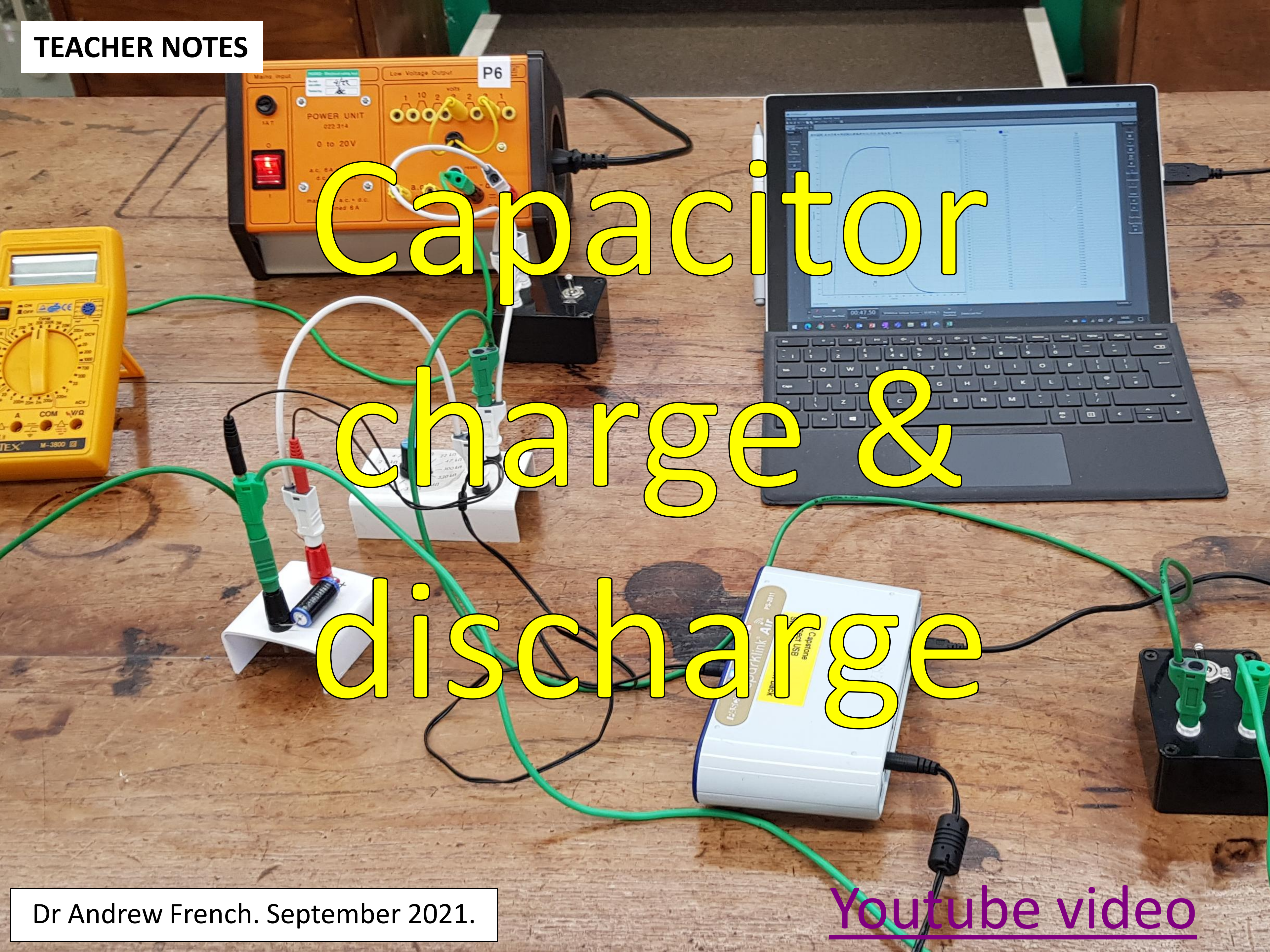
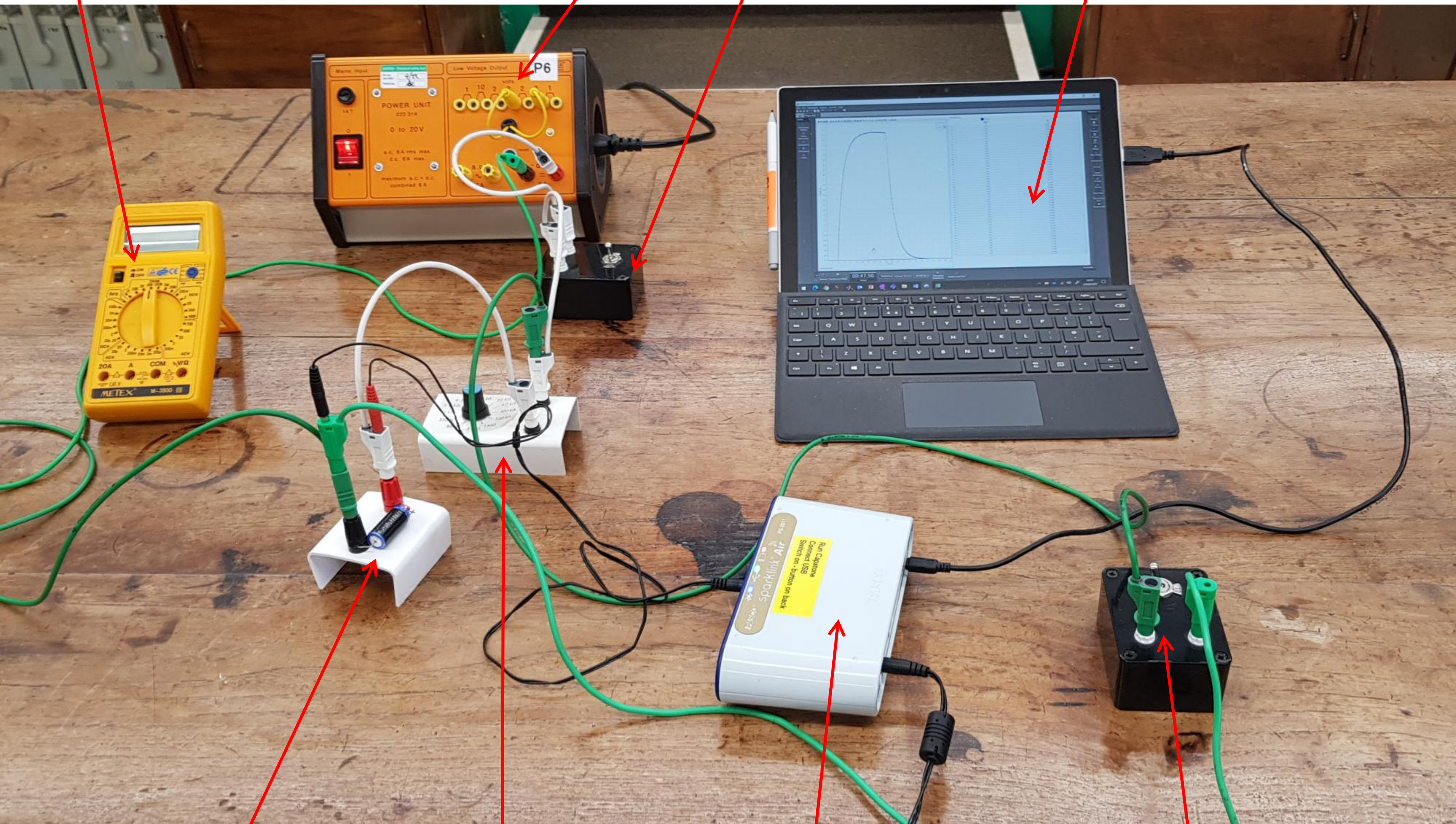
TEACHER NOTES

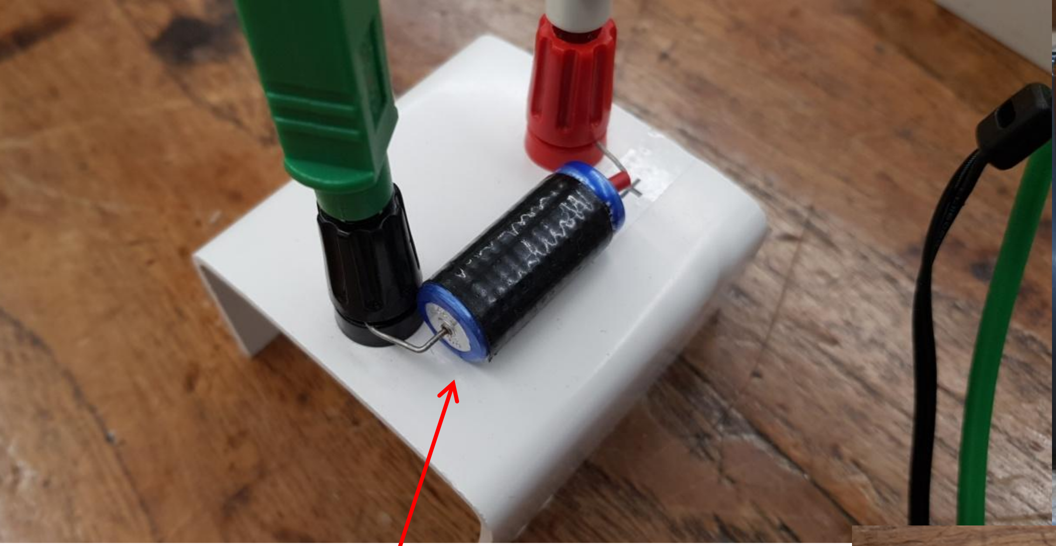
Capacitor charge & discharge



Dr Andrew French. September 2021.

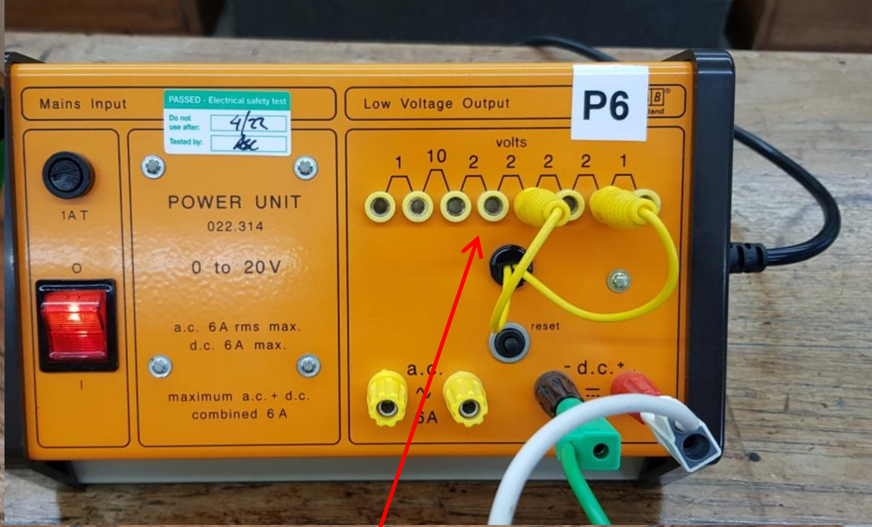
Youtube video


Multimeter for measuring resistance
6V DC supply
Charging circuit switch
Laptop running PASCO Capstone
Electrolytic capacitor
'blue top' resistors
PASCO USB hub (voltmeter in this case)
Discharge circuit switch

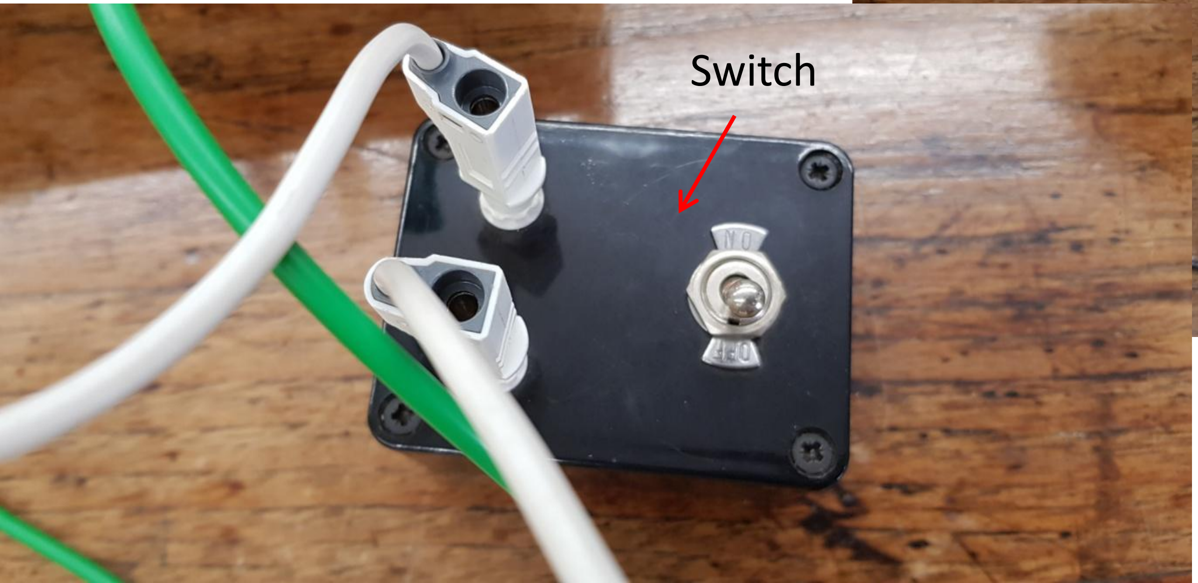


Electrolytic capacitor

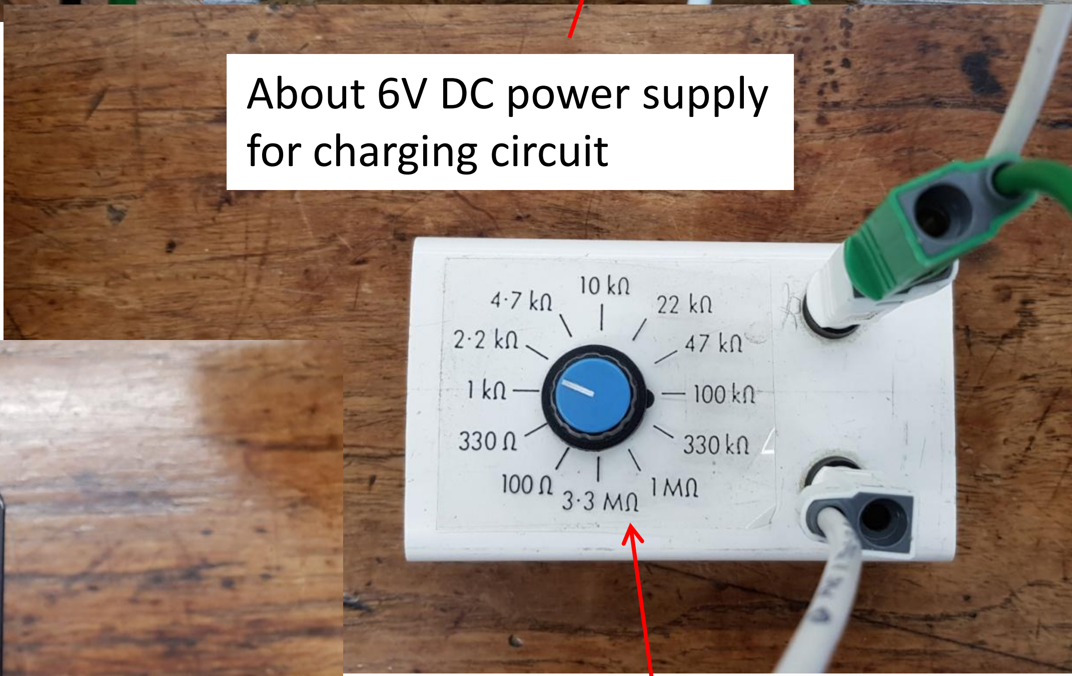
Take care to connect **positive** to the **positive** voltage terminal!



About 6V DC power supply for charging circuit



Switch

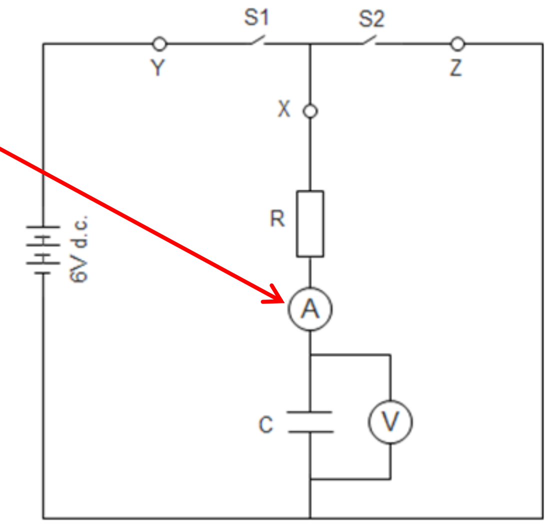


Multiple resistors, with a selector dial. (Measure accurately with a multimeter).

INSTRUCTIONS

1. Set up the equipment. **TAKE CARE THAT THE CAPACITOR IS WIRED THE CORRECT WAY ROUND**. *A reverse bias (i.e. where the negative (black) capacitor terminal is connected to the +ve power supply terminal) on an electrolytic capacitor may cause them to be damaged irreparably.* ***Check with your teacher before switching on!***

Don't use the ammeter. The PASCO datalogger ammeters don't work so well at µA levels, and may introduce noise (and possibly oscillations) in the circuit.



2. Experiment using the datalogger and **Capstone software** and charge then discharge. Determine the optimal resistor value to charge and discharge in about ten seconds. **Set the datalogger voltmeter data rate to be 20Hz.**

3. Record data *separately* for (i) charging and (ii) discharging. Copy the data from Capstone to a pre-prepared Excel sheet.

4. Plot: (i) charging V vs t ; (ii) discharging V vs t and (iii) ln$V$ vs t.
Use the latter to determine the **RC time** for the circuit.

5. Use a multimeter to determine R, and hence calculate the capacitance (in µF).

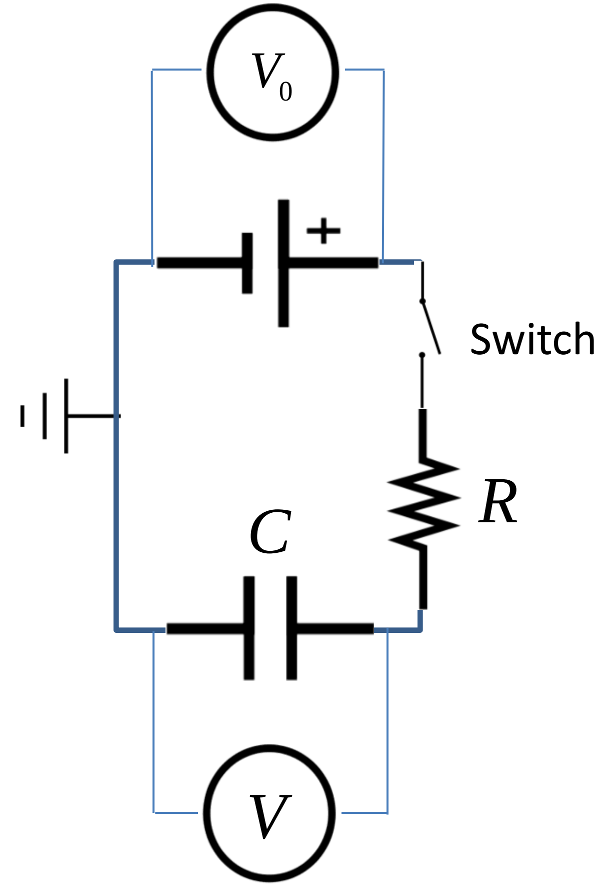
Charging a capacitor using a DC source

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 between them. 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

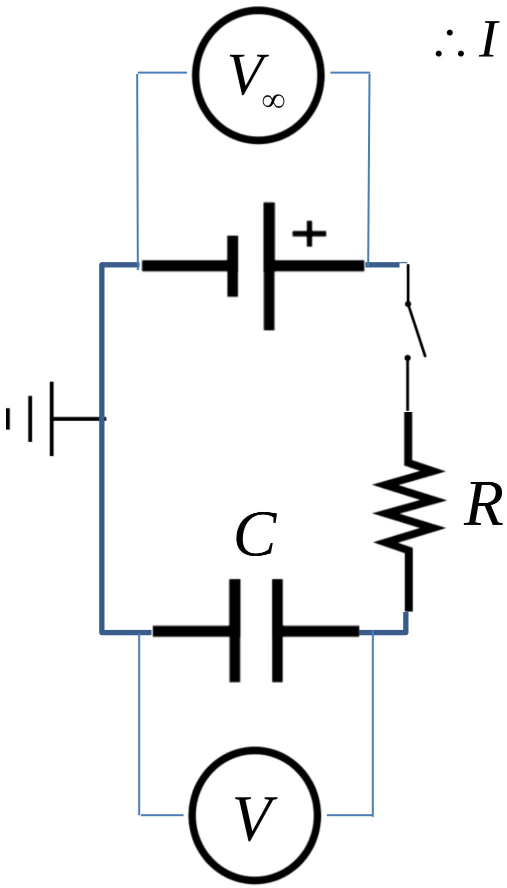
$$V_\infty - V = IR$$

Ohm's law

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

Definition of current

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

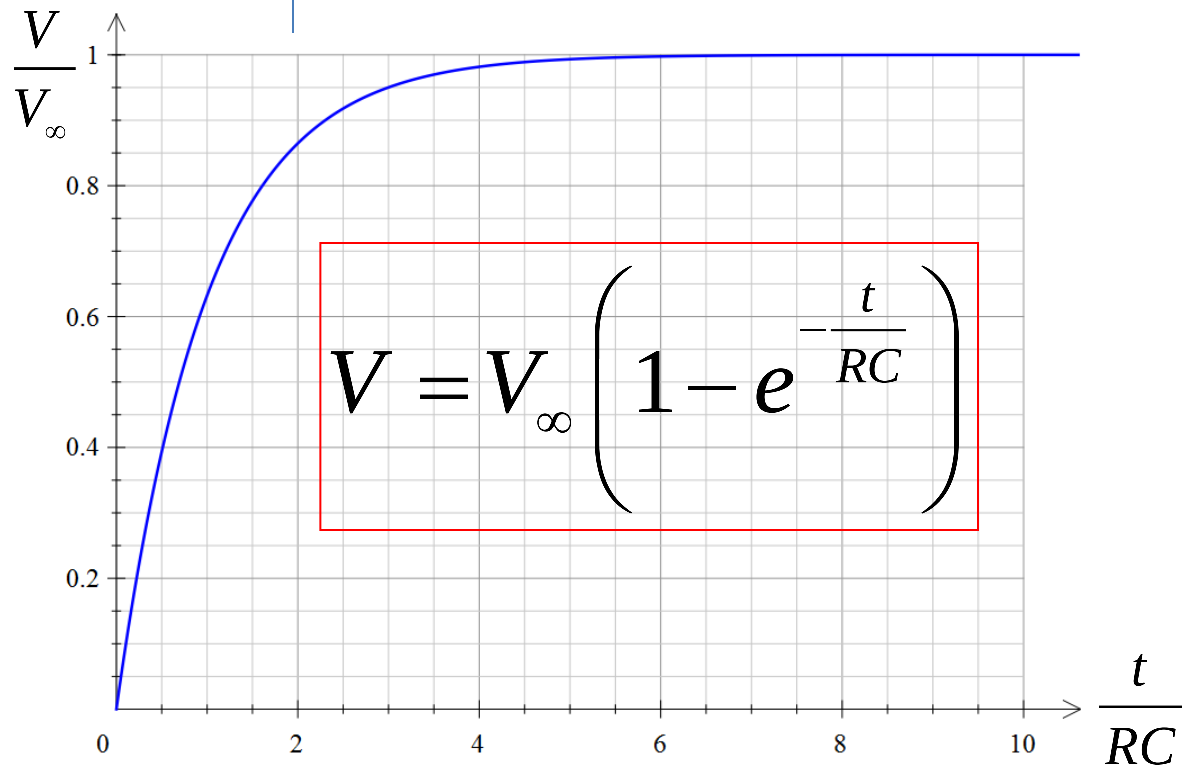


$$\frac{1}{RC}\int_0^t dt = \int_0^V \frac{dV}{V_\infty - V} = -\int_0^V \frac{-dV}{V_\infty - V}$$

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

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

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



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

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

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

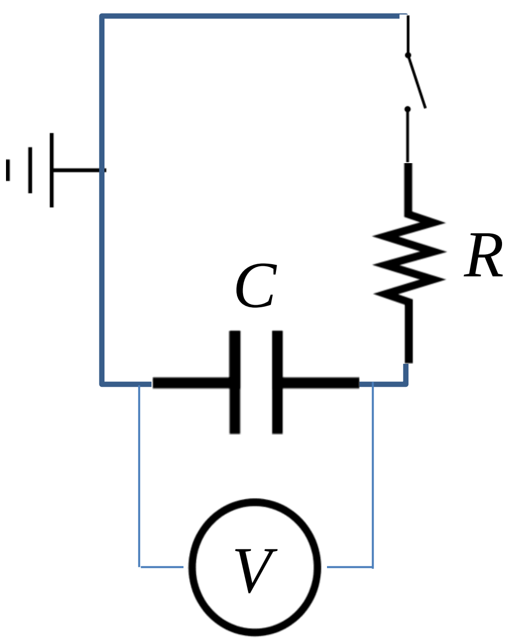
Note $V = V_0$ when $t = 0$

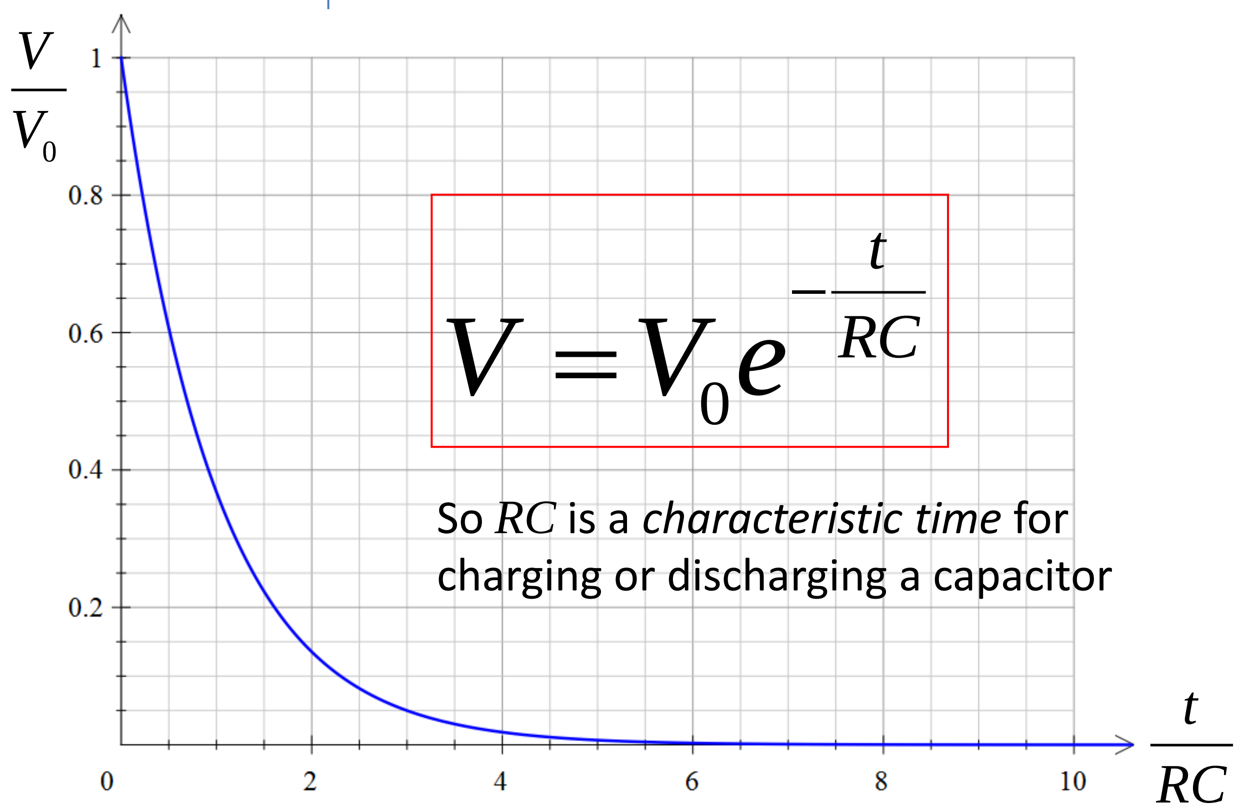
$$\frac{1}{RC}\int_0^t dt = -\int_{V_0}^{V}\frac{dV}{V}$$

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

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

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

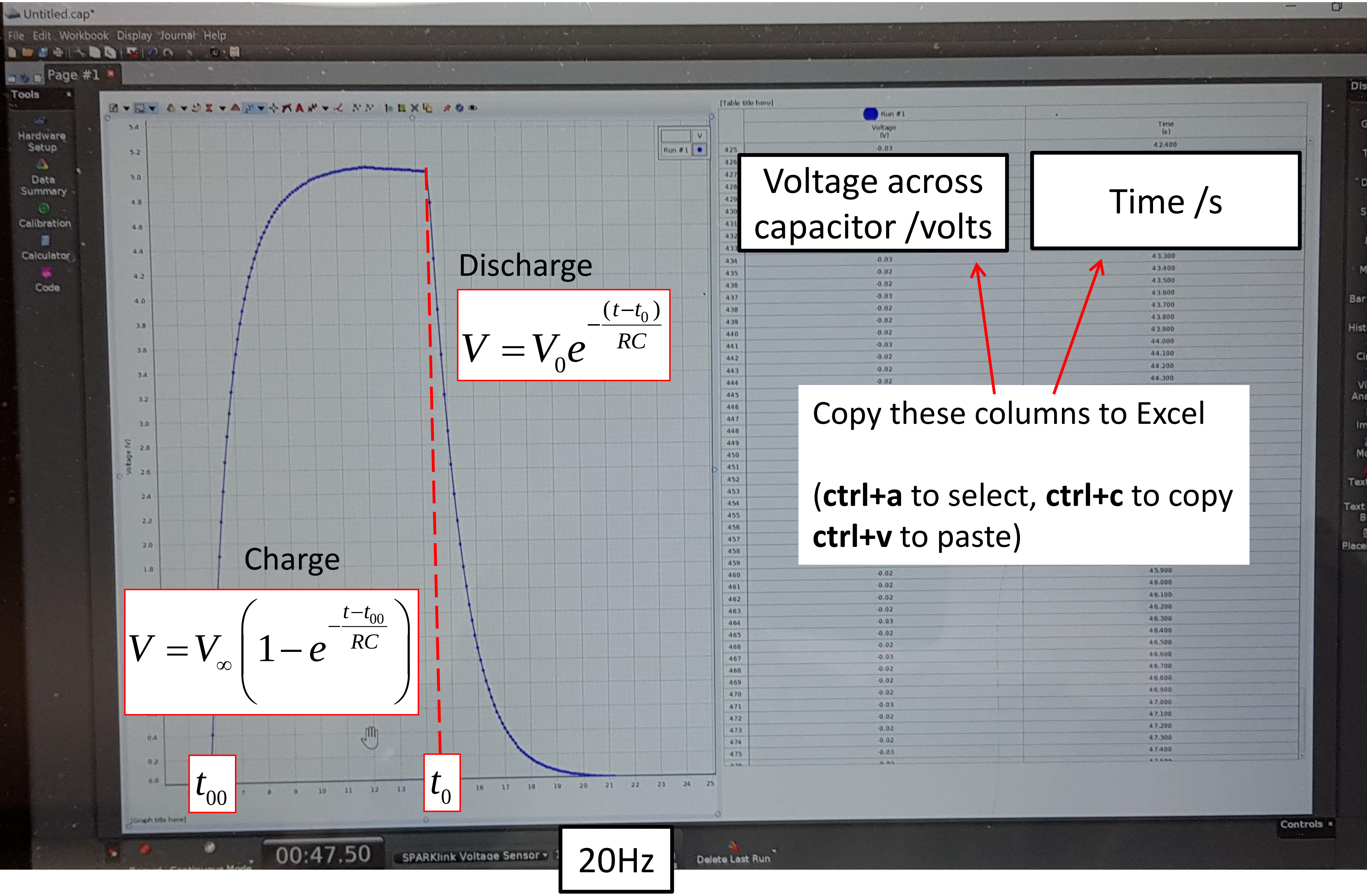




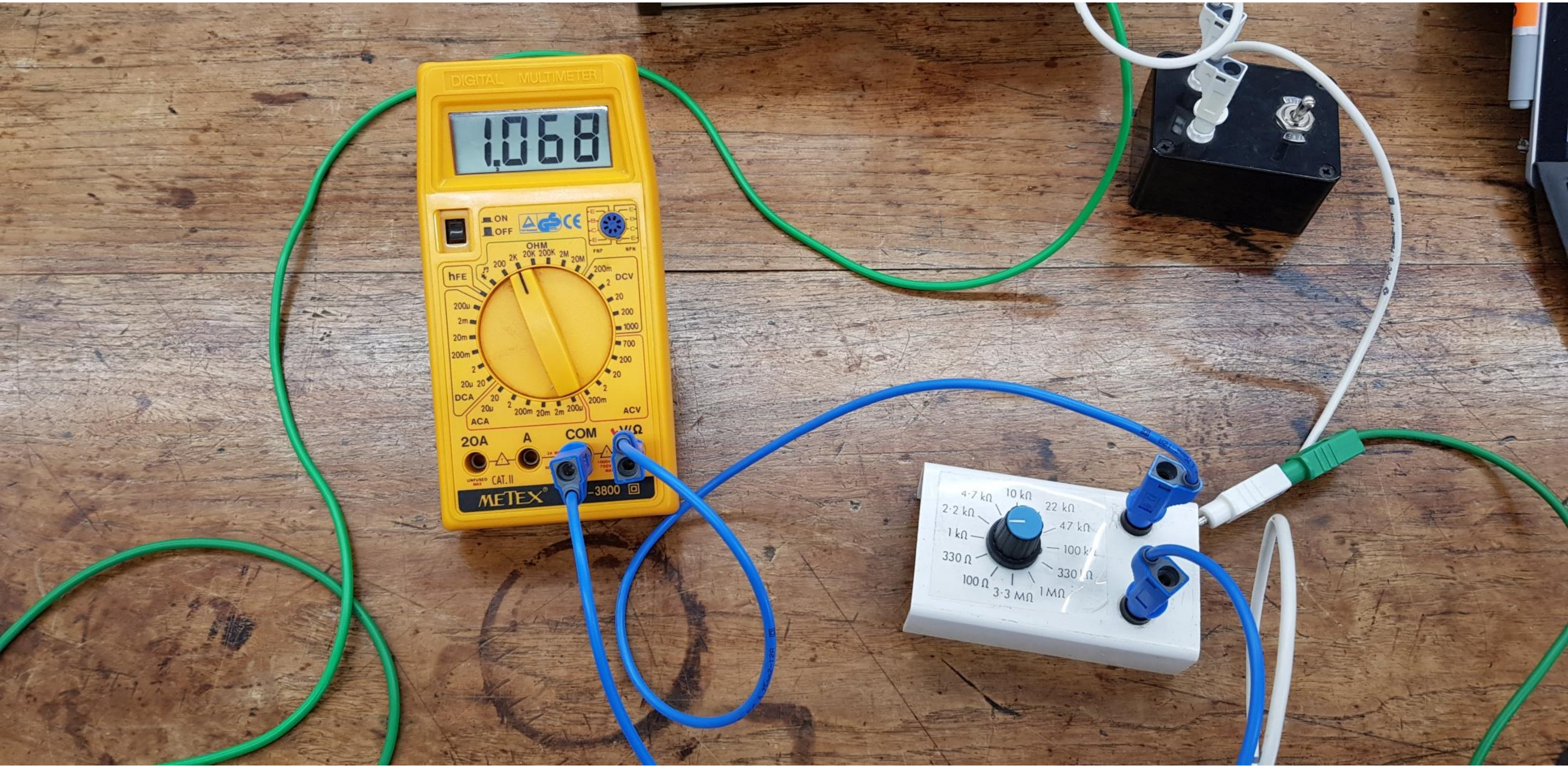
$$\boxed{V = V_0 e^{-\frac{t}{RC}}}$$

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

Time, current and voltage data copied and pasted into **Excel** from **Capstone**.



Use a multimeter to determine a precise measurement of the resistor chosen.
Write this into your spreadsheet!



Make sure your **disconnect** the resistor from the circuit first.

Resistance measurement from multimeter reading

Plot charging and discharging voltage vs time curves using Excel

CAPACITOR CHARGE AND DISCHARGE

A. French. 20/9/2021

R /ohms	1068

RC /s	1.048
C /microF	981

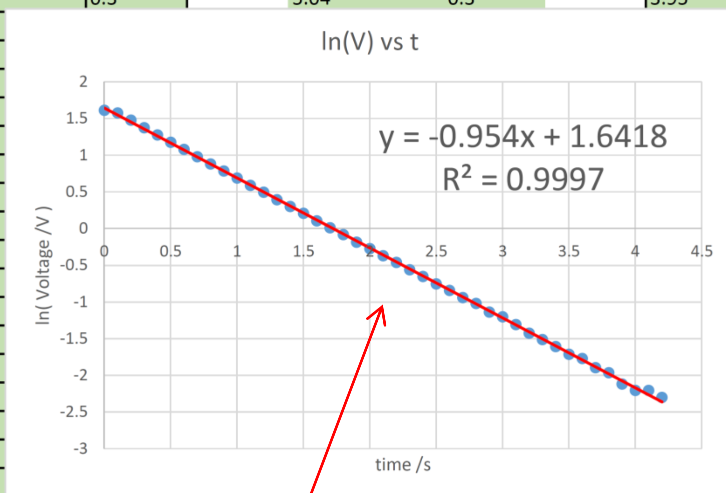
CHARGING

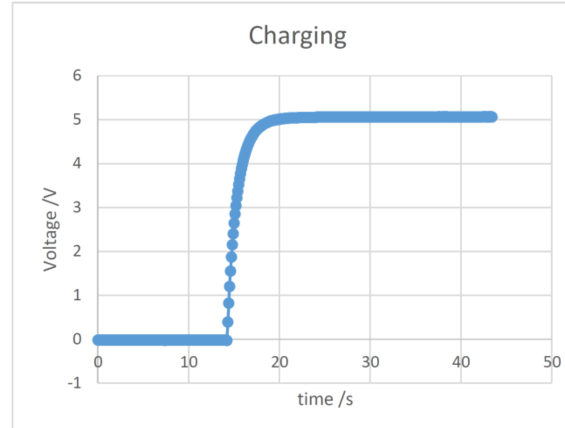
Voltage (V)	Time (s)
-0.02	0
-0.02	0.1
-0.02	0.2
-0.02	0.3
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	
-0.02	2.1
-0.02	2.2
-0.02	2.3
-0.02	2.4
-0.02	2.5
-0.02	2.6
-0.02	2.7
-0.02	2.8
-0.02	2.9

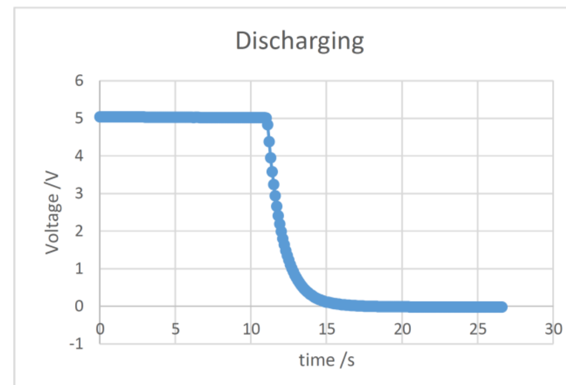
DISCHARGING

Voltage (V)	Time (s)
5.04	0
5.04	0.1
5.04	0.2
5.04	0.3
5.04	2.1
5.04	2.2
5.04	2.3
5.04	2.4
5.04	2.5
5.04	2.6
5.04	2.7
5.04	2.8
5.04	2.9

Voltage (V)	Time (s)	t-t0 /s	ln(V)
5.01	11	0	1.611436
4.83	11.1	0.1	1.574846
4.38	11.2	0.2	1.477049
3.95	11.3	0.3	1.373716
	11.4	0.4	1.275363
	11.5	0.5	1.175573
	11.6	0.6	1.07841
	11.7	0.7	0.978326
	11.8	0.8	0.879627
	11.9	0.9	0.783902
	12	1	0.688135
	12.1	1.1	0.587787
	12.2	1.2	0.494696
	12.3	1.3	0.392042
	12.4	1.4	0.300105
	12.5	1.5	0.207014
	12.6	1.6	0.10436
	12.7	1.7	0.00995
	12.8	1.8	-0.08338
	12.9	1.9	-0.18633
	13	2	-0.27444
0.69	13.1	2.1	-0.37106
0.63	13.2	2.2	-0.46204
0.57	13.3	2.3	-0.56212
0.52	13.4	2.4	-0.65393
0.47	13.5	2.5	-0.75502
0.43	13.6	2.6	-0.84397
0.39	13.7	2.7	-0.94161
0.36	13.8	2.8	-1.02165
0.32	13.9	2.9	-1.13943







lnV vs discharge time t

Extract just the discharge curve. Shift the time measurements so they start from zero.

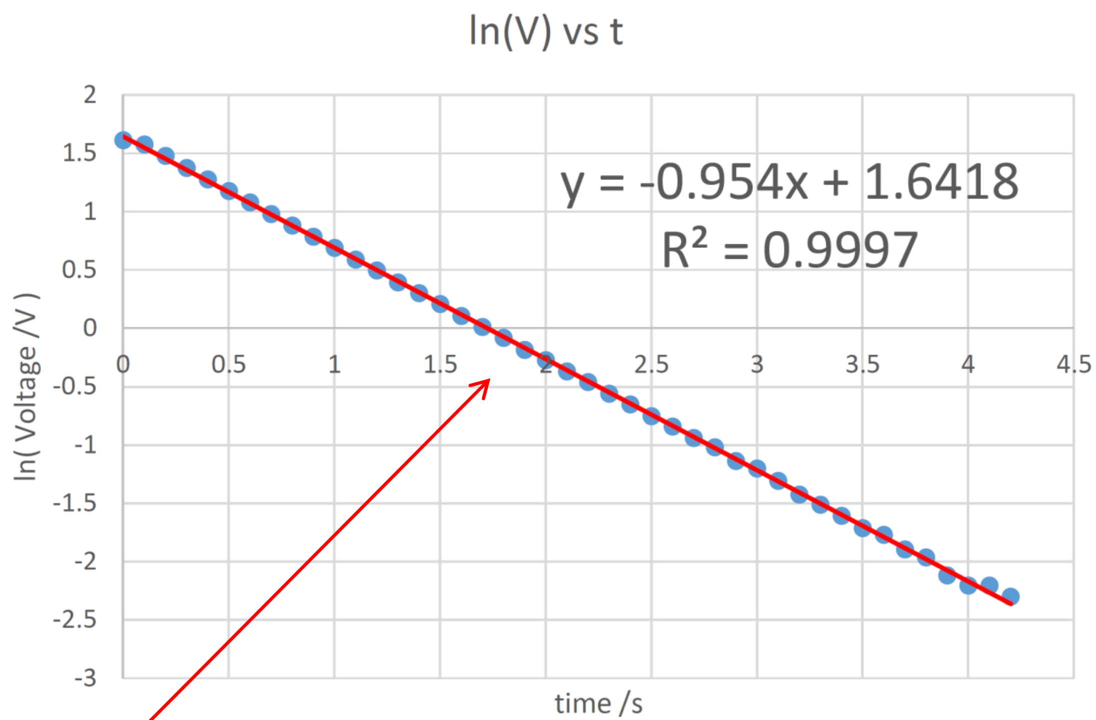
For **discharge**:

$$\boxed{V = V_0 e^{-\frac{t}{RC}} \qquad \therefore \ln V = \ln V_0 - \frac{t}{RC}}$$

$$\boxed{\ln V_0 = 1.642 \qquad \therefore V_0 = 5.17\text{V}}$$

$$\boxed{-\frac{1}{RC} = -0.954 \qquad \therefore RC = 1.048\text{s}}$$

So a graph of $\ln V$ vs t should be a straight line graph, with gradient $-1/RC$



High degree of correlation, so we can justify the exponential decay model.

Using a multimeter: R = 1,068Ω.

Hence:

$$\boxed{C = 981\mu\text{F}}$$

i.e. capacitance is about 1mF