Electric Forces and Fields

Problem A

COULOMB'S LAW

P R O B L E M

Suppose you separate the electrons and protons in a gram of hydrogen and place the protons at Earth's North Pole and the electrons at Earth's South Pole. How much charge is at each pole if the magnitude of the electric force compressing Earth is 5.17×10^5 N? Earth's diameter is 1.27×10^7 m.

S O L U T I O N

1. DEFINE　**Given:**

$$F_{electric} = 5.17 \times 10^5 \text{ N}$$
$$r = 1.27 \times 10^7 \text{ m}$$
$$k_C = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

Unknown:　$q = ?$

2. PLAN　**Choose the equation(s) or situation:** Rearrange the magnitude of the electric force using Coulomb's law.

$$q = \sqrt{\frac{F_{electric} r^2}{k_C}}$$

3. CALCULATE　**Substitute the values into the equation(s) and solve:** .

$$q = \sqrt{\frac{(5.17 \times 10^5 \text{ N})(1.27 \times 10^7 \text{ m})^2}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}}$$

$$q = \boxed{9.63 \times 10^4 \text{ C}}$$

4. EVALUATE　The electrons and the protons have opposite signs, so the electric force between them is attractive. The large size of the force (equivalent to the weight of a 52 700 kg mass at Earth's surface) indicates how strong the attraction between opposite charges in atoms is.

ADDITIONAL PRACTICE

1. The safe limit for beryllium in air is 2.0×10^{-6} g/m^3, making beryllium one of the most toxic elements. The charge on all electrons in the Be contained in 1 m^3 of air at the safe level is about 0.085 C. Suppose this charge is placed 2.00 km from a second charge. Calculate the value of the second charge if the magnitude of the electric force between the two charges is 8.64×10^{-8} N.

2. Kalyan Ramji Sain, of India, had a mustache that measured 3.39 m from end to end in 1993. Suppose two charges, q and $3q$, are placed 3.39 m apart. If the magnitude of the electric force between the charges is 2.4×10^{-6} N, what is the value of q?
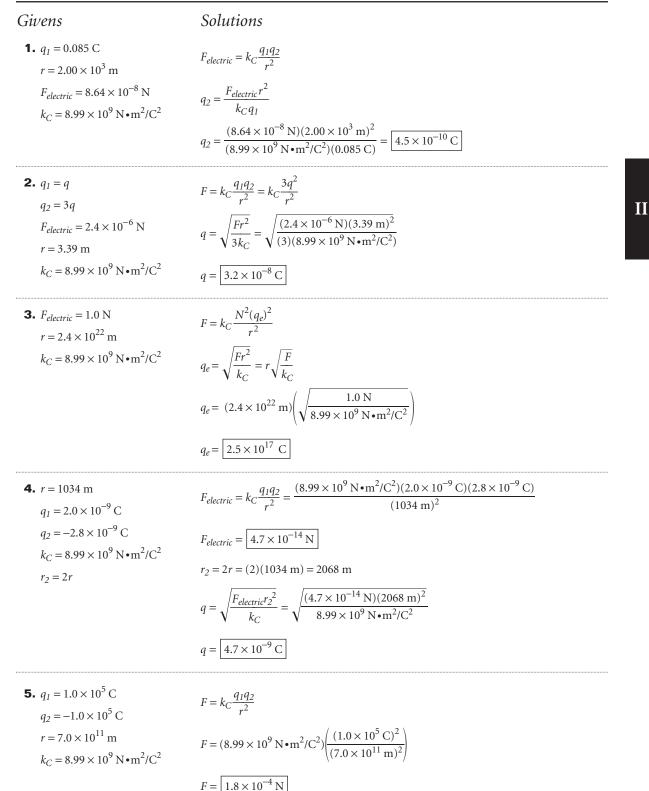
3. The remotest object visible to the unaided eye is the great galaxy Messier 31 in the constellation Andromeda. It is located 2.4×10^{22} m from Earth. (By comparison, the sun is only about 1.5×10^{11} m away.) Suppose two clouds containing equal numbers of electrons are separated by a distance of 2.4×10^{22} m. If the magnitude of the electric force between the clouds is 1.0 N, what is the charge of each cloud?

4. In 1990, a French team flew a kite that was 1034 m long. Imagine two charges, +2.0 nC and −2.8 nC, at opposite ends of the kite. Calculate the magnitude of the electric force between them. If the separation of charges is doubled, what absolute value of equal and opposite charges would exert the same electric force?

5. Betelgeuse, one of the brightest stars in the constellation of Orion, has a diameter of 7.0×10^{11} m (500 times the diameter of the sun). Consider two compact clouds with opposite charge equal to 1.0×10^{5} C. If these clouds are located 7.0×10^{11} m apart, what is the magnitude of the electric force of attraction between them?

6. An Italian monk named Giovanni Battista Orsenigo was also a dentist. From 1868 to 1903 he extracted exactly 2 000 744 teeth, which on average amounts to about 156 teeth per day. Consider a group of protons equal to the total number of teeth. If this group is divided in half, calculate the charge of each half. Also calculate the magnitude of the electric force that would result if the two groups of charges are placed 1.00 km apart.

7. The business district of London has about 4000 residents. However, every business day about 320 000 people are there. Consider a group of 4.00×10^{3} protons and a group of 3.20×10^{5} electrons that are 1.00 km apart. Calculate the magnitude of the electric force between them. Calculate the magnitude of the electric force if each group contains 3.20×10^{5} particles and if the separation distance remains the same.

8. In 1994, element 111 was discovered by an international team of physicists. Its provisional name was unununium (Latin for "one-one-one"). Find the distance between two equal and opposite charges, each having a magnitude equal to the charge of 111 protons, if the magnitude of the electric force between them is 2.0×10^{-28} N.

9. By 2005, the world's tallest building will be the International Finance Center in Taipei, Republic of China. Suppose a 1.00 C charge is placed at both the base and the top of the International Finance Center. If the magnitude of the electric force stretching the building is 4.48×10^{4} N, how tall is the International Finance Center?

10. A 44 000-piece jigsaw puzzle was assembled in France in 1992. Suppose the puzzle were square in shape, and that a 5.00 nC charge is placed at the upper right corner of the puzzle and a charge of −2.50 nC is placed at the lower left corner. If the magnitude of the electric force the two charges exert on each other were 1.18×10^{-11} N, what would be the distance between the two charges? What would be the length of the puzzle's sides?

Electric Forces and Fields

Additional Practice A

Givens	*Solutions*

1. $q_1 = 0.085$ C

$r = 2.00 \times 10^3$ m

$F_{electric} = 8.64 \times 10^{-8}$ N

$k_C = 8.99 \times 10^9$ N•m^2/C^2

$$F_{electric} = k_C \frac{q_1 q_2}{r^2}$$

$$q_2 = \frac{F_{electric} r^2}{k_C q_1}$$

$$q_2 = \frac{(8.64 \times 10^{-8} \text{ N})(2.00 \times 10^3 \text{ m})^2}{(8.99 \times 10^9 \text{ N•m}^2/\text{C}^2)(0.085 \text{ C})} = \boxed{4.5 \times 10^{-10} \text{ C}}$$

2. $q_1 = q$

$q_2 = 3q$

$F_{electric} = 2.4 \times 10^{-6}$ N

$r = 3.39$ m

$k_C = 8.99 \times 10^9$ N•m^2/C^2

$$F = k_C \frac{q_1 q_2}{r^2} = k_C \frac{3q^2}{r^2}$$

$$q = \sqrt{\frac{Fr^2}{3k_C}} = \sqrt{\frac{(2.4 \times 10^{-6} \text{ N})(3.39 \text{ m})^2}{(3)(8.99 \times 10^9 \text{ N•m}^2/\text{C}^2)}}$$

$$q = \boxed{3.2 \times 10^{-8} \text{ C}}$$

3. $F_{electric} = 1.0$ N

$r = 2.4 \times 10^{22}$ m

$k_C = 8.99 \times 10^9$ N•m^2/C^2

$$F = k_C \frac{N^2 (q_e)^2}{r^2}$$

$$q_e = \sqrt{\frac{Fr^2}{k_C}} = r\sqrt{\frac{F}{k_C}}$$

$$q_e = (2.4 \times 10^{22} \text{ m})\left(\sqrt{\frac{1.0 \text{ N}}{8.99 \times 10^9 \text{ N•m}^2/\text{C}^2}}\right)$$

$$q_e = \boxed{2.5 \times 10^{17} \text{ C}}$$

4. $r = 1034$ m

$q_1 = 2.0 \times 10^{-9}$ C

$q_2 = -2.8 \times 10^{-9}$ C

$k_C = 8.99 \times 10^9$ N•m^2/C^2

$r_2 = 2r$

$$F_{electric} = k_C \frac{q_1 q_2}{r^2} = \frac{(8.99 \times 10^9 \text{ N•m}^2/\text{C}^2)(2.0 \times 10^{-9} \text{ C})(2.8 \times 10^{-9} \text{ C})}{(1034 \text{ m})^2}$$

$$F_{electric} = \boxed{4.7 \times 10^{-14} \text{ N}}$$

$$r_2 = 2r = (2)(1034 \text{ m}) = 2068 \text{ m}$$

$$q = \sqrt{\frac{F_{electric} r_2^2}{k_C}} = \sqrt{\frac{(4.7 \times 10^{-14} \text{ N})(2068 \text{ m})^2}{8.99 \times 10^9 \text{ N•m}^2/\text{C}^2}}$$

$$q = \boxed{4.7 \times 10^{-9} \text{ C}}$$

5. $q_1 = 1.0 \times 10^5$ C

$q_2 = -1.0 \times 10^5$ C

$r = 7.0 \times 10^{11}$ m

$k_C = 8.99 \times 10^9$ N•m^2/C^2

$$F = k_C \frac{q_1 q_2}{r^2}$$

$$F = (8.99 \times 10^9 \text{ N•m}^2/\text{C}^2)\left(\frac{(1.0 \times 10^5 \text{ C})^2}{(7.0 \times 10^{11} \text{ m})^2}\right)$$

$$F = \boxed{1.8 \times 10^{-4} \text{ N}}$$

II

Givens	*Solutions*

6. $N = 2\,000\,744$

$q_p = 1.60 \times 10^{-19}$ C

$r = 1.00 \times 10^3$ m

$k_C = 8.99 \times 10^9$ N•m²/C²

$q = \dfrac{Nq_p}{2} = \dfrac{(2\,000\,744)(1.60 \times 10^{-19}\text{ C})}{2} = \boxed{1.60 \times 10^{-13}\text{ C}}$

$F_{electric} = k_C \dfrac{q^2}{r^2}$

$F_{electric} = (8.99 \times 10^9\text{ N•m}^2/\text{C}^2)\left(\dfrac{(1.60 \times 10^{-13}\text{ C})^2}{(1.00 \times 10^3\text{ m})^2}\right)$

$F_{electric} = \boxed{2.30 \times 10^{-22}\text{ N}}$

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7. $N_1 = 4.00 \times 10^3$

$N_2 = 3.20 \times 10^5$

$q = 1.60 \times 10^{-19}$ C

$r = 1.00 \times 10^3$ m

$k_C = 8.99 \times 10^9$ N•m²/C²

$F_{electric} = \dfrac{k_C q_1 q_2}{r^2} = \dfrac{k_C N_1 N_2 q^2}{r^2}$

$F_{electric} = \dfrac{(8.99 \times 10^9\text{ N•m}^2/\text{C}^2)(4.00 \times 10^3)(3.20 \times 10^5)(1.60 \times 10^{-19}\text{ C})^2}{(1.00 \times 10^3\text{ m})^2}$

$F_{electric} = \boxed{2.95 \times 10^{-25}\text{ N}}$

$F_{electric} = k_C \dfrac{N_2^2 q^2}{r^2} = \dfrac{(8.99 \times 10^9\text{ N•m}^2/\text{C}^2)(3.20 \times 10^5)^2(1.60 \times 10^{-19}\text{ C})^2}{(1.00 \times 10^3\text{ m})^2}$

$F_{electric} = \boxed{2.36 \times 10^{-23}\text{ N}}$

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8. $F_{electric} = 2.0 \times 10^{-28}$ N

$N = 111$

$q_p = 1.60 \times 10^{-19}$ C

$k_C = 8.99 \times 10^9$ N•m²/C²

$F_{electric} = k_C \dfrac{q^2}{r^2} = k_C \dfrac{N^2 q_p^2}{r^2}$

$r = \sqrt{\dfrac{k_C N^2 q_p^2}{F_{electric}}} = \sqrt{\dfrac{(8.99 \times 10^9\text{ N•m}^2/\text{C}^2)(111)^2(1.60 \times 10^{-19}\text{ C})^2}{2.0 \times 10^{-28}\text{ N}}}$

$r = \boxed{1.2 \times 10^2\text{ m}}$

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9. $q = 1.00$ C

$F_{electric} = 4.48\text{ m} \times 10^4$ N

$k_C = 8.99 \times 10^9$ N•m²/C²

$r = \sqrt{k_C \dfrac{q^2}{F_{electric}}} = \sqrt{\dfrac{(8.99 \times 10^9\text{ N•m}^2/\text{C}^2)(1.0\text{ C})^2}{4.48 \times 10^4\text{ N}}} = \boxed{448\text{ m}}$

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10. $F_{electric} = 1.18 \times 10^{-11}$ N

$q_1 = 5.00 \times 10^{-9}$ C

$q_2 = -2.50 \times 10^{-9}$ C

$k_C = 8.99 \times 10^9$ N•m²/C²

$F_{electric} = k_C \dfrac{q_1 q_2}{r^2}$

$r = \sqrt{\dfrac{k_C q^2}{F_{electric}}} = \sqrt{\dfrac{(8.99 \times 10^9\text{ N•m}^2/\text{C}^2)(5.00 \times 10^{-9}\text{ C})(2.50 \times 10^{-9}\text{ C})}{1.18 \times 10^{-11}\text{ N}}}$

$r = \boxed{97.6\text{ m}}$

$L = r\cos\theta = (97.6\text{ m})\cos 45° = \boxed{69.0\text{ m}}$

II