9. Black box

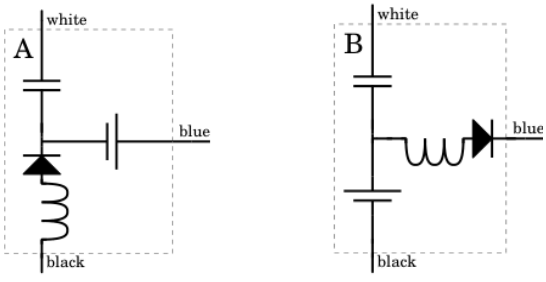
By measuring current with with positive lead of multimeter connected to "blue"

and negative lead connected to "black"

we get $I_0 \approx 95\,\mathrm{mA}$.

From this measurement alone, since we made a circuit that continuously conducted current,

we can deduce that the circuit inside the black box has to be one of following:



Note that the order of the inductor and diode in series does not change anything.

The actual measured current value varies a bit from one black box to another and also changes very slightly due battery voltage dropping and inductor heating up slightly.

i)

Measuring voltage between "blue" and "black" we determine the electromotive force of the battery $U = 9.5\,\mathrm{V}$.

ii)

We get the internal resistance of the inductor from $R_l = U/I_0 \approx 100\,\mathrm{ohm}$. We can also get some hint to the magnitude of the inductance as we saw no exponential ramp up of current when measuring, meaning $L/R \ll t$.

iii)

Determining which of the two possible circuits is inside the black box is trickier. One way to do it, is to notice that when we disconnect "blue" and "black" we can get a small spark, or feel a small pulse of current if we happen to touch the wires at that point. That is because $L\frac{\partial I}{\partial t} = U_l$ – the current through the inductor can't change instantaneously and the voltage will generated by the inductor enough for spark or high voltage pulse. Meanwhile if we have capacitor in parallel with inductor while disconnecting the circuit we wont get the effect. By testing with "white" lead parallel with "black" or with "blue" we can determine that no spark happens in latter case and the circuit in the black box is circuit B from the figure.

iv)

By connecting voltmeter between "white" and "black" or "white" and "blue" we can see the voltage decaying exponentially. That means indeed, that the capacitor is connected to the "white" wire and depending if the other lead is connected to "black" or "blue" we are charging the capacitor to negative battery voltage through voltmeter or discharging it through voltmeter and inductor and diode. We have to be careful not to touch both wires at the same time, since the resistance of good skin conductance is much smaller then the resistance of the voltmeter.

We can measure the capacitance by measuring the exponent: for example by taking two voltage readings and measuring the time interval between the readings. $C = \frac{\ln \frac{U_1}{U_2}}{\tau R_m} \approx 1\,\mathrm{uF}$.

v)

First we connect all three wires together. That means we have current running through

inductor and the capacitor is charged to negative of battery voltage. We connect voltmeter between "white" and "black", so that we measure the total of the capacitor and battery voltage. The reading is zero at the start since all black box leads are connected. Now we disconnect the inductor battery current loop by disconnecting "black" from other box leads and the multimeter reading will jump to $U_c + U \approx 32\,\mathrm{V}$ and starts to decay exponentially as before. We can do this many times to get a maximum reading.

After disconnecting the "black", the current goes through LCR circuit formed by inductor and capacitor, but instead of oscillating it stops due to the diode when current through inductor has reached zero.

We can get the upper and lower bounds for the inductance value by considering two different cases.

Upper bound we can get when we neglect the resistive losses. In that case all the energy at the end is in the capacitor. When we write down the energy balance we get:

$$\frac{U^2 C}{2} + \frac{I^2 L}{2} = \frac{U_c^2 C}{2} \Rightarrow L \approx 130\,\mathrm{mH}$$

Lower bound we can get when we assume that most of the energy went to resistive losses, in that case the inductor current decays exponentially and we can write expression for the down the total charge:

$$(U_c + U) * C = I \frac{R_l}{L} \Rightarrow L \approx 33.6\,\mathrm{mH}$$

The correct value for the inductor $L \approx 100\,\mathrm{mH}$ is between those bounds and closer to the upper bound as we may guess since $U_c > U$.

It is possible to get more accurate value by looking at it without the assumptions – as a damped harmonic oscillation.