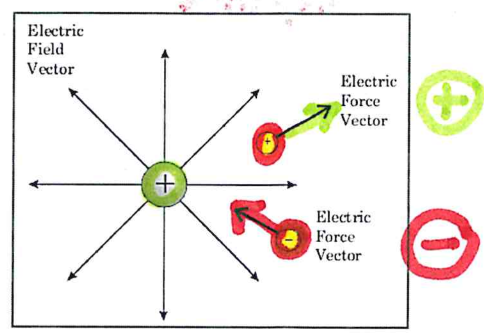
U3:L3 Electric Fields Part 2

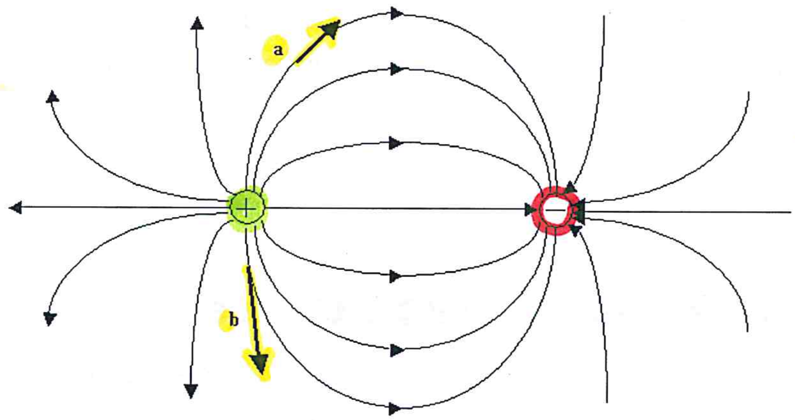
Electric Fields and Vectors



Electric field lines are drawn based on the magnitude and direction of the force of the field.

The force felt by a charge at any point in a field can be represented by a vector arrow (similarly to our force vectors with U2:Dynamics!).

Consider the field diagram below of two opposite charges:

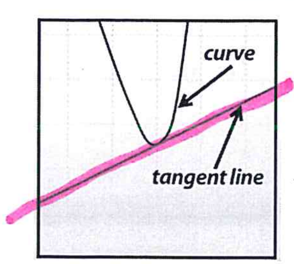


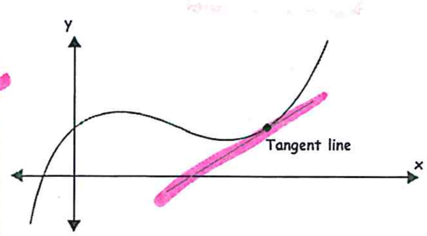
Notice the vector arrows for charges (a) and (b).

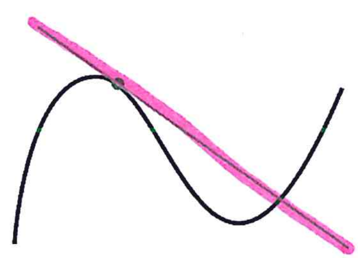
*Note that the vectors show how a **positive** test charge would be forced. If a negative charge were to be placed at these points, it would be forced in the **opposite direction.***

The vector arrows are not following the field lines. The arrow is **tangent to the field lines**, at the specific point of the charge.

Reminder: A tangent line is a line that goes through a specific point, and is perpendicular to the curve that the point lies on...

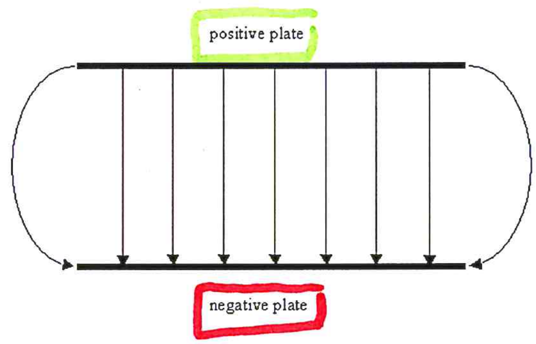






Two Parallel Charged Plates

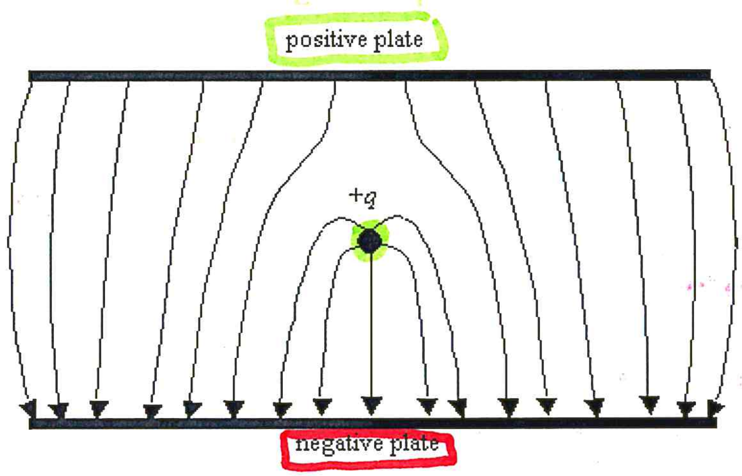
The electric field lines point away from the positive plate towards the negative plate. There is a slight bulge at each edge of the plates.



In the region between the plates, the electric field lines are parallel and evenly spaced. This indicates that the electric field has the same magnitude and direction at all points.

Two Charged Plates and a Single Charge

The following diagram shows the electric field line pattern between a single positive charge and two charged plates when the charge is between the plates.



Note that the electric field lines move away from the positive charge and the positive plate, and towards the negative plate.

Field Simulation

Go to the following website to play with the Electric Field Simulation:

https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

(If that link does not work, Google: "*PHET Charges and Fields Simulation*")

With the simulator, do the following tasks and respond with what you see:

1) Begin with one positive charge.
a) In what direction are the field lines pointing? (draw!)

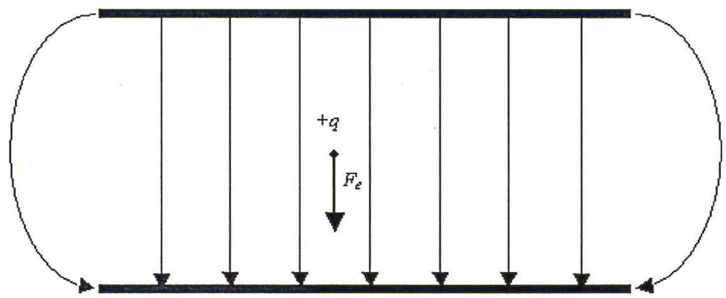
b) How does the separation between the field lines change as you move away from the charge, and does this say about the strength of the electric field?

c) As you increase the magnitude of the charge, what happens to the number of field lines and their direction? (Increase magnitude by clicking and dragging another positive charge and dropping it on top of your first charge!)

2) Set the simulation to two charges: positive on the left and a negative charge on the right. Both charges should be the same magnitude.
a) In what direction do the field lines point? (draw!)

b) Increase the magnitude of the negative charge. How does the number of field lines moving towards the negative charge on the right compare with the number of field lines leaving the positive charge on the left?

Force and Charged Parallel Plates



- The diagram above shows two charges parallel plates with a positive charge (q) placed between them.
- F_e and the arrow, represent the force on this charge (q) due to the plates.

- In the region between the plates, the electric field lines are parallel and evenly spaced. This indicates that the electric field has the same magnitude and direction at all points.

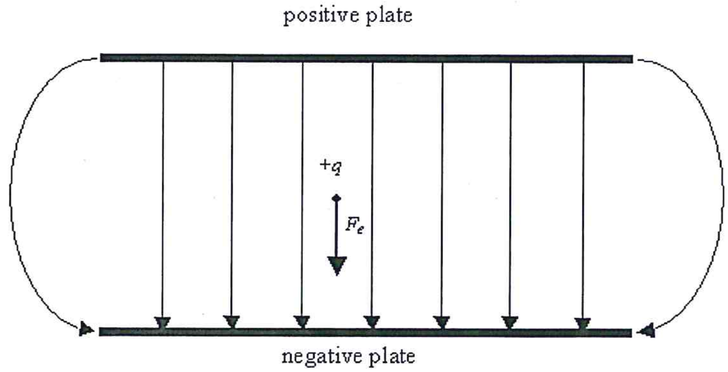
- If a positive point charge is placed between the plates, the net force on the charge will be in the same direction as the electric field lines.
- A negative point charge will move in a direction opposite the electric field line direction.

- The amount of the electric force on the charged particle can be determined by:

$$F_e = qE.$$

- If the electric force is the only force acting on the charged object, then the acceleration of the object can be determined from Newton's second law:

$$F = ma$$



Calculations:

a) If the <u>electric field strength</u> between the charged plates is 10.0 N/C, and the object has a charge of q =+ 2.00 C and a mass of m = 4.00 x 10^{-4} kg, then the <u>acceleration</u> of the particle is:

$$a = \frac{F_e}{m} = \frac{qE}{m} = \frac{(2.00C)(10.0N/C)}{4.00x10^{-4}\,kg} = \boxed{5.00 \text{ x } 10^4 \text{ m/s}^2.}$$

The direction of the acceleration is in the same direction as the force. For the diagram above, the charge would accelerate in the down direction.

b) If the charged plates are oriented in an up and down direction as shown above, then the particle also experiences a <u>force of gravity</u> F_g acting downwards. The magnitude of this force is:

$$F_g = \boxed{mg} = \boxed{3.92 \text{ x } 10^{-3} \text{ N.}}$$

4.00×10^{-4} kg · 9.8 m/s²

c) Since both the electrical force and the force of gravity are acting downwards, the <u>net force</u> is:

$$F_{net} = F_e + F_g = qE + mg = (2.00C)(10.0N/C) + (4.00x10^{-4})(9.8N/kg) = \boxed{20.0 \text{ N}}$$

U3:L4 Electric Fields Part 3

(Final Part!)

In U1: Kinematics we worked with a few important equations:

Average Velocity	$\frac{displacement}{time}$	$\frac{\Delta d}{\Delta t} = \frac{d_f - d_0}{t_f - t_0}$
Average Velocity	$\frac{velocity\ 1 + velocity\ 2}{time}$	$\frac{v_1 + v_2}{2}$
Average Acceleration	$\frac{change\ in\ velocity}{time}$	$\frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$

These kinematics concepts can also be applied to fields!

Consider a charge of +2.00 C accelerated downwards at a rate of $5.00\text{x}10^4$ m/s² downwards, or -5.00×10^4 m/s².

If the particle accelerates downwards for 6.00 µs (6.00×10^{-6} s), then the change in velocity is:

$$\Delta v = a\Delta t = (-5.00\text{x}10^4\ \text{m/s}^2)(6.00\text{x}10^{-6}) = \boxed{-0.300\ \text{m/s}}$$

⊖ is the direction!

If the initial velocity of the charged object is zero, then after 6.00 µs, the new velocity of the particle is 0.300 m/s and the average velocity is:

$$\frac{V_1 + V_2}{2} = V_{avg}$$

$$\bar{v}_{ave} = \frac{1}{2}(0.00\text{m/s} + -0.300\text{m/s}) = \boxed{-0.150\ \text{m/s.}}$$

The downward displacement of the charged particle is:

$$\vec{v} = \frac{\Delta d}{\Delta t}$$

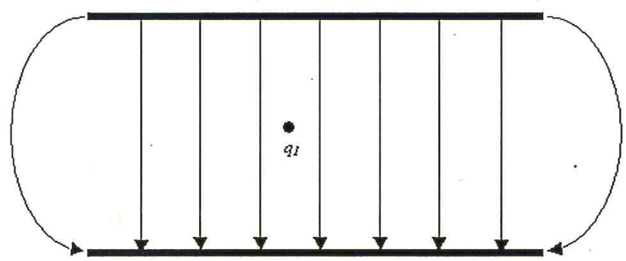
$$\Delta d = v_{avg}\Delta t$$

$$\vec{v}\Delta t = \Delta d$$

$$v_{ave}\Delta t = (-0.150\text{m/s})(6.00\text{x}10^{-6}) = \boxed{= -9.00 \times 10^{-7}\ \text{m.}}$$

Try it:

A charge, $q_1 = +5.00$ C is placed in an electric field between two charged plates. The electric field strength is $E = 4.00$ N/C. The mass of the charged particle is $m = 2.00 \times 10^{-4}$ kg.



a) Determine the magnitude and direction of the acceleration of the charged particle between the plates.

$\varepsilon = \frac{F}{q}$

$F = \varepsilon q$

$F = 4\,N/C\,(5C)$

$F = 20N$

$F = m \times a$

$a = \frac{F}{m}$

$a = \frac{20N}{2 \times 10^{-4}\,kg}$

$\boxed{a = 1 \times 10^{5}\,m/s^2 \text{ downwards}}$

b) If the particle is released from rest, what will be the displacement of the particle after a time of 8.00 μs (8.00 x 10^{-3})?

$\Delta d = \frac{1}{2}\vec{a}\Delta t^2$

$\Delta d = \frac{1}{2}(1 \times 10^{5}\,m/s^2)(8.00 \times 10^{-3}s)^2$

$\boxed{\Delta d = 3.2m}$

Millikan's Experiment

At the turn of the century, when the understanding of electric forces was beginning to increase, two fundamental questions arose regarding the nature of electric charge.

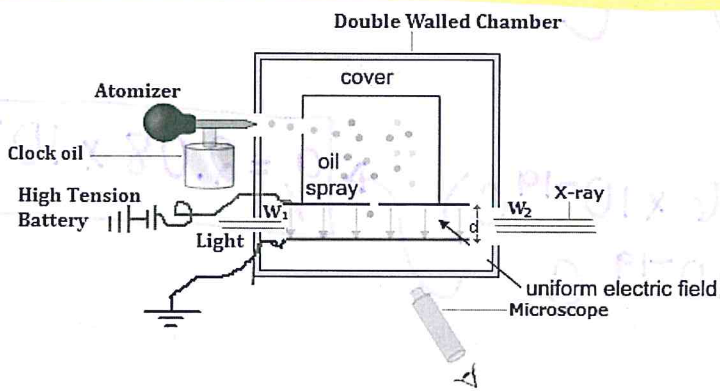
1) Does there exist in nature a smallest unit of electric charge of which all other units are multiples?
2) If so, what is this elementary charge, and what is its magnitude, in Coulombs?

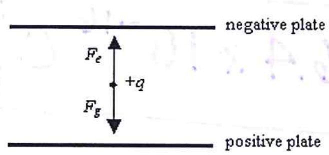
To answer these questions, an American physicist, Robert Andrews Millikan (1868-1953) devised and performed a series of very creative experiments.

Watch the YouTube video "Millikan's Oil Drop Experiment to Determine Charge of an Electron – Chemistry" by *Elearnin* (1 min 58 s)

The next video is a bit longer, but a very good explanation of the experiment (by a very cool dude):

Watch "Charge of an Electron: Millikan's Oil Drop Experiment" by *Tyler DeWitt* (12 mins 52 s)





When the oil droplet is in balance, then $F_e = F_g$, and $qE = mg$. The charge on the charged particle can then be determined by $q = \frac{mg}{E}$.

The currently accepted value for the elementary charge is $1.602\ 177\ 33 \times 10^{-19}$ C. The value we will use in our calculations is 1.60×10^{-19} C

Thus the total charge, q, on any object is a whole number multiple, N, of this elementary charge, e.

$\boxed{q = Ne}$

How many "e"s

electron

charge of particle

If the total charge on an object is 1C, then it is possible to determine the number of elementary charges in this 1C.

$$\boxed{N = \frac{1}{1.60 x 10^{-19} C/e} = 6.25 \times 10^{18}\ e}$$

q=Ne Problems

So…

$$q = N \times e$$
$$1\ C = 6.25 \times 10^{18}\ e$$

and

$$e = \frac{1}{6.25 \times 10^{18}}\ C$$

$$e = 1.6 \times 10^{-19}\ C$$

What is the charge of a single electron (magnitude and sign)?

$-1.6 \times 10^{-19}\ C$

What is the charge of a single proton (magnitude and sign)?

$+1.6 \times 10^{-19}\ C$

An object has an "excess" of 13 electrons. What is this object's net charge?

$q = Ne$
$q = 13\ (-1.6 \times 10^{-19}\ C)$
$q = 20.8 \times 10^{-19}\ C$

$\boxed{q = 2.08 \times 10^{-18}\ C}$

Another object has a "deficit" (or lack of) of 4,000 electrons. What is this object's charge?

$q = Ne$
$q = (-4000)\ (-1.6 \times 10^{-19}\ C)$
$q = 6400 \times 10^{-19}\ C$

$\boxed{q = 6.4 \times 10^{-16}\ C}$

An object has a net charge of 8μC (or 8×10^{-6} C). Does it have an excess or deficit of electrons? How many too few or too many?

$q = Ne$

$\frac{q}{e} = N$

$\frac{8 \times 10^{-6}\ C}{-1.6 \times 10^{-19}\ C} = N$

$-5.0 \times 10^{13} = N$
too few
a "deficit"
because $N = \ominus$

Charges Between Parallel Plates

There are a few different situations that could exist with a charged particle between two plates:

At Rest (not moving)	$F_e = -F_g$	the sphere is stationary between the plates
Accelerating opposite the force of gravity	$F_e < F_g$	Acceleration due to electric field is less than acceleration due to gravity
Accelerating opposite the force of gravity	$F_e > F_g$	Acceleration due to electric field is more than zero
Accelerating in same direction as force of gravity	$F_e > 0$	in the same direction as Fg when a > *g*

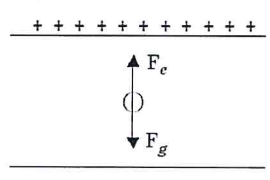
Example:

A negatively charged 2.0 x 10^{-5} kg droplet of oil is placed between two oppositely charged plates. The oil drop is balanced when the electric field is adjusted to 4.2x10^{-7} N/C.

$$m = 2.0 \times 10^{-7}\ \text{kg}$$

$$E = 4.2 \times 10^{5}\ \text{N/C}$$

a) Diagram to indicate the charge on each plate.



b) How many elementary charges are on the oil drop?

$$F_e = F_g$$

$$q\mathcal{E} = mg$$

$$q = \frac{mg}{\mathcal{E}} = \frac{2.0\times10^{-7}(9.8)}{4.2\times10^{5}}$$

$$q = 4.7\times10^{-13}\ \text{C}$$

$$q = Ne \quad \text{so} \quad N = \frac{q}{e}$$

$$N = \frac{4.7\times10^{-13}\ \text{C}}{1.6\times10^{-19}\ \text{C}}$$

$$\boxed{N = 2.9\times10^{6}}$$