Electric and Gravitational Forces

Two students happen to carry electric charges of opposite signs. When they stand apart from each other by 5 meters, these charges produce an attractive force between them of magnitude 1 Newton. If they move apart to a distance of 15 meters, the force is now

1. 1 Newton
2. 1/2 Newton
3. 1/3 Newton
4. 1/6 Newton
5. 1/9 Newton
6. 1/30 Newton
7. Need more information.

ANS: **5**—The force is 1/9 Newton when the charges are 15 meters apart.

The electric force is an inverse-square force, which means that the force decreases in magnitude as the square of the distance between the forces. When the separation is 15 meters, the charges are three times farther apart than when the separation is 5 meters. The force at the greater separation, therefore, will be nine times weaker than the original 1 Newton force.

Two satellites A and B, of the same mass, are going around Earth in concentric orbits. The distance of satellite B from Earth's center is twice that of satellite A. What is the ratio of the centripetal force acting on B to that acting on A?

1. 1/8
2. 1/4
3. 1/2
4. $\sqrt{1/2}$
5. 1

ANS: **2**—The centripetal force on *B* is 1/4 the centripetal force on *A*.

The gravitational force is also an *inverse-square* force, so at twice the radius of *A*, the gravitational force on *B* will be 1/4 the gravitational force on *A*. The key here is to recognize that the gravitational force on the satellites *is the centripetal force*. Remember, centripetal force is the net force on an object in a circular orbit with constant speed. The gravitational force is the only force on a satellite, to the centripetal force is equal to the gravitational force.

A hydrogen atom is composed of a nucleus containing a single proton, about which a single electron orbits. The electric force between the two particles is 2.3×10^{39} times greater than the gravitational force! If we can adjust the distance between the two particles, can we find a separation at which the electric and gravitational forces are equal?

1. Yes, we must move the particles farther apart.
2. Yes, we must move the particles closer together.
3. no, at any distance

ANS: **3**—The electric and gravitational forces will not be equal in magnitude at any distance.

Both forces are inverse-square forces. If you double the distance between the electron and proton, the electrical force will be four times smaller than before. The gravitational force will also be four times smaller. Therefore, the ratio of the electrical to gravitational force will be independent of the separation of the particles.

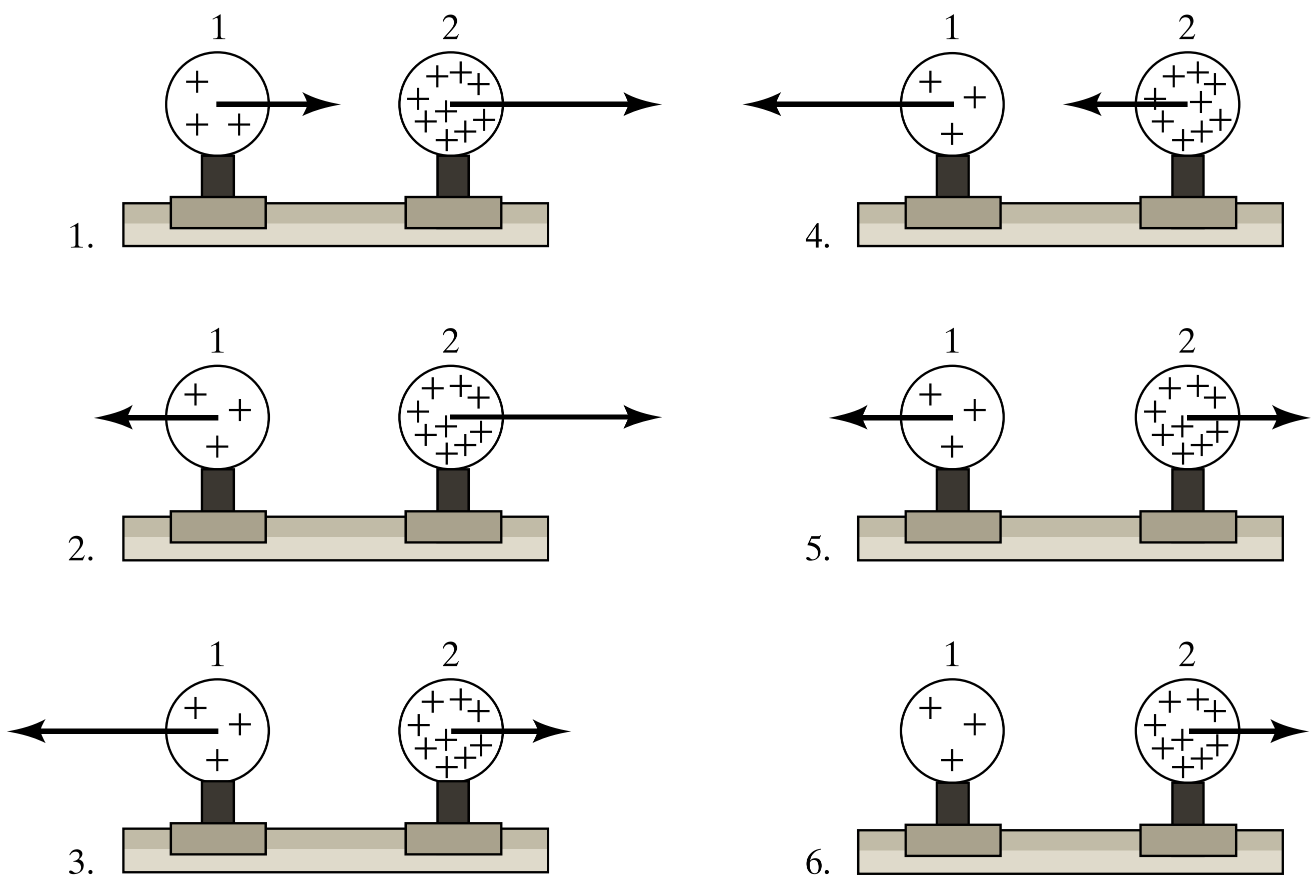
Three pithballs are suspended from thin threads. Various objects are then rubbed against other objects (nylon against silk, glass against polyester, etc.) one or more of the pithballs is charged by touching with one of these objects. It is found that pithballs 1 and 2 attract each other and that pithballs 2 and 3 repel each other. From this we can conclude that

1. 1 and 3 carry charges of opposite sign.
2. 2 and 3 carry charges of equal sign.
3. all three carry the charges of the same sign.
4. one of the objects carries no charge.
5. we need to do more experiments to determine anything about the charges.

ANS: **2**—You can conclude that 2 and 3 carry charges of equal sign.

Charged objects can attract neutral objects whether these objects are conductors or insulators. From the first experiment you can only tell that one of the pithballs (1 or 2) is charged, but not necessarily both. However, charged objects cannot repel neutral objects. Therefore, from the second experiment, you can conclude that both pithballs (2 and 3) carry the same type of charge (both positive or both negative).

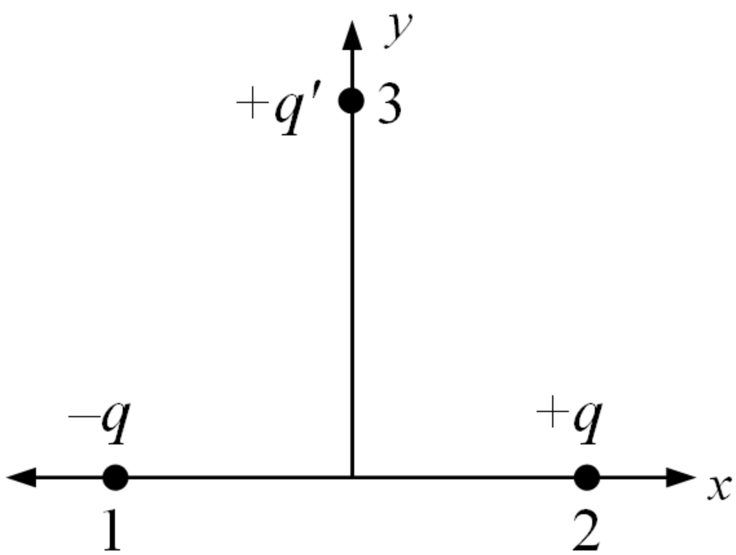
Two uniformly charged spheres are firmly fastened to and electrically insulated from frictionless pucks on an air table. The charge on sphere 2 is three times the charge on sphere 1. Which force diagram correctly shows the magnitude and direction of the electrostatic forces:



ANS: Diagram **5** 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.

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.



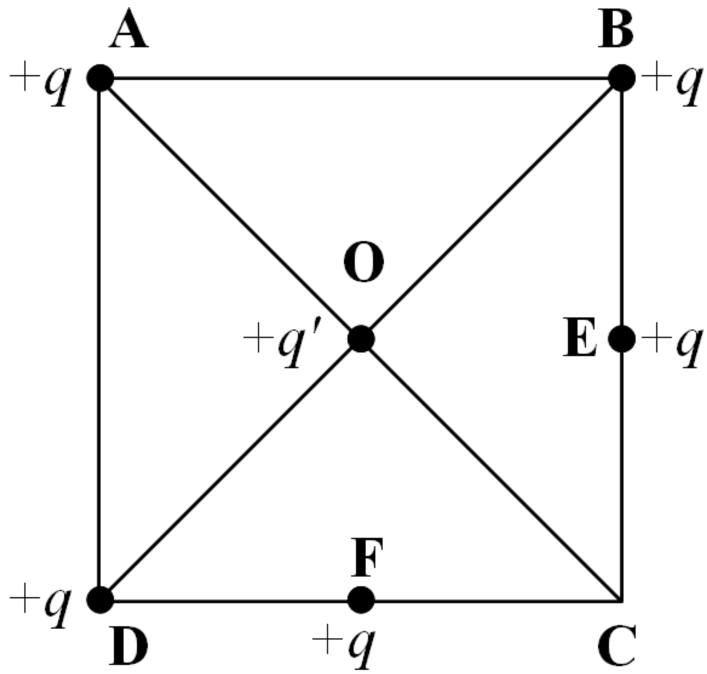
The vector sum of the forces exerted by 1 and 2 on 3 is directed

1. in the $+x$ direction
2. in the $-x$ direction
3. along the *y* axis
4. toward particle 1
5. along another direction

ANS: **2**—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'?

1. along OA
2. along OC
3. along OB
4. along OD
5. other

ANS: **1**—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? We can calculated them in component form to find that the net force of E and F on O will be greater than the force of A on O. If you use the vector expression

$$F = \frac{k_e q q' \vec{\mathbf{r}}}{r^3}$$

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 $\vec{\mathbf{r}}_{\text{AO}}$ and $\vec{\mathbf{r}}_{\text{EO}}$ are equal, but r_{AO} is greater than r_{EO}. The same statement is true for the vertical components of the forces.

Warmup Question

Given the universal constants

- Newton's constant:
  $G = 6.7 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2$
- Coulomb's constant:
  $k_e = 9 \times 10^9\,\text{N}\cdot\text{m}^2/\text{C}^2$
- the electron and proton masses:
  $m_e = 9 \times 10^{-31}\,\text{kg}$,
  $m_p = 1836 m_e = 1.7 \times 10^{-27}\,\text{kg}$
- and the elementary unit of charge:
  $e = 1.6 \times 10^{-19}\,\text{C}$

estimate the ratio of the electric force between a proton and an electron relative to the gravitational force between them (F_e/F_g). Assume they are separated by one meter from each other. And hey, don't use your calculator. Concentrate on getting the order of magnitude right (and show your work!)

ANS:

$$\frac{F_e}{F_g} = \frac{\left(\frac{k_e|q_e q_p|}{r^2}\right)}{\left(\frac{G|m_e m_p|}{r^2}\right)} = \frac{k_e e^2}{G m_e m_p}$$

$$\approx \frac{(9 \times 10^9 \text{N·m}^2/\text{Cg}^2)(2 \times 10^{-19}\text{C})(2 \times 10^{-19}\text{C})}{(7 \times 10^{-11}\text{N·m}^2/\text{kg}^2)(9 \times 10^{-31}\text{kg})(2 \times 10^{-27}\text{kg})}$$

$$= \left(\frac{2}{7}\right) \times 10^{40} \approx 3 \times 10^{39}$$