Discharge unknown C through known R

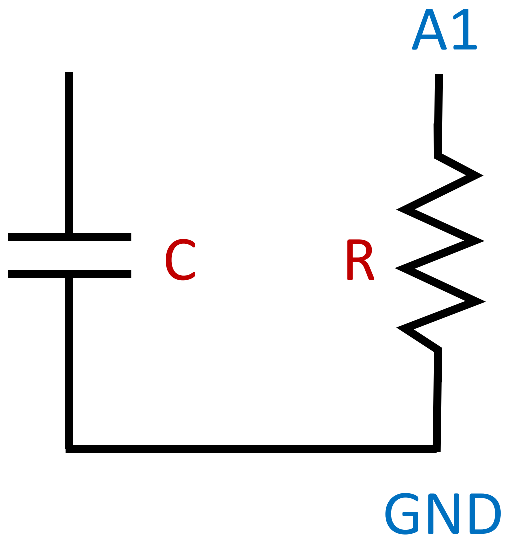
(Measure time constant. Calculate Q_0 two different ways)

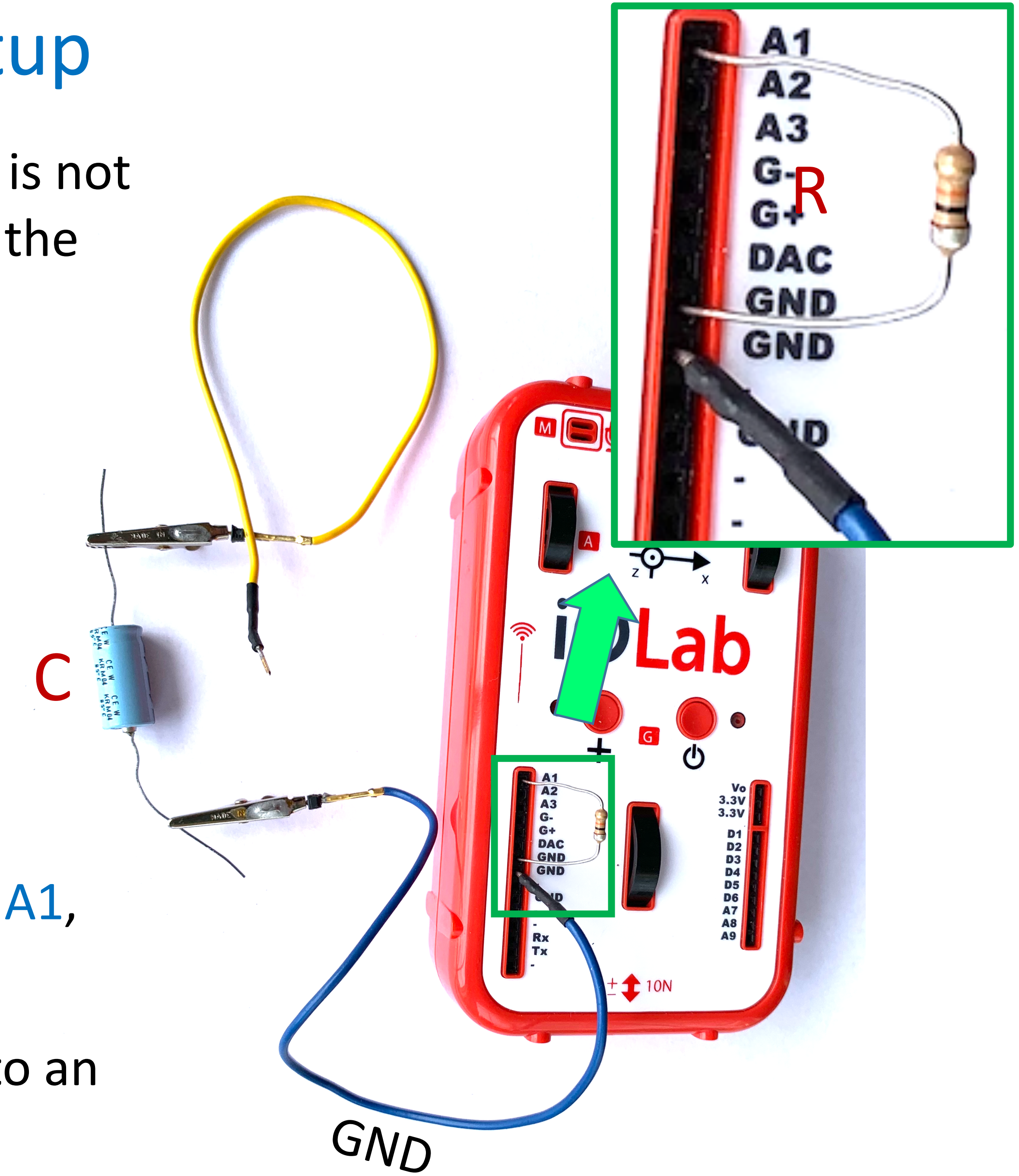
Materials:

- An IOLab
- A capacitor in the 10-50 μf range.
- A 10kΩ resistor.
- Two wires with clips at one end (and a single strand at the other end so they can be pushed into the IOLab expansion connector.)

Experimental Setup

The circuit is initially open and the capacitor is not charged. One side of both the capacitor and the resistor are connected to GND on the IOLab.

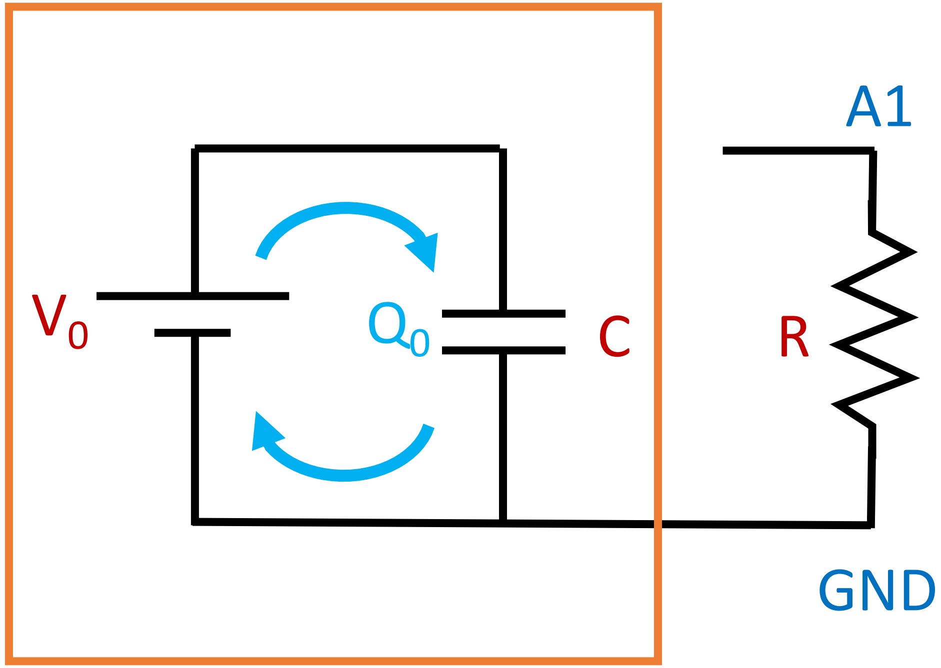


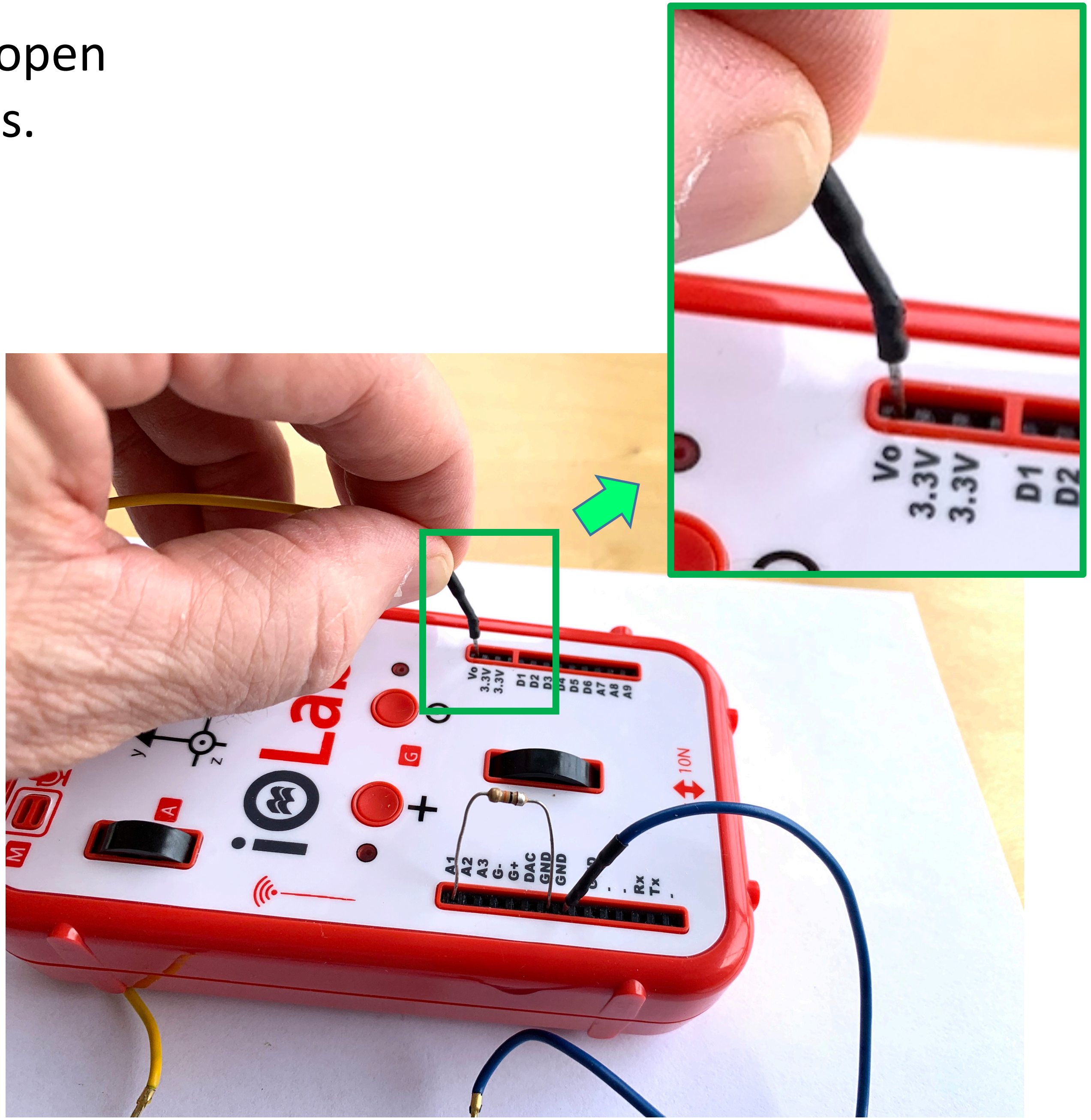


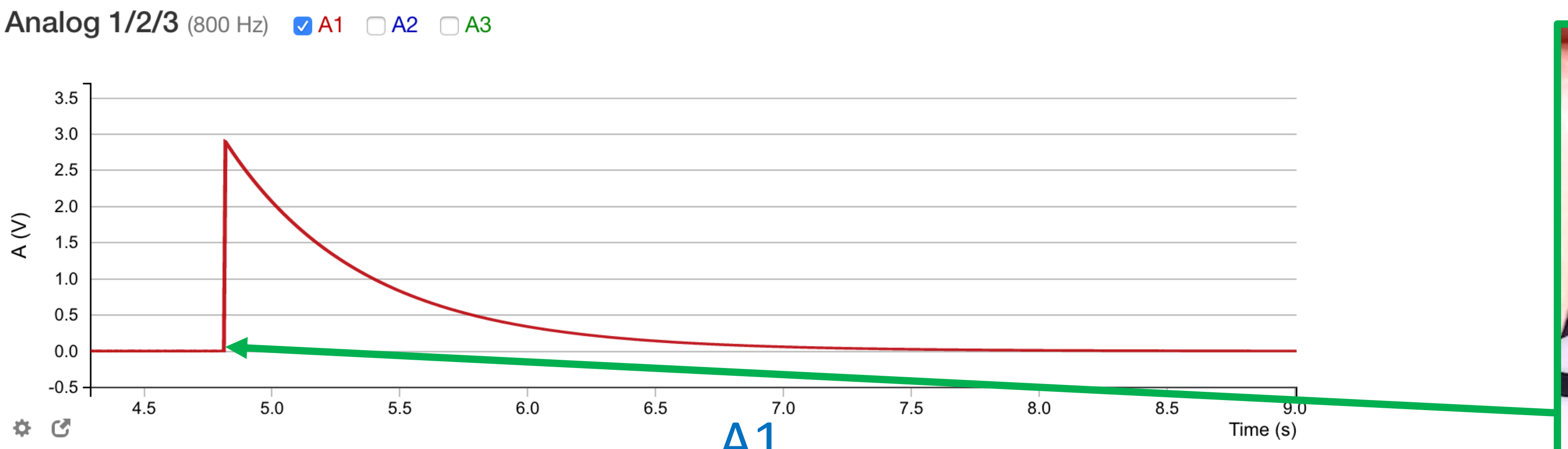
The other end of the resistor is connected to A1, which will be used to measure its voltage.

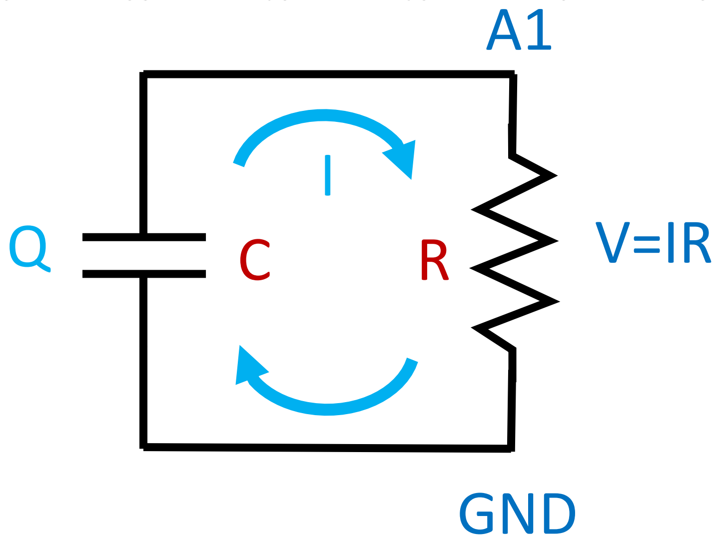
The other end of the capacitor is connected to an open wire to begin with.

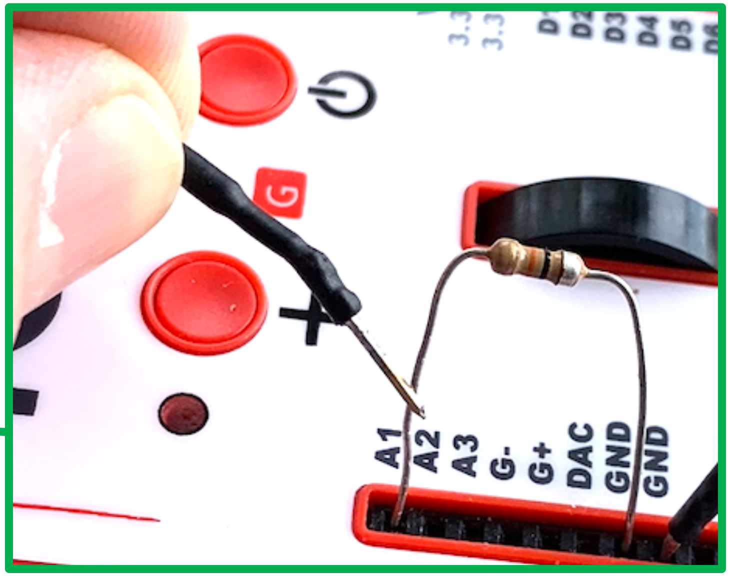
The capacitor is charged by plugging its open wire into the V_0 output for a few seconds.

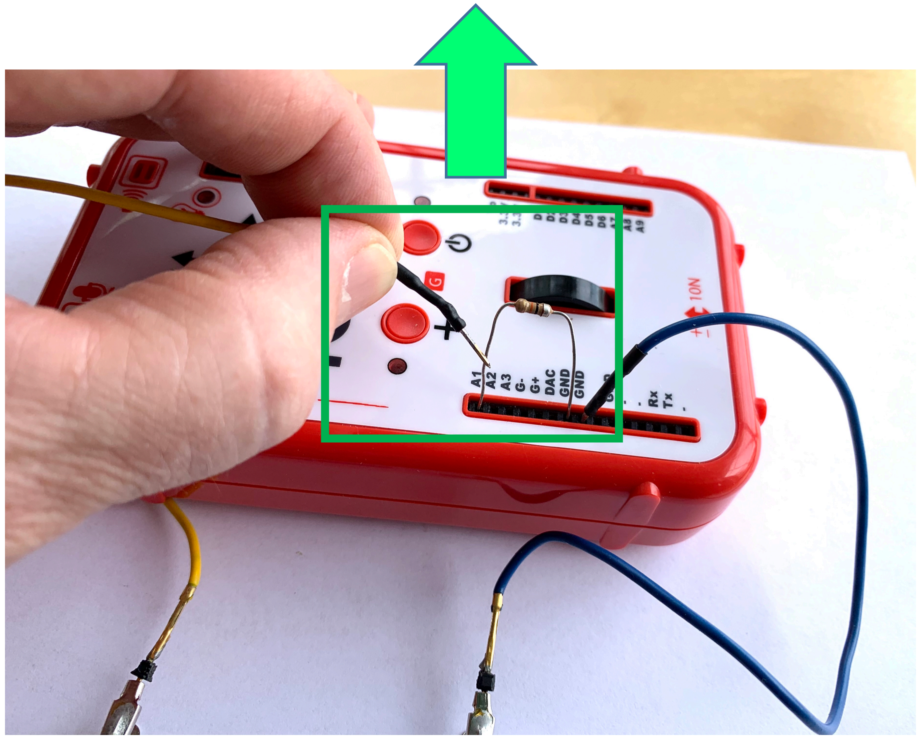












While the voltage across the resistor is recorded using A1, the capacitor is discharged by touching its open wire to the ungrounded end of the resistor for a few seconds.

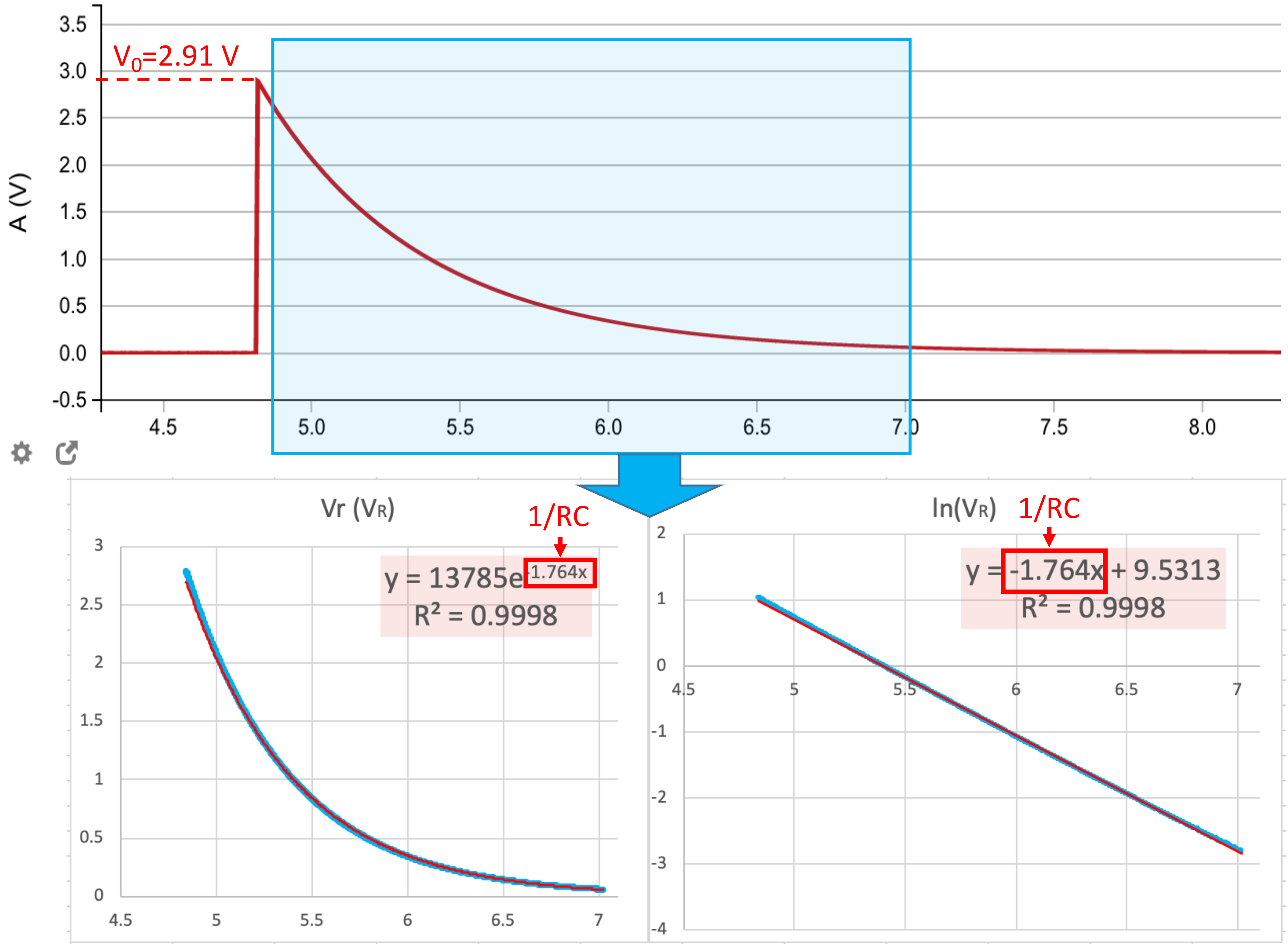
Analysis

Exported blue region to Excel (or Google Sheets) and fit with trendline.

Raw | Calculated

Time (s)	Vr (V_R)	ln(V_R)
4.8400002	2.794987	1.0278274
4.8412499	2.7883868	1.0254632
4.8425002	2.7817864	1.0230933
4.84375	2.7751865	1.020718
4.8449998	2.7685862	1.0183368
4.8462501	2.761986	1.01595
4.8474998	2.7553859	1.0135575
4.8487501	2.7487857	1.0111593
4.8499999	2.7429113	1.0090199
4.8512502	2.7363179	1.0066132
4.8525	2.7297177	1.0041982
4.8537502	2.7238457	1.0020447
4.855	2.7172499	0.9996203
4.8562498	2.71065	0.9971884
4.8575001	2.7047801	0.9950206

Analog 1/2/3 (800 Hz) A1 A2 A3



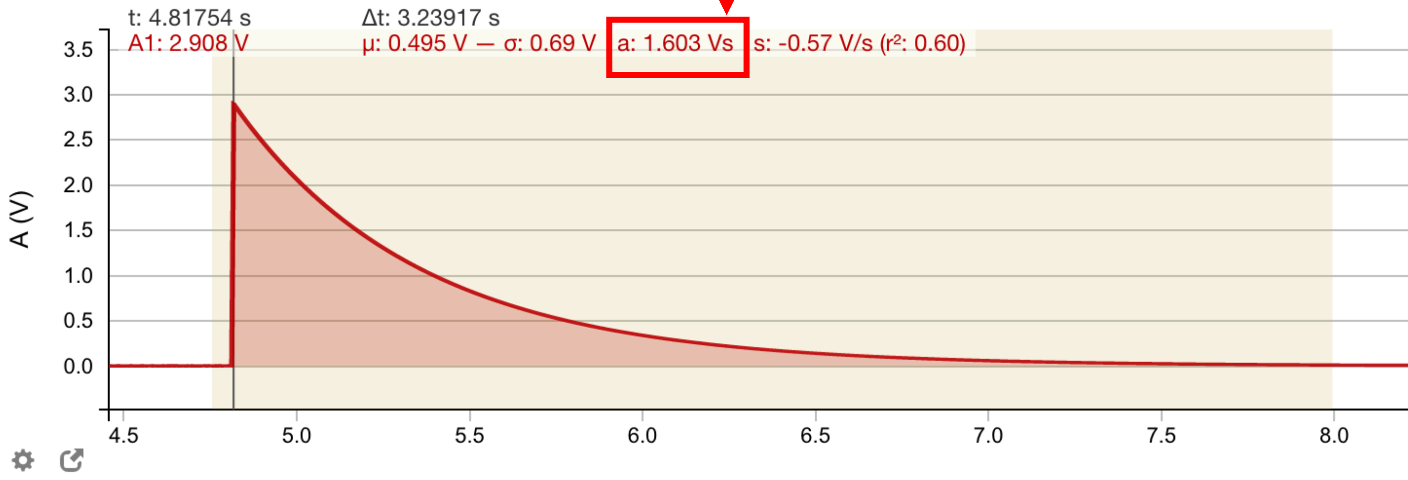
Analysis

There are several ways to use these data. One might be to have the value of the capacitor C be unknown and ask students to calculate the initial charge on the capacitor Q_0 using their data.

There are two different ways of doing this, which allows a comparison to be made:

1) Find C and V_0 then use $Q_0 = V_0 C$:
   a) Fitting the data on the previous page to find the exponential time constant we get 1/RC = 1.76 s.
   b) Since the resistance is known, R = 10 kΩ, we find a capacitance of C = 56.7 μf.
   c) We can use the data on the previous slide to measure the initial voltage across the capacitor to be V_0 = 2.91 V.
   d) From these values we get $Q_0 = V_0 C$ = 165 μC.

2) Integrate the current through the discharging capacitor $Q_0 = \int I dt = \frac{1}{R}\int V dt$:
   a) Using IOLab's integration tool $\int V dt$ = 1.6 Vs.
   b) Using R = 10 kΩ get $Q_0 = \frac{1}{R}\int V dt$ = 160 μC.



There are various ways of estimating the uncertainty on these values (multiple trials, error on the fitted slope, etc), so the two values of Q_0 can be compared.

Notes on the Experimental Setup

1) Using the A1/2/3 inputs (sampled at 800 Hz) is preferable to the A7/8/9 inputs (sampled at 100 Hz), especially when studying smaller time constants.
2) It is nice if RC can be at least 0.1 s so that the exponential decay can be observed by students even before zooming in on the data.
3) I suggest using an R of no greater than 10kΩ to make sure that this is much smaller than the input impedance of the IOLab's analog inputs. If R = 10kΩ then you will need $C \geq 10\ \mu f$ to get $RC \geq 0.1$ s (in this example I used R = 10kΩ and C around 50 μf.)
4) I had the best luck using electrolytic capacitors (the top one shown in the picture below). These have the disadvantage that they tend to be polarized (i.e. they have + and – terminals), but they are easy to find with large capacitance values.
5) I found some very inexpensive ceramic capacitors from a Chinese supplier selling on Amazon that had values up to 10 μf, however many of them did not display truly exponential decays so I recommend that you avoid these. Since I am working from home (COVID) my selection of components is not very extensive, so I recommend experimenting a bit to see what caps work best for you.