Performance Task

18.5 Capacitors and Dielectrics 35.

Newton's law of universal gravitation is

$F = \frac{Gm_1m_2,}{r^2,}$

18.46

where $G = 6.67 \times 10^{-11}\mathrm{m}^3/\mathrm{kg}\cdot\mathrm{s}^2$. This describes the gravitational force between two point masses m_1 and m_2.

Coulomb's law is

$F = \frac{kq_1q_2}{r^2}$

18.47

where $k = 8.99 \times 10^9\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2$. This describes the electric force between two point charges q_1 and q_2.

(a) Describe how the force in each case depends on the distance r between the objects. How do the forces change if the distance is reduced by half? If the distance is doubled?

(b) Describe the similarities and differences between the two laws. Consider the signs of the quantities that create the interaction (i.e., mass and charge), the constants G and k, and their dependence on separation r.

(c) Given that the electric force is much stronger than the gravitational force, discuss why the law for gravitational force was discovered much earlier than the law for electric force.

(d) Consider a hydrogen atom, which is a single proton orbited by a single electron. The electric force holds the electron and proton together so that the hydrogen atom has a radius of about $0.5 \times 10^{-10}\mathrm{m}$. Assuming the force between electron and proton does not change, what would be the approximate radius of the hydrogen atom if $k = 6.67 \times 10^{-11}\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2$?

Teacher Support

Teacher Support HS-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to describe and predict the gravitational and electrostatic forces between objects. Clarification statement—Emphasis is on quantitative and conceptual descriptions of gravitational and electric fields.

Assessment boundary—Assessment is limited to systems with two objects.

(a) For both laws, the force varies as the inverse of the distance between the objects. The forces increase fourfold if the distance is reduced by half and decrease fourfold if the distance is doubled.

(b) Both laws vary as the inverse distance squared between the objects. Because charge can be positive or negative, the electric force can be attractive or repulsive, whereas the force of gravity is only attractive because mass is a strictly positive quantity. Finally, the constants involved show that the electric force is typically much stronger than the force of gravity.

(c) Because gravity is only attractive, it is noticeable on a macroscopic scale. The electric force between most macroscopic objects is very small, because such objects typically contain equal amounts of positive and negative charge. Thus, the electric force between macroscopic objects is typically not noticeable.

(d)

$$\begin{aligned}
\frac{k_{\text{real}} q_1 q_2}{r_{\text{real}}^2} &= \frac{k_{\text{gravity}} q_1 q_2}{r_{\text{gravity}}^2} \\
r_{\text{gravity}} &= r_{\text{real}} \sqrt{\frac{k_{\text{real}}}{k_{\text{gravity}}}} = \left(0.5 \times 10^{-10}\text{m}\right) \sqrt{\frac{8.99 \times 10^{9}\text{N}\cdot\text{m}^2/\text{C}^2}{6.67 \times 10^{-11}\text{N}\cdot\text{m}^2/\text{C}^2}} \\
&\approx 0.6 \text{ m}
\end{aligned}$$