This is really a Newton's Third Law question.

Two particles carrying charges of equal magnitude but opposite sign are placed along the x axis at equal distance from the origin. A third particle carrying a positive charge is placed on the y axis. The vector sum of the forces exerted by 1 and 2 on 3 is directed

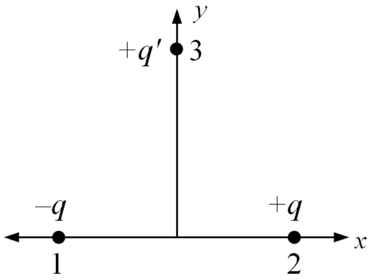
A. in the $+x$ direction

B. in the $-x$ direction

C. along the y axis

D. toward particle 1

E. along another direction

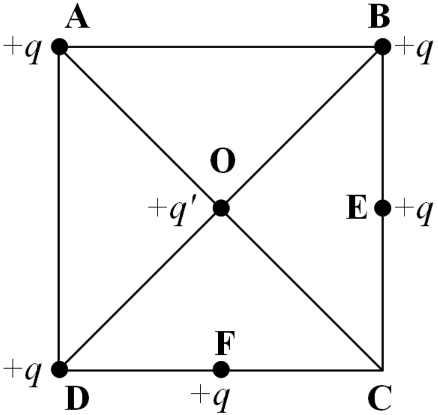


ANS: B—The net force is in the $-x$ direction.

The electric forces exerted by charges 1 and 2 on 3 are equal in magnitude because the charges and separations are equal in magnitude. However, the force exerted by 1 on 3 will point toward charge 1 (down and to the left), while the force exerted by 2 on 3 will point away from charge 2 (up and to the right). By symmetry, the vertical components of these two forces are equal in magnitude, but point in opposite directions, so the vertical components add to zero. Also by symmetry, the horizontal components of these two forces are equal in magnitude and direction (to the left, the $-x$ direction), so these two components add to a greater component in the $-x$ direction.

Five equal charges $+q$ are placed on a square at points A, B, D, E, and F as illustrated. A sixth charge $+q'$ is placed at the center, O. What is the direction of the resultant force on q'?

A. along OA
B. along OC
C. along OB
D. along OD
E. other



ANS: A—The net force on O points along OA.

The forces exerted on q' by B and D will be equal in magnitude, but opposite in direction, and therefore will add to zero. The forces exerted by E and F will be equal in magnitude, and add together to give a resultant vector along OA. The force exerted by A will point along OC.

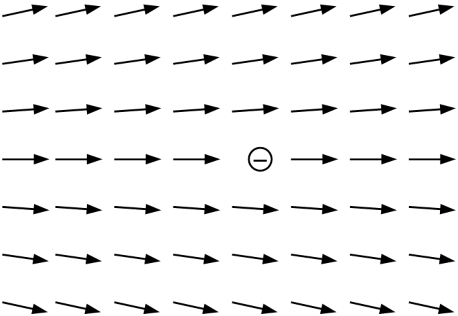
How do we know which force is bigger? Because E and F are each closer to O than is A, each of these forces will exert a greater force on O than will A. Let F_{EO} be the magnitude of the force of E on O. The magnitude of the force of F on O, F_{FO} will also equal F_{EO}. These two forces are perpendicular components of a combined force. Pythagorizing these forces, we find that the magnitude of the combined forces of E on O and F on O is $\sqrt{2}F_{\mathrm{EO}}$, even larger than the force of A on O.

We can also calculate the forces in component form to find that the combined force of E and F on O will be greater than the force of A on O. Noting that $\widehat{r} = \vec{r}/r$, we can write Coulomb's law as

$$F = \left(k_e q q'\right) \frac{\vec{r}}{r^3}$$

you will see that the horizontal component of the force exerted by E on O is greater than the horizontal component of force exerted by A on O — the horizontal components of $\vec{r}_{\mathrm{AO}}$ and $\vec{r}_{\mathrm{EO}}$ are equal, but r_{AO} is greater than r_{EO}, so the force component from A on O is smaller than from E on O. The same statement is true for the vertical components of the forces.

A negatively charged object is placed in an electric field as shown on the right. The electric force on the object



A. is to the right

B. is to the left

C. is neither to the left nor to the right

D. depends on whether the field is created by a positively or negatively charged object

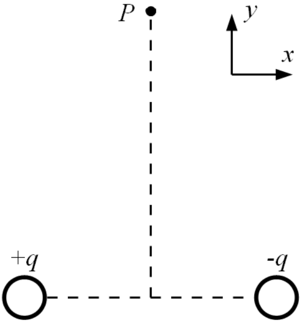
E. There is no force on the object at the location shown in the figure.

ANS: B—The force on the object is directed to the left.

The force on a negative test charge always points opposite the direction of the electric field. (The force on a positive test charge points in the direction of the electric field.)

A pair of equal and opposite charges are placed as illustrated. The electric field at point P is

A. along $+x$
B. along $-x$
C. along $+y$
D. along $-y$
E. in another direction
F. The electric field at P is zero

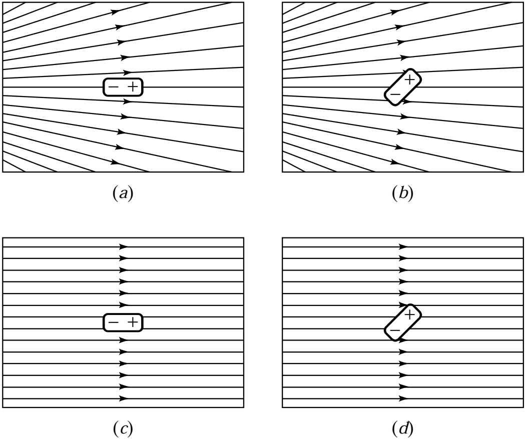


ANS: A—The electric field points in the $+x$ direction.

The two charges are equidistant from P and have charges of equal magnitude, so the electric fields at P due to the two charges are equal in magnitude. The field at P due to the $+q$ charge points up and to the right, away from $+q$. The field at P due to the $-q$ charge points down and to the right, toward $-q$. By symmetry the vertical components of these vectors are equal in size, but opposite in direction, and add to zero. The horizontal components are equal in magnitude and direction, and add to a larger component to the right (the $+x$ direction).

An electrically neutral dipole is placed in an external field. In which situation(s) is the net force on the dipole zero?

A. (a)
B. (c)
C. (b) and (d)
D. (a) and (c)
E. (c) and (d)
F. some other combination
G. none of the above



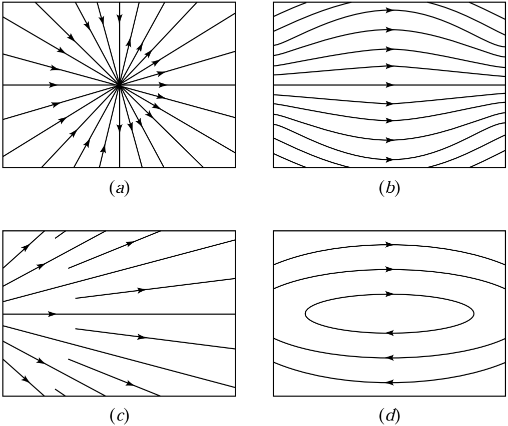
ANS: E—The net force on the dipole is zero in cases (c) and (d).

In these cases, the field is uniform in magnitude and direction. Therefore, the field at the − charge of the dipole is equal to the field at the + charge of the dipole. Since the two charges that make up a dipole are equal in magnitude, the two forces will be equal in magnitude, but opposite in direction and will add to zero. In cases (a) and (b), the field is weaker at the + charge than it is in at the − charge (the field lines are spaced farther apart). Therefore, the leftward-directed force on the − charge will be greater than the rightward-directed force on the + charge, so the net force in both cases will be to the left.

Note that in cases (b) and (d), there will be a net torque on the dipoles that will tend to cause them to re-orient themselves into the configurations of (a) and (c), but that is not the point of the question.

Assuming there are no charges in the regions shown, which of the patterns below represent(s) a possible electrostatic field:

A. (a)
B. (b)
C. (b) and (d)
D. (a) and (c)
E. (b) and (c)
F. some other combination
G. none of the above



ANS: B—Pattern (b) is the only one that represents a possible electric field.

Patterns (a) and (c) can be eliminated because both show electric field lines starting or ending on a point in the image, even though there are no charges there. Electric field lines can only start and end on charges or infinity.

Pattern (d) is not correct because the electric field lines in that image neither start nor end. They (or at least one of them) form a closed loop. Electric field lines must start and end.

Pattern (b) is fine. It suggests some kind of positive charge to the left of the region shown, and some kind of negative charge to the right.

Warmup Question

What does the direction of an electric field mean?

ANS: The direction of an electric field is the direction of the force that a positive charge would experience if placed in that field.

The electric field points opposite of the force that a negative charge would experience if placed in that field.

Warmup Question

Can there be an electric field at a position in space where there is no electric charge? How could that be possible?

Can there be a charge at a position in space where the field is zero?

Discuss thoroughly.

ANS: Yes, it is possible to have an electric field at a position in space where there is no charge. Electric fields at a point are created by charges *not at* that point. You don't need a charge at a location to have a field there. However, if there is no charge at that point, there will be no electric *force* applied at that point. Electric forces don't exist in empty space; they act on charges.

On the other hand, you can have a charge at a position in space where the field is zero. Consider two equal positive charges. At the point exactly between them, the electric field will be zero (the two field vectors add to zero). If you put a test charge exactly between them, the force on them will be zero. Therefore the field at that point will be zero.

Warmup Question

An old fashioned (non-flat screen!) television tube works by accelerating electrons ($m = 9.11 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C) using an electric field and firing them toward a phosphorescent screen. They actually hit the screen moving at about one quarter of the speed of light! (The speed of light is 3×10^{8} m/s). Calculate (using reasonable estimates for the input quantities) the electric field, assuming it provides a uniform acceleration over the entire distance.

ANS: The electrons accelerate from rest to a speed of around 10^8 m/s over a distance of around $d = 0.5$ m. Then the acceleration of the charge will be

$$a = \frac{v^2}{2d} = \frac{(10^8\,\mathrm{m/s})^2}{1\,\mathrm{m}} = 10^{16}\,\mathrm{m/s^2}\ .$$

This will result in a force of around $(10^{-30}\,\mathrm{kg})(10^{16}\,\mathrm{m/s^2}) = 10^{-14}\,\mathrm{N}$. This force, applied to a charge of around $10^{-19}\,\mathrm{C}$, will be due to an electric field of around $(10^{-14}\,\mathrm{N})/(10^{-19}\,\mathrm{C}) = 10^5\,\mathrm{N/C}$.

Warmup Question

The electric field from a lone charge looks most like a

A. Sea squirt
B. Sea urchin
C. Sea horse
D. Sea gull

ANS: B—The electric field from a lone point charge (see pic on left) looks like a sea urchin, a spikey aquatic animal (see pic on right).