Non-ideal capacitors (10 points)

Capacitance measurement method:

First, measure the highest voltage the capacitor can reach by connecting it to the voltage source via jumper wire W2. Before each measurement, connect capacitor to starting voltage source with jumper wire W2 and to a final voltage source (U_f) with jumper wire W1 via the resistor R1. Capacitor C2 should be prepared that way for at least 10 s, while C1 measurement can be started immediately by disconnecting jumper wire W2 from the starting voltage source. To determine a precise value of the final voltage U_f, it should be measured after capacitor has been connected to final source via R1 for a long time (at least 3 minutes). Then, the capacitance can be calculated from:

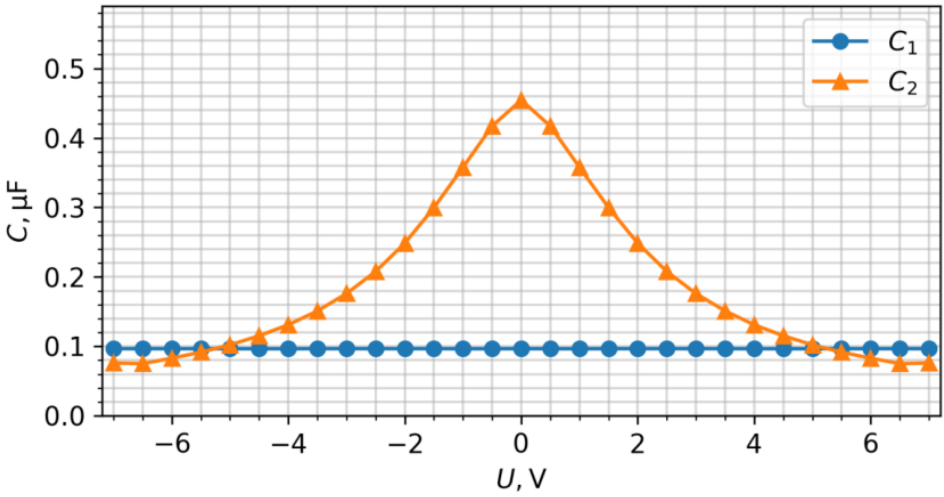
$$C(U) = \frac{U_f - U(t)}{R1} \Big/ \frac{\mathrm{d}U}{\mathrm{d}t}$$

When measuring C2, to ensure minimal change in charging current, capacitance should only be calculated in conditions where U_f and $U(t)$ have different polarities. This way, capacitance dependence on voltage should be symmetrical around 0 V.

Part A: Capacitors at room temperature (4 points)

A.1 (2.3 pt)

Graph $C_1(U)$ should be constant, $C_2(U)$ must be highest at 0 V. Example results measured at room temperature of 29 °C.



	C_1	C_2
0 V	0.100 µF	0.473 µF
3 V	0.100 µF	0.183 µF
6 V	0.100 µF	0.086 µF

$$C(U) = \frac{U_f - U(t)}{R1} \Big/ \frac{\mathrm{d}U}{\mathrm{d}t}\,.$$

A.2 (0.5 pt)

$U_{\text{max change}} = 1.6\,\text{V}$ at capacitor C2

A.3 (1.2 pt)

It's important to calculate $\int_{0\text{V}}^{6\text{V}} C(U)\,dU$, not just attempt to multiply $C(6\,\text{V}) \cdot 6\,\text{V}$

$$q_1 = 0.60\,\mu\text{C}; \quad q_2 = 1.3\,\mu\text{C}$$

Part B: Calibrating NCT thermistor (1 point)

B.1 (1.0 pt)

$$R_0 = \frac{U_{T0} R_3}{U - U_{T0}} \, \mathrm{e}^{-B/T},$$

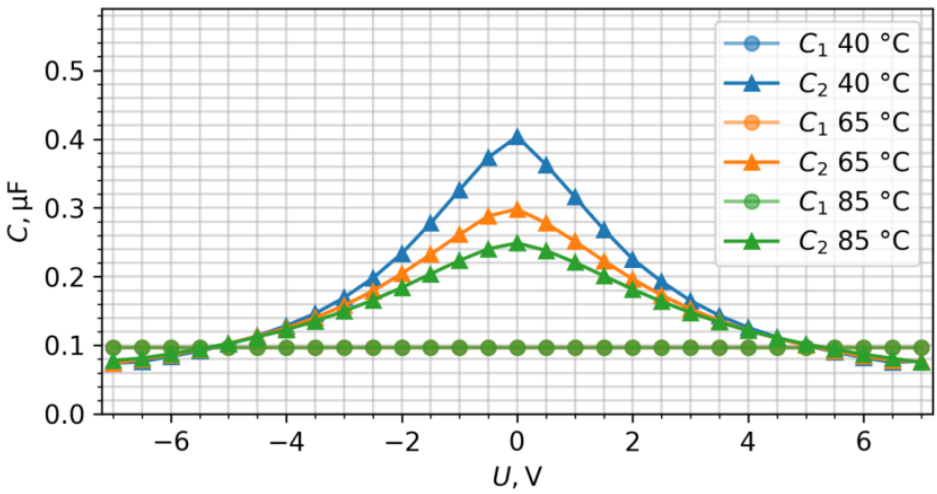
where $U = 3.3\,\mathrm{V}$, U_{T0} – uT at room temperature, T – room temperature in kelvins

$$R_0 = 0.0341\,\Omega.$$

Part C: Capacitors at different temperatures (3 points)

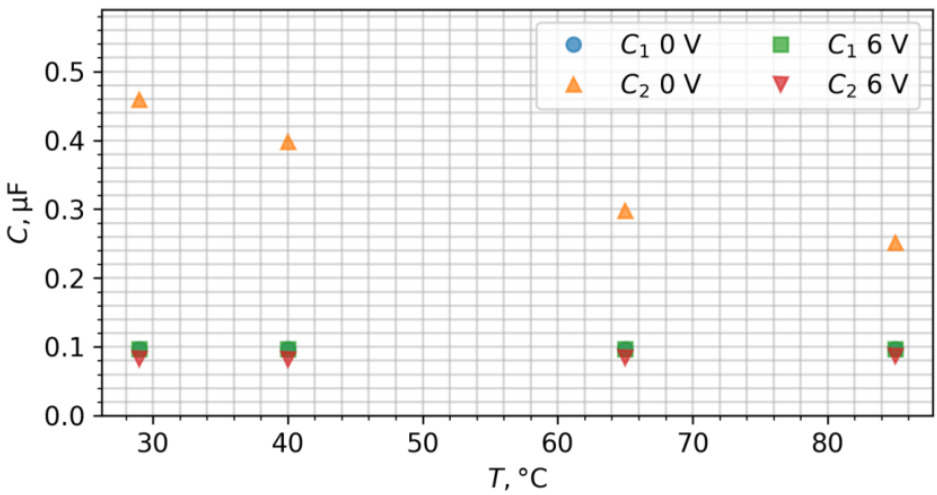
C.1 (1.3 pt)

Graphs $C_1(U, T)$ should always stay constant, $C_2(U)$ must be highest at 0 V



C.2 (0.5 pt)

Graph $C_1(T)$ should always stay constant



C.3 (1.2 pt)

$$C_1(85\,^\circ\mathrm{C})/C_1(40\,^\circ\mathrm{C})\big|_{0\mathrm{V}} = 1.00$$

$$C_1(85\,^\circ\mathrm{C})/C_1(40\,^\circ\mathrm{C})\big|_{6\mathrm{V}} = 1.00$$

$$C_2(85\,^\circ\mathrm{C})/C_2(40\,^\circ\mathrm{C})\big|_{0\mathrm{V}} = 0.63$$

$$C_2(85\,^\circ\mathrm{C})/C_2(40\,^\circ\mathrm{C})\big|_{6\mathrm{V}} = 1.06$$

Part D: Sources of measurement errors (2 points)

D.1 (1.0 pt)

Initial settings:

S1 position	IN connection
C1	-9V or GND

Process:

Step number	S1 position	IN connection	Duration, s	Me
1	C1	+9V	0.2 s (any short time is good)	
2	C1	Free		$\|\mathrm{d}u$
3	C1	+9V	5 s (has to be much longer than first)	
4	C1	Free		$\|\mathrm{d}u$

Verification: $|\mathrm{d}uC(t)|/\mathrm{d}t|_2 = |\mathrm{d}uC(t)|/\mathrm{d}t|_4$

Main source of error: 1 (Leakage current.)

D.2 (1.0 pt)

Initial settings:

S1 position	IN connection
C2	-9V or GND

Process:

Step number	S1 position	IN connection	Duration, s	Me
1	C2	+9V	0.2 s (any short time is good)	
2	C2	Free		$\|\mathrm{d}u$
3	C2	+9V	5 s (has to be much longer than first)	
4	C2	Free		$\|\mathrm{d}u$

Verification: $|\mathrm{d}uC(t)|/\mathrm{d}t|_2 \gg |\mathrm{d}uC(t)|/\mathrm{d}t|_4$

Alternatively,

$$\frac{|\mathrm{d}uC(t)|/\mathrm{d}t|_2}{|\mathrm{d}uC(t)|/\mathrm{d}t|_4} > 2\,.$$

Main source of error: 2 (Polarization properties of the capacitor's dielectric media)