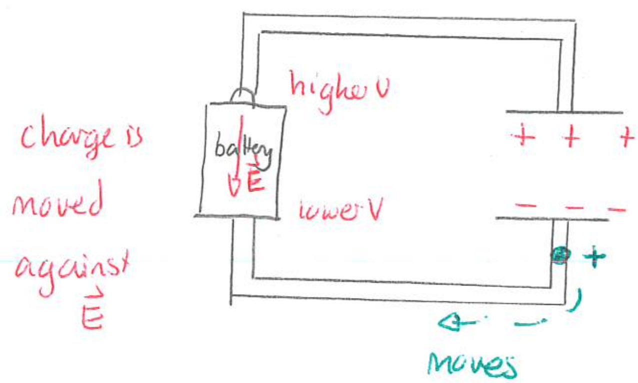
Weds: Review Ex I

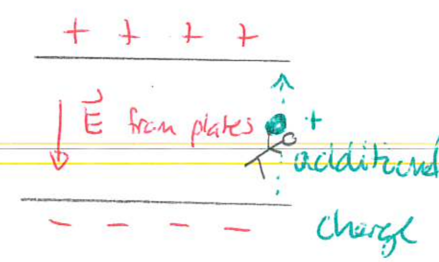
Thurs: Ex I

## Energy stored in a capacitor

Consider the process by which a capacitor is charged. This is usually done by connecting a capacitor to a battery. During the charging process the battery can be regarded as moving positive charge as illustrated. This will require work.




In terms of calculating we can view the process at the capacitor and consider the work done to move the charge against the field established by the charged plates.




We can determine that the work done to entirely charge the capacitor. This is

$$W_{\text{assemble all charges}} = \frac{1}{2}\frac{Q^2}{C}$$

We can regard this as the energy stored in the capacitor.

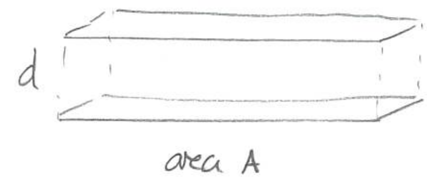
$$\boxed{U_C = \frac{1}{2}\frac{Q^2}{C}}$$

Alternatively with $Q = C\Delta V$ we get

$$\boxed{U_c = \frac{1}{2} C (\Delta V)^2}$$

## Warm Up 1

We can relate this to electric fields for simple cases such as parallel plate capacitors. Here




$$E = -\frac{\Delta V}{\Delta x}$$

$$\Rightarrow \quad E \Delta x = -\Delta V$$

$$\Rightarrow \quad \Delta V = -Ed$$

But $C = \frac{\epsilon_0 A}{d}$ and thus

$$U_c = \frac{1}{2} \frac{\epsilon_0 A}{d} E d^2 \Rightarrow U_c = \frac{1}{2} \epsilon_0 E^2 \underbrace{Ad}_{\text{volume between plates}}$$

We define the electrostatic energy per unit volume "stored in the electric field" as

$$u_c = \frac{1}{2} \epsilon_0 E^2$$

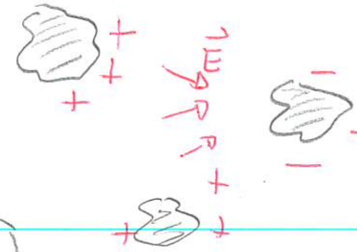
Then the total energy stored in the capacitor is

$$U_c = u_c V$$

where $V$ is the volume occupied by the fields.

This is actually a general result for all electrostatic charge arrangements. We can always do

Charge distribution → Electric field $\vec{E}$ → Energy density $u = \frac{1}{2}\epsilon_0 E^2$ → Integrate to get total stored energy



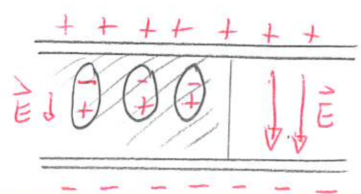

Eventually this strategy gives:

* understanding of energy propagation in electromagnetic waves $\equiv$ light
* a starting point for a quantum physics treatment of electromagnetism.

## Dielectrics

The charge storage ability of a capacitor can be altered by inserting a material that can become polarized between the plates.

Suppose that the capacitor were charged and then is disconnected. The charge on each plate stays constant. Inserting a material of this type decreases the electric field and potential difference. Then




$$Q = C\Delta V \quad \Rightarrow \quad C \text{ increases.}$$

same ↑ ↓

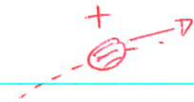
So the additional material increases the capacitance. This is called a dielectric.

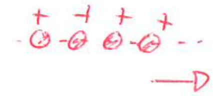
Demo: Capacitor Lab PhET

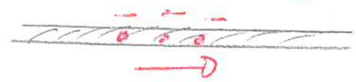
* Do with dielectric in/out + plate disconnected
* Observe drop in V

# Moving charges : currents

In general charges do not need to be stationary. We will eventually have to consider

1) isolated moving charges 

2) beams of moving charged particles 

3) charges moving through wires 

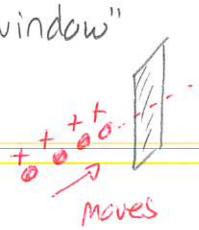
We would like to address questions such as

* what fields do these produce?
* how are such situations created and sustained?

The easiest situation to consider is a continuous stream of moving charges. This is called a <u>current</u>. How can we quantify and describe this? There will be two aspects: a magnitude and a direction.

<u>Magnitude</u>: The process for determining magnitude of current is:

Construct an imaginary "window"




→ Observe charge passing in time $\Delta t$. Let $\Delta Q$ be the charge that passes in this time

→ Magnitude of current

$$I = \left| \frac{\Delta Q}{\Delta t} \right|$$

Then this means

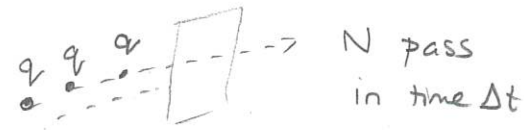
Current ≈ rate at which charge passes

The units of current are Amperes. $A = C/s$.

Quiz 1 70%

Note that if each particle has charge $q$ and $N$ pass in time $\Delta t$ then

$$\Delta Q = qN$$

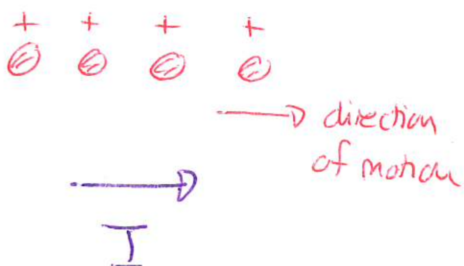



and

$$I = \frac{Nq}{\Delta t}.$$

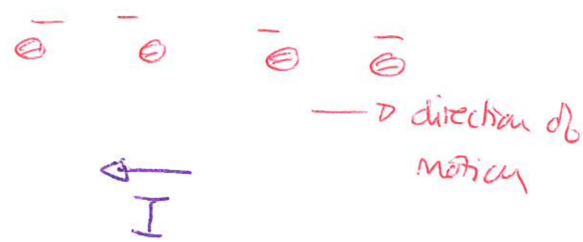
Direction: We can assign a current direction based on the type of moving charge.

Moving charges are positive




Current direction is same as direction of motion

Moving charges are negative




Current direction is opposite to direction of motion

Warm Up 2