Department of biology

((Biophysics))

Stage 1

LEC 5

Coulomb’s Law

By

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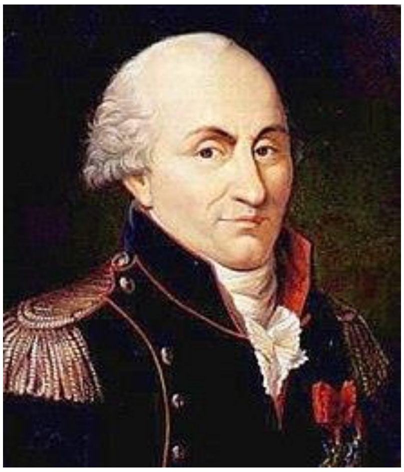
Coulomb's Law:

When two charged particles are brought near each other, they each exert an electrostatic force on the other. The direction of the force vectors depends on the signs of the charges. If the particles have the same sign of charge, they repel each other, meaning that the force vector on each is directed away from the other particle. Conversely, if the particles have opposite signs of charge, they attract each other. Figure 1

Coulomb's Law describes the force of interaction between two point charges. It states that:

"The magnitude of the electrostatic force between two charges is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance between them."



Mathematical Expression:

Coulomb's law after Charles-Augustin de Coulomb, whose experiments in 1785 led him to it. Let's write the equation in vector form and in terms of the particles shown in Figure 2, where particle 1 has charge q_1 and particle 2 has charge q_2 .

$$f = k\frac{q_1 . q_2}{r^2}$$

Where:

- F: Magnitude of the electrostatic force (in Newtons, N).
- k: Coulomb's constant ($k \approx 8.99 \times 10^9\ N.m^2/C^2$) .
- q_1, q_2 : Magnitudes of the charges (in Coulombs, C).
- r: Distance between the charges (in meters, m).

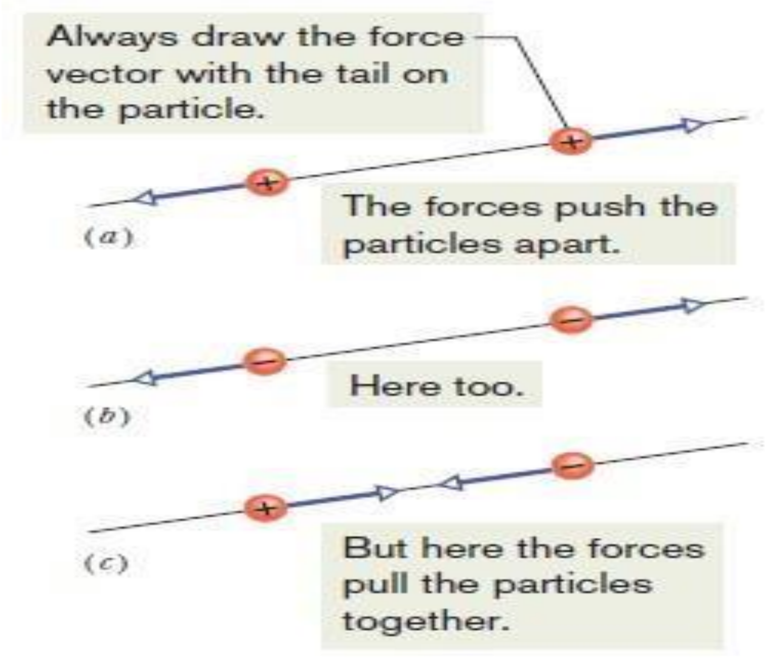


Figure 1: Two charged particles repel each other if they have the same sign of charge, either (*a*) both positive or (*b*) both negative. (*c*) They attract each other if they have opposite signs of charge.

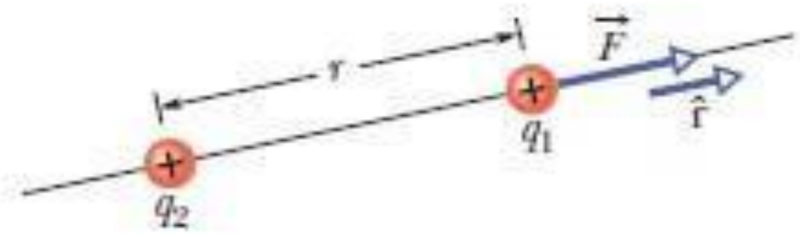


Figure 2: The electrostatic force on particle 1 can be described in terms of a unit vector along an axis through the two particles, radially away from particle 2.

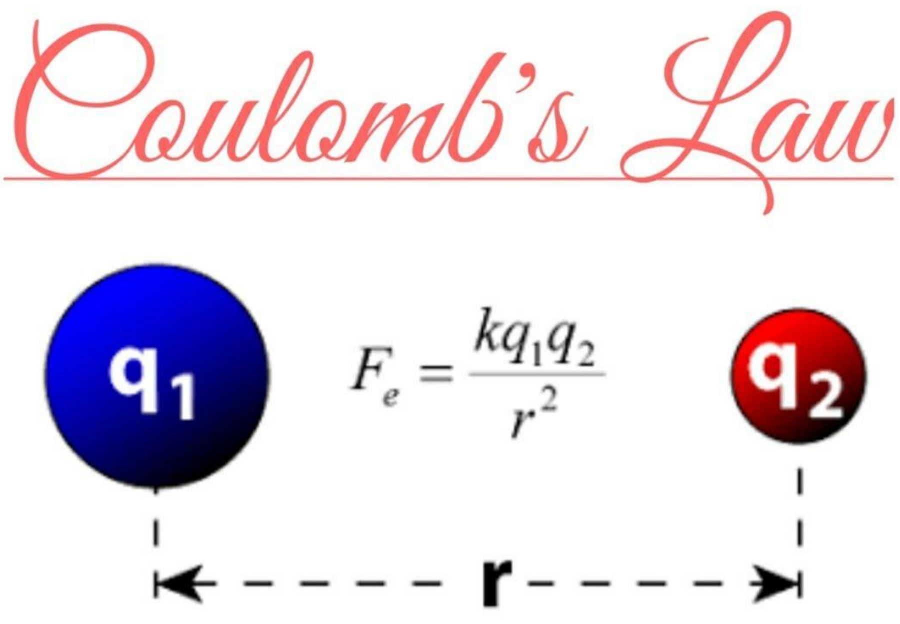
Coulomb's Constant (k)

Coulomb's constant, denoted by k, is a proportionality constant in **Coulomb's Law**, which relates the electrostatic force between two point charges to the product of their charges and the inverse square of the distance between them.

$$K = \frac{1}{4\pi\varepsilon_0}$$

Where:

- ε_0: Permittivity of free space, $\varepsilon_0 = 8.85\times10^{-12}$ ($C^2/N.m^2$)
- The factor 4π: arises due to the geometry of a spherical charge distribution in three-dimensional space.



Examples:

1- Two charges are placed 1 meter apart:

- Charge $q_1 = -4\ \mu C$
- Charge $q_2 = +5\ \mu C$

Calculate the following:

- The electric force between the two charges.
- The direction of the force acting on each charge.

Solution:

Electric Force:

Using Coulomb's law:

$$f = k\frac{q_1 . q_2}{r^2}$$

Where:

- $K = 8.99\times10^9\ N.m^2/C^2$
- $q_1 = -4\times10^{-6}\ C$
- $q_2 = +5\times10^{-6}\ C$
- $r = 1m$

$$f = (8.99\times10^9)\ .\ \frac{|(-4\times10^{-6}).(5\times10^{-6})|}{1^2}$$

$$f = (8.99\times10^9)\times\ (4\times10^{-6})\times(5\times10^{-6})$$

$$f = (8.99\times10^9)\times20\times10^{-12}$$

$$f = 0.179\ N$$

$$f = (8.99\times10^9)\ \text{Attractive}$$

Final Answer:

- **Electric Force:** $F \approx 0.18$ N
- **Direction:** The force is **attractive**. q_1 is pulled towards q_2, and q_2 is pulled towards q_1.

2- Two charges are placed 0.5 meter apart: Charge $q_1= -7\ \mu C$, Charge $q_2= -10\ \mu C$

Calculate the following:

- The electric force between the two charges.
- The direction of the force acting on each charge.

Solution:

Electric Force:

Using Coulomb's law:

$$f = k\frac{q_1 . q_2}{r^2}$$

Where:

- $K=8.99x10^9\ N.m^2/C^2$
- $q_1=-7x10^{-6}\ C$
- $q_2=+10x10^{-6}\ C$
- r=0.5m

$$f = (8.99 \times 10^9)\ .\ \frac{|(-7 \times 10^{-6}).(-10 \times 10^{-6})|}{(0.5)^2}$$

$$f = (8.99 \times 10^9) \times \frac{(7 \times 10^{-6}) \times (10 \times 10^{-6})}{0.25}$$

$$f = (8.99 \times 10^9) \times \frac{70 \times 10^{-12}}{0.25}$$

$$f = (8.99 \times 10^9) \times 280\ \times 10^{-12}$$

$$f = 2.517\ N\ \ \textbf{Similarly}$$

- **On q_1:** Since both charges are positive, q_1 is **repelled** away from q2 .
- **On q_2:** Similarly, q_2 is **repelled** away from q1.

3- Three charges are placed in a straight line: (q_1 =+2μC), (q_2 =+3μC), and (q_3 =-1μC). The distance between (q_1) and \(q_2) is 1 meter, and the distance between (q_2) and \(q_3) is 2 meters. What is the net force on (q_2)?

q1←------ 1m ------→q2←-------- 2m --------→q3

+2μC   +3μC   -1μC

Solution:

Here's how to calculate the net force on q_2:

1. Define the forces:
   - F_{12}: The force on q_2 due to q_1. Since both are **positive**, this force is **repulsive** (to the right).
   - F_{23}: The force on q_2 due to q_3. Since q_2 is **positive** and q_3 is **negative**, this force is **attractive** (to the left).
2. Calculate F_{12}:
   - Coulomb's Law: $\boldsymbol{f = k\frac{q_1 \cdot q_2}{r^2}}$
   - k (Coulomb's constant) = 8.99×10^9 N·m²/C²
   - $q_1 = +2$ μC = 2×10^{-6} C
   - $q_2 = +3$ μC = 3×10^{-6} C
   - $r_{12} = 1$ m
   - $F_{12} = (8.99 \times 10^9) \times (2 \times 10^{-6} \times 3 \times 10^{-6}) / (1)^2$
   - $F_{12} = 0.05394$ N (to the **right**)
3. Calculate F_{23}:
   - $q_3 = -1$ μC = -1×10^{-6} C
   - $r_{23} = 2$ m
   - $F_{23} = (8.99 \times 10^9) \times (3 \times 10^{-6} \times 1 \times 10^{-6}) / (2)^2$
   - $F_{23} = 0.006$ N (to the **left**)

4. Calculate the net force on q_2:

Since F_{12} is to the right and F_{23} is to the left, we subtract the magnitudes:

- $F_{net} = F_{12} - F_{23}$
- $F_{net} = 0.053\ N - 0.006\ N$
- $F_{net} = 0.047\ N$

5. Direction of the net force:
Since F_{12} is larger than F_{23}, the net force is in the same direction as F_{12}, which is to the *right*.
Final Answer:
The net force on q_2 is approximately 0.0472 N to the right.

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Question 1

Two charges q_1=+3 μC and q2=+5 μC are placed 2 meters apart. What is the magnitude of the electric force between them?
$k=8.99\times10^9\ N\cdot m^2/C^2$

A) 0.067 N0.067\ N **B)** 0.0337 N0.0337\ N
C) 0.1079 N0.1079\ N **D)** 0.2247 N0.2247\ N

Question 2

Two charges q_1=−2 μC and q_2=+3 μC are placed 1 meter apart. What is the nature of the force between them?

A) Repulsive **B)** Attractive
C) Zero force **D)** None of the above

Question 3

What is the magnitude of the electrostatic force between two charges q1=−4 μC and q2=−6 μC placed 0.3 meters apart?
$k=8.99\times10^9\ N\cdot m^2/C^2$

A) 2.4 N2.4\ N **B)** 3.6 N3.6\ N
C) 4.8 N4.8\ N **D)** 5.9 N5.9\ N

Question 4

If the distance between two charges is doubled, what happens to the force between them?

A) Doubled **B)** Halved
C) Quartered **D)** Tripled

Question 5

Which of the following correctly describes Coulomb's Law?

A) The force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.
B) The force is inversely proportional to the product of the charges.
C) The force depends on the mass of the charges.
D) The force is independent of distance.

Question 6

Two charges $q_1=+8\ \mu C$ and $q_2=-8\ \mu C$ are placed 0.5 meters apart. What is the electric force between them?
$k=8.99\times10^9\ N\cdot m^2/C^2$

A) 11.5 N11.5\ N **B)** 14.4 N14.4\ N
C) 23.0 N23.0\ N **D)** 28.7 N28.7\ N

Question 7

Three charges are placed in a straight line: $q_1=+2\ \mu C$, $q_2=+3\ \mu C$, and $q_3=-1\ \mu C$. The distance between $q_1$and q_2 is 1 meter, and the distance between q_2 and q_3 is 2 meters. What is the net force on q_2?

A) 1.35 N1.35\ N **B)** 2.15 N2.15\ N
C) 1.80 N1.80\ N **D)** 2.75 N2.75\ N

Question 8

If the magnitude of the charges is halved and the distance remains the same, what happens to the force between them?

A) Force is halved **B)** Force is doubled
C) Force becomes one-fourth **D)** Force is unchanged

Question 9

Two charges of $+10\ \mu C$ and $-5\ \mu C$ are placed 1.5 meters apart. Calculate the force between them.
$k=8.99\times10^9\ N\cdot m^2/C^2$

A) 2.0 N2.0\ N **B)** 1.2 N1.2\ N
C) 2.5 N2.5\ N **D)** 3.0 N3.0\ N

Question 10

Two point charges are placed such that they experience a repulsive force of 0.3 N0.3\ N. If the distance between the charges is reduced to one-third, what will be the new force??????

A) 0.1 N0.1\ N **B)** 0.6 N0.6\ N
C) 0.9 N0.9\ N **D)** 2.7 N2.7\ N