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

A. 1 Newton
B. 1/2 Newton
C. 1/3 Newton
D. 1/6 Newton
E. 1/9 Newton
F. 1/30 Newton
G. Need more information.

ANS: E—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?

A. $1/8$
B. $1/4$
C. $1/2$
D. $\sqrt{1/2}$
E. 1

ANS: B—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.

The Moon does not fall to Earth because

A. The net force on it is zero.
B. It is beyond the main pull of Earth's gravity.
C. It is being pulled by the Sun and planets as well as by Earth.
D. all of the above
E. none of the above

ANS: E—None of the above answers is correct.

The moon is constantly accelerating toward Earth, but it does not "fall to" earth because it has a velocity tangent to the circle. The gravitational force is precisely large enough to keep it in a (nearly) circular orbit. The net force on the moon is certainly not zero. The moon is in Earth's gravitational field and is subject to Earth's gravitational force. The moon is also pulled by the sun, which determines its orbit around the sun as well as Earth, and by the other planets (to a very small effect).

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?

A. Yes, we must move the particles farther apart.

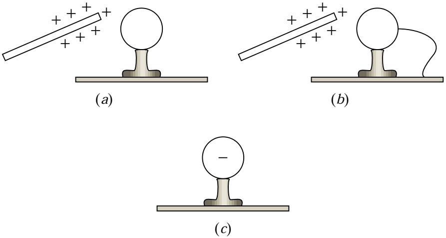
B. Yes, we must move the particles closer together.

C. no, at any distance

ANS: C—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.

A positively charged object is placed close to a conducting object attached to an insulating glass pedestal (a). After the opposite side of the conductor is grounded for a short time interval (b), the conductor becomes negatively charged (c).



We can conclude that within the conductor

A. positive and negative charges move freely.

B. only negative charges move freely.

C. only positive charges move freely.

D. We can't really conclude anything.

ANS: D—We cannot conclude anything about the conductor. Explanations involving moving negative charges and moving positive charges both work.

Here's the explanation of what is observed if it were the positive charges that move. The positively charged rod repels positive charges in the conducting sphere, leaving a negative charge on the near side. When the wire is connected to the ground, the positive charges on that side of the conductor will readily move even farther from the positive rod, all the way to the ground, leaving the conducting sphere negatively charged. When the wire is removed, a net negative charge remains on the sphere because there are fewer positive than negative charges in it.

Here's the explanation of what is observed if it were the negative charges that move. The positively charged rod attracts negative charges to the near side, leaving a positive charge on the opposite side. When the wire is connected to the ground, more negative charges will be attracted to the positive charge on that far side and be drawn into the sphere, leaving the sphere negatively charged. When the wire is removed, a net negative charge remains on the sphere because there are more negative than positive charges in it.

In reality, the second explanation is correct, but you cannot conclude that from experiments like this. It was not until the 20th century that we had a good understanding about the structure of matter to determine this.

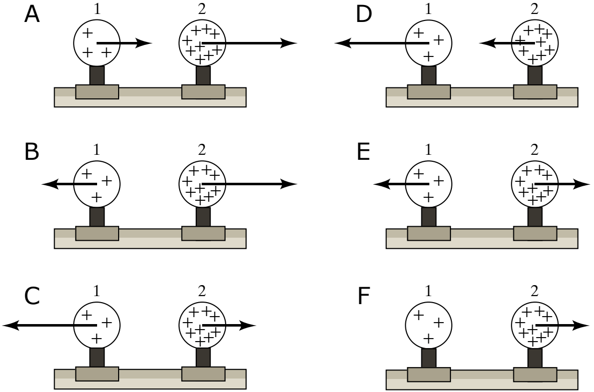
Three pithballs are suspended from thin threads. Various objects are then rubbed against other objects (nylon against silk, glass against polyester, etc.) one or more of the pithballs is charged by touching with one of these objects. It is found that pithballs 1 and 2 attract each other and that pithballs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

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

ANS: B—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 **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.

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: $k_\text{e} = 9 \times 10^9\,\text{N}\cdot\text{m}^2/\text{C}^2$

the electron and proton masses: $m_\text{e} = 9 \times 10^{-31}\,\text{kg}$,
$m_p = 1836 m_\text{e} = 1.7 \times 10^{-27}\,\text{kg}$

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: It's easy to do an order-of-magnitude calculation.

$$\frac{F_{\mathrm{e}}}{F_{\mathrm{g}}} = \frac{\left(\dfrac{k_{\mathrm{e}}|q_{\mathrm{e}}q_p|}{r^2}\right)}{\left(\dfrac{G|m_{\mathrm{e}}m_p|}{r^2}\right)} = \frac{k_{\mathrm{e}}e^2}{Gm_{\mathrm{e}}m_p} \approx \frac{(10^{10}\,\mathrm{N{\cdot}m^2/C^2})(10^{-19}\,\mathrm{C})(10^{-19}\,\mathrm{C})}{(10^{-10}\,\mathrm{N{\cdot}m^2/kg^2})(10^{-30}\,\mathrm{kg})(10^{-27}\,\mathrm{kg})}$$

$$= \frac{10^{-28}}{10^{-67}} = 10^{39}$$

Wow! The graviational force is completely ignorable compared to the electrical force in a hydrogen atom. It is simply not relevant at all.

If you really want more precision, it is easy to do a little better by rounding the mantissa values to convenient integers and working with fractions

$$\frac{F_{\mathrm{e}}}{F_{\mathrm{g}}} = \frac{\left(\dfrac{k_{\mathrm{e}}|q_{\mathrm{e}}q_p|}{r^2}\right)}{\left(\dfrac{G|m_{\mathrm{e}}m_p|}{r^2}\right)} = \frac{k_{\mathrm{e}}e^2}{Gm_{\mathrm{e}}m_p} \approx \frac{(9\times10^{9}\,\mathrm{N{\cdot}m^2/Cg^2})(2\times10^{-19}\,\mathrm{C})(2\times10^{-19}\,\mathrm{C})}{(7\times10^{-11}\,\mathrm{N{\cdot}m^2/kg^2})(9\times10^{-31}\,\mathrm{kg})(2\times10^{-27}\,\mathrm{kg})}$$

$$= \left(\frac{2}{7}\right)\times10^{40} \approx 3\times10^{39}$$

Warmup Question

What might the universe have looked like if opposite charges repelled and like charges attracted one another? Try to connect that hypothetical condition to whatever conclusions you draw rather than just fantasizing something vague.

ANS: This is challenging to consider. I'm curious to read your responses.