PH170 Laboratory 3

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AIM:

1. Measurement of elementary charge using Millikan oil drop experiment.

2. Relate the electrostatic force magnitude to the charges and the distance between them

THEORY:

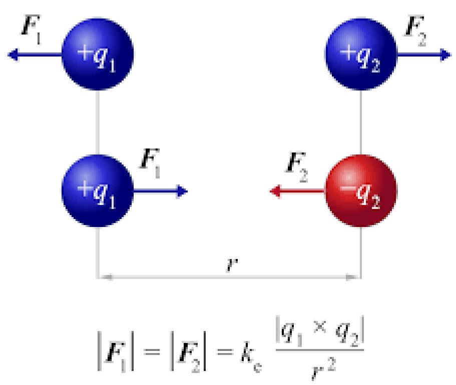
1. COULOMB'S LAW:

In order to obtain both the magnitude and direction of the force on a charge, q1 at position r1, experiencing a field due to the presence of another charge, q2 at position r2, in free space, the Coulomb's law is stated as below.

$$\mathbf{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2(\mathbf{r}_1 - \mathbf{r}_2)}{|\mathbf{r}_1 - \mathbf{r}_2|^3} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}\hat{\mathbf{r}}_{21}$$

where r is the separation of the two charges. This is simply the scalar definition of Coulomb's law with the direction given by the unit vector, parallel with the line from charge q2 to charge q1.

If both charges have the same sign (like charges) then the product q1q2 is positive and the direction of the force on q1 is given by the charges repel each other. If the charges have opposite signs then the product q1q2 is negative and the direction of the force on q1 is given by the charges attract each other.



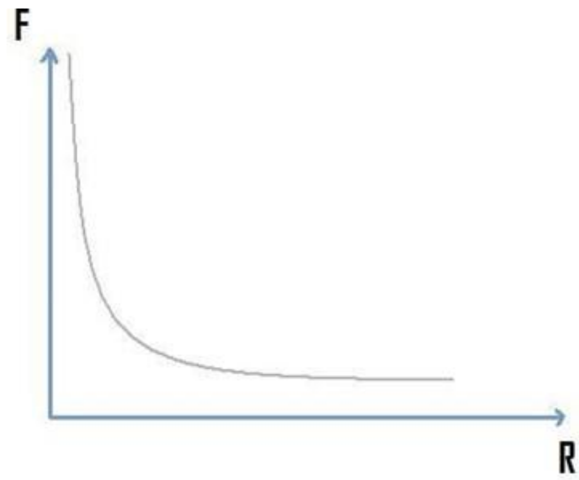
The proportionality constant 1/4πε0, called the Coulomb constant (k) (sometimes called the Coulomb force constant), is related to defined properties of space.

k = 1/4πε0

$\varepsilon_0 = 8.85 \times 10^{-12}$ $C^2/N\text{-}m^2$ (ε0 is the "permittivity of free space") hence $k = 9 \times 10^9$

If both charges have the same sign (like charges) then the product q1q2 is positive and the direction of the force on q1 is shown in above figure and the charges repel each other. If the charges have opposite signs then the product q1q2 is negative and the direction of the force on q1 is shown in above figure and the charges attract each other.

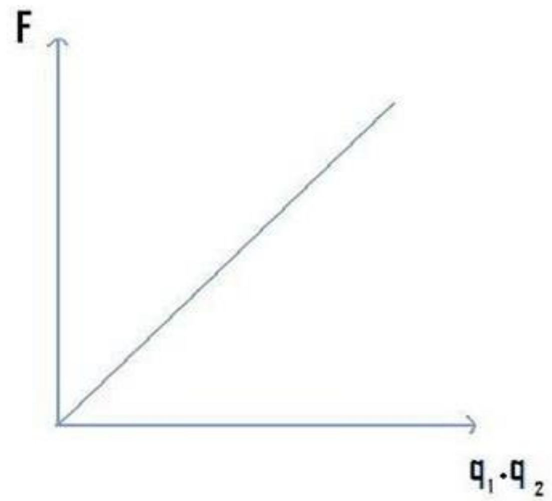
force on q2 due to q1 is **F21** = -**F12** and it is consistent with Newton's 3rd law. In this experiment, initially $F \sim 1/R^2$ will be verified using graph:



On keeping the value of charges fixed, if value of **R** ,i.e. distance between 2 point charges is changed we get a graph which shows F ~$1/R^2$

Hence it can be easily seen that F ~ $1/R^2$
After verifying F ~ $1/R^2$, now F ~ q1q2 will be verified:

On keeping **R**, i.e. distance between 2 point charges constant, now if values of q1 or q2 or both are variedit can be seen from the graph that change in value of **F** will be according to the change in product of charges.



It can be seen that F ~ q1q2

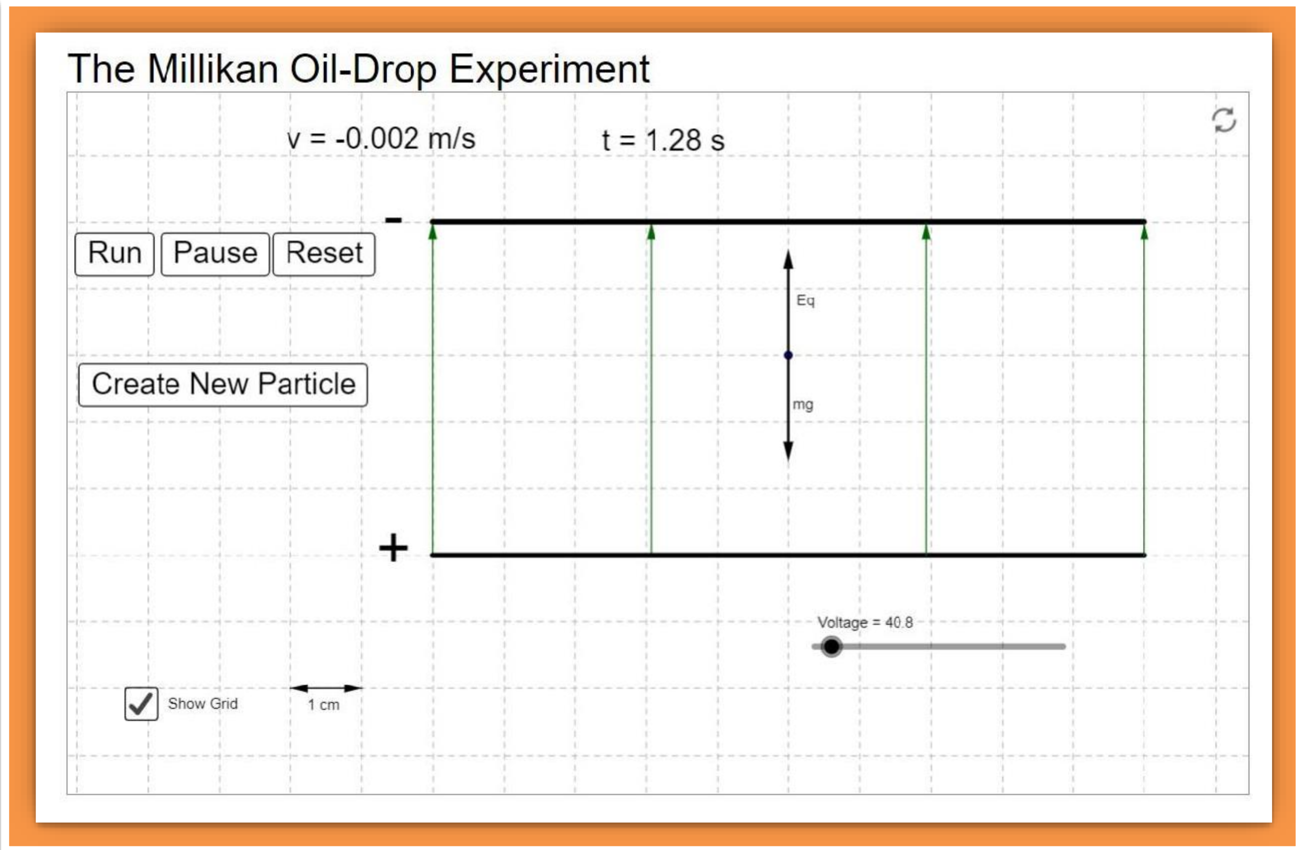
The Oil Drop Experiment:

In 1909, Robert Millikan and Harvey Fletcher conducted the oil drop experiment to determine the charge of an electron. They suspended tiny charged droplets of oil between two metal electrodes by balancing downward gravitational force with upward drag and electric forces. The density of the oil was known, so Millikan and Fletcher could determine the droplets' masses from their observed radii (since from the radii they could calculate the volume and thus, the mass). Using the known electric field and the values of gravity and mass, Millikan and Fletcher determined the charge on oil droplets in mechanical equilibrium. By repeating the experiment, they confirmed that the charges were all multiples of some fundamental value. They calculated this value to be 1.5924×10^{-19}Coulombs (C), which is within 1% of the currently accepted value of $1.602176487 \times 10^{-19}$ C. They proposed that this was the charge of a single electron.

Milliken sprayed slightly ionized oil droplets into an electric field and made observations of the droplets. When the voltage is zero and the run button is pressed, the drop will fall due to the force of gravity. It will reach a terminal velocity (vt) as it falls. Pause the simulation while you record the terminal velocity. This terminal velocity can be used to determine the mass of the drop. Use the equation: mass = kv^2 to determine the mass of the particle. The value of k in this simulation is 4.086×10^{-17} kg s^2/m^2. Once the terminal velocity is recorded and the mass calculated, with the simulation still paused increase the voltage between the plates until the two force vectors are approximately equal length. This will produce an upward field and an upward force on the positive droplets. If the upward force of the electric field is equal to the downward force of gravity, and the drag force is zero, the particle will not accelerate. To be sure that the lack of acceleration is not related to drag forces, the velocity must also be zero as well as the acceleration in order to be sure that the two forces are balanced. Increase and decrease the voltage (use the left/right arrow keys) until both the acceleration and velocity are at zero. The velocity may not stay at exactly zero, but find the voltage that has the velocity changing most slowly as it passes v = 0.

OBSERVATIONS:

Millikan Oil drop experiment:



Mass = kv^2

The value of k is 4.086 x

10^{-17} kg s^2/m^2E = V / d

where, d = 0.05m

qE = mg

S.no.	Terminal Velocity (v) (m/s)	Mass of charge(m) (10^{-17}kg)	Field Strength(E) (N-m)	Voltage(V), For v = 0	Charge (q) (10^{-19})	n = q/e
1	-1.4	8.00856	820	41	9.57	5.98

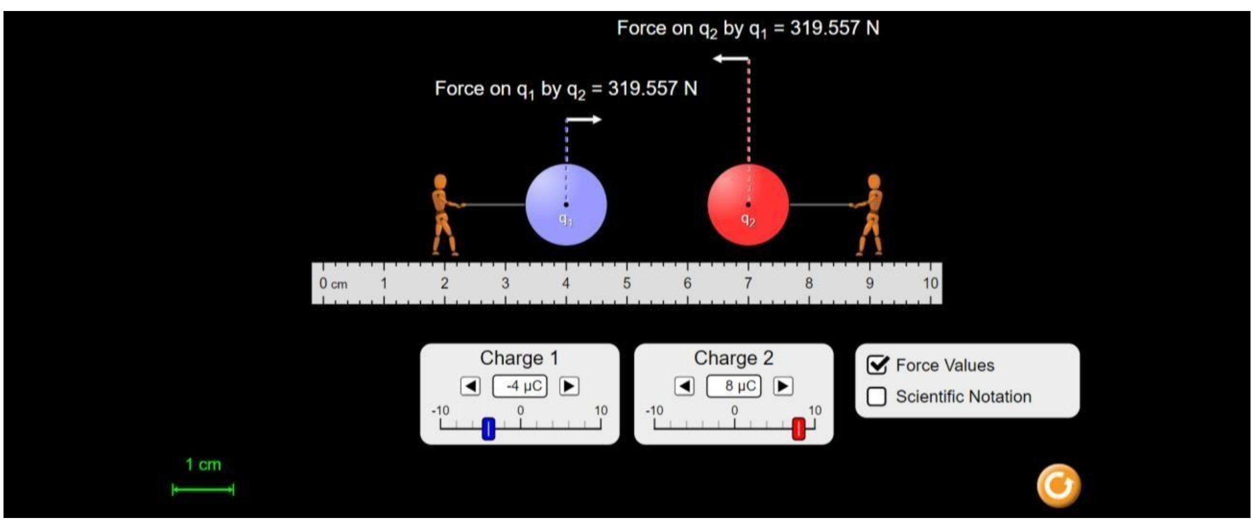
2	-1.002	4.10236	280	14	14.3582	8.974
3	-1.202	5.90346	520	26	11.12575	6.954
4	-0.99	4.00468	310	15.5	12.66	7.912
5	-1.365	7.61314	930	46.5	8.0224	5.014
6	-1.14	5.31016	360	18	14.4554	9.0346
7	-1.391	7.9059	540	27	14.348	8.96
8	-1.026	4.30123	660	33	6.3866	3.99
9	-1.107	5.00718	760	38	6.4566	4.035
10	-1.212	6.0021	370	18.5	15.8974	9.94

While observing the table, we conclude that the charge on particle is proportional to the square of the terminal velocity and invers proportional to the Voltage. Hence q is:

$$q = kgd\,(\frac{v^2}{V})$$

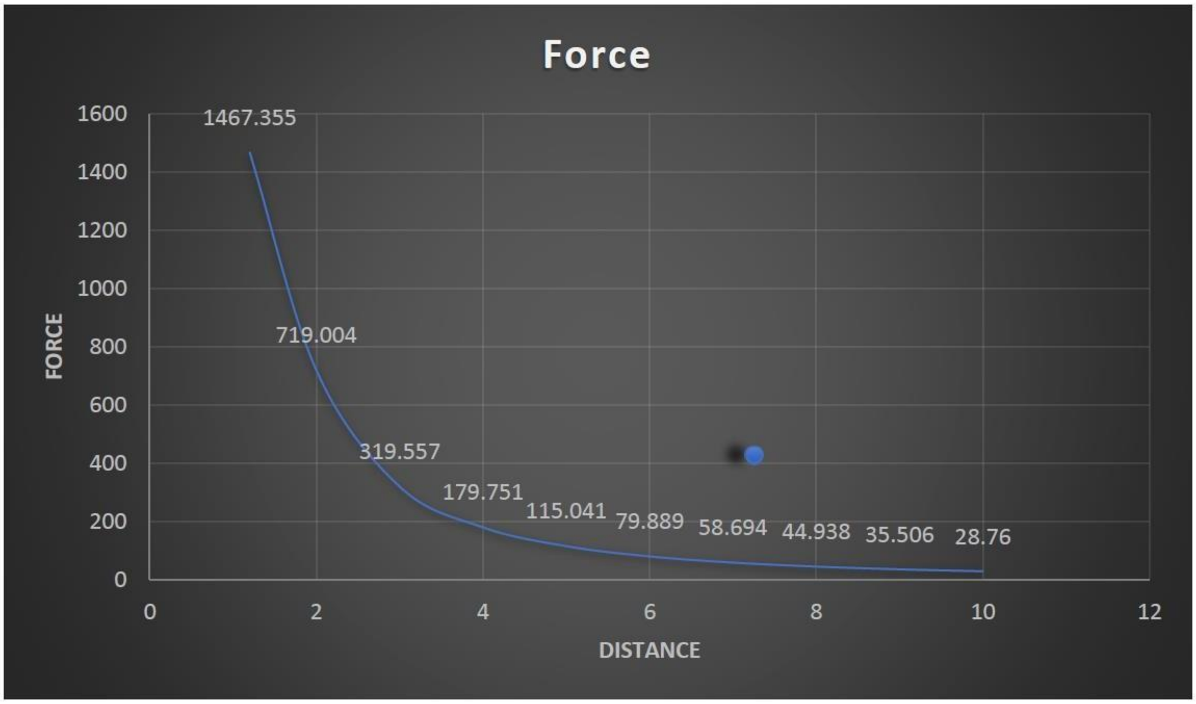
2. COULOMB'S LAW:

MACRO-LEVEL:

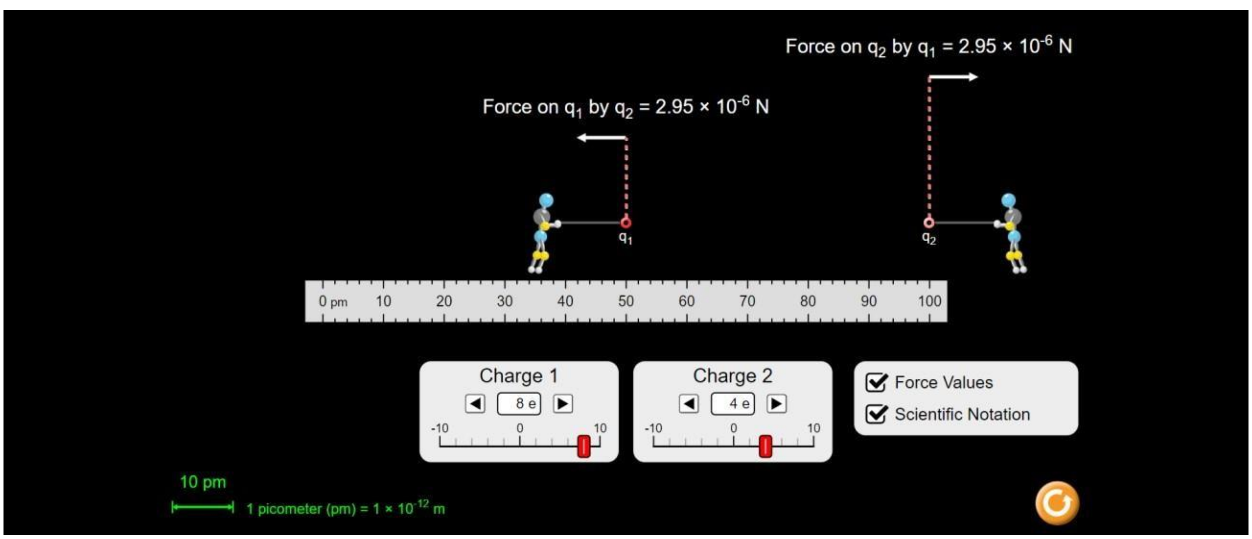


S. no.	Charge on first body (q_1 -µC)	Charge on second body (q_2 -µC)	Distance (r) (cm)	Force(F) (N)
1	-4	8	10	28.760
2	-4	8	9	35.506
3	-4	8	8	44.938
4	-4	8	7	58.694
5	-4	8	6	79.889
6	-4	8	5	115.041

7	-4	8	4	179.751
8	-4	8	3	319.557
9	-4	8	2	719.004
10	-4	8	1.2	1467.355

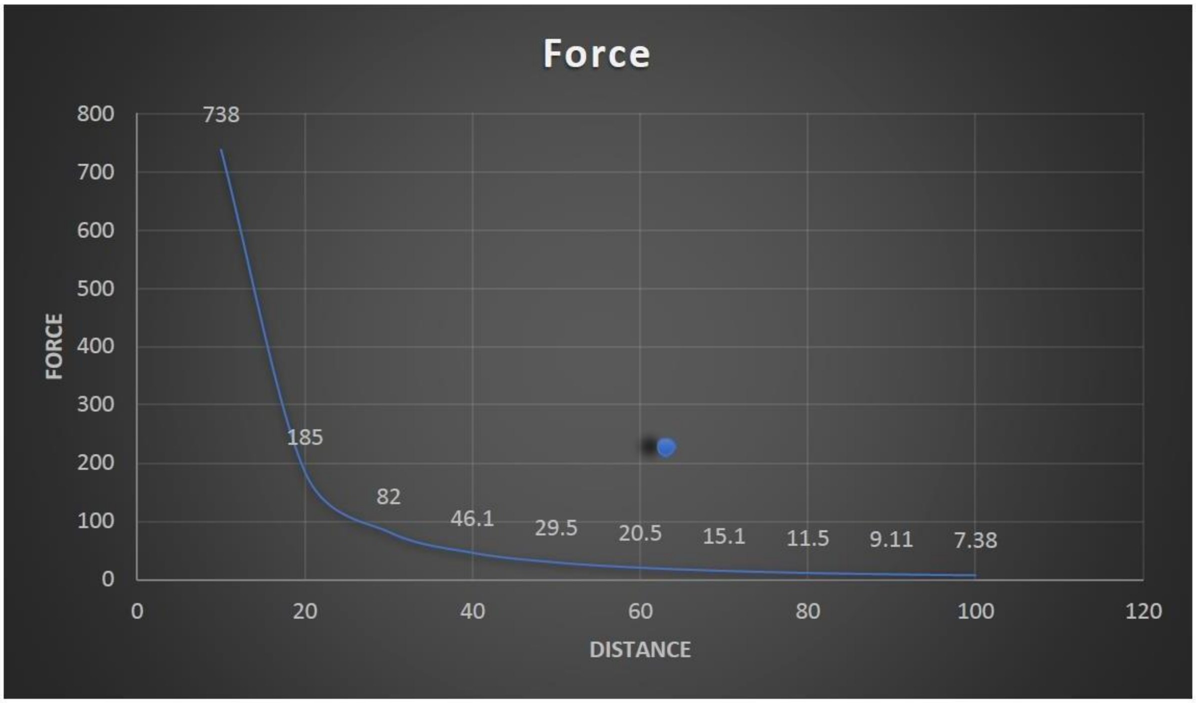


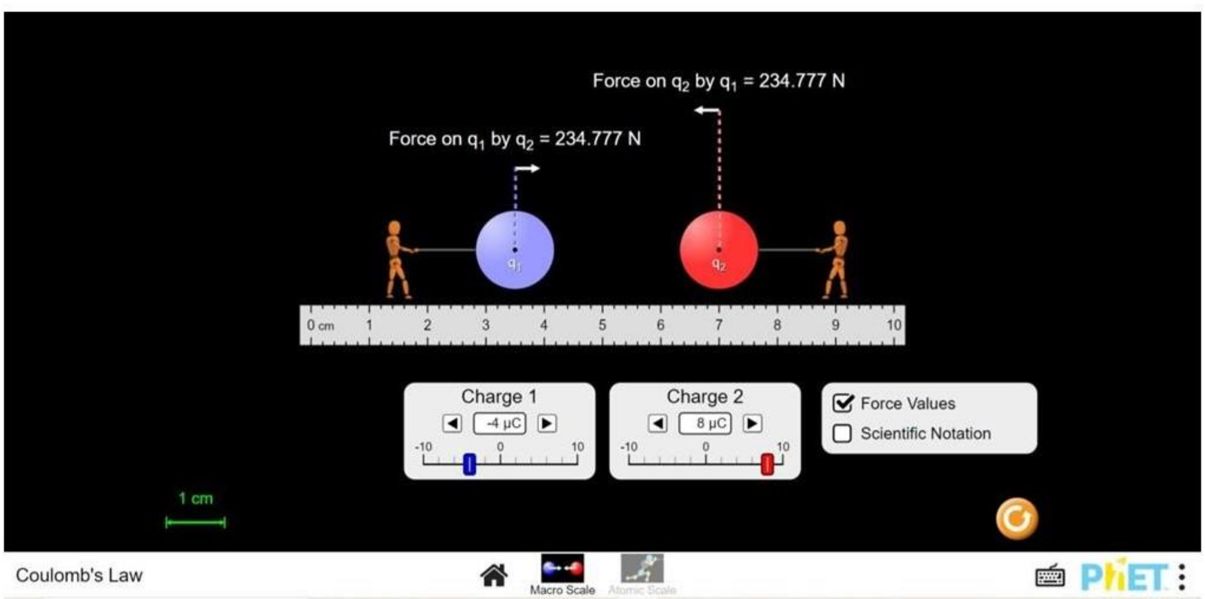
ATOMIC LEVEL:



S. no.	Charge on first body (q_1 -e)	Charge on second body (q_2 -e)	Distance (r) (pm)	Force(F) (10^{-7})
1	8	4	100	7.38

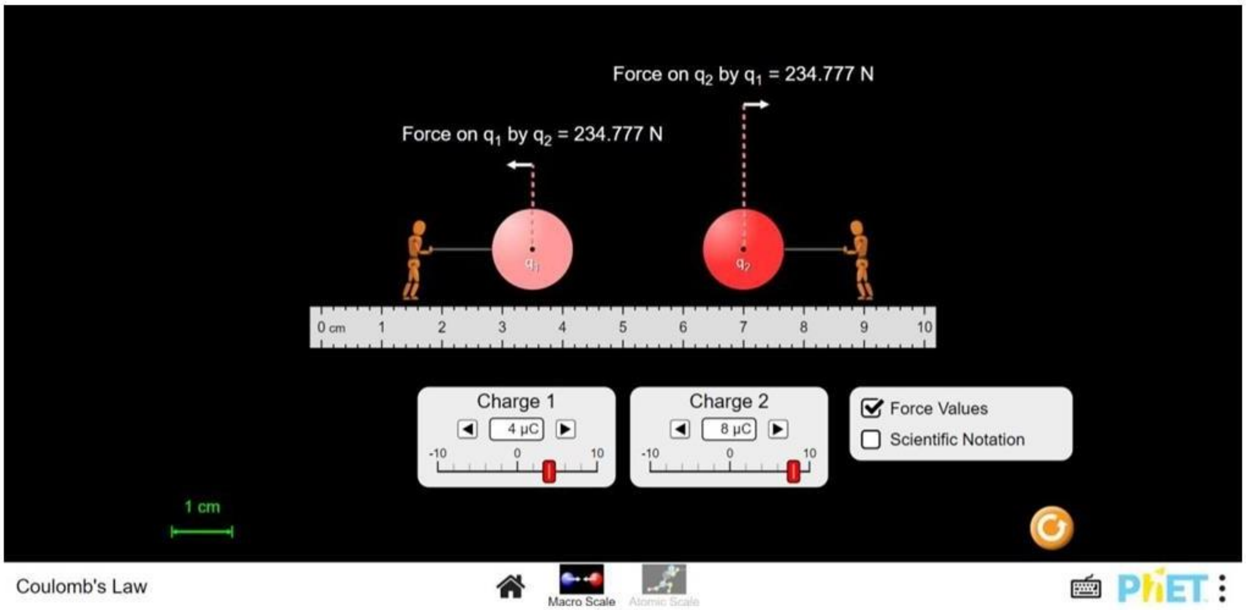
2	8	4	90	9.11
3	8	4	80	11.5
4	8	4	70	15.1
5	8	4	60	20.5
6	8	4	50	29.5
7	8	4	40	46.1
8	8	4	30	82.0
9	8	4	20	185.0
10	8	4	10	738.0





While observing the experiment, we conclude that both the bodies are experiencing same magnitude of force, but the direction of both the forces are opposite. Hence, Newton's third law is valid here.

In this experiment both the bodies have opposite nature of charge and the force experienced by one body is pointing towards the other body. Hence, we can conclude that if the charges on the bodies are of opposite nature, then they will attract each other.



While observing the experiment, we conclude that both the bodies are experiencing same magnitude of force, but the direction of both the forces are opposite. Hence, Newton's third law is valid here. In this experiment both the bodies have same nature of charge and the force experienced by one body is pointing away from the other body. Hence, we can conclude that if the charges on the bodies are of same nature, then they will repel each other.

One more thing we can observe and conclude here is that as the distance/ separation between charges increases, the electrostatic force of interaction between them decreases. This follows inverse square law, i.e. the electrostatic force varies with $1/r^2$.

CONCLUSIONS:

- In Millikan Oil drop experiment, we conclude that the charge on particle is proportional to the square of the terminal velocity andinvers proportional to the Voltage. Hence q is,

$$q = kgd\,(\frac{v^2}{V})$$

- In Coulombs law experiment, we conclude that both the bodies are experiencing same magnitude of force, but the direction of both the forces are opposite. Hence, Newton’s third law is here.
- If the charges on the bodies are of opposite nature, then they will attract each other.
- If the charges on the bodies are of same nature, then they will repel each other.
- The electrostatic force of interaction between two charges also depends on the separation between them; it varies inversely with the square of distance between them.

Thank you