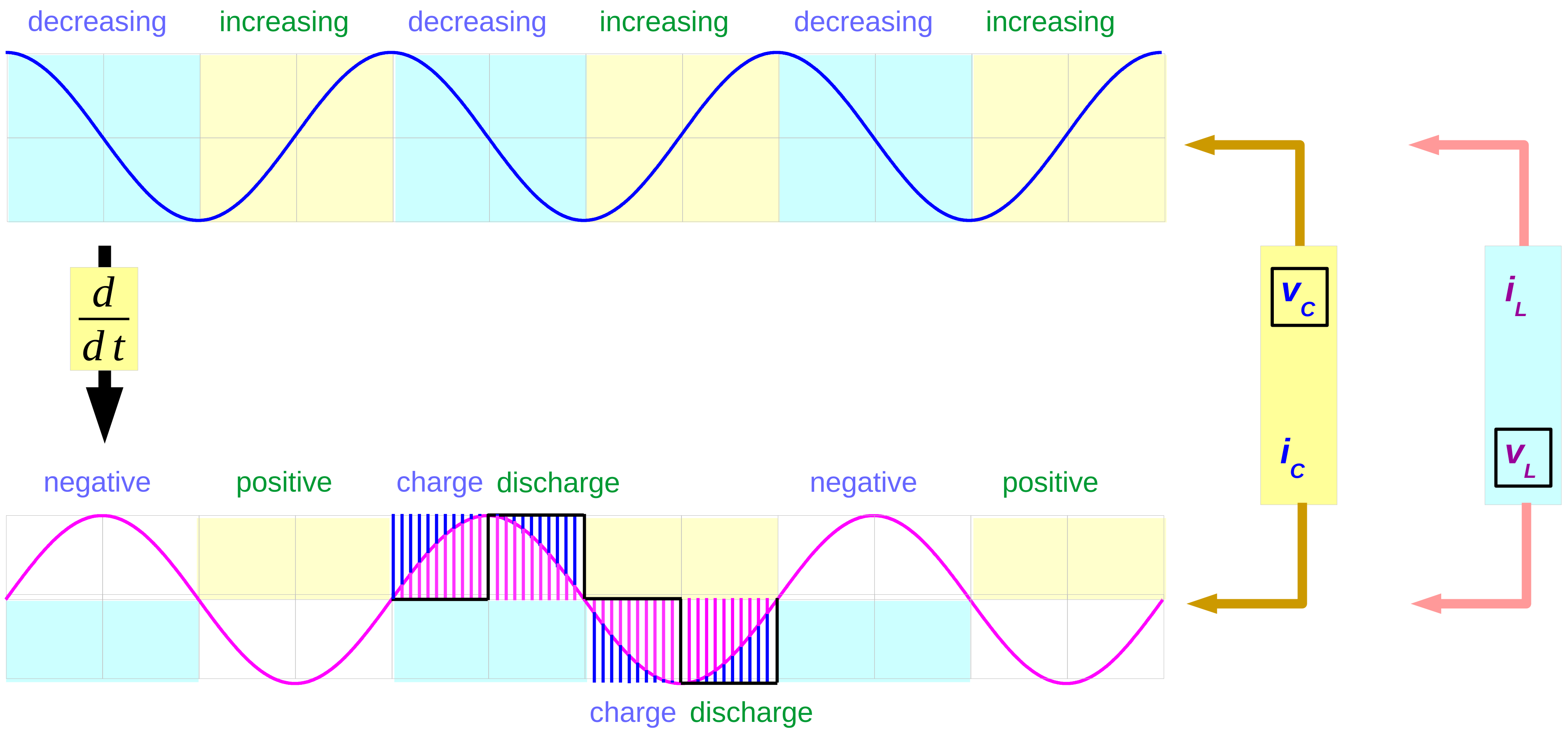
Capacitor in an AC circuit

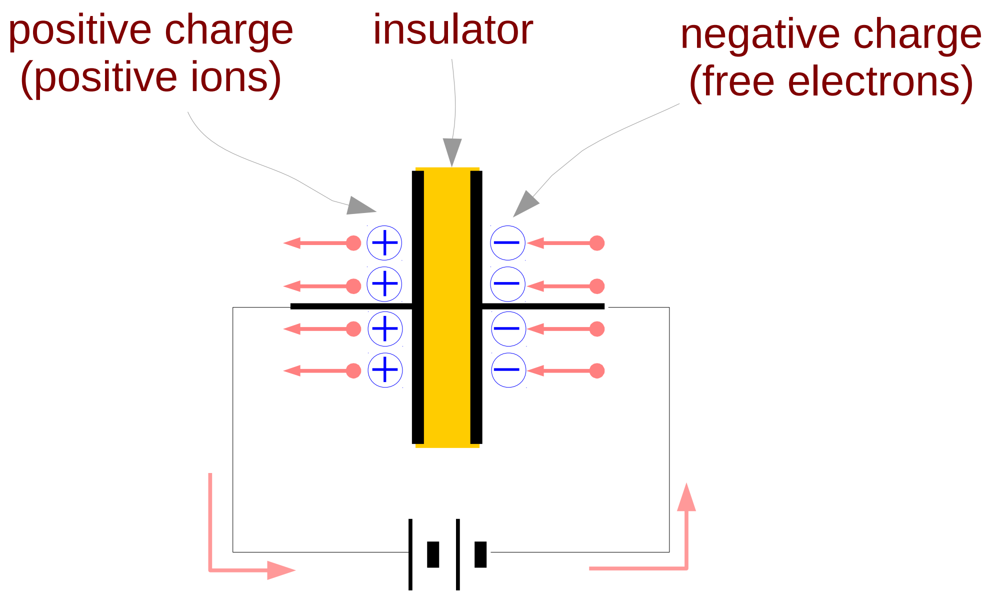
Please send corrections (or suggestions) to youngwlim@hotmail.com.

This document was produced by using OpenOffice and Octave.

Everchanging signal pairs

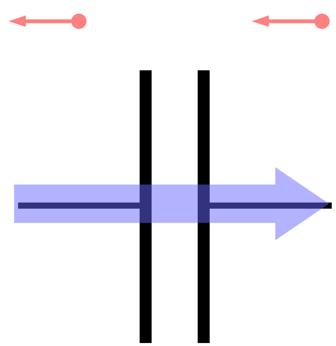


Capacitor Current



No actual electrons movement
across insulator materials

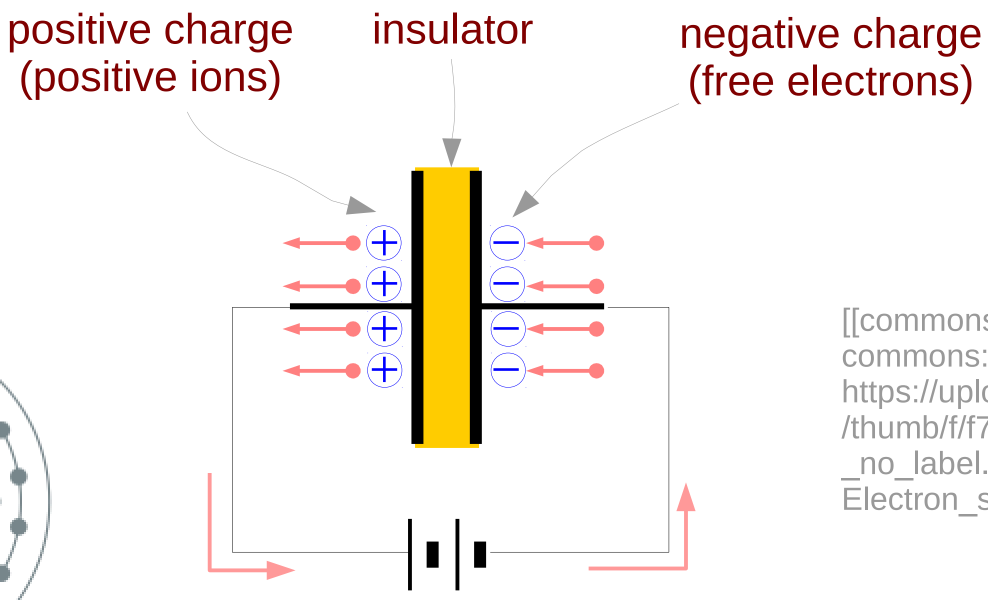
But, think as

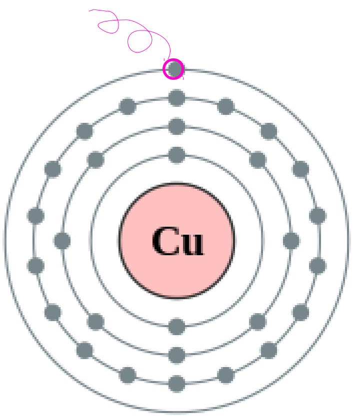


Displacement Current

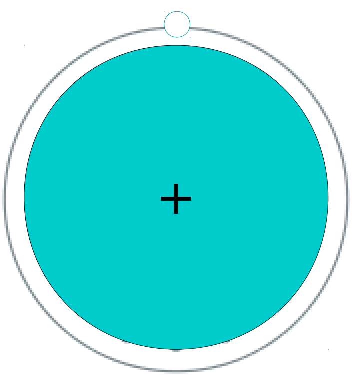
flows through the capacitor

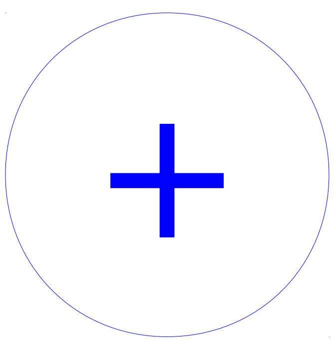
Positive ions and free electrons

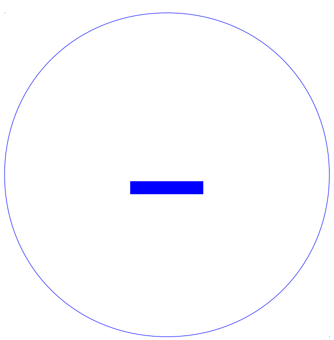




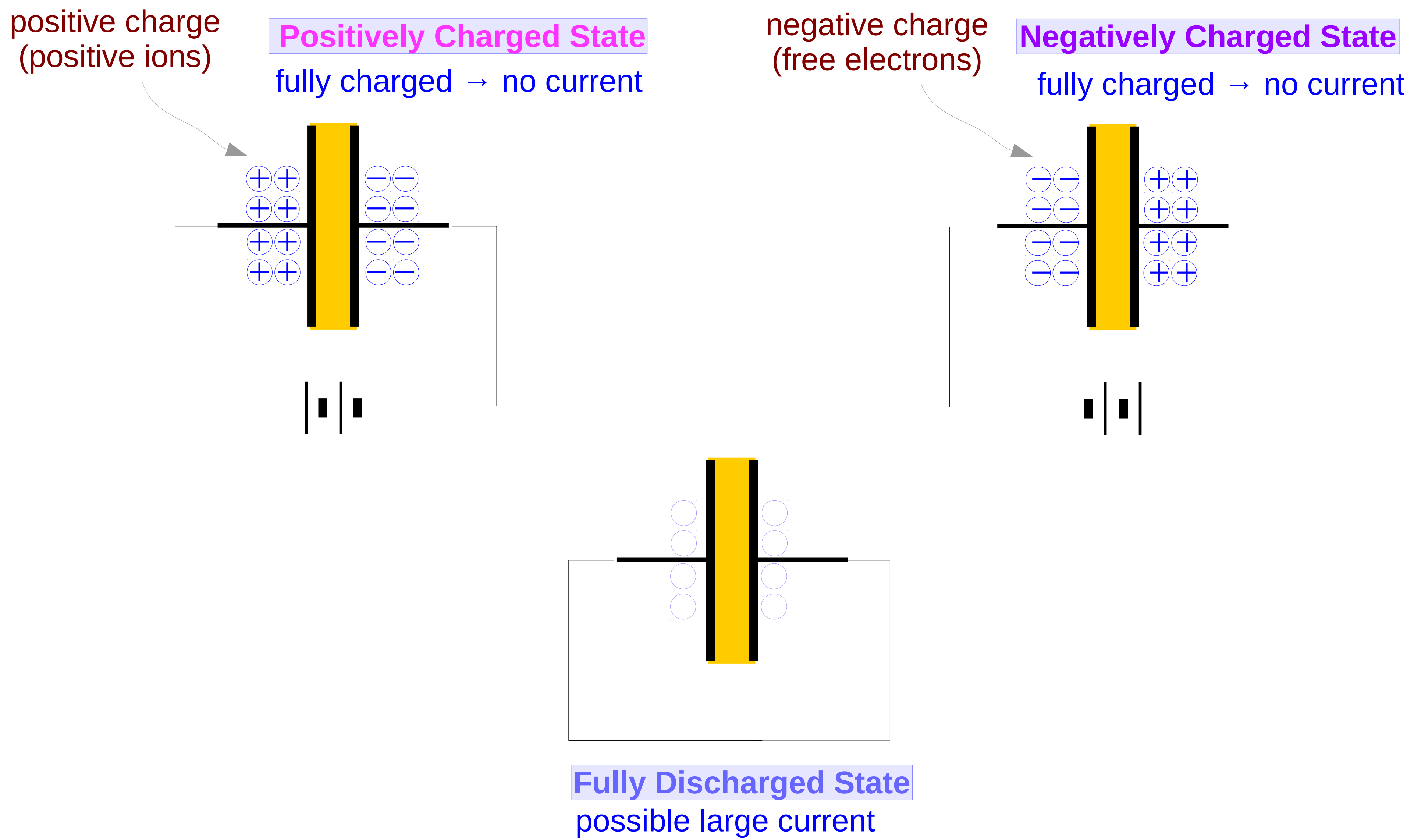
[[commons:User crap]] (original work by commons:User:Greg Robson)
https://upload.wikimedia.org/wikipedia/commons/thumb/f/f7/Electron_shell_029_Copper_-_no_label.svg/200px-Electron_shell_029_Copper_-_no_label.svg.png



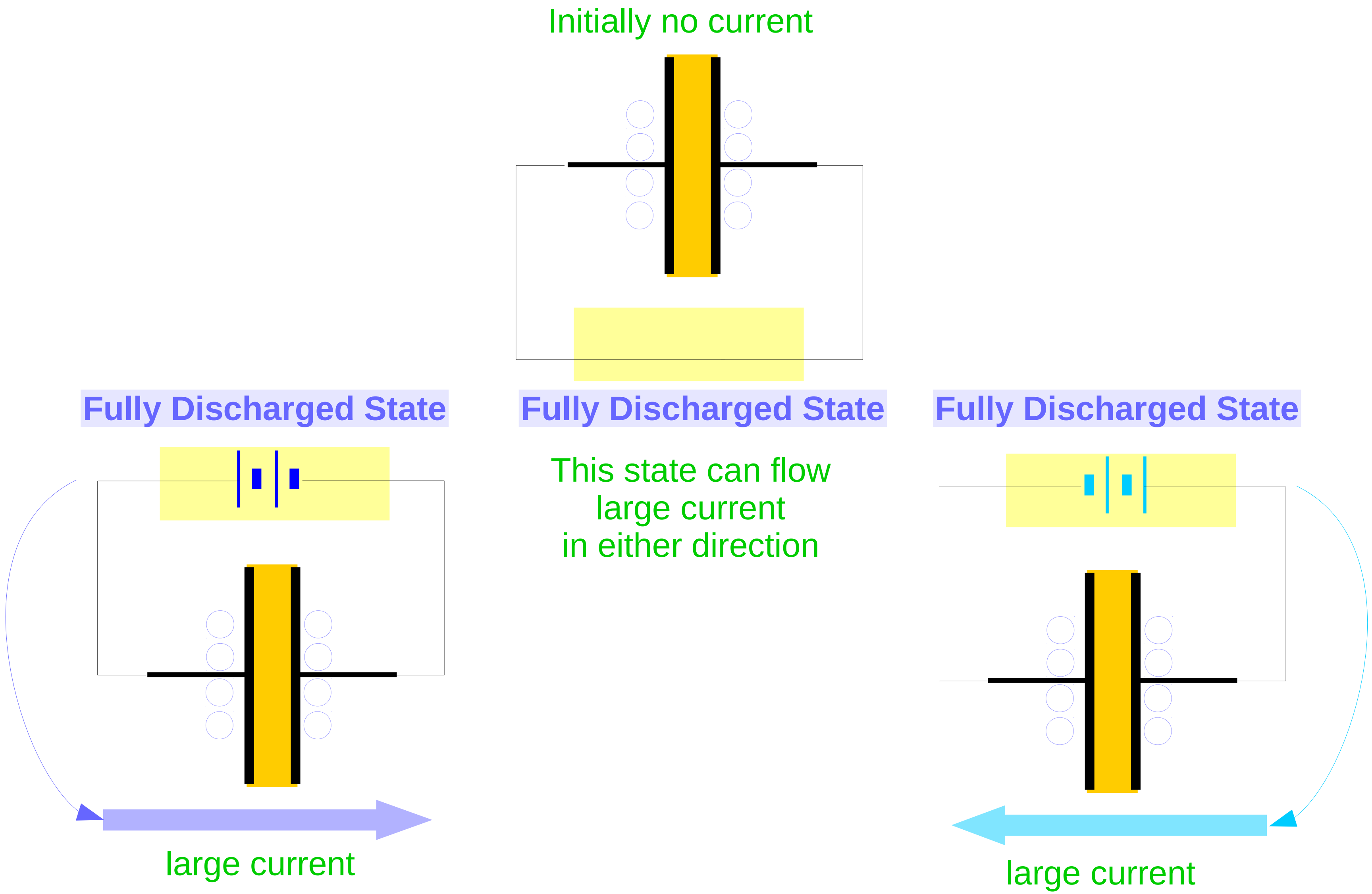




Three States



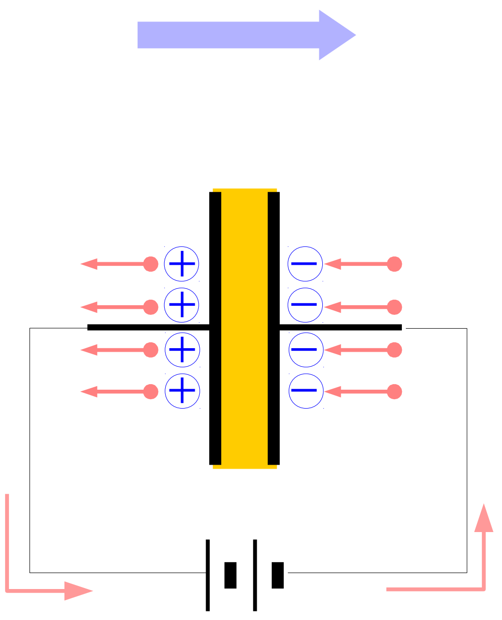
Currents in the Fully Discharged State



Inter-State Current Flowing

Under Positively Charging

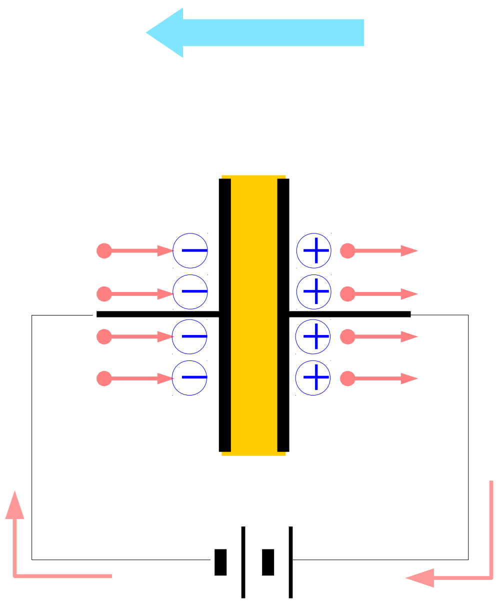
(+) current flow
direction



electron flow
direction

Under Negatively Charging

(–) current flow
direction

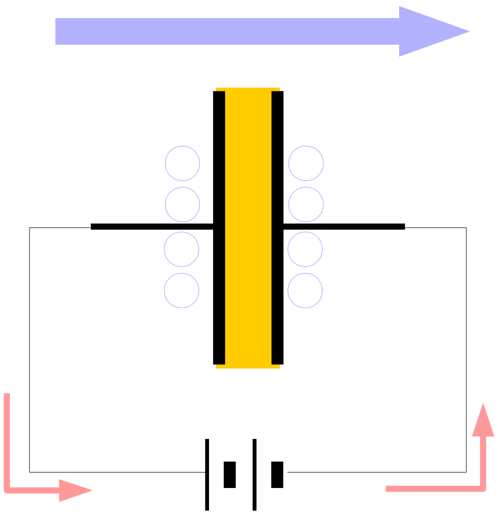


electron flow
direction

Inter-State Current Flowing

Fully Discharged State

(+) current flow direction

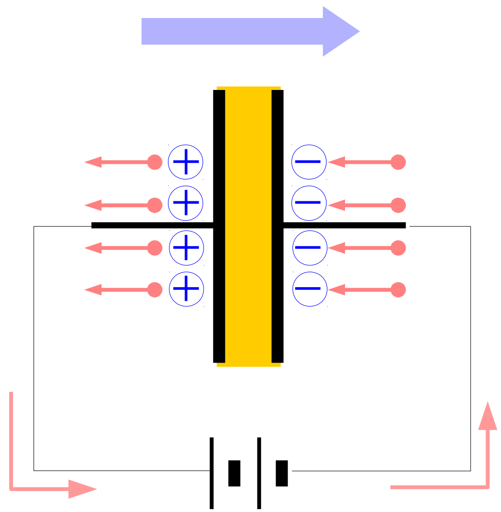


electron flow direction

Initial large current

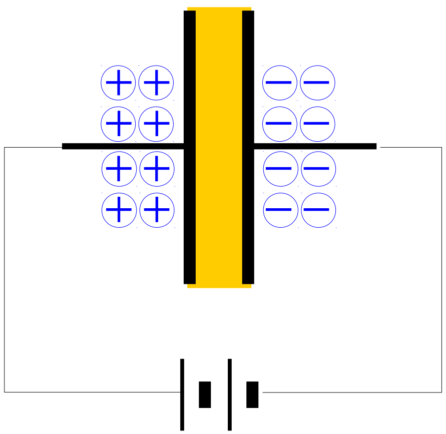
Under Positively Charging

(+) current flow direction



electron flow direction

Positively Charged State



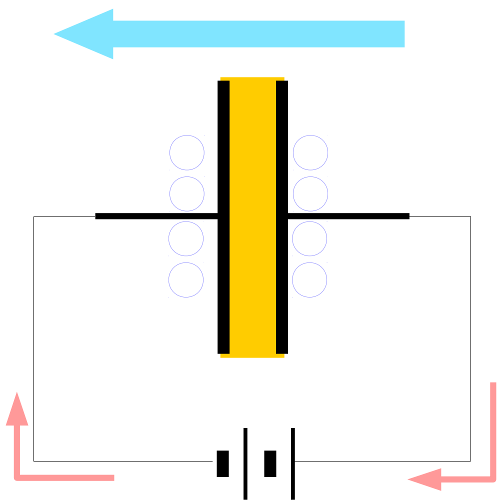
Crowded →
No more space

no current

Inter-State Current Flowing

Fully Discharged State

(–) current flow direction

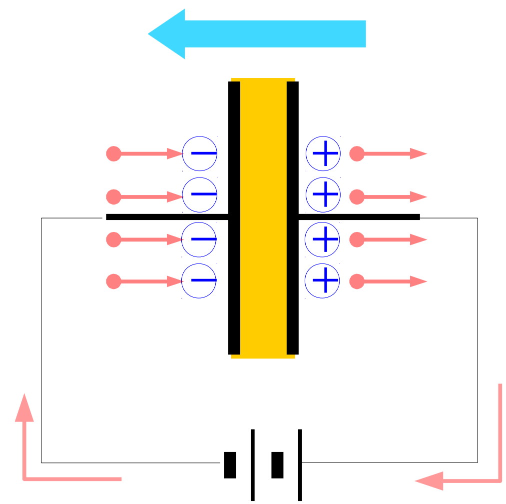


electron flow direction

Initial large current

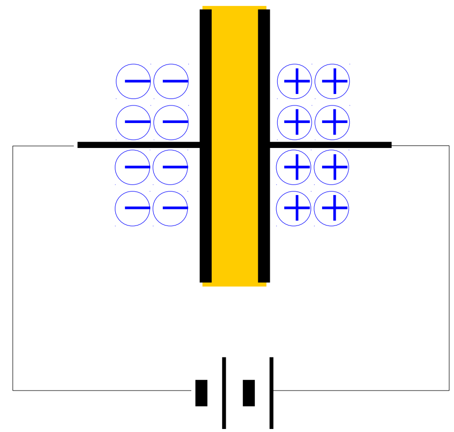
Under Negatively Charging

(–) current flow direction



electron flow direction

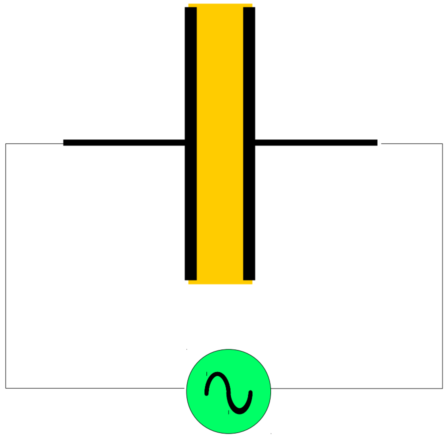
Negatively Charged State

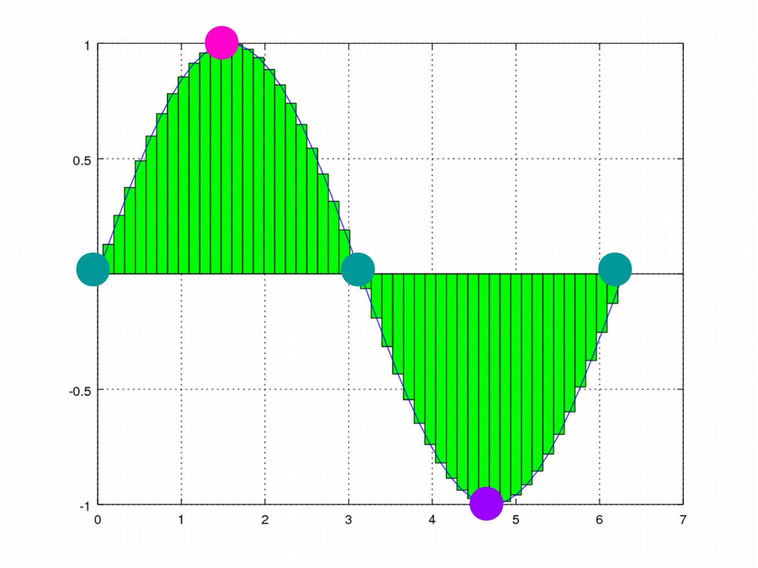


Crowded →
No more space

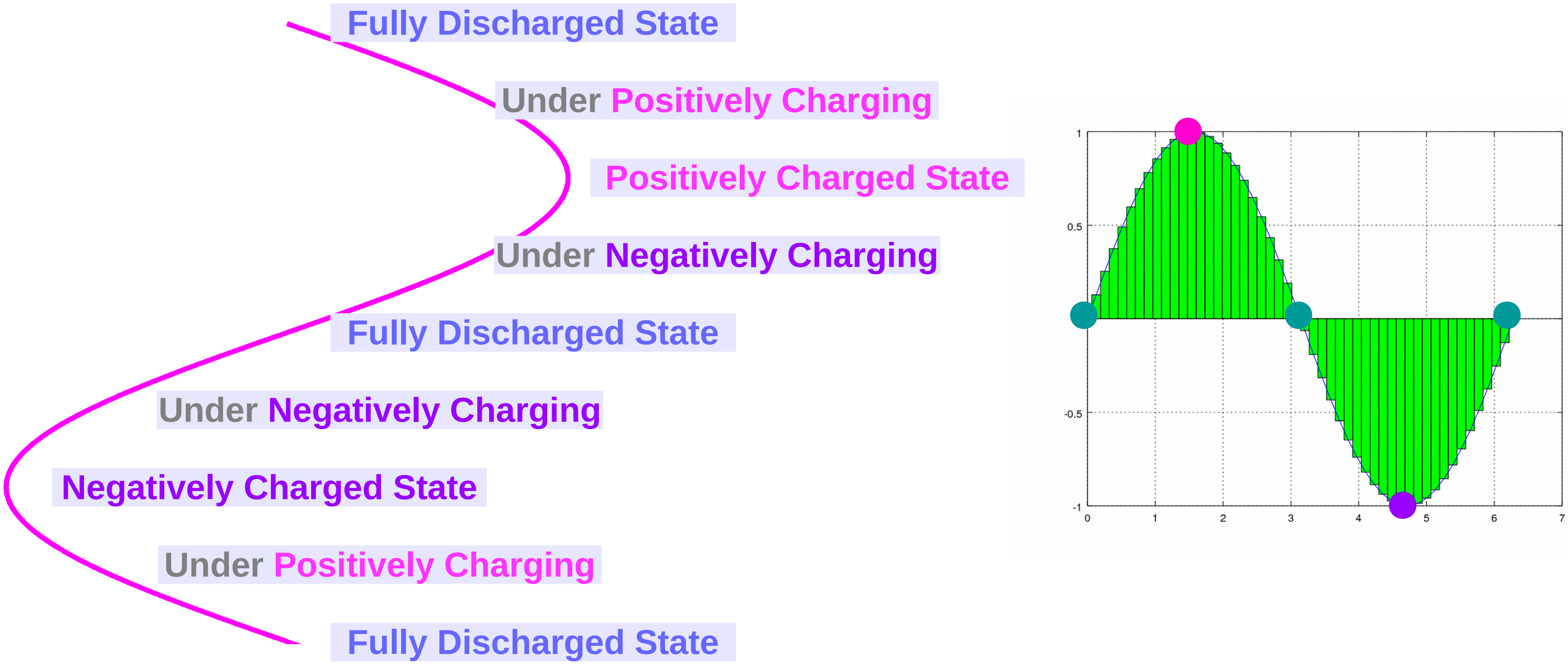
no current

An AC Voltage Source



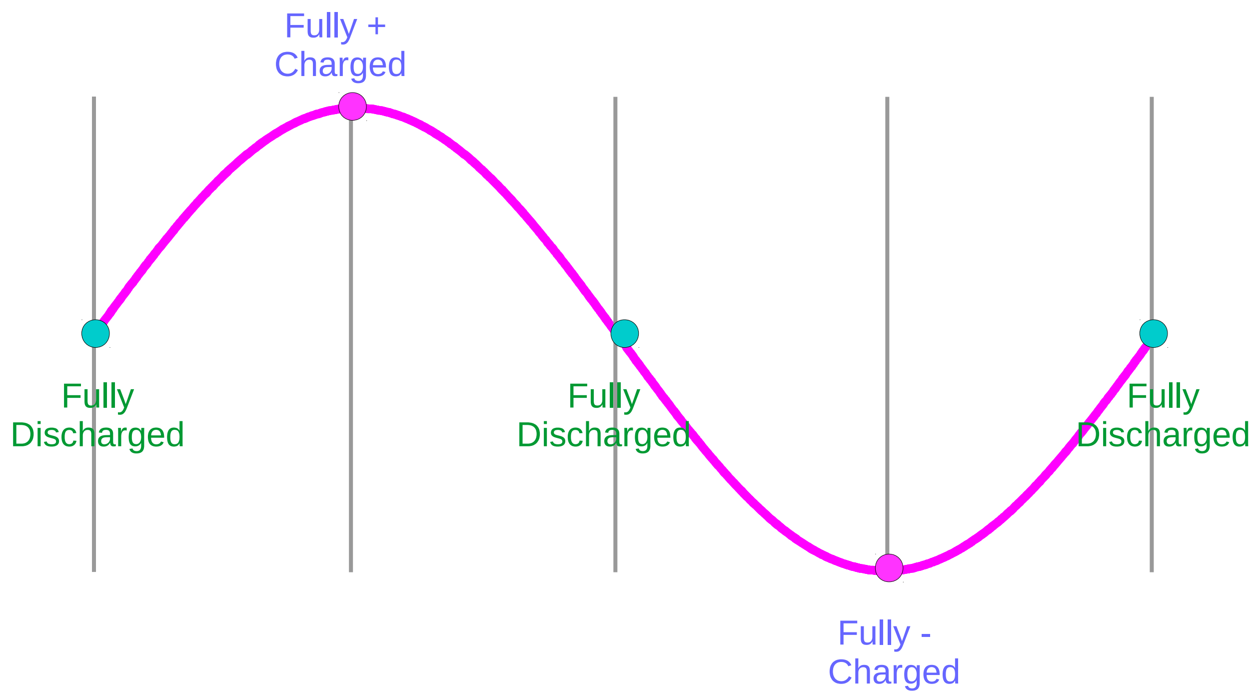


An AC Voltage Source



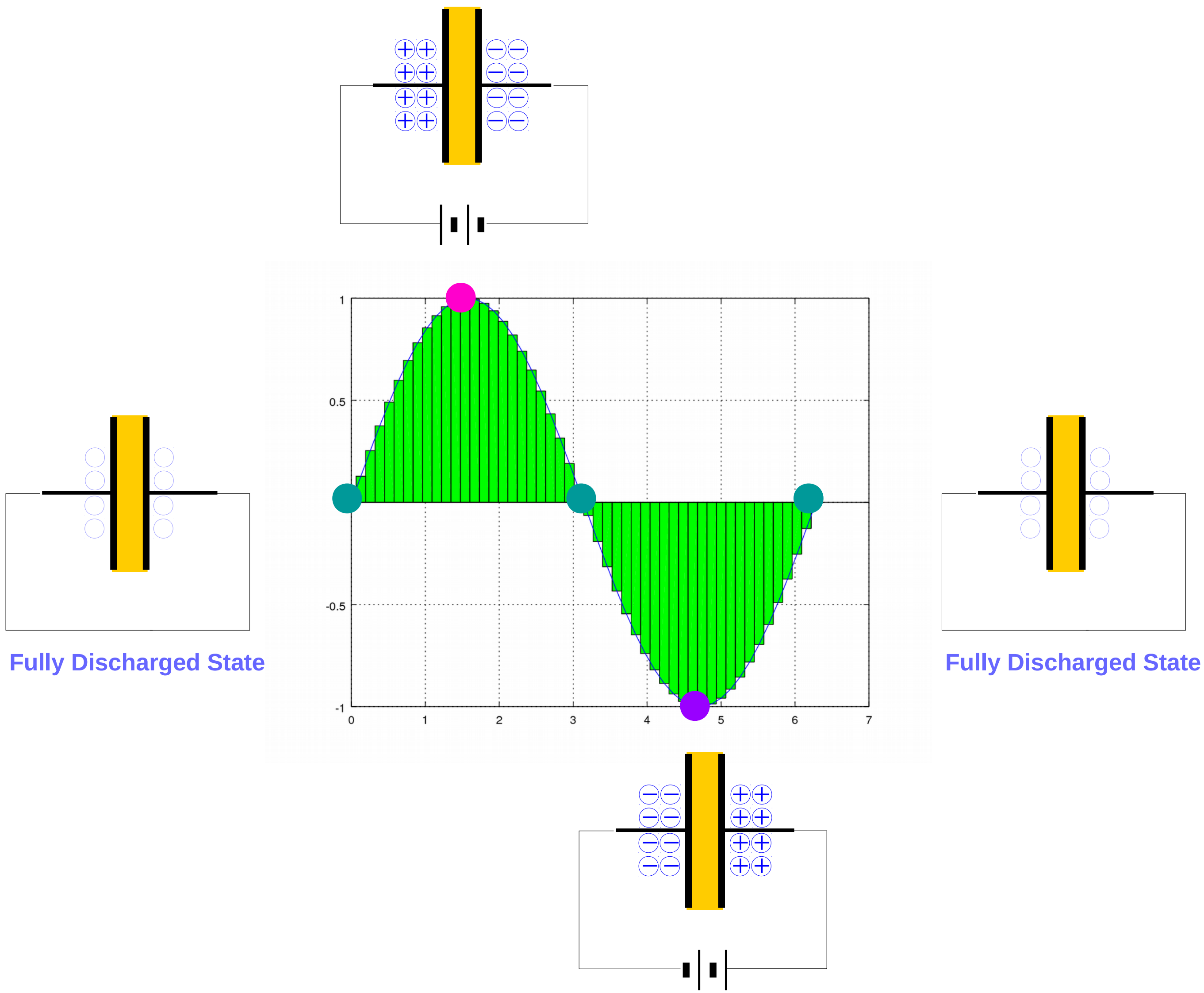
Young Won Lim
07/27/2017

Fully Charged and Fully Discharged



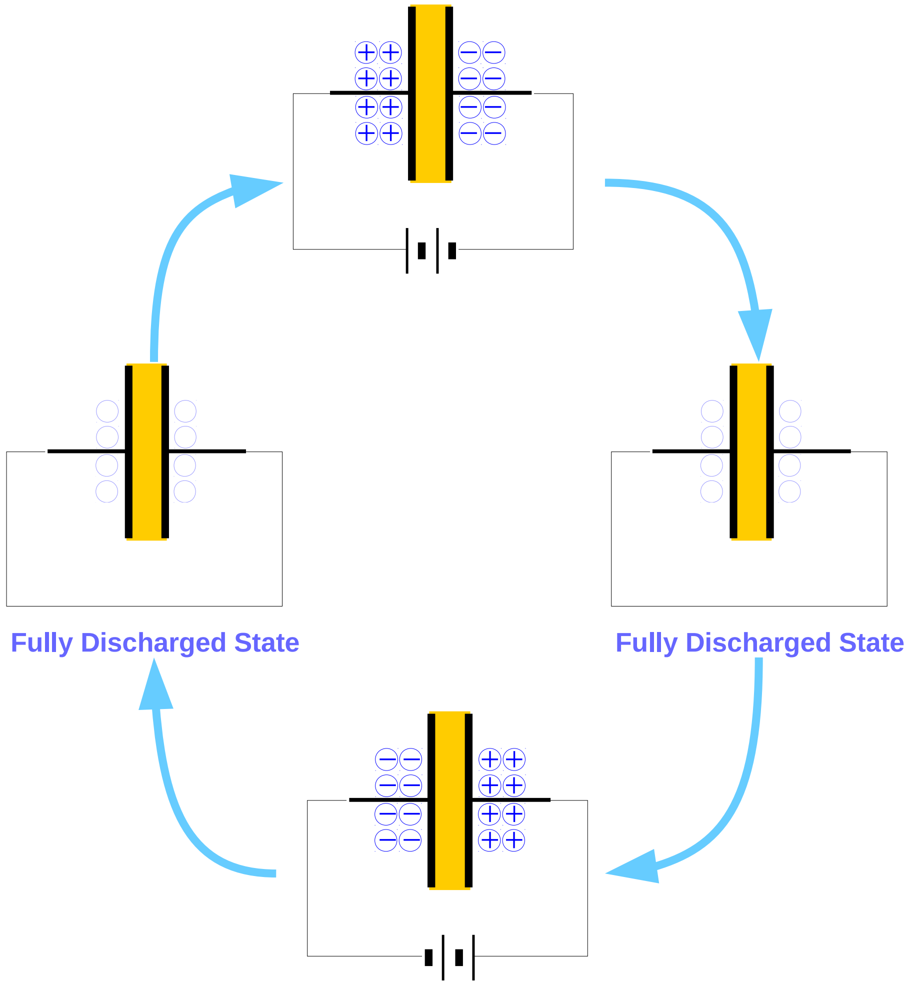
(+) Charging	(–) Charging	(–) Charging	(+) Charging
(+) current	(–) current	(–) current	(+) current
(+) Charging	(+) **Dis**charging	(–) Charging	(–) **Dis**charging

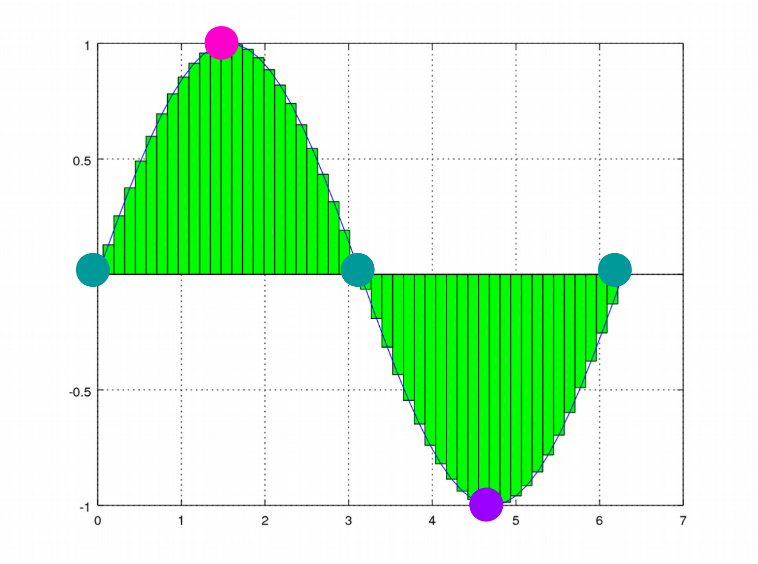
A Cycle



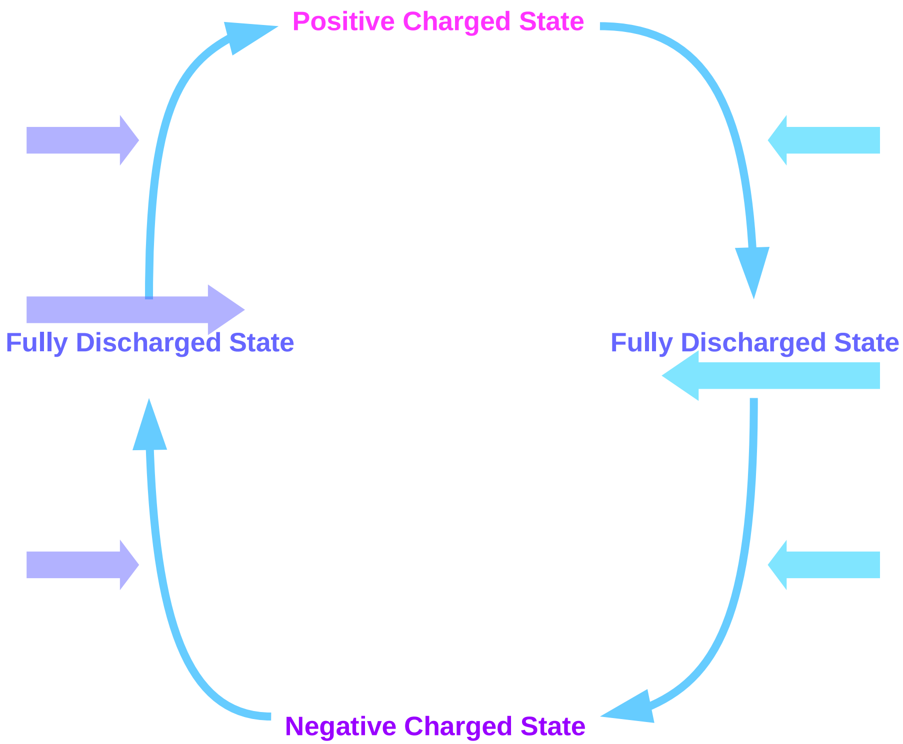
Fully Discharged State
Fully Discharged State
1
0.5
-0.5
-1
0
1
2
3
4
5
6
7

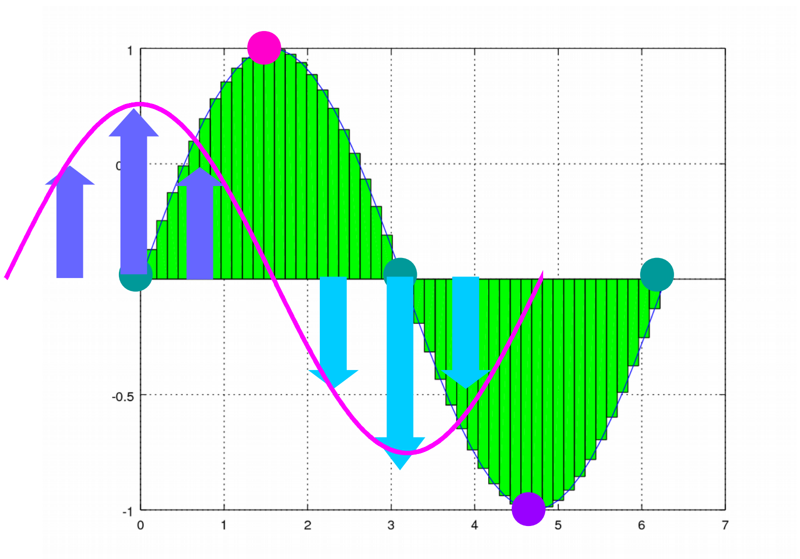
State Transition Diagram





Current Flow

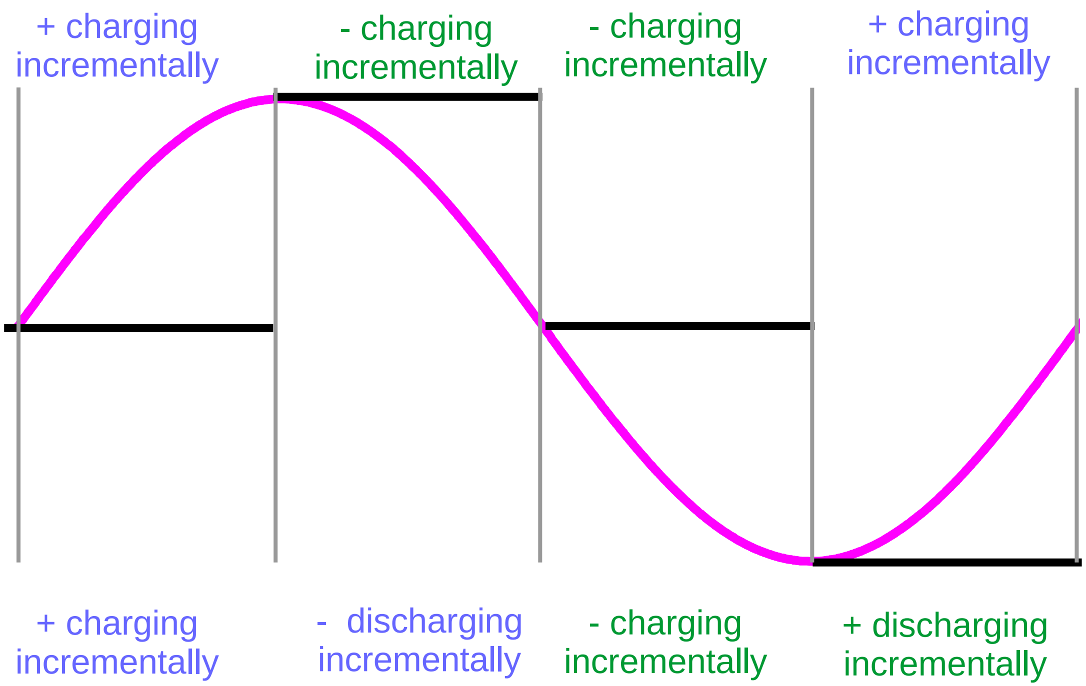




Continuous Charing and Discharging Operations

Incremental Voltage Increment ➡ **+ Charging incrementally**

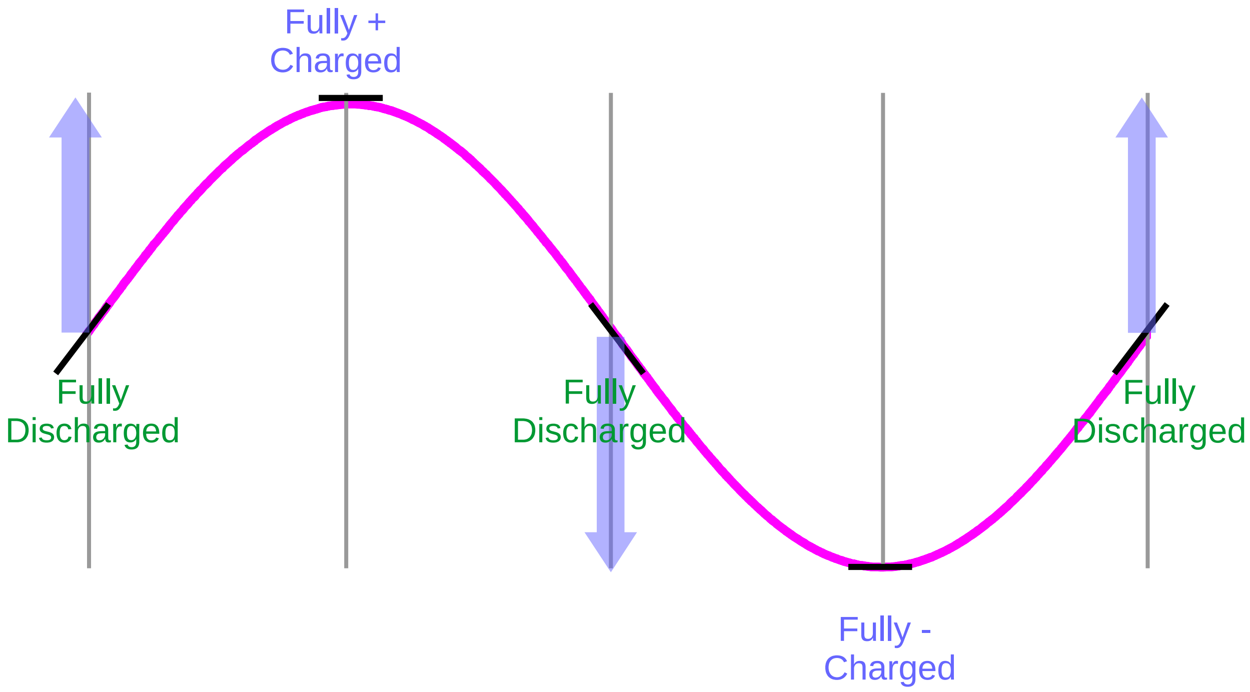
Incremental Voltage Decrement ➡ **– Charging incrementally**



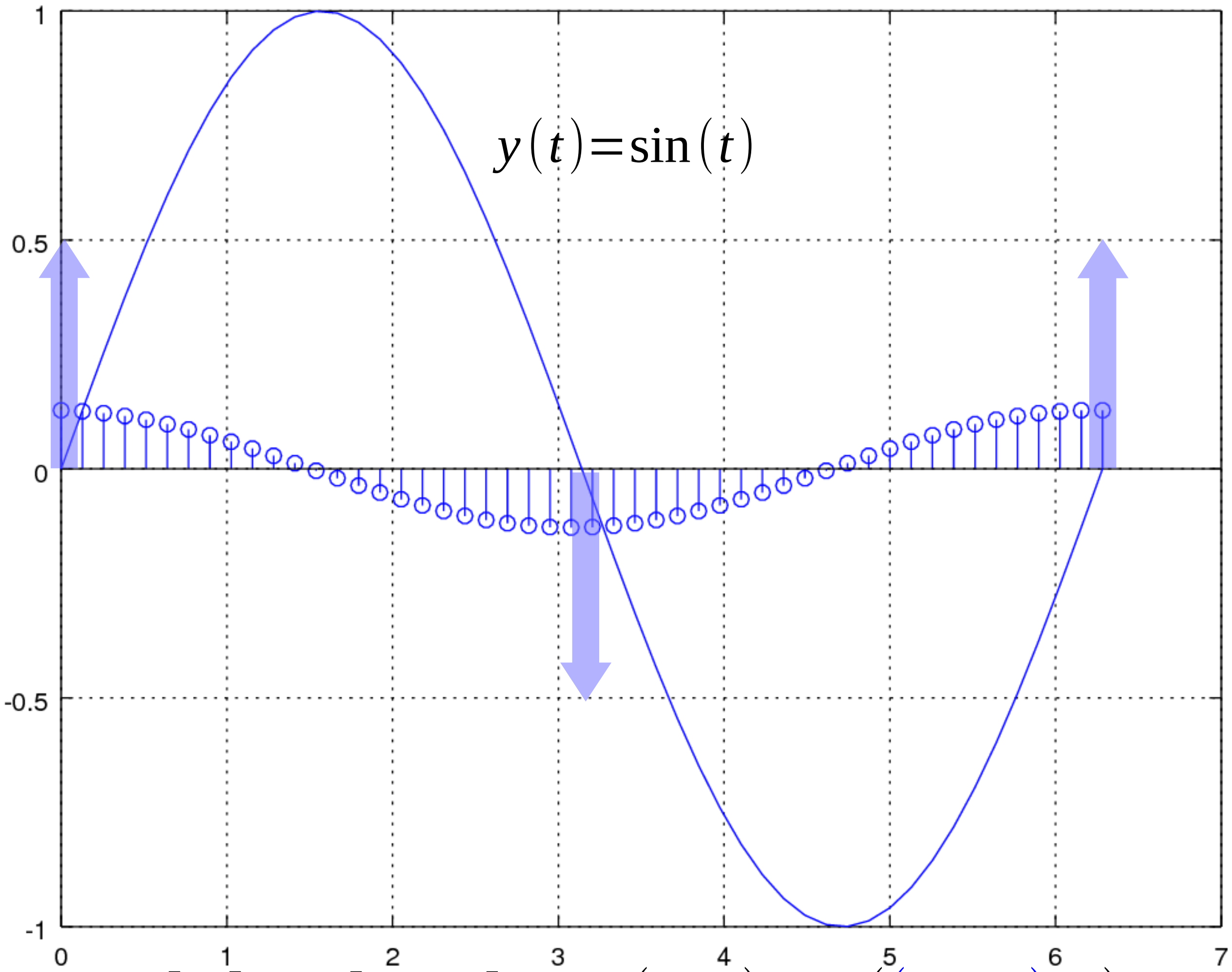
Fully Discharged : Large Current

Incremental Voltage Increment ➡ **Continuous Charging**

Incremental Voltage Decrement ➡ **Continuous Discharging**



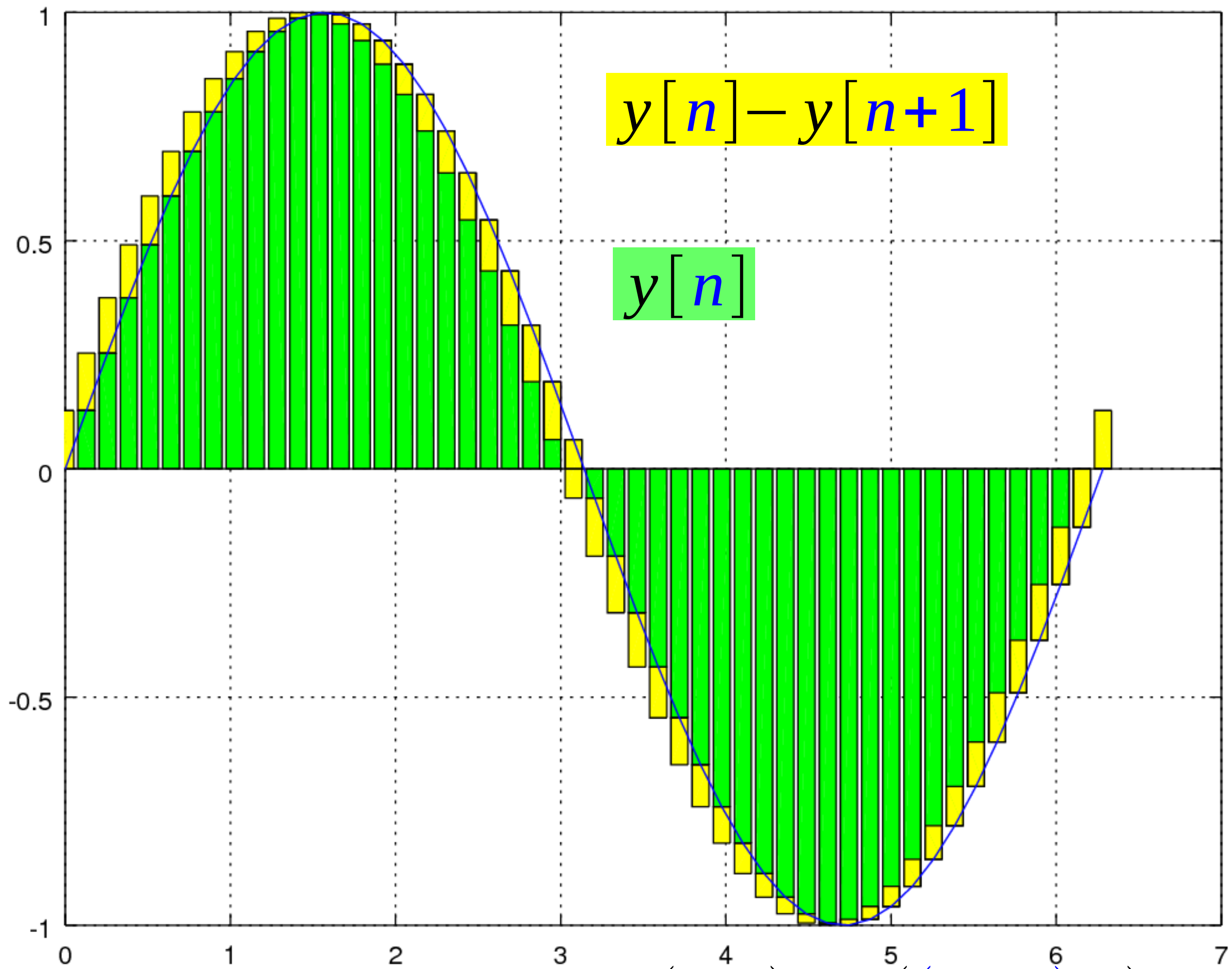
y[n+1] – y[n]




```
t = linspace(0, pi*2, 50);
t1 = t;
t2 = t + t(2);
y1 = sin(t1);
y2 = sin(t2) - sin(t1);
stem(t1, y2)
hold on
plot(t1, y1)
```

$$y[n] - y[n+1] = y(nT) - y((n+1)T) = \sin(nT) - \sin((n+1)T)$$

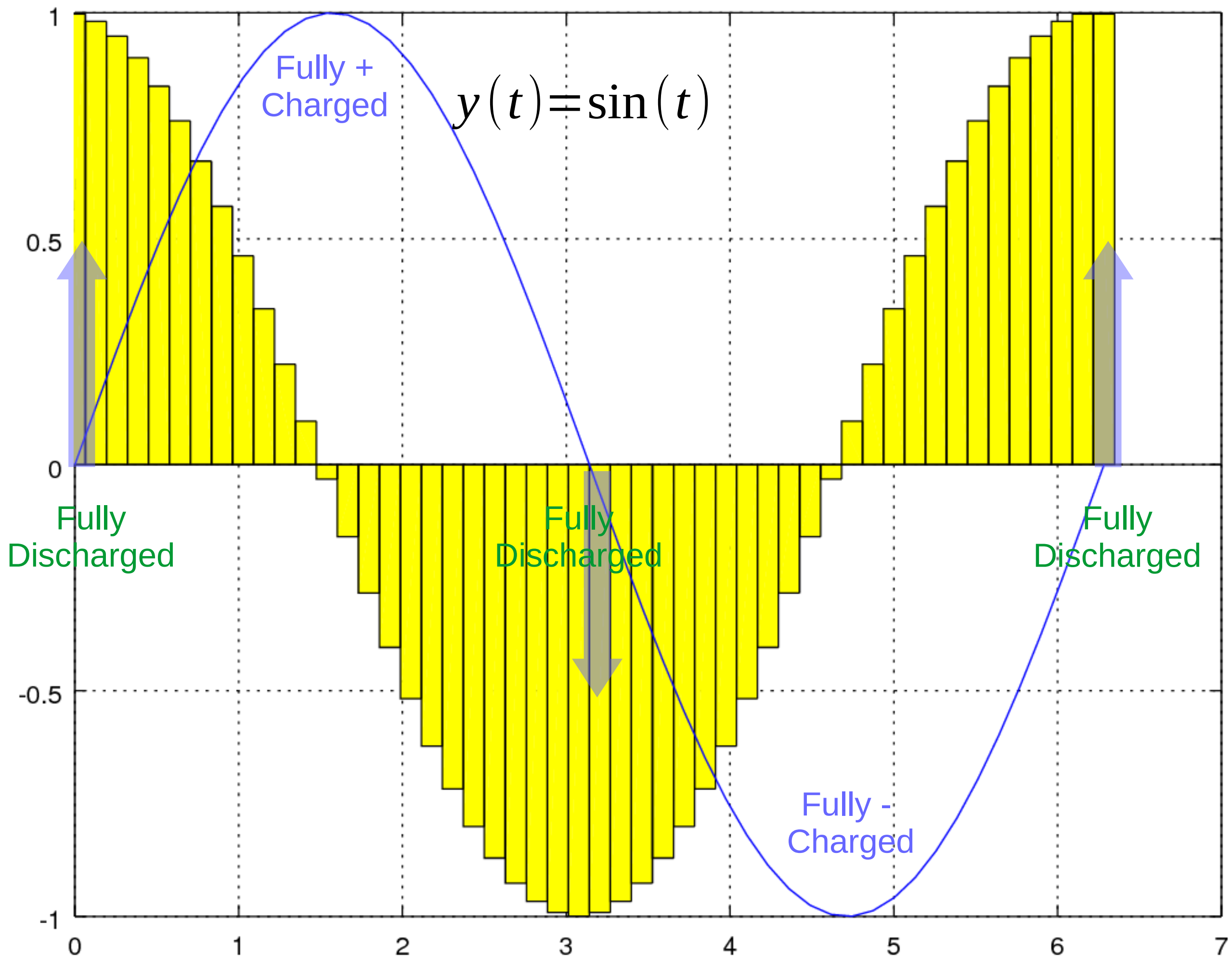
Fully Charged and Fully Discharged




```
h = bar(t1, [y1' y2'], "stacked")
set(h(1), "facecolor", "g");
set(h(2), "facecolor", "y");
hold on
plot(t1, y1)
axis([0 7 -1 1]);
```

$$y[n]-y[n+1] = y(nT)-y((n+1)T)=\sin(nT)-\sin((n+1)T)$$

Fully Charged and Fully Discharged

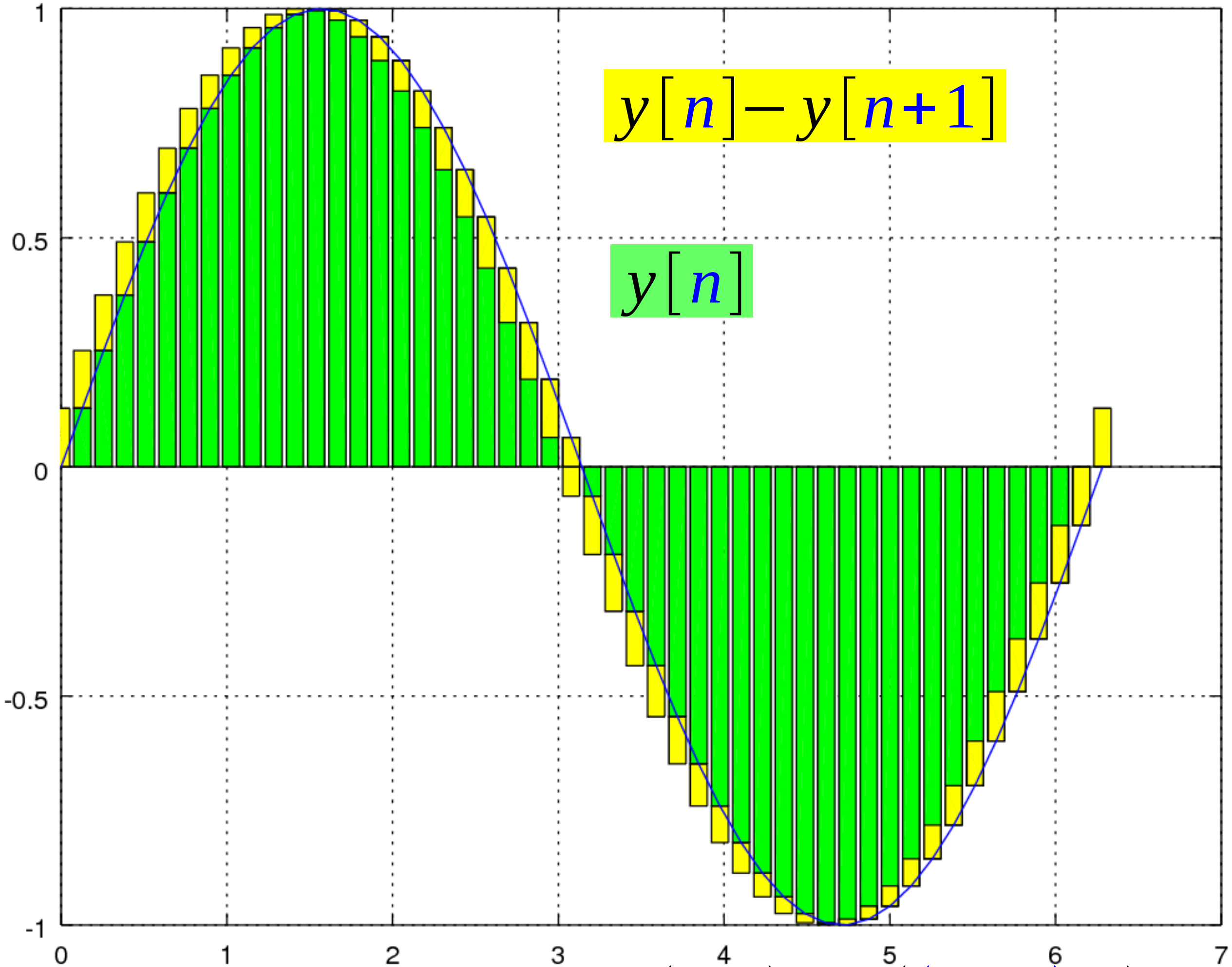



```
h = bar(t1, y2/t(2), "hist")
set(h(1), "facecolor", "y");
hold on
plot(t1, y1)
axis([0 7 -1 1]);
```

$$\frac{y[n] - y[n+1]}{T}$$

$$\propto \frac{dy}{dt}$$

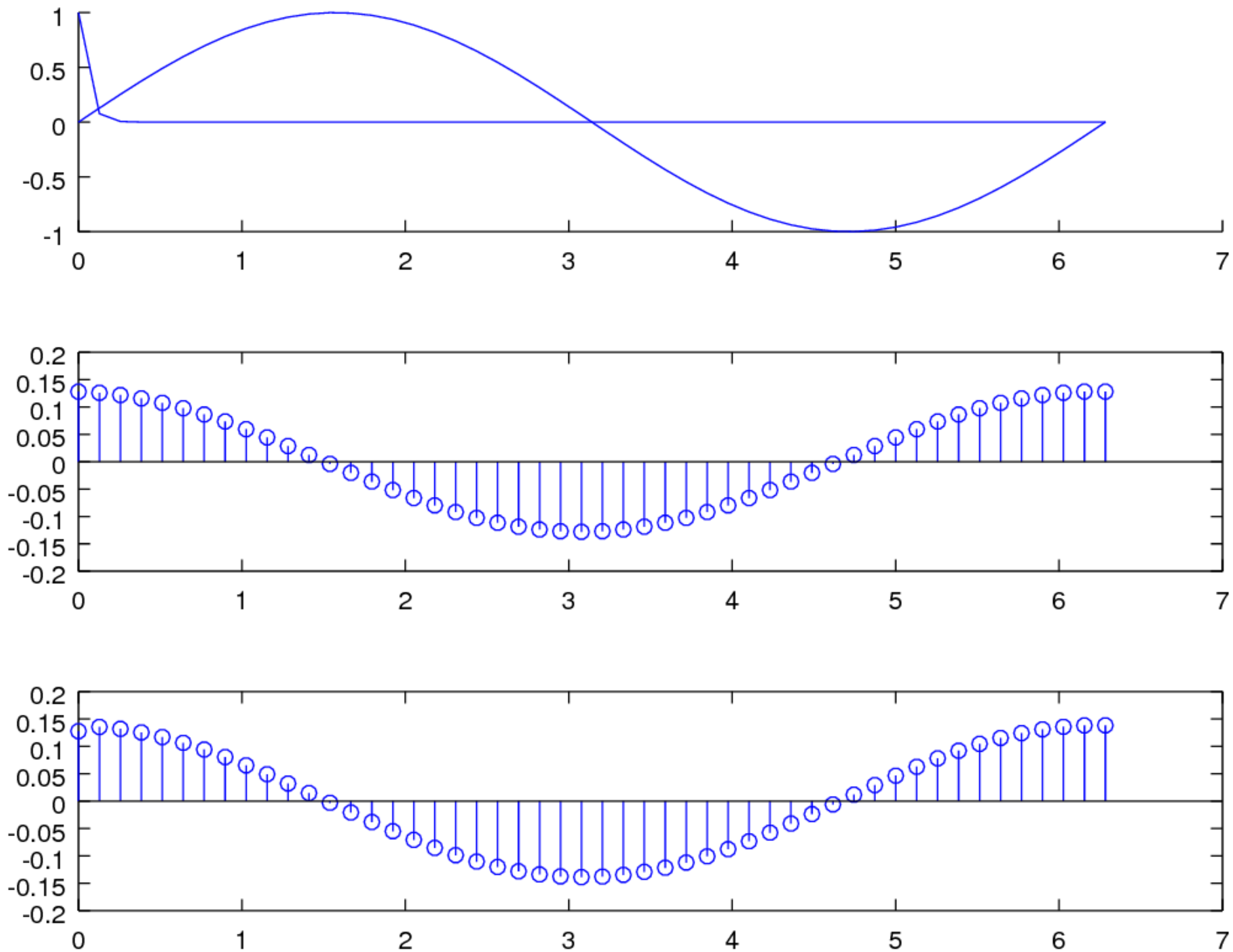
Fully Charged and Fully Discharged




```
h = bar(t1, [y1' y2'], "stacked")
set(h(1), "facecolor", "g");
set(h(2), "facecolor", "y");
hold on
plot(t1, y1)
axis([0 pi]);
```

$$y[n]-y[n+1] = y(nT)-y((n+1)T)=\sin(nT)-\sin((n+1)T)$$

Fully Charged and Fully Discharged

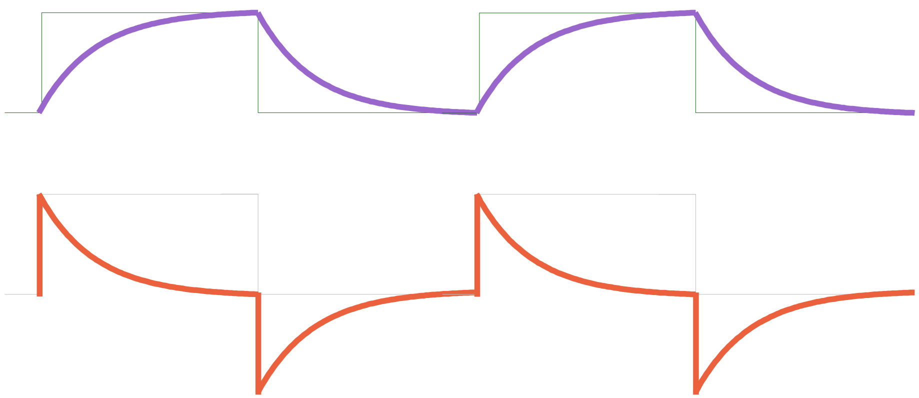



```
clf
t = linspace(0, pi*2, 50);
t1 = t;
t2 = t + t(2);
y1 = sin(t1);
y2 = sin(t2) - sin(t1);
y3 = e.^(-20*t);
y4 = conv(y2, y3);
y5 = y4([1:length(t1)]);

subplot(3, 1, 2);
stem(t1, y2)
subplot(3, 1, 1);
hold on
plot(t1, y1);
plot(t1, y3);
subplot(3, 1, 3);
stem(t1, y5);
```

Pulse

v_C

i_C

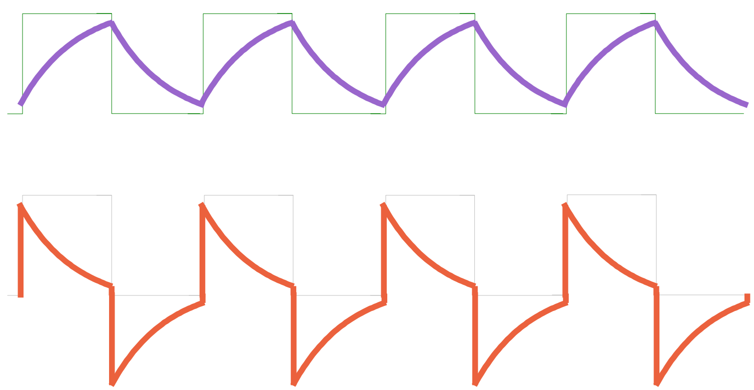


$$i_C = C \frac{d\,v_C}{d\,t}$$

ω ↑ i_c ↑ X_c ↓

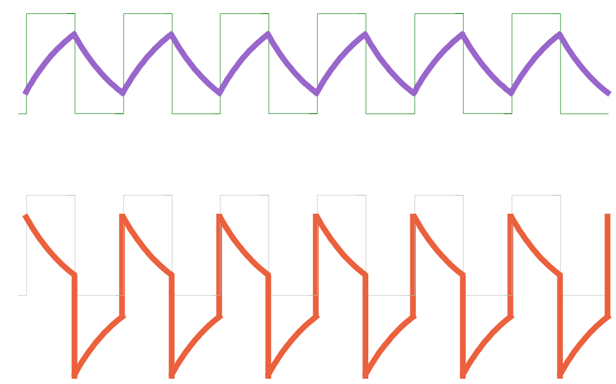
v_C

i_C

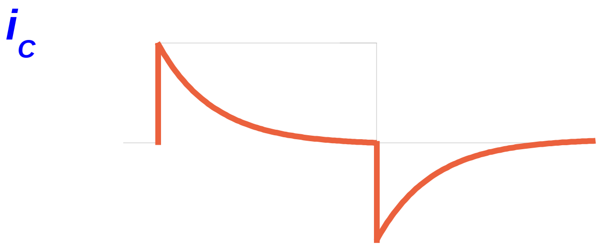


v_C

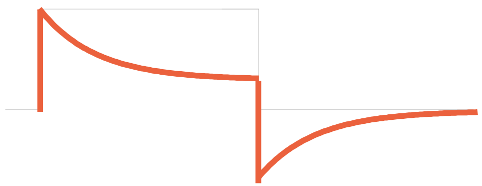
i_C



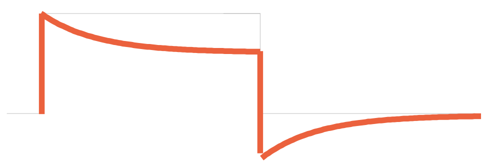
Time Constants



$\tau = RC$ *small time constant*



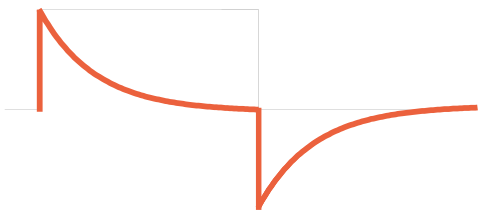
$\tau = RC$ *medium time constant*



$\tau = RC$ *large time constant*

Time Constants

i_c



$$\tau = RC$$

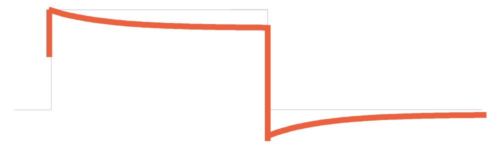
$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$

$small\ \tau$

$small\ C$

$$large\ \frac{1}{\omega C} \gg R$$

Fully Capacitative



$$\tau = RC$$

$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$

$large\ \tau$

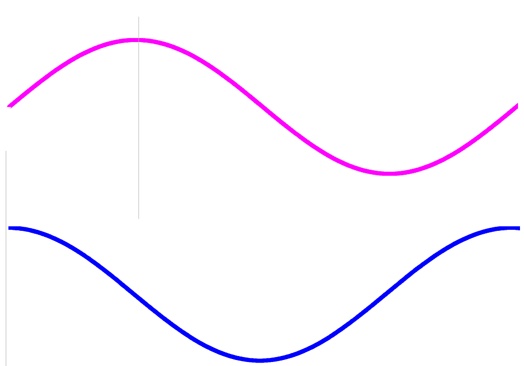
$large\ C$

$$small\ \frac{1}{\omega C} \ll R$$

Fully Resistive

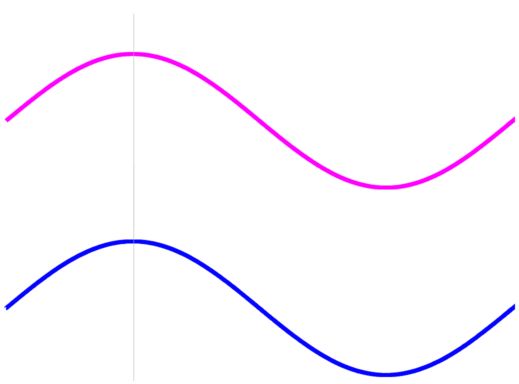
$v_C(t)$

$i_C(t)$

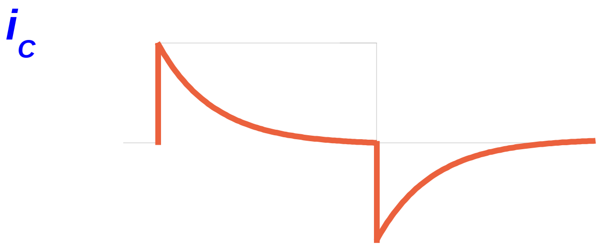


$v_C(t)$

$i_C(t)$



Time Constants



$$\tau = RC$$

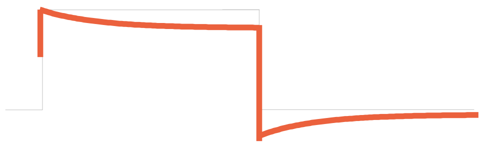
$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$

small τ

small C

large $\frac{1}{\omega C} \gg R$

Fully Capacitative



$$\tau = RC$$

$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$

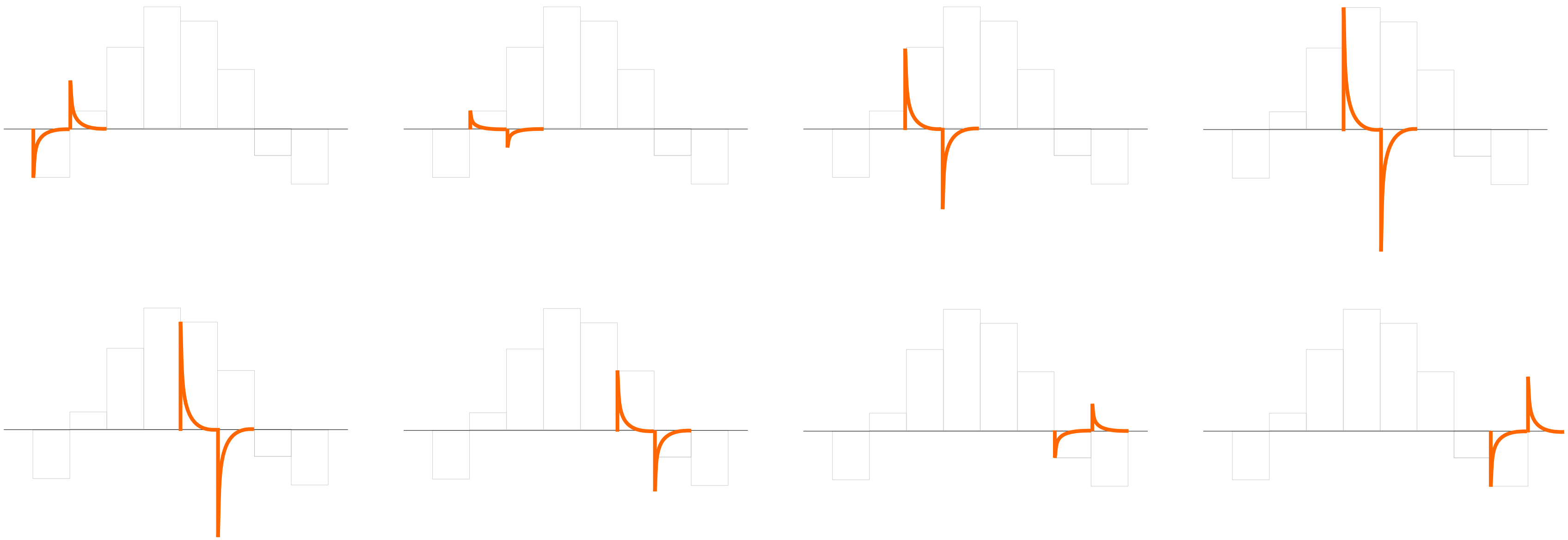
large τ

large C

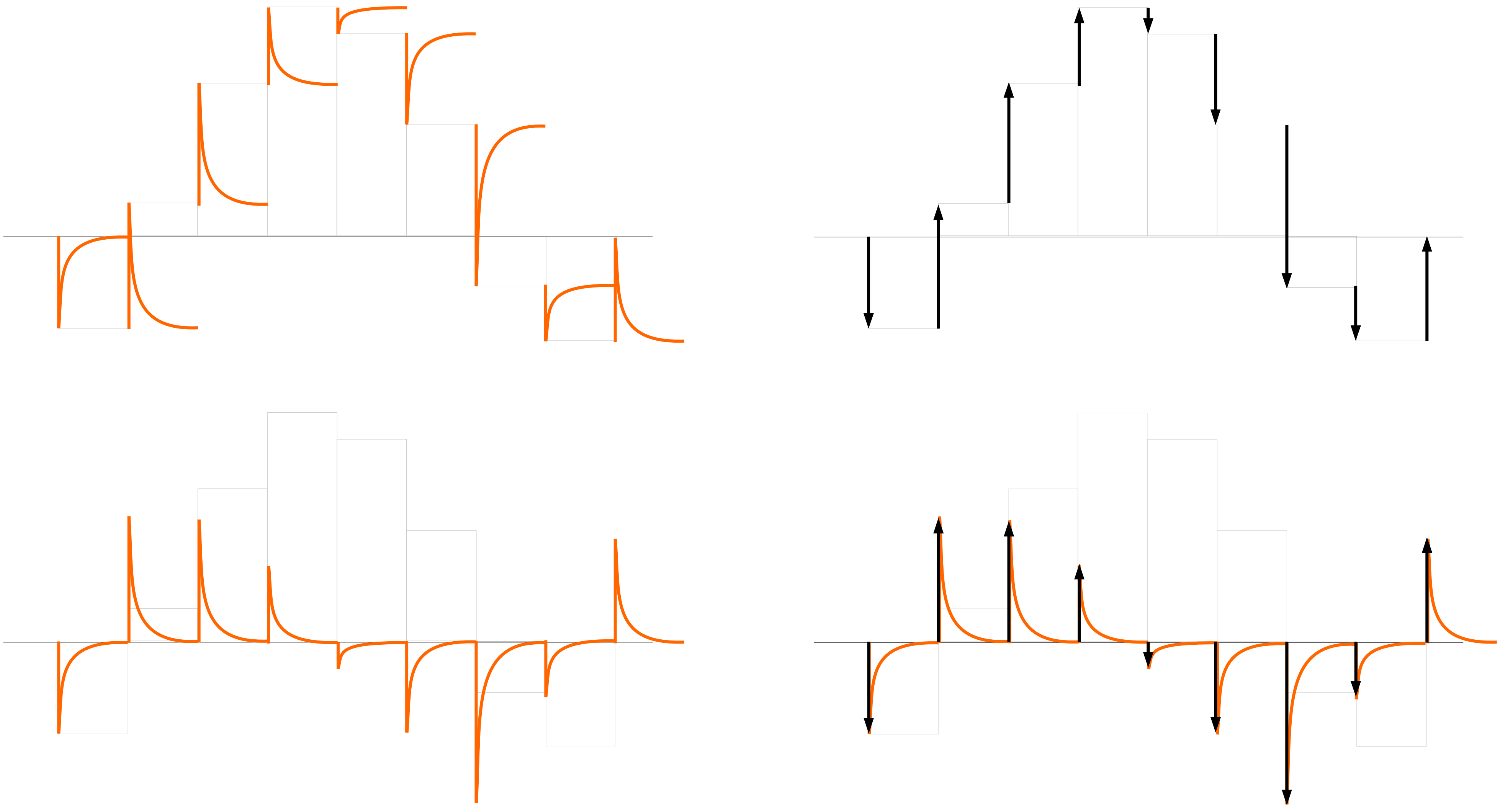
small $\frac{1}{\omega C} \ll R$

Fully Resistive

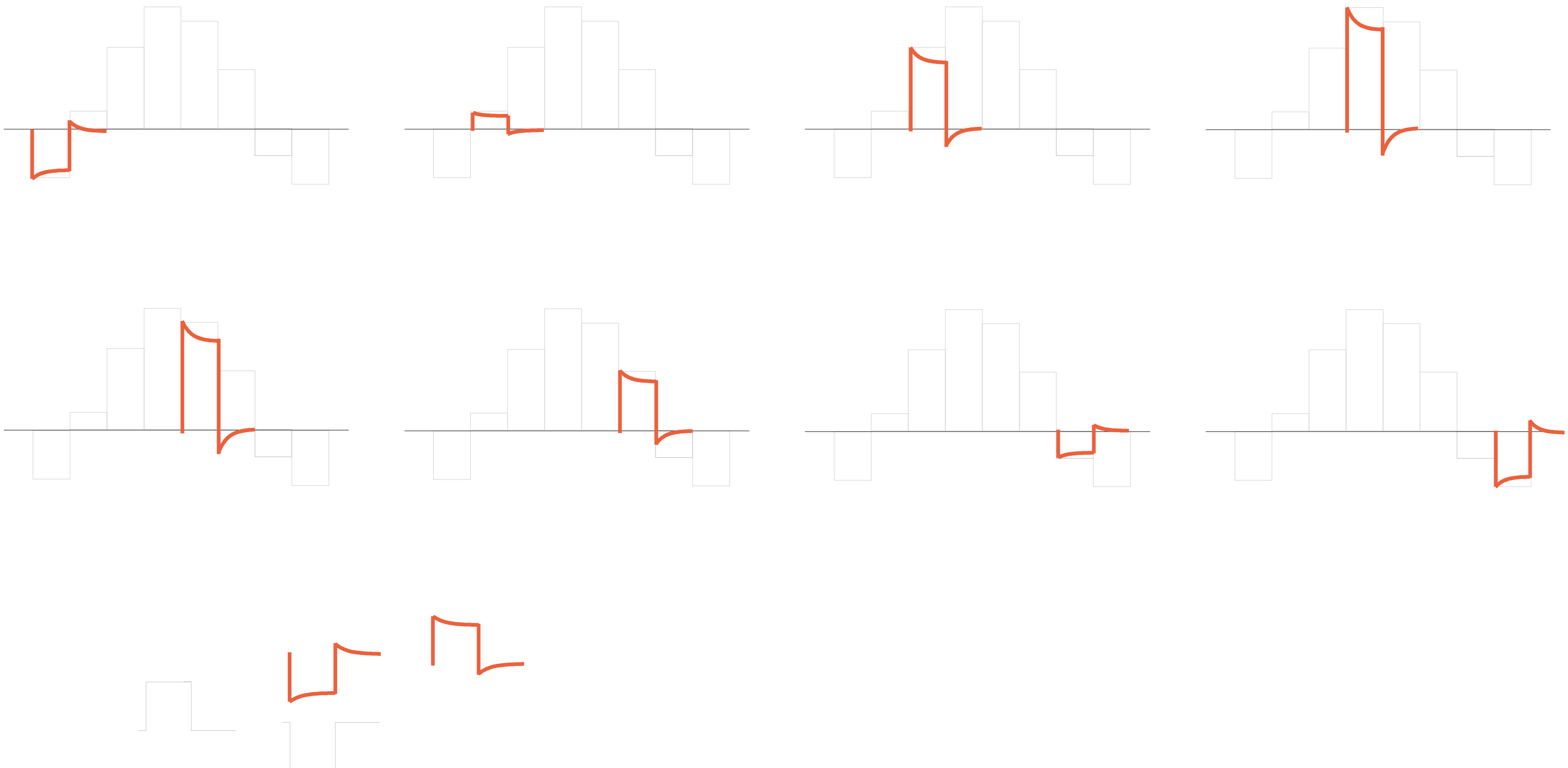
Superposition - Small Time Constant



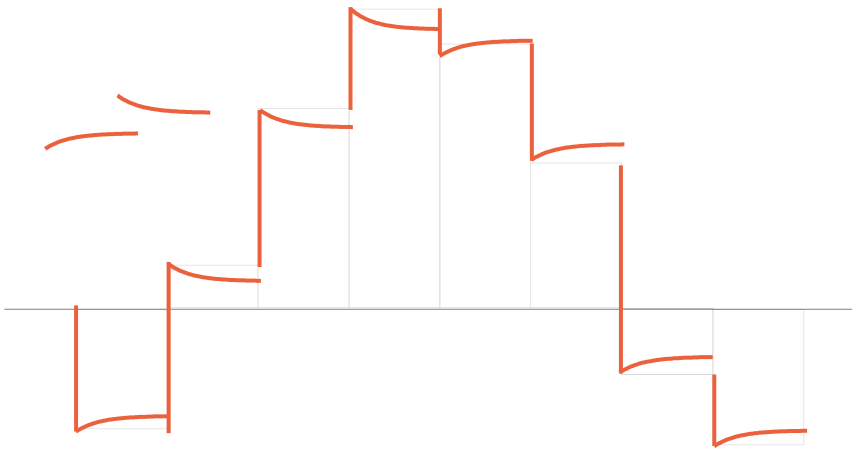
Small Time Constants

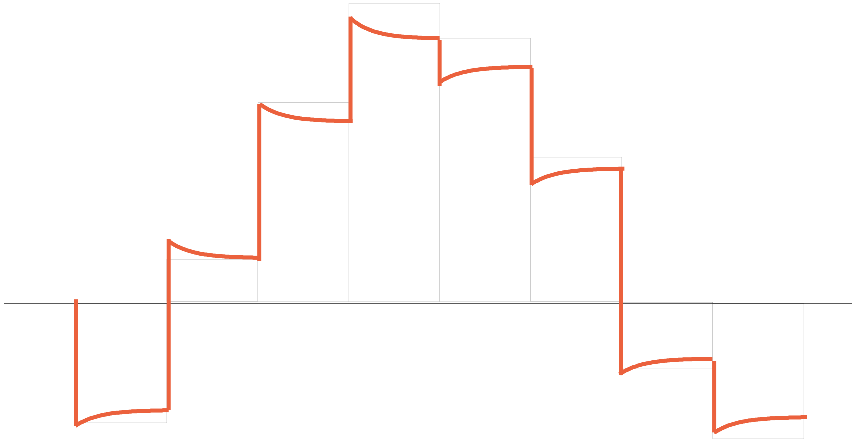


Superposition – Large Time Constant



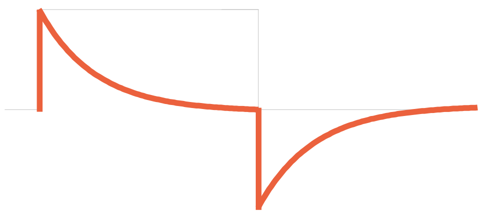
Large Time Constants





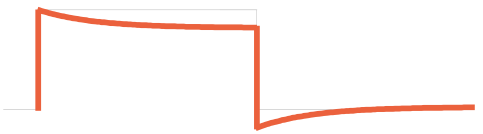
Time Constants

i_C



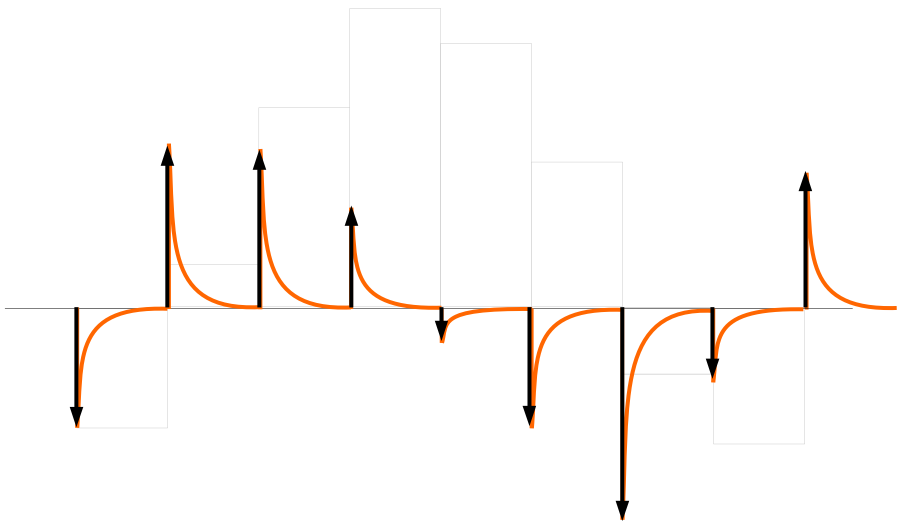
$$\tau = RC$$

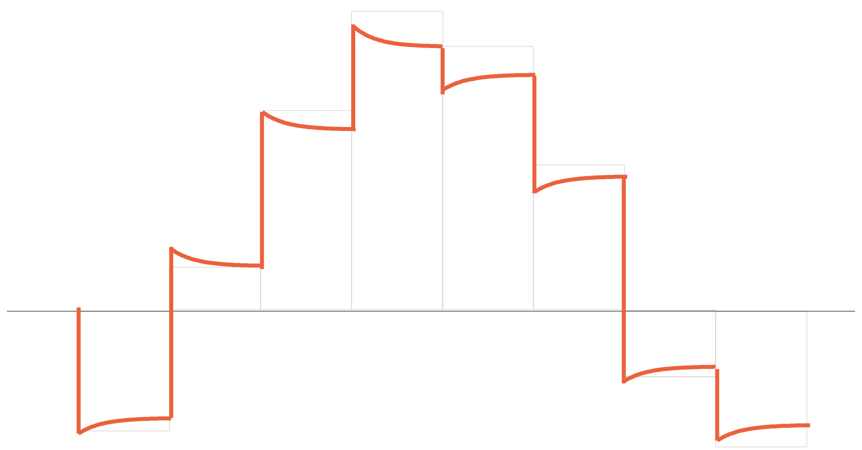
$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$



$$\tau = RC$$

$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$





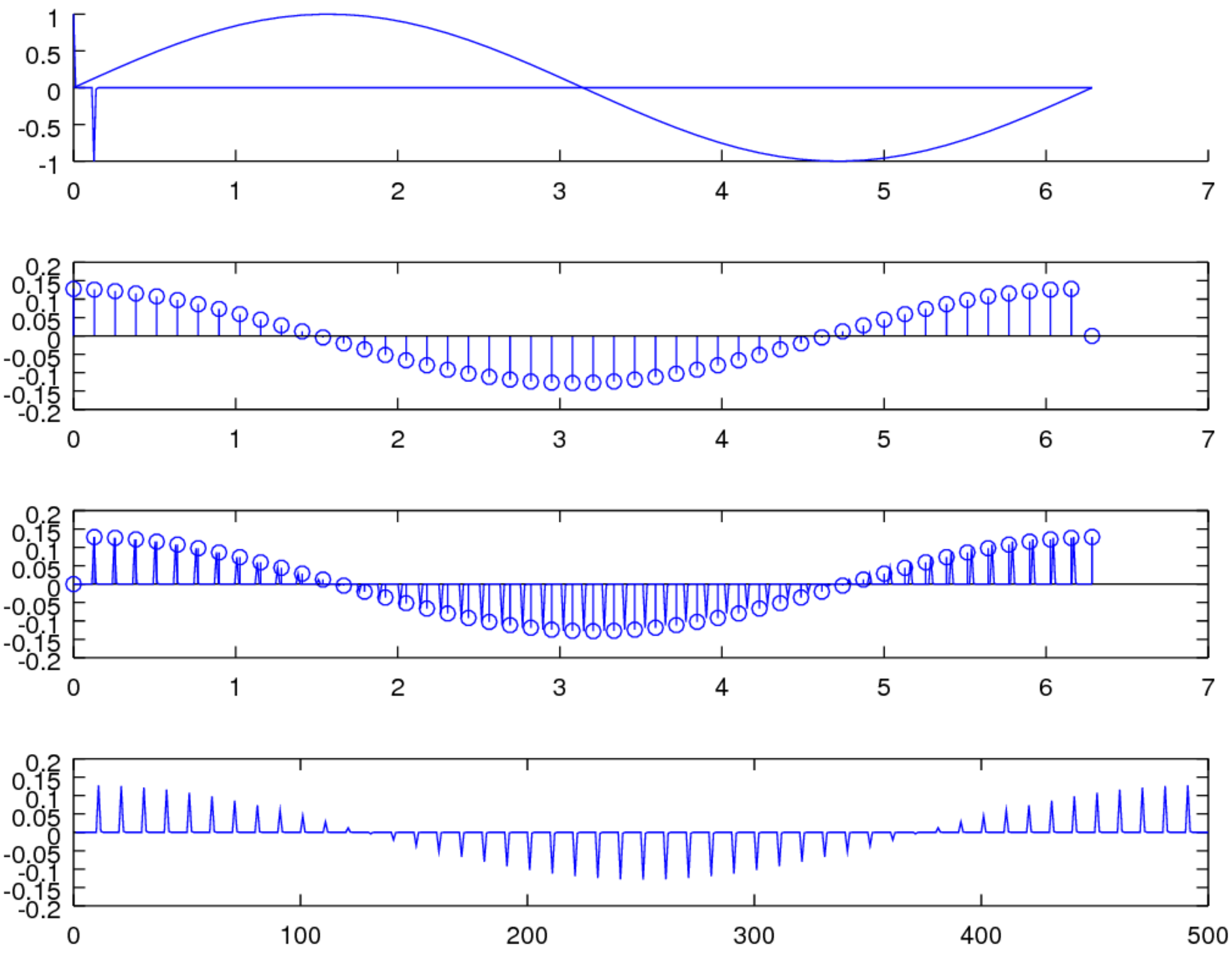
Fully Charged and Fully Discharged

```
clf
t = linspace(0, pi*2, 50);
tt= linspace(0, pi*2, 500);
N = length(t);
NN= length(tt);

t1 = t;
t2 = [t(2:N), t(N)];
y1 = sin(t1);
y2 = sin(t2) - sin(t1);

yy = [y1; zeros(NN/N-1, N)];
yy2= yy(:)';
a = 1/300;
yy3= e.^(-a*tt);
yy3 =yy3 - [zeros(1, NN/N),
e.^(-a*tt)](1:NN);
```

```
svec = zeros(1, NN);
for i = 1:NN;
  tvec = zeros(1, NN);
  tvec = [zeros(1, i-1), yy3];
  tvec = yy2(i) * tvec(1:NN);
  svec = svec + tvec;
endfor
yy4 = svec;
% yy4= conv(yy2, yy3);
y5 = yy4([1:NN/N:NN]);
yy5= yy4([1:NN]);
```

```
subplot(4, 1, 2);
stem(t1, y2)
subplot(4, 1, 1);
hold on
plot(t1, y1);
plot(tt, yy3);
subplot(4, 1, 3);
stem(t1, y5); hold on
plot(tt, yy5)
subplot(4, 1, 4);
plot(yy4);
```

Fully Charged and Fully Discharged




```
yy = [y1;
zeros(NN/N-1, N)];
yy2= yy(:)';
a = 300;
yy3= e.^(-a*tt);
yy3 =yy3 -
[zeros(1, NN/N),
e.^(-a*tt)](1:NN);
```

$$\tau = RC$$

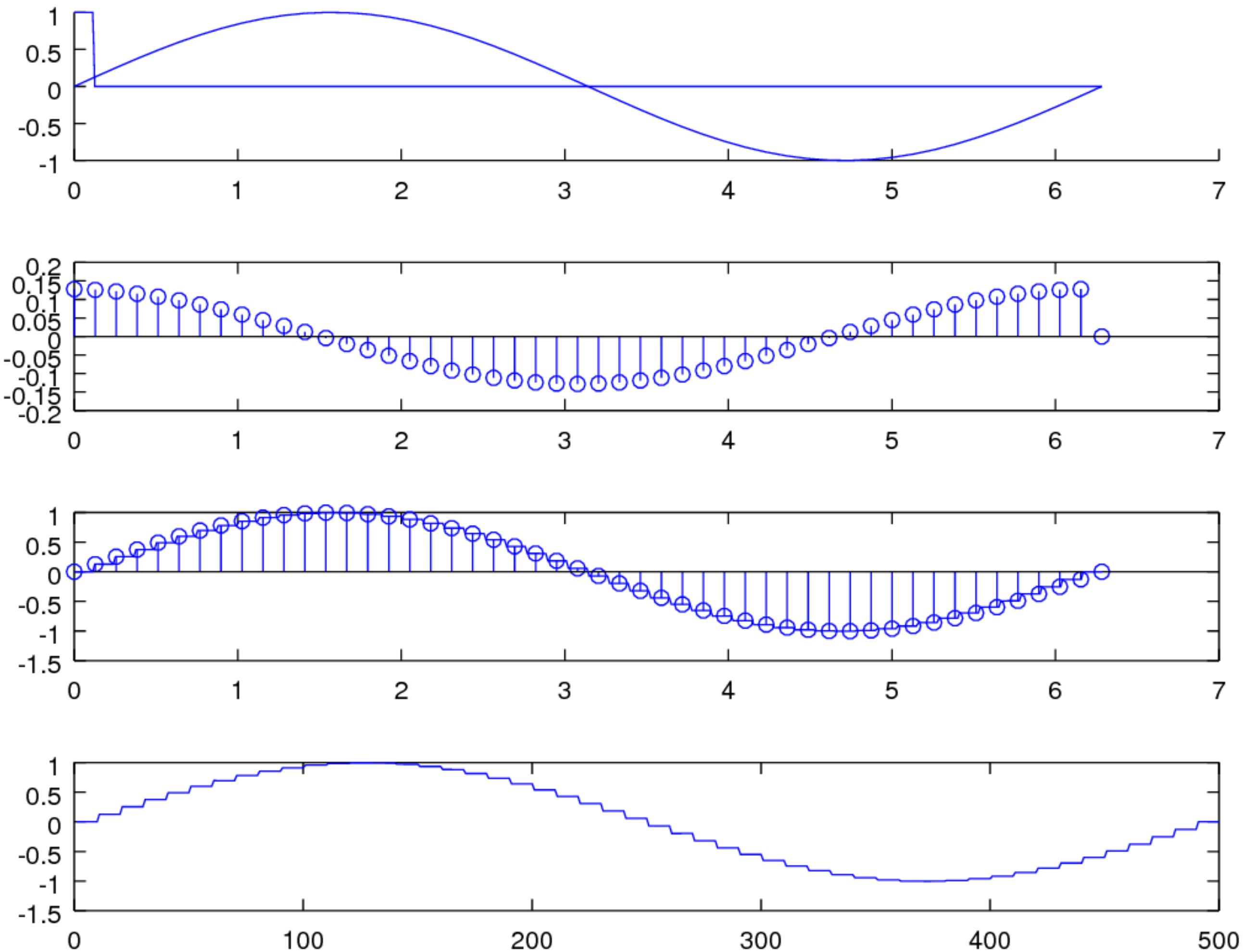
$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$

small τ

small C

large $\frac{1}{\omega C}$

Fully Charged and Fully Discharged




```
yy = [y1;
zeros(NN/N-1, N)];
yy2= yy(:)';
a = 1/300;
yy3= e.^(-a*tt);
yy3 =yy3 -
[zeros(1, NN/N),
e.^(-a*tt)](1:NN);
```

$$\tau = RC$$

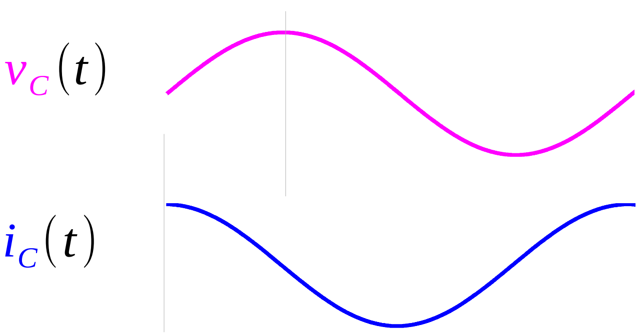
$$e^{-\frac{t}{\tau}} = e^{-\frac{t}{RC}}$$

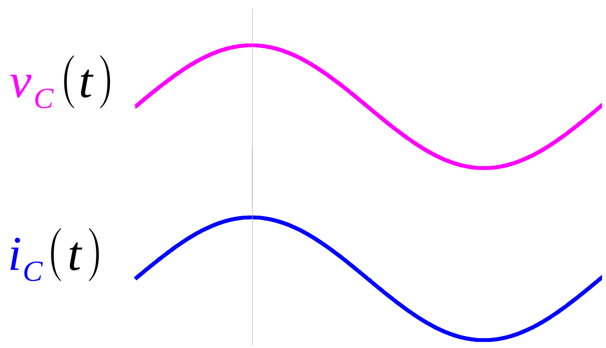
large τ

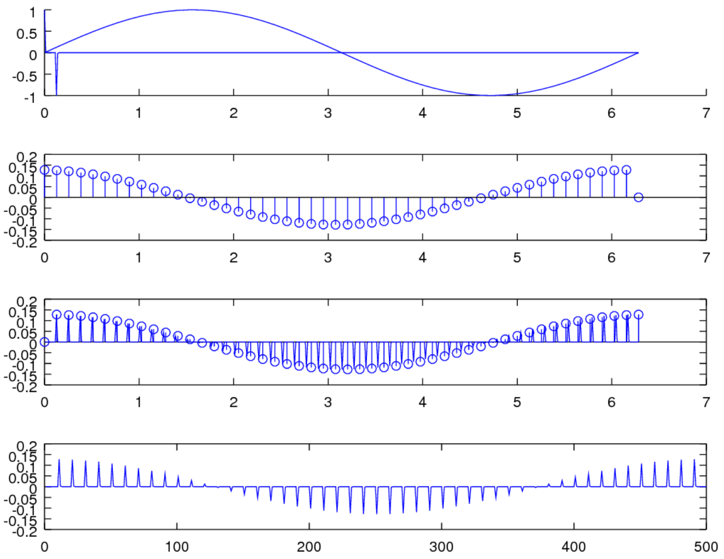
large C

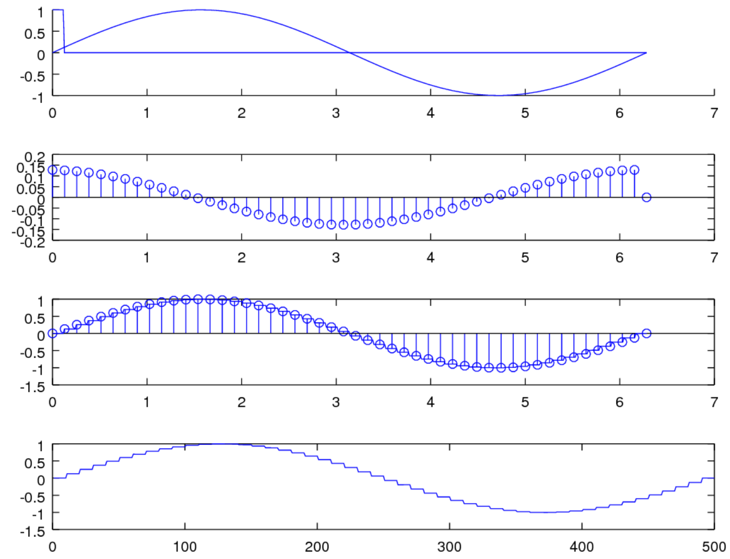
small $\frac{1}{\omega C}$

Time Constants

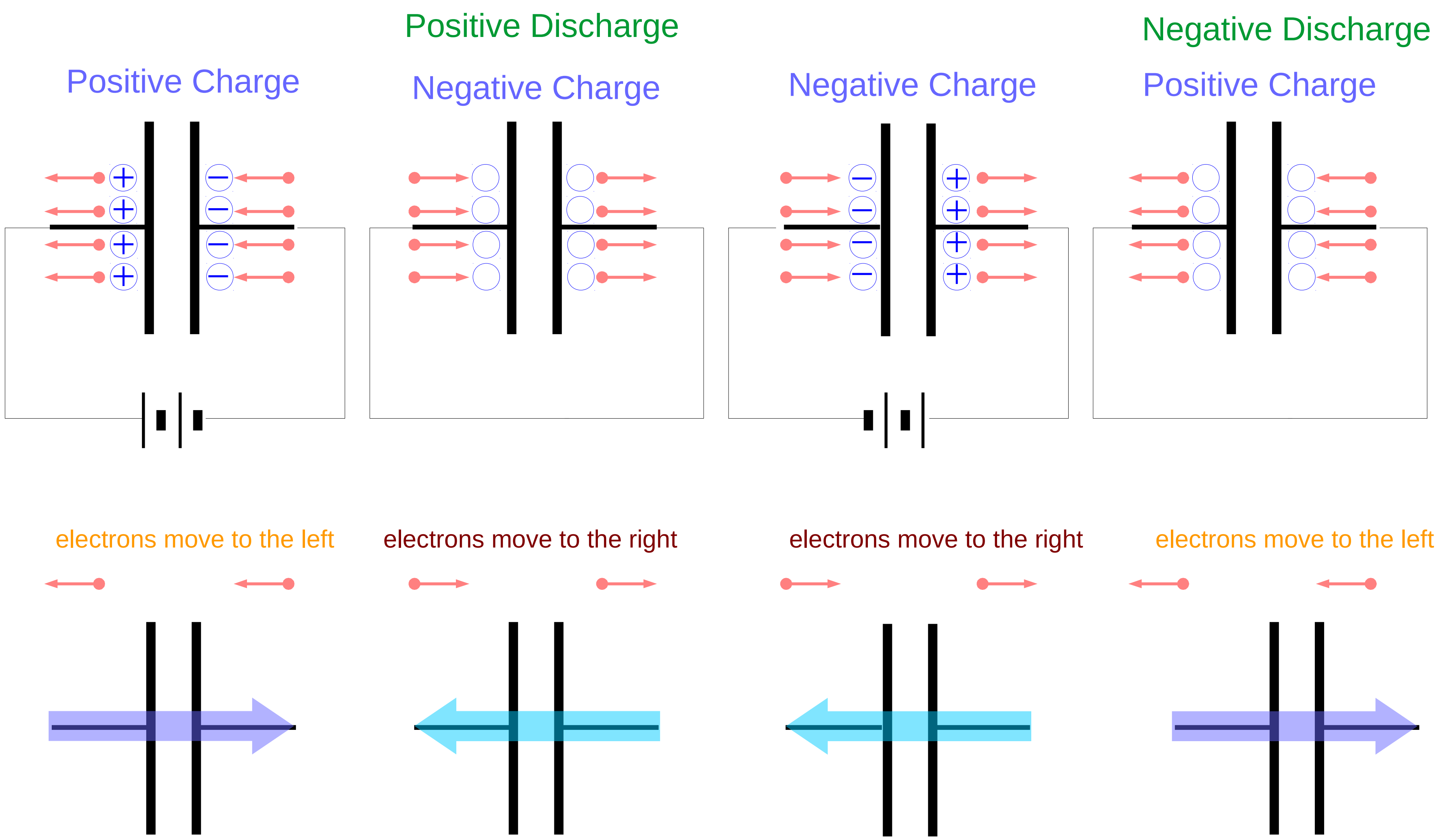




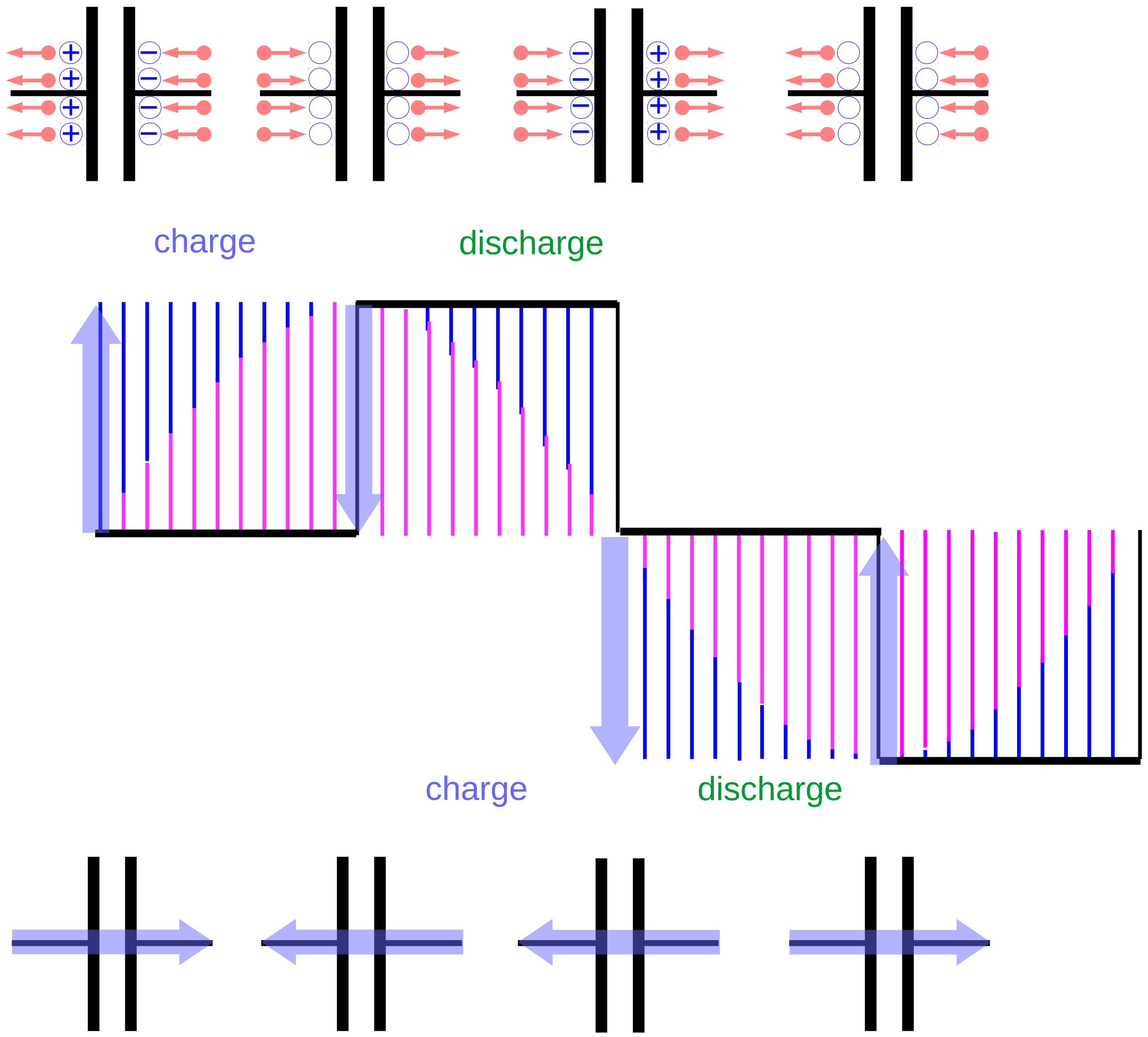




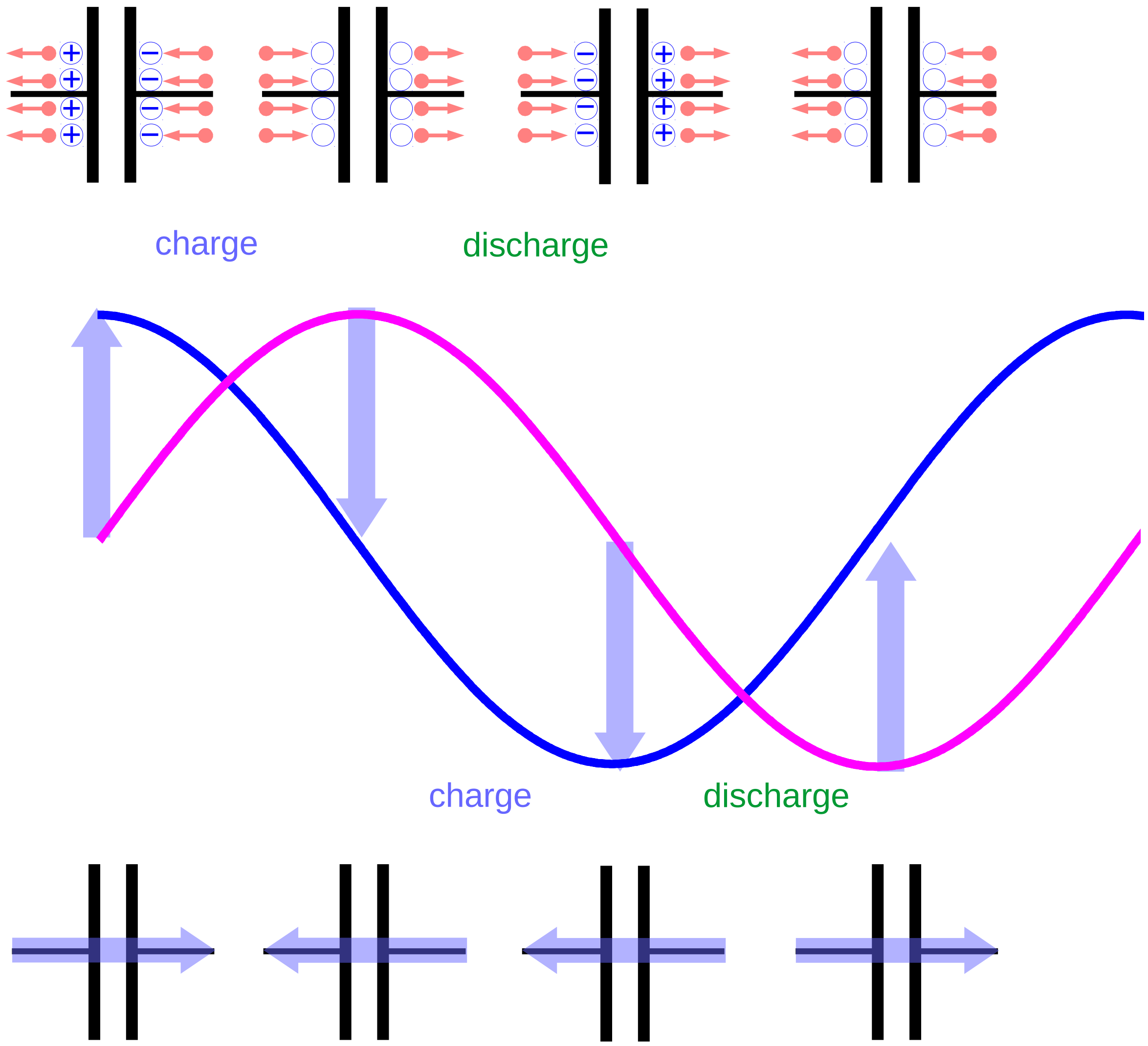
Evercharging signal pairs



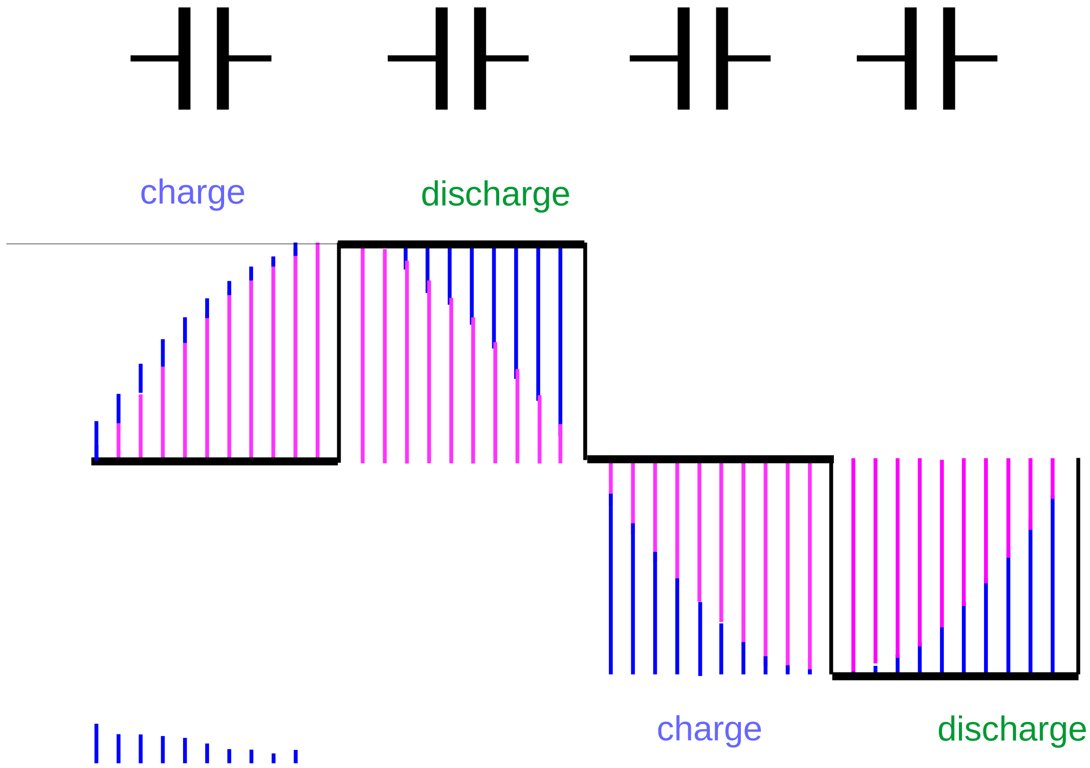
Everchanging signal pairs



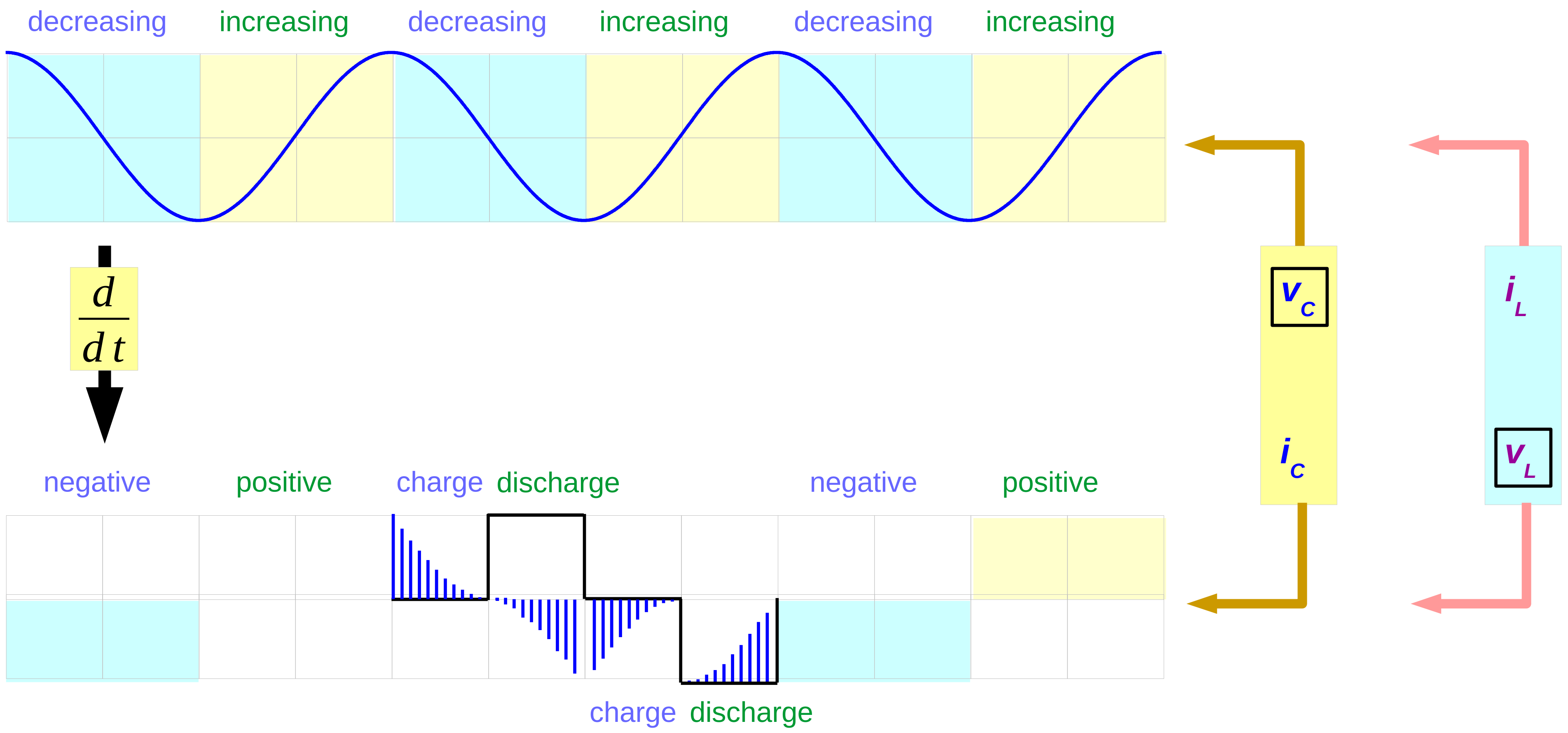
Everchanging signal pairs



Everchanging signal pairs

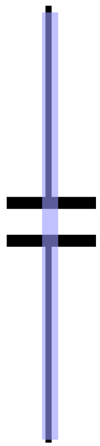


Everchanging signal pairs



I leads V by 90°

Initial charge

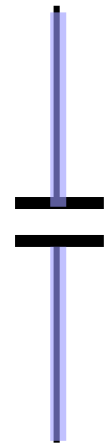


SHORT

V = 0

I : peak

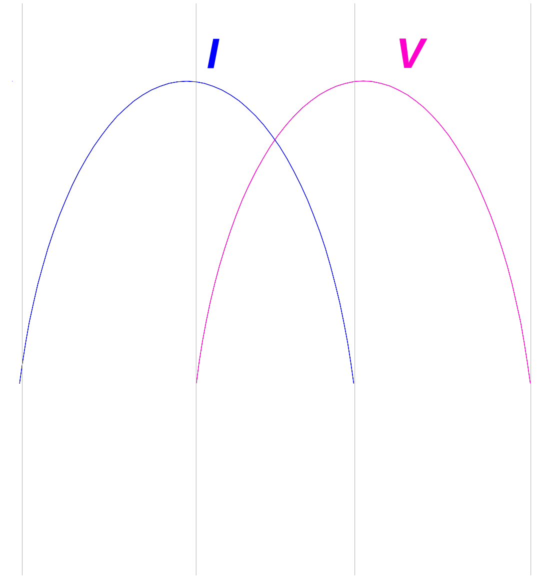
Full charge



OPEN

I = 0

V : peak



References

[1] http://en.wikipedia.org/
[2] J.H. McClellan, et al., Signal Processing First, Pearson Prentice Hall, 2003