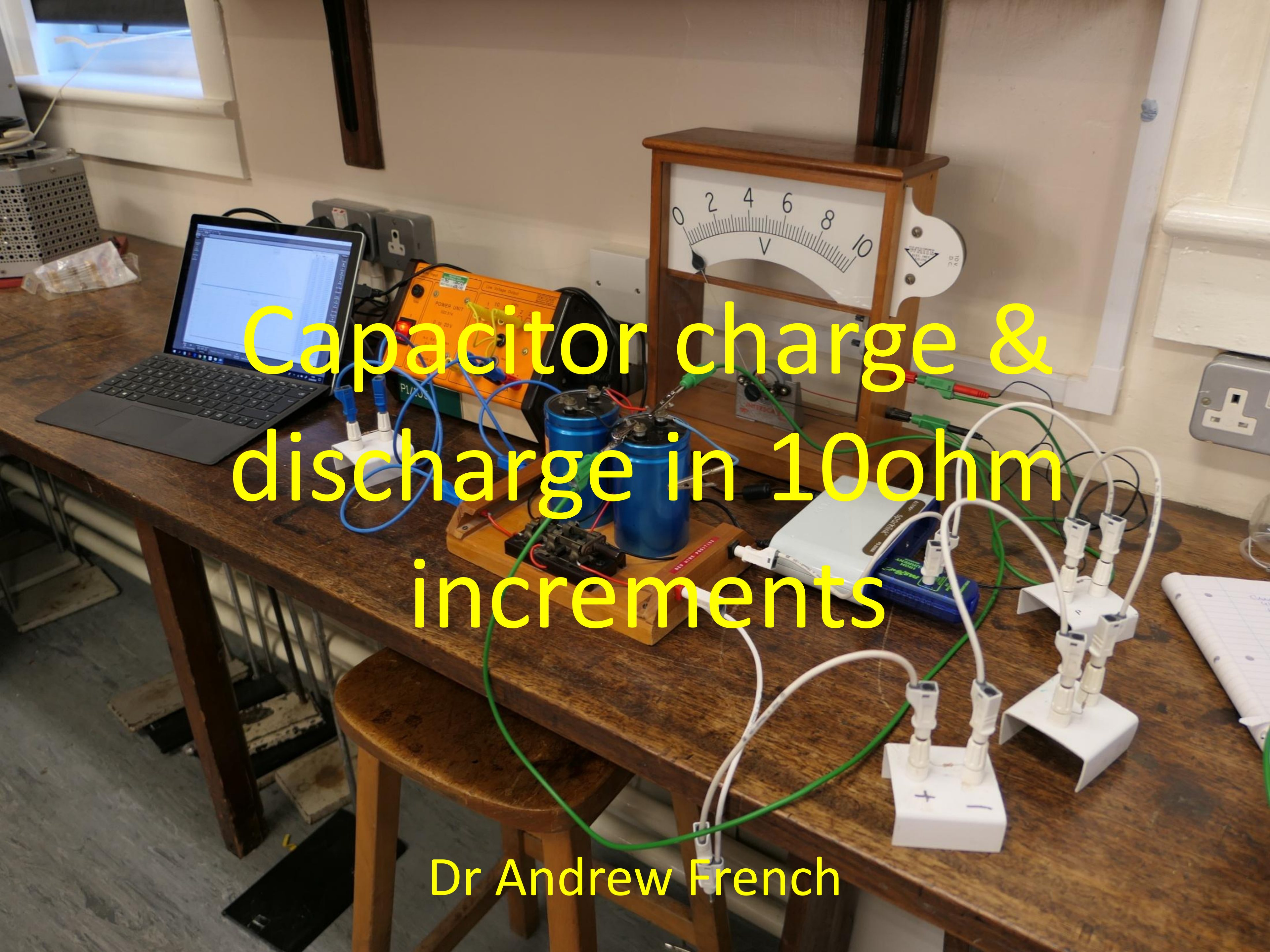


Capacitor charge & discharge in 10ohm increments

Dr Andrew French

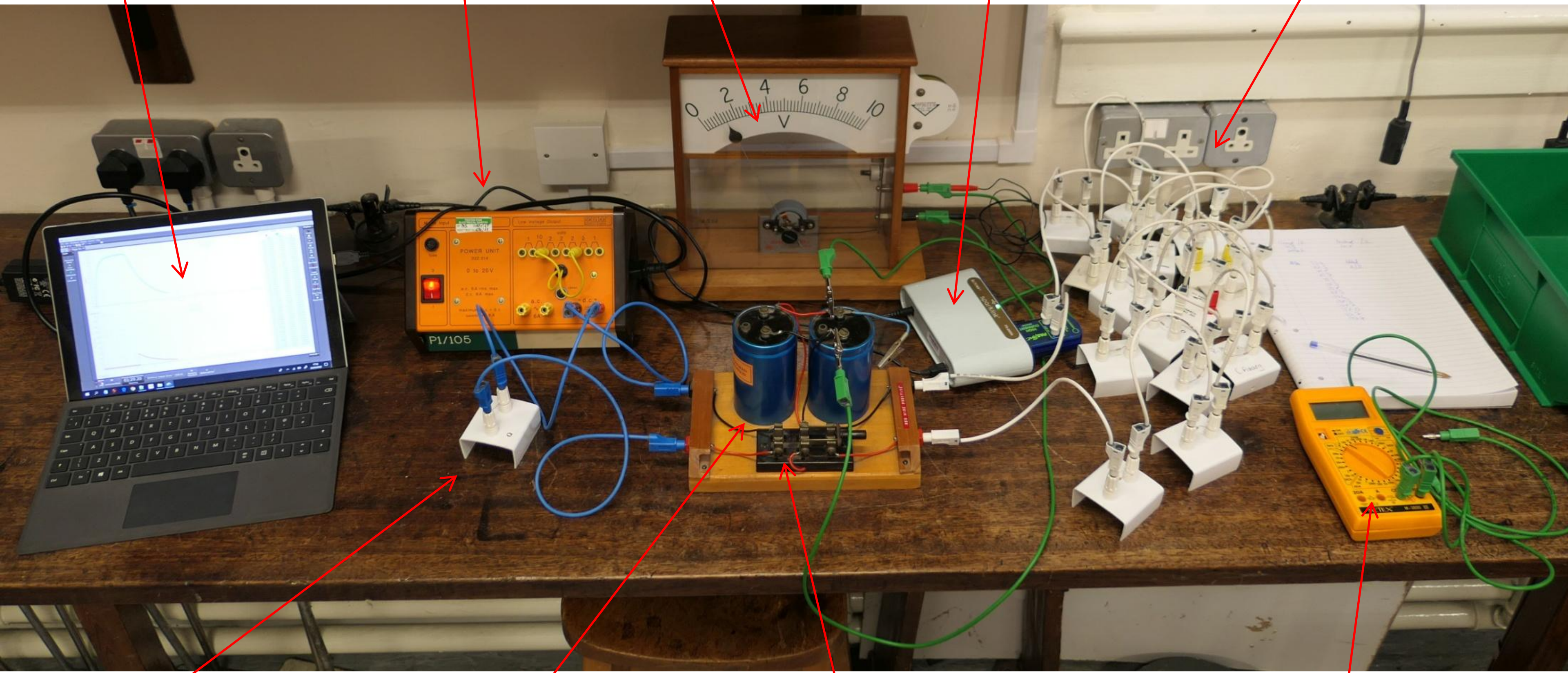
Laptop running PASCO Capstone

8V DC supply

Large analogue voltmeter

PASCO USB hub (voltmeter, ammeter

10ohm resistors mounted in terminal blocks, wired in series



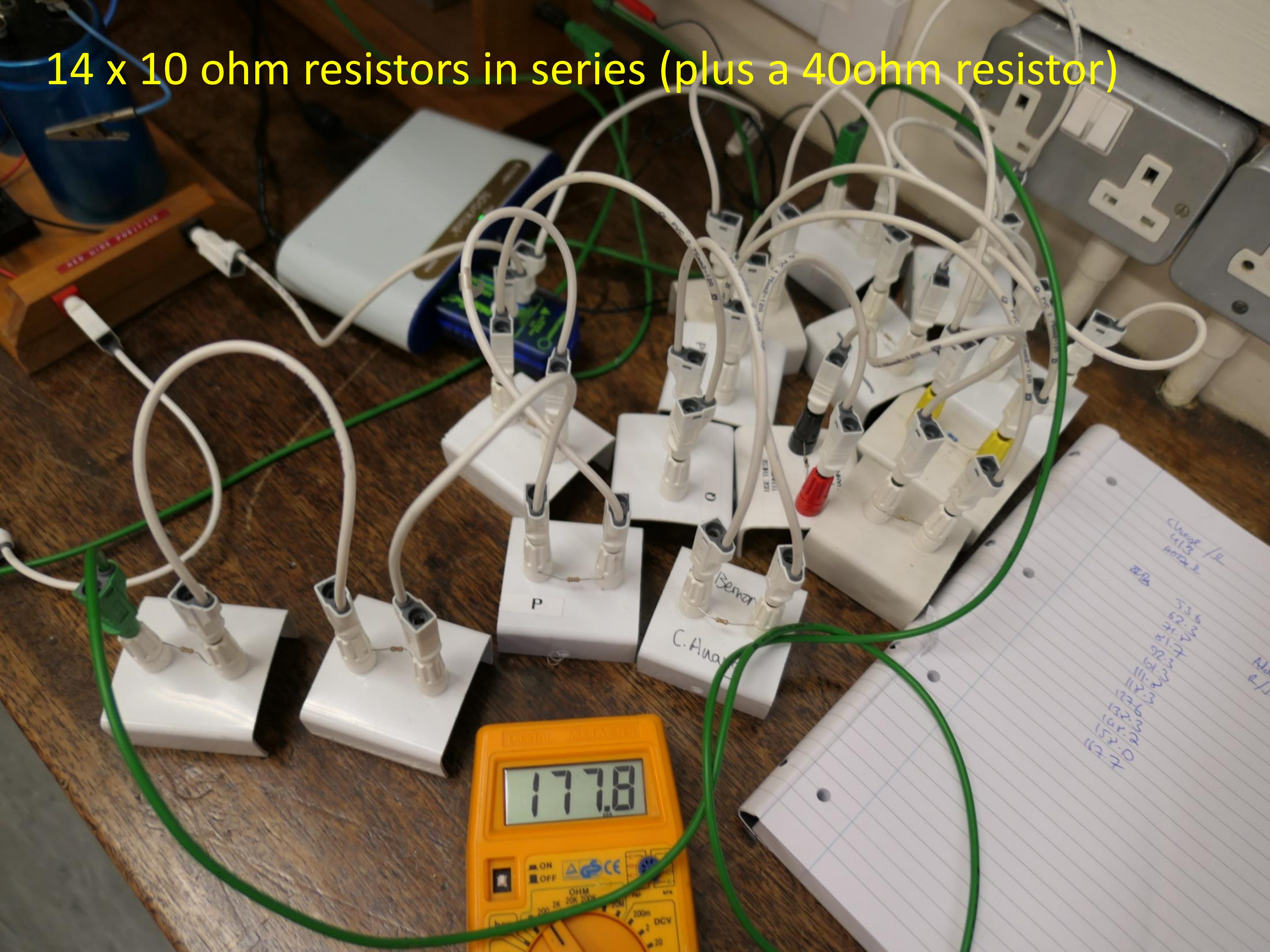
40.8ohm charging resistor in a terminal block

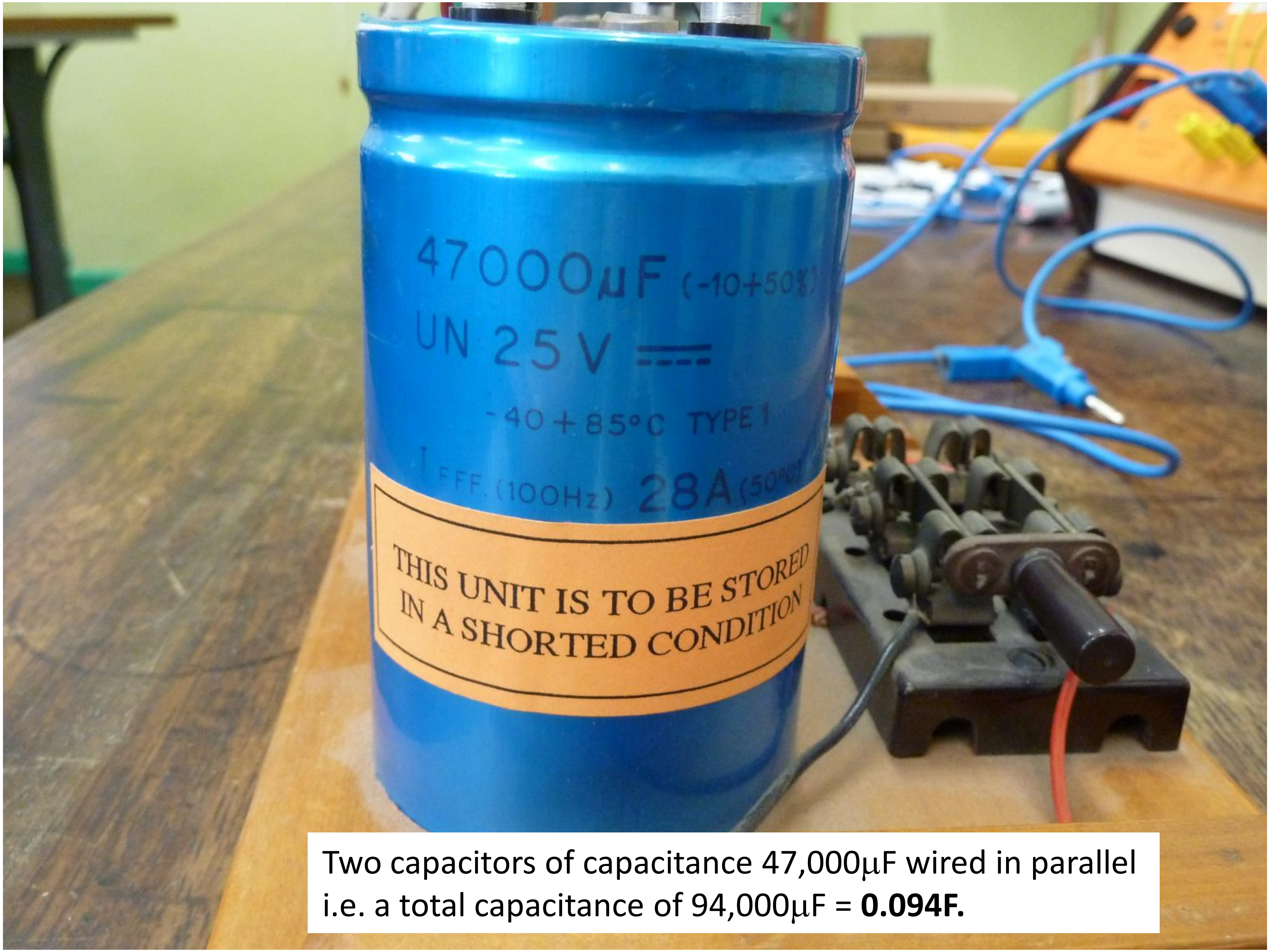
Capacitors wired in parallel to yield a total capacitance of about 0.1F

Charge /discharge switch

Multimeter for testing total resistance of resistors (unplug resistors from circuit before testing)

14 x 10 ohm resistors in series (plus a 40ohm resistor)





Two capacitors of capacitance 47,000μF wired in parallel
i.e. a total capacitance of 94,000μF = **0.094F.**

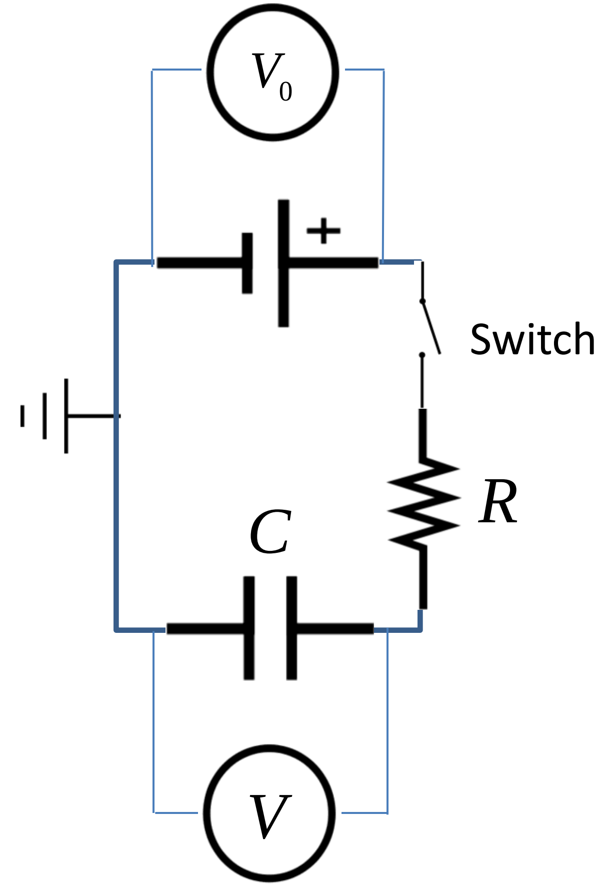
Charging a capacitor using a DC source

1. Switch closed. Current flows through resistor and positive charge builds up on right capacitor plate. An equal amount of negative charge builds up on left plate.

2. *Electrical field* set up between capacitor plates as no current can flow. Voltage V between the plates is $V = Q/C$ where Q is the total charge deposited and C is the *capacitance* ('charge per unit volt')

3. As charge builds up on right plate, potential difference between capacitor and source reduces. This reduces the current flowing onto the plate. Eventually the voltage V becomes V_0 and hence no more current can flow.

4. Note the amount of charge which can be deposited depends on the resulting *electrical field strength* between the plates. Above the breakdown field strength, current will flow between the plates.



Dielectric	Breakdown field strength /Vm^{-1}
Air	3×10^6
Mineral oil	15×10^6
Neoprene	16×10^6
Water	65×10^6
Mica	118×10^6

Charging a capacitor using a DC source

$$Q = CV$$

capacitor charge, voltage relationship

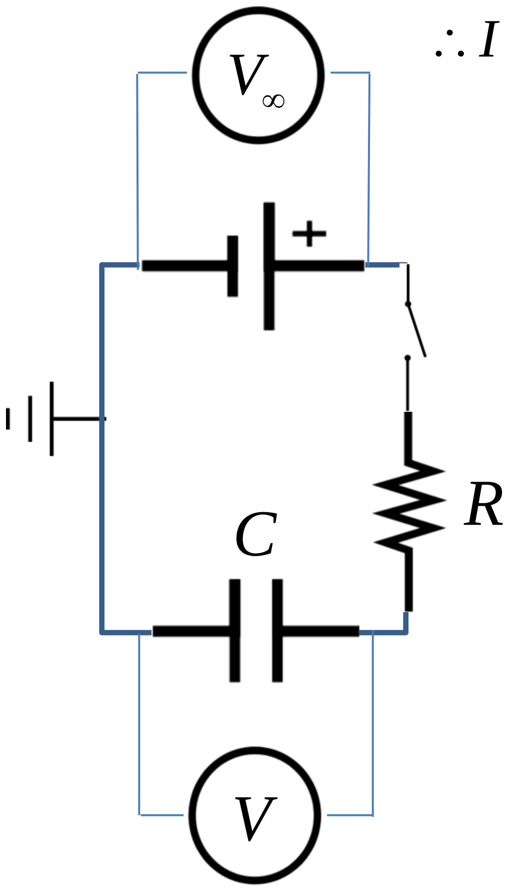
$$V_\infty - V = IR$$

Ohm's law

$$I = \frac{dQ}{dt}$$

Definition of current

$$\therefore I = \frac{V_\infty - V}{R} = C\frac{dV}{dt}$$

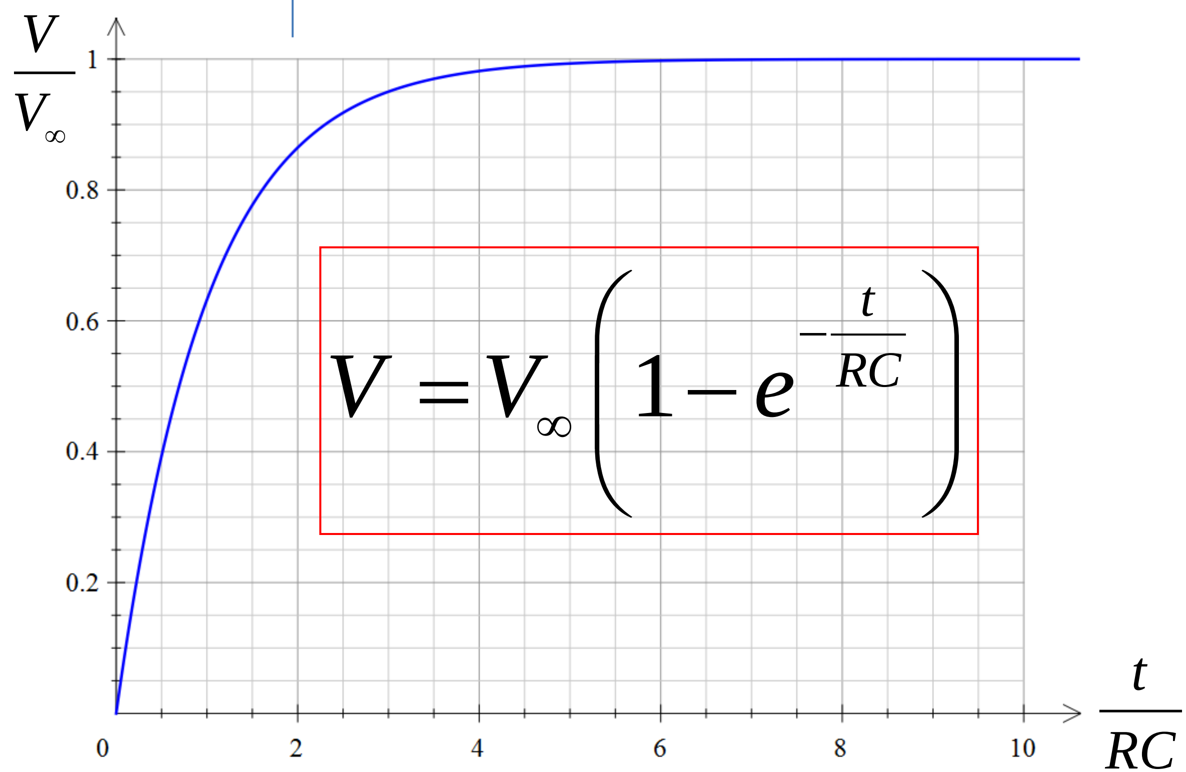


$$\frac{1}{RC}\int_0^t dt = \int_0^V \frac{dV}{V_\infty - V} = -\int_0^V \frac{-dV}{V_\infty - V}$$

$$\frac{t}{RC} = -\left[\ln\left|V_\infty - V\right|\right]_0^V$$

$$-\frac{t}{RC} = \ln\left(V_\infty - V\right) - \ln\left(V_\infty\right) = \ln\left(\frac{V_\infty - V}{V_\infty}\right)$$

$$\frac{V_\infty - V}{V_\infty} = e^{-\frac{t}{RC}}$$



$$V = V_\infty\left(1 - e^{-\frac{t}{RC}}\right)$$

Discharging a capacitor

$$Q = CV$$

capacitor charge, voltage relationship

$$V = IR$$

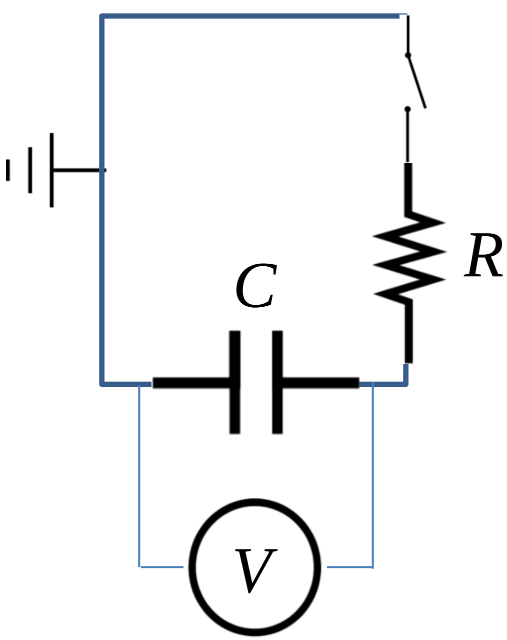
Ohm's law

$$I = -\frac{dQ}{dt}$$

Definition of current, and negative since charge is discharged from plates

$$\therefore I = \frac{V}{R} = -C\frac{dV}{dt}$$

Note $V = V_0$ when $t = 0$

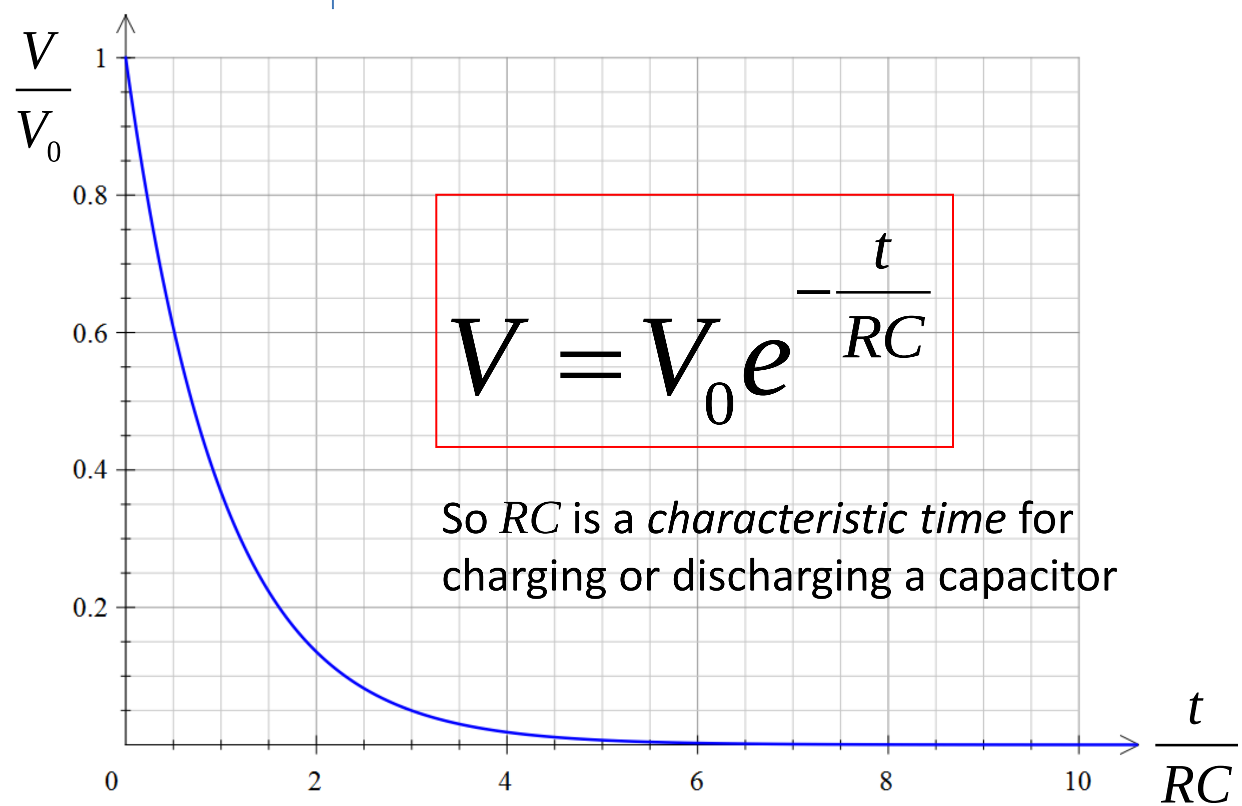


$$\frac{1}{RC}\int_0^t dt = -\int_{V_0}^{V} \frac{dV}{V}$$

$$\frac{t}{RC} = -\left[\ln|V|\right]_{V_0}^{V}$$

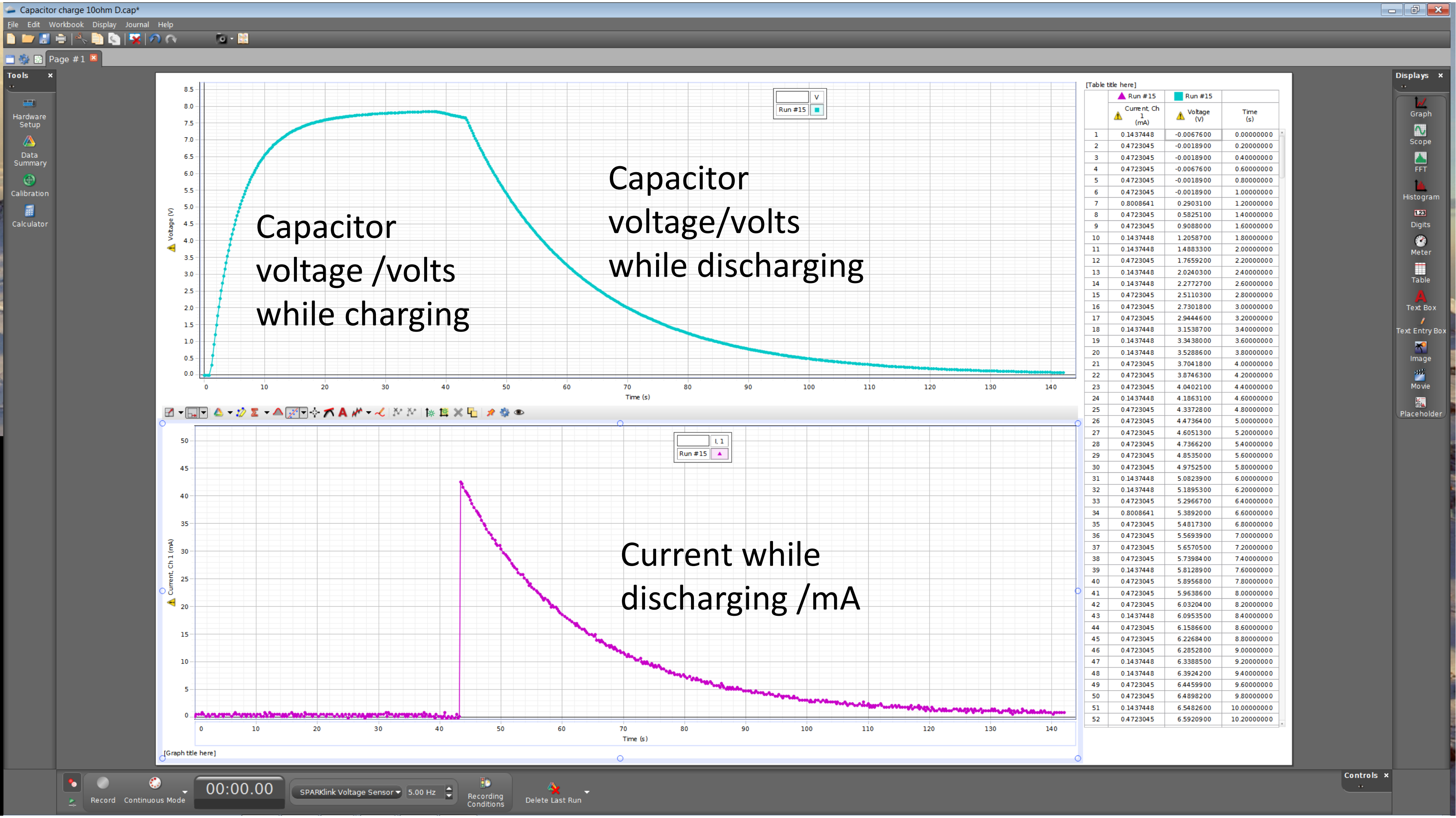
$$\frac{t}{RC} = -\ln\left(\frac{V}{V_0}\right)$$

$$V = V_0 e^{-\frac{t}{RC}}$$



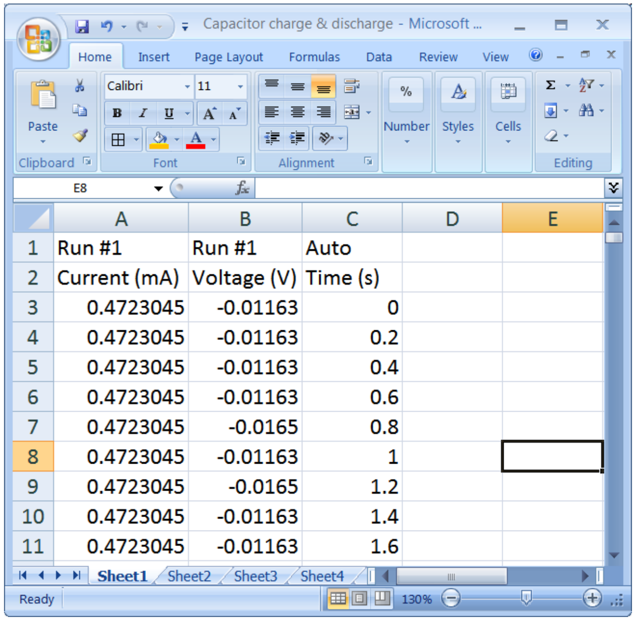
$$V = V_0 e^{-\frac{t}{RC}}$$

So RC is a *characteristic time* for charging or discharging a capacitor



Charge and discharge recorded using Capstone software, interfacing via USB to the PASCO datalogger hub. Note Ammeter is in series with discharge loop, so no current recorded during charging.

Capstone → Copy and paste data to text files (one per discharge resistance)

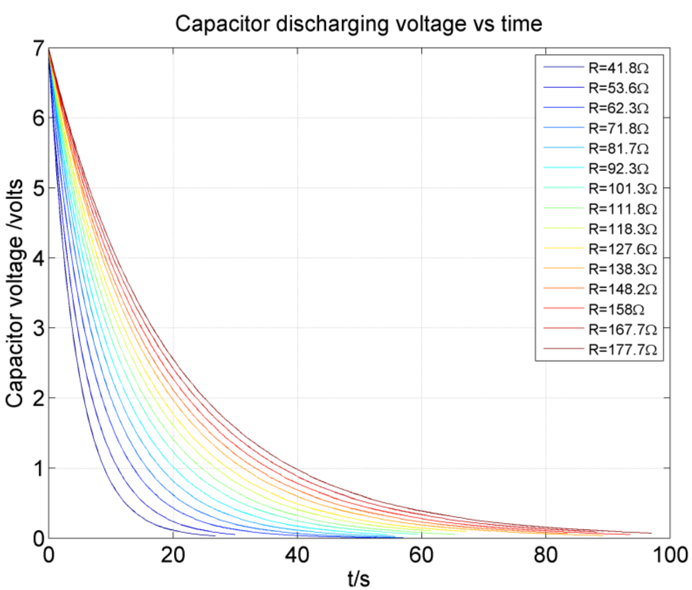


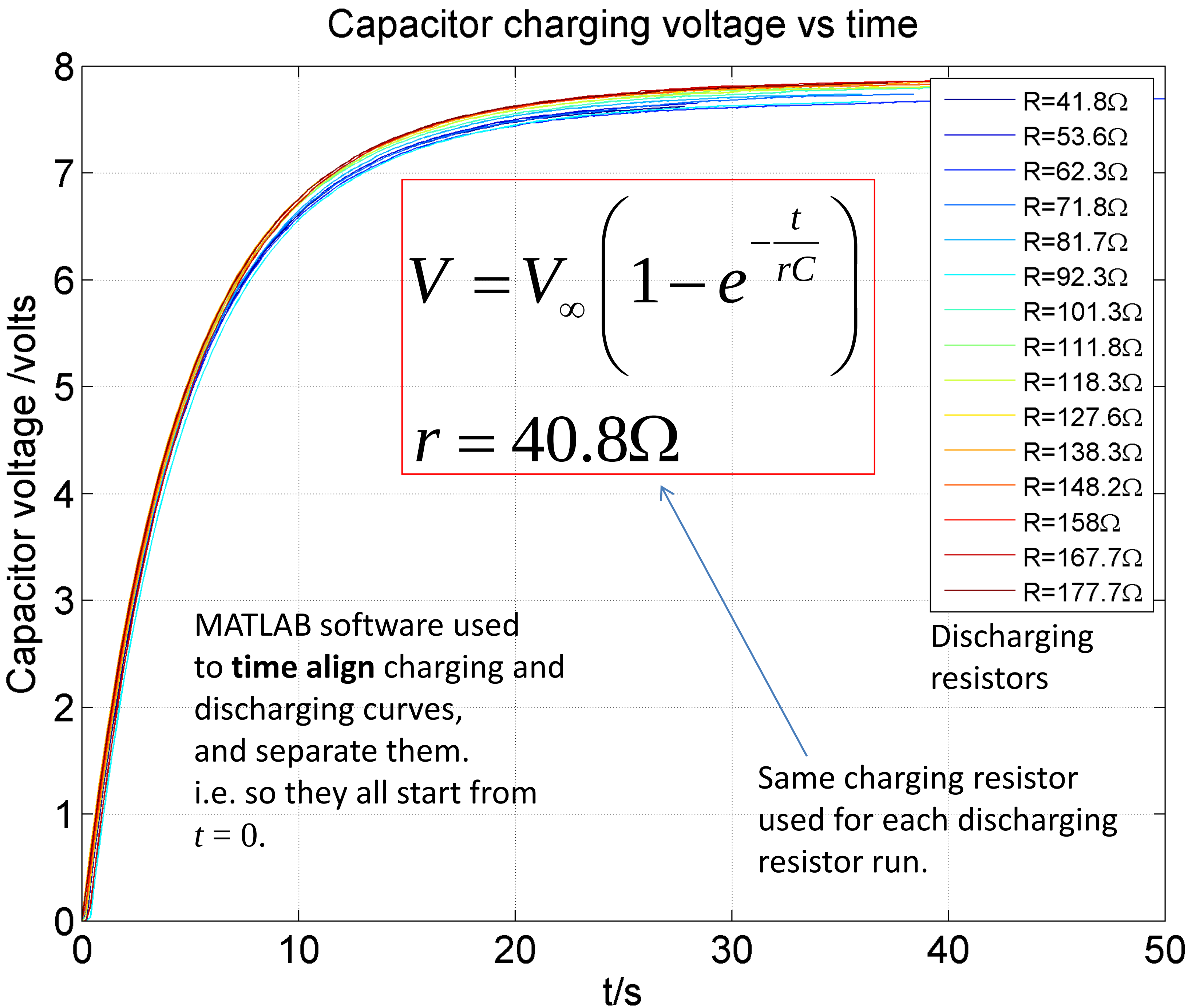
	A	B	C	D	E
1	Run #1	Run #1	Auto		
2	Current (mA)	Voltage (V)	Time (s)		
3	0.4723045	-0.01163	0		
4	0.4723045	-0.01163	0.2		
5	0.4723045	-0.01163	0.4		
6	0.4723045	-0.01163	0.6		
7	0.4723045	-0.0165	0.8		
8	0.4723045	-0.01163	1		
9	0.4723045	-0.0165	1.2		
10	0.4723045	-0.01163	1.4		
11	0.4723045	-0.01163	1.6		

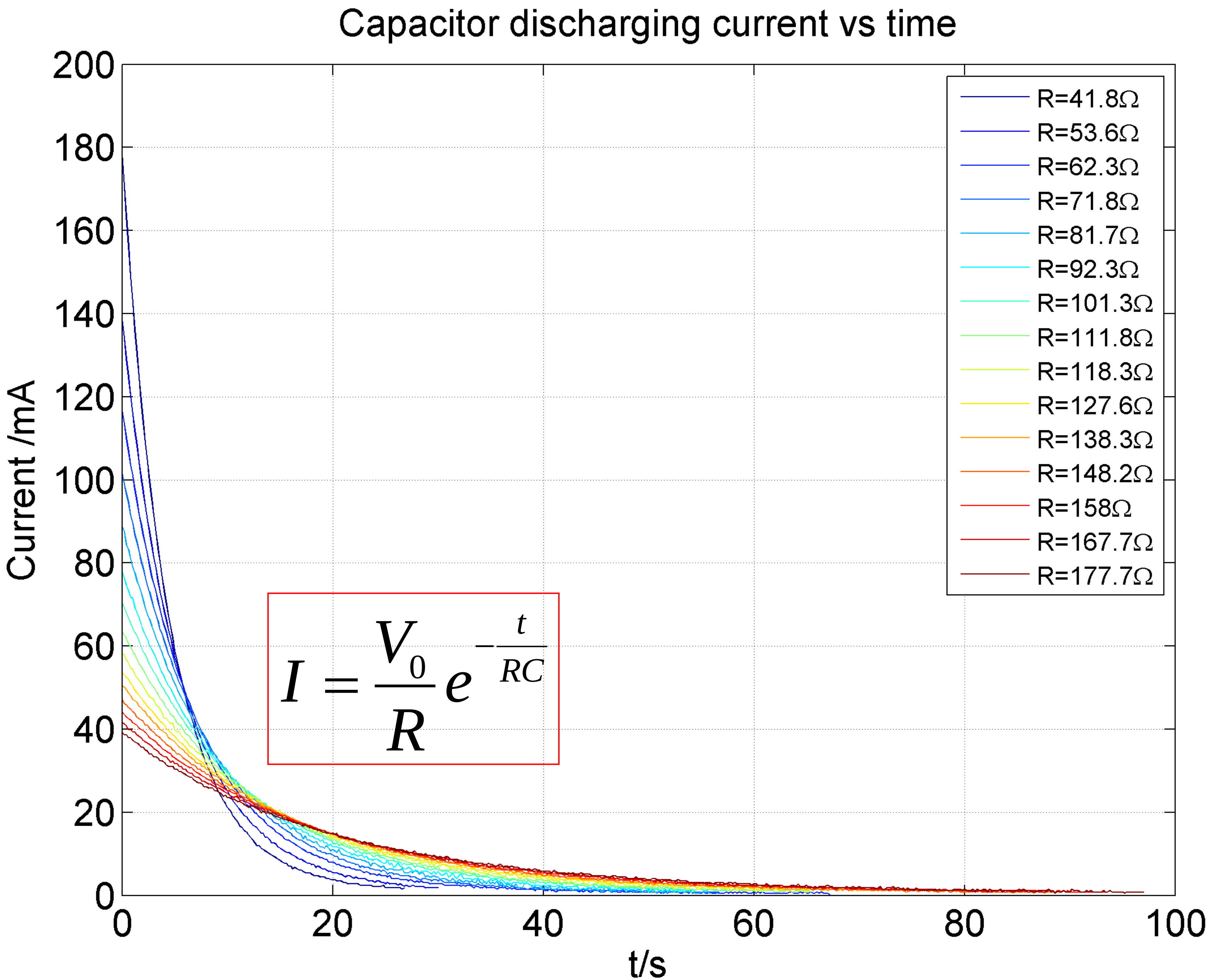
```
%Import Capacitor charge & discharge data
% LAST UPDATED by Andy French Mar 2020

function import_data
disp(' '); disp(' Importing data from Excel...' )

%Import resistances /ohms
[num,txt,raw] = xlsread( 'Capacitor charge & discharge.xlsx',...
    'Resistances' );
R = num(:,2).';

%Import data from Excel
num_runs = 15;
for n=1:15
    [num,txt,raw] = xlsread( 'Capacitor charge & discharge.xlsx',...
        ['Sheet',num2str(n)] );
    data(n).I_mA = num(:,1);
    data(n).V_volts = num(:,2);
    data(n).t_s = num(:,3);
    data(n).R_ohms = R(n);
end

%Save data to a .mat file
save( 'capacitor data','data','R' );
disp(' Data saved to file capacitor_data.mat. ']);

%End of code
```

MATLAB

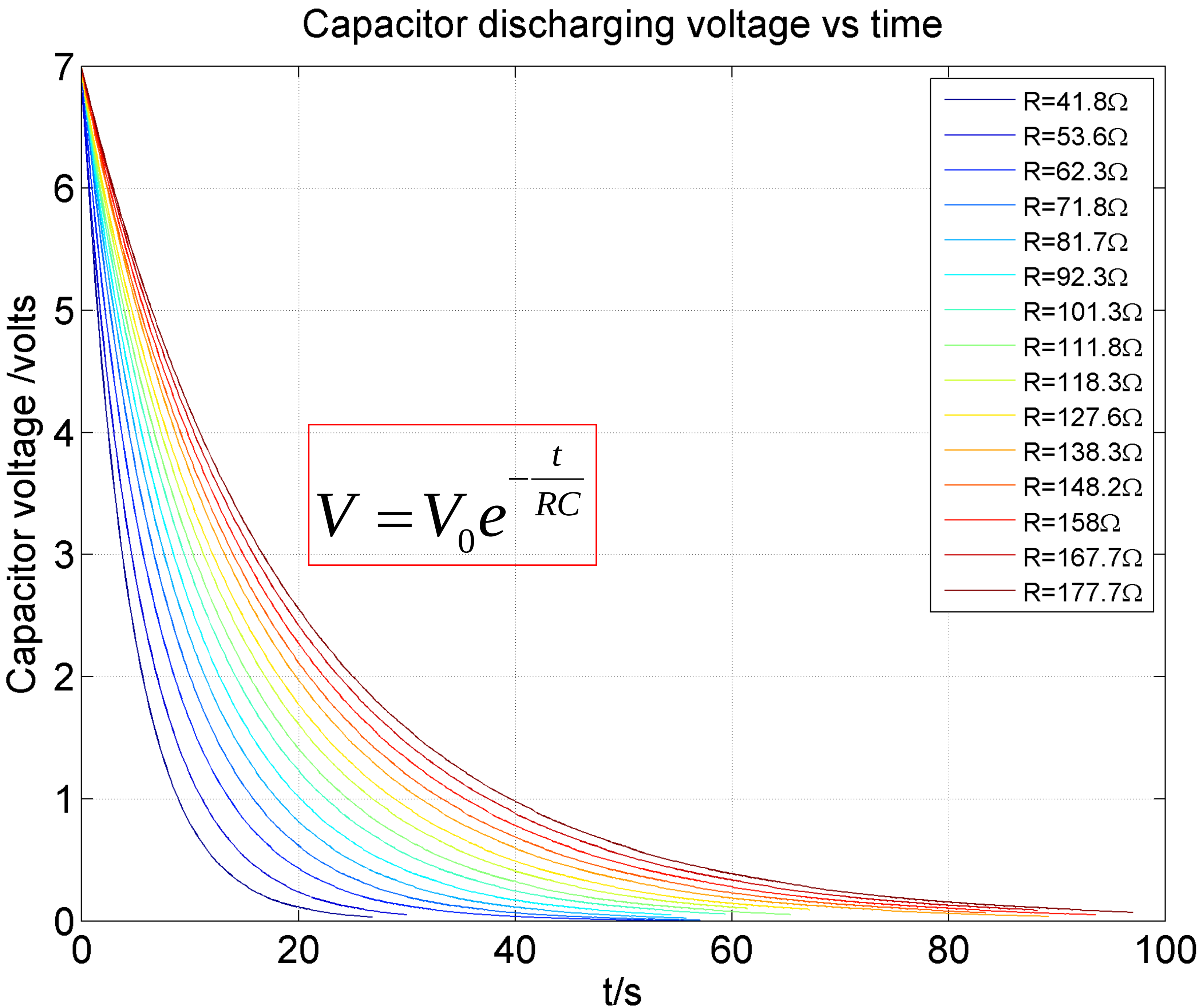
```
%Process Capacitor charge & discharge data
% LAST UPDATED by Andy French Mar 2020
function process_data

%Fontsize for graphs
fsize = 16;

%Load imported data
load('capacitor data')

%Initialize charge, discharge and line of best fit curves
fig_Vcharge = figure; ax_V_charge = axes('nextplot','add'); grid on; set(gca,'f
xlabel('t/s','fontsize',fsize); ylabel('Capacitor voltage /volts','fontsize',fs
title('Capacitor charging voltage vs time','fontsize',fsize)
fig_Vdischarge = figure; ax_V_discharge = axes('nextplot','add'); grid on; set(
xlabel('t/s','fontsize',fsize); ylabel('Capacitor voltage /volts','fontsize',fs
title('Capacitor discharging voltage vs time','fontsize',fsize)
fig_Idischarge = figure; ax_I_discharge = axes('nextplot','add'); grid on; set(
xlabel('t/s','fontsize',fsize); ylabel('Current /mA','fontsize',fsize);
title('Capacitor discharging current vs time','fontsize',fsize)
fig_best_fit = figure; ax_best_fit = axes('nextplot','add'); grid on; set(gca,'
xlabel('t/s','fontsize',fsize); ylabel('ln(V/volts)','fontsize',fsize);
title('ln(V) vs t line of best fit to find RC time','fontsize',fsize)
fig_V_over_I = figure; ax_V_over_I = axes('nextplot','add'); grid on; set(gca,'
xlabel('t/s','fontsize',fsize); ylabel('R = V/I /\Omega','fontsize',fsize);
title('R = V/I for capacitor discharge','fontsize',fsize)

%Determine legend string
lgnd_str = {};
```



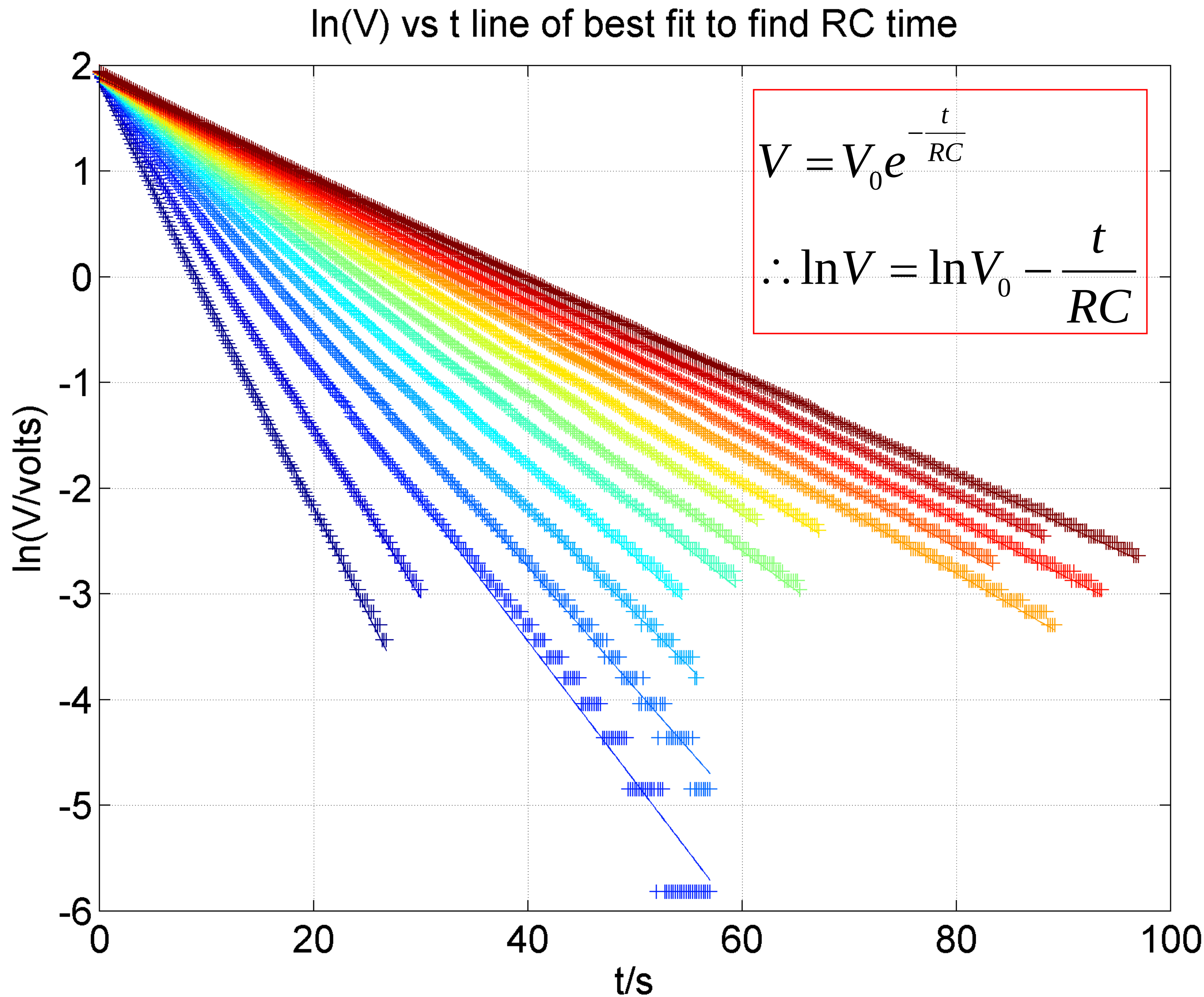

Capacitor charging voltage vs time
Capacitor voltage /volts
t/s
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
R=41.8Ω
R=53.6Ω
R=62.3Ω
R=71.8Ω
R=81.7Ω
R=92.3Ω
R=101.3Ω
R=111.8Ω
R=118.3Ω
R=127.6Ω
R=138.3Ω
R=148.2Ω
R=158Ω
R=167.7Ω
R=177.7Ω
$V = V_\infty \left(1 - e^{-\frac{t}{rC}}\right)$
$r = 40.8\Omega$
MATLAB software used
to **time align** charging and
discharging curves,
and separate them.
i.e. so they all start from
$t = 0$.
Discharging
resistors
Same charging resistor
used for each discharging
resistor run.



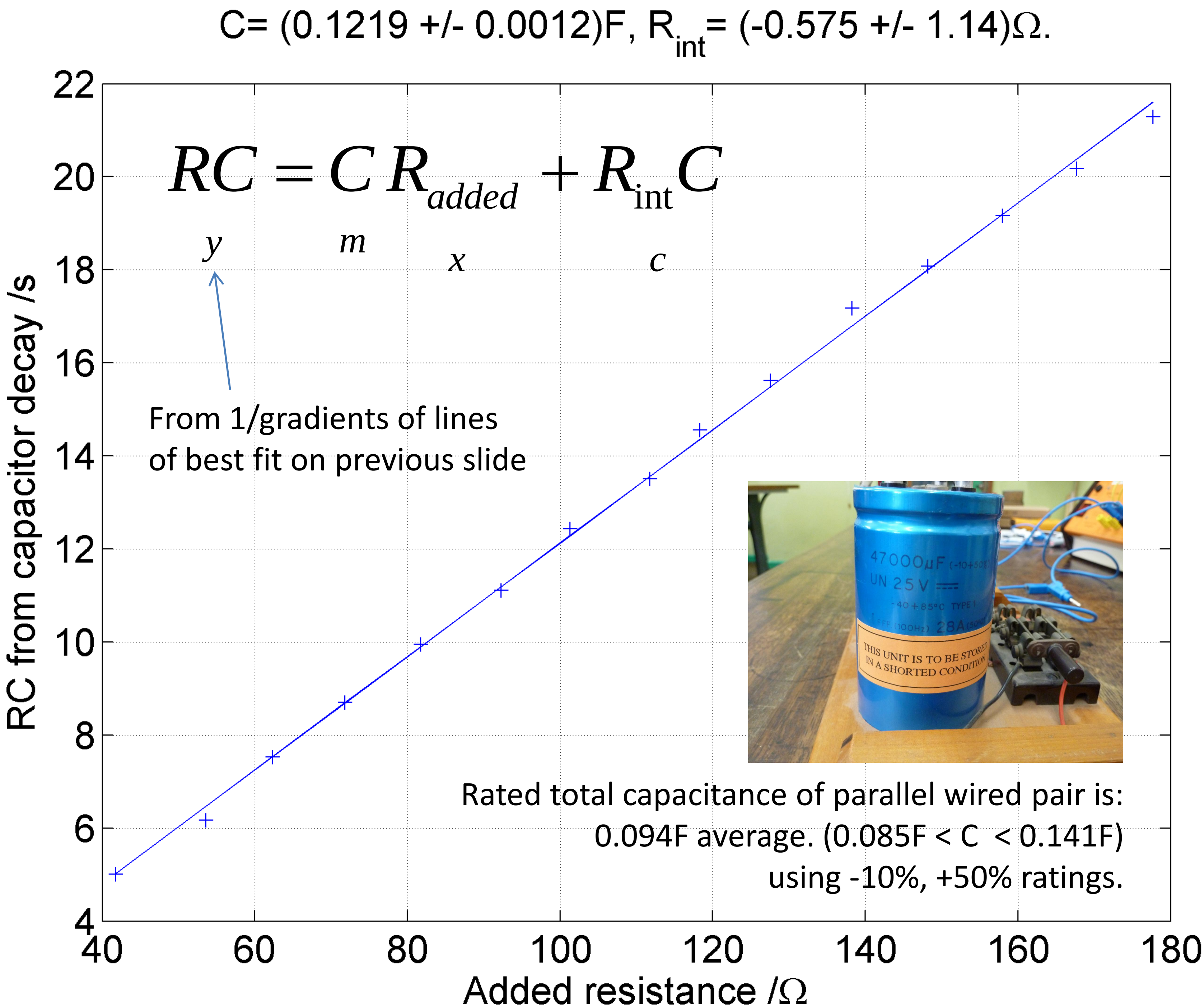
Capacitor discharging current vs time
Current /mA
t/s
0
20
40
60
80
100
120
140
160
180
200
0
20
40
60
80
100
R=41.8Ω
R=53.6Ω
R=62.3Ω
R=71.8Ω
R=81.7Ω
R=92.3Ω
R=101.3Ω
R=111.8Ω
R=118.3Ω
R=127.6Ω
R=138.3Ω
R=148.2Ω
R=158Ω
R=167.7Ω
R=177.7Ω
$I = \frac{V_0}{R} e^{-\frac{t}{RC}}$



Capacitor discharging voltage vs time
Capacitor voltage /volts
t/s
0
1
2
3
4
5
6
7
0
20
40
60
80
100
R=41.8Ω
R=53.6Ω
R=62.3Ω
R=71.8Ω
R=81.7Ω
R=92.3Ω
R=101.3Ω
R=111.8Ω
R=118.3Ω
R=127.6Ω
R=138.3Ω
R=148.2Ω
R=158Ω
R=167.7Ω
R=177.7Ω
$V = V_0 e^{-\frac{t}{RC}}$



ln(V) vs t line of best fit to find RC time
$V = V_0 e^{-\frac{t}{RC}}$
$\therefore \ln V = \ln V_0 - \frac{t}{RC}$
ln(V/volts)
t/s
2
1
0
-1
-2
-3
-4
-5
-6
0
20
40
60
80
100



C= (0.1219 +/- 0.0012)F, R_{int}= (-0.575 +/- 1.14)Ω.
$$RC = C\,R_{added} + R_{int}C$$
y m x c
From 1/gradients of lines
of best fit on previous slide
47000µF
UN 25 V
THIS UNIT IS TO BE STORED
IN A SHORTED CONDITION
Rated total capacitance of parallel wired pair is:
0.094F average. (0.085F < C < 0.141F)
using -10%, +50% ratings.
RC from capacitor decay /s
Added resistance /Ω
22
20
18
16
14
12
10
8
6
4
40
60
80
100
120
140
160
180

Notice overall resistance of circuit appears *not* to be quite constant during full discharge.