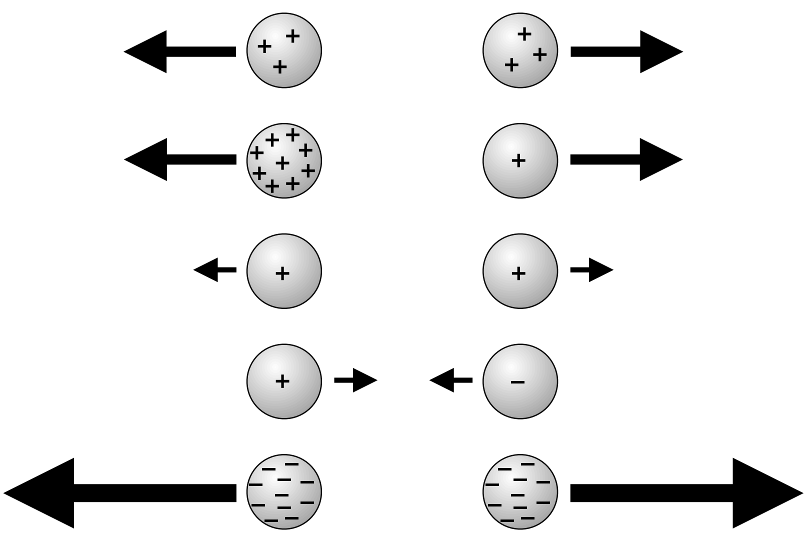
PhyzGuide: Coulomb's Law

While experimenting with electrostatic charges, French physicist Charles Coulomb discovered that the force between two charged objects depends on two things: the amount of excess *charge* on the objects and the *distance* between the two objects.

Part 1. Force and Charge: $F \propto q_1 q_2$
The electrostatic force between two charged objects is proportional to the product of the excess charges on them.



PUBLISH OR PERISH
Question:
Who discovered Coulomb's Law?

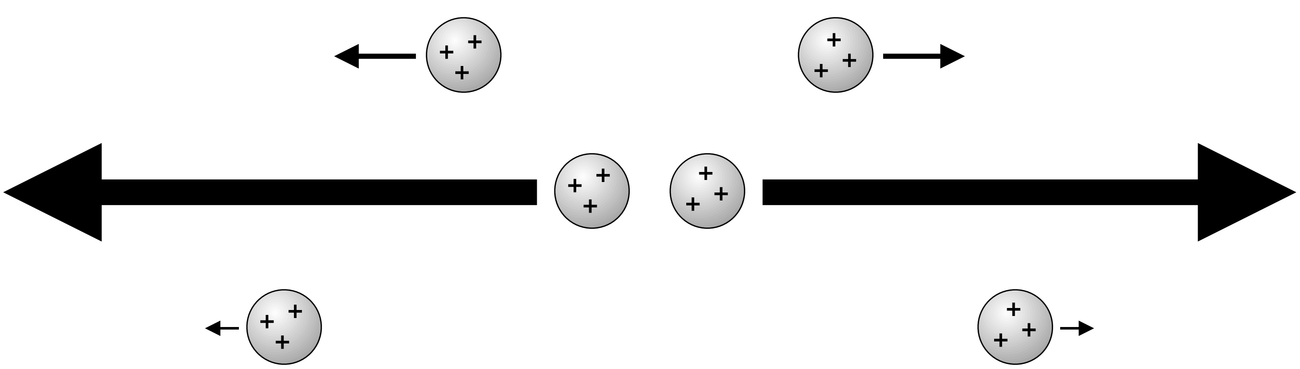
Answer:
Surprise! NOT Charles Coulomb—it was Henry Cavendish!

Henry Cavendish (1731–1810) was a brilliant scientist, but he was also a "perverse recluse." He was also the first to determine the value of G—the universal gravitation constant. He discovered that water was a molecular compound and not an element (as had been thought). He also determined the force law for electric charges ($F=kq_1q_2/R^2$).

However, he rarely published his findings. So years later, when Charles Coulomb (1736–1806) discovered the law for electric force—and published it—HE got all the credit!

Next Question:
Guess who first discovered what we now call Ohm's Law? Hint: He didn't publish his findings and therefore didn't get the credit.

Part 2. Force and Distance: $F \propto 1/R^2$
The electrostatic force between two charged objects is inversely proportional to the square of the distance between them.



All together now: $F \propto q_1 q_2/R^2$
Coulomb's Law indicates that the electrostatic force between two charged objects is proportional to the product of the excess charges on them and inversely proportional to the square of the distance between them.

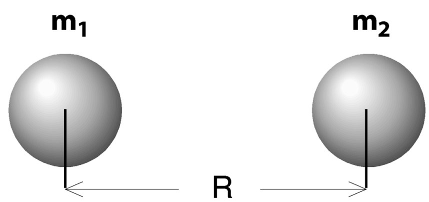
The numerical value of electrostatic force between two charged objects can be calculated using the equation of **Coulomb's law** or **the law of electrostatic force:**

$$F_E = k\,\frac{q_1 q_2}{R^2}$$

F is the electrostatic force (newtons)
k is the electric force constant: $k = 9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$
q_1 is the quantity of charge on 1st charge (coulombs)
q_2 is the quantity of charge on 2nd charge (coulombs)
R is the distance between the centers of the charged objects (meters)

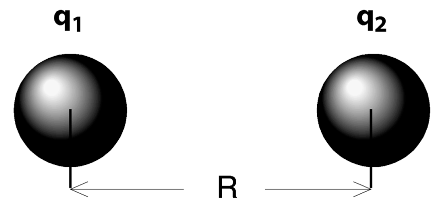
Coulomb's law for electrostatic force is very similar to Newton's law for gravitational force. One significant difference between electrical and gravitational force is that while gravitational force is *always* attractive, electrical force can be attractive *or* repulsive (depending on the charges).

Consider this side-by-side comparison of **gravitational** and **electrical** force:



$$F_G = G\,\frac{m_1 m_2}{R^2}$$

Gravity acts between any two objects with **mass.** The universal gravitational constant G has very **small** magnitude: $G = 6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$.



$$F_E = k\,\frac{q_1 q_2}{R^2}$$

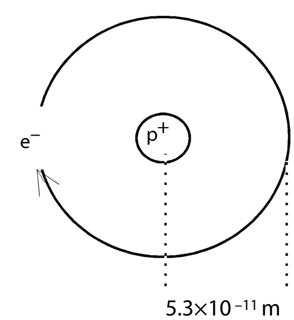
Electric force acts between any two objects with **charge.** The electrostatic force constant k has very **large** magnitude: $k = 9.0\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$.

To compare the relative strengths of gravity and electricity, consider those forces as they act in a hydrogen atom.

electron: $m = 9.1\times10^{-31}$ kg
$q = -1.6\times10^{-19}$ C

proton: $m = 1.7\times10^{-27}$ kg
$q = +1.6\times10^{-19}$ C

Simplified diagram of a hydrogen atom



$F_G = Gm_1m_2/R^2$

$$= \frac{6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2\,(9.1\times10^{-31}\ \text{kg})(1.7\times10^{-27}\ \text{kg})}{(5.3\times10^{-11}\ \text{m})^2}$$

$F_G = 3.7\times10^{-47}$ N

$F_E = kq_1q_2/R^2$

$$= \frac{9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\,(-1.6\times10^{-19}\ \text{C})(1.6\times10^{-19}\ \text{C})}{(5.3\times10^{-11}\ \text{m})^2}$$

$F_E = -8.2\times10^{-8}$ N

In the hydrogen atom, electric force is ~1,000,000,000,000,000,000,000,000,000,-000,000,000,000 (i.e. 10^{39}) times stronger than gravitational force!