PHYSICS EXPERIMENT

Charging and Discharging a Capacitor

DETERMINE THE CHARGING AND DISCHARGING TIMES

- Record the change in the capacitor voltage over time while a capacitor is charging by measuring the time taken to reach specific points.
- Record the change in the capacitor voltage over time while a capacitor is discharging by measuring the time taken to reach specific points.
- Determine resistance and capacitance by measuring the times it takes to charge and discharge and make a comparison with known external parameters.

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Fig. 1: Charge/discharge equipment in operation with external (left) und internal (right) resistor/capacitor pair.

BASIC PRINCIPLES

In a DC circuit, current only flows through a capacitor while it is being turned on or off. The current causes the capacitor to charge when the circuit is switched on until it reaches the full voltage applied. When the circuit is turned off, the capacitor is discharged until its voltage falls to zero.

For a DC circuit with capacitance *C*, resistance *R* and DC voltage U_0, the following applies when the circuit is switched on:

$$(1) \quad U(t) = U_0 \cdot (1 - e^{-\frac{t}{\tau}})$$

The following applies when the circuit is switched off:

$$(2) \quad U(t) = U_0 \cdot e^{-\frac{t}{\tau}}$$

In both cases the time constant is

$$(3) \quad \tau = R \cdot C \,.$$

To check these relationships, the time to reach certain pre-determined comparison voltages is measured during the course of the experiment. A stopwatch is started at the same time as the circuit is switched on or off and then stopped by means of a comparator circuit once the comparison voltage has been reached. By measuring the times for various comparison voltages, the charging and discharging curves can be sampled and plotted point by point.

In practice, the following time is also of interest:

$$(4) \quad t_{5\%} = -\ln(5\%) \cdot R \cdot C \approx 3 \cdot R \cdot C \,,$$

This is the time it takes for the capacitor voltage to reach 5% of the initial voltage U_0 during discharge or to reach within 5% of the final value U_0 when charging. By measuring $t_{5\%}$ it is possible to determine the parameters *R* and *C*, for example.

LIST OF EQUIPMENT

1	Charge and Discharge Apparatus @230V	1017781 (U10800-230)
or		
1	Charge and Discharge Apparatus @115V	1017780 (U10800-115)
1	Capacitor 1000 µF, 16 V, P2W191009957	1017806 (U333106)
1	Resistor 10 kΩ, 0,5 W, P2W19	1012922 (U333030)

Additionally recommended:

1	Digital Multimeter P1035	1002781 (U11806)

TURNING ON

- Connect the charge and discharge apparatus to the mains via the plug-in power supply provided.

GENERAL NOTES

When the selector switch is set to INTERN 1, INTERN 2 or INTERN 3, the internal capacitor will be connected to the terminals used for an external capacitor. Internal and external capacitors are connected in parallel in this case.

- Do not connect an external capacitor when carrying out measurements on the internal RC pairs.

The charging and discharging times measured are affected by bounce periods, which can be made worse if the charge/discharge switch is turned tentatively.

- Always turn the switch quickly.
- To determine the time more accurately, it may be advisable to carry out each measurement at least three times and take the average.
- Only choose external RC pairings which have a time constant $R \cdot C > 4\,\mathrm{s}$.

PROCEDURE

Measurements on internal resistor-capacitor pairs

- Remove any external resistors or capacitors.
- Set the selector knob to INTERN 1, INTERN 2 or INTERN 3.

Measurements on external resistor-capacitor pairs

- Plug an external resistor and capacitor into the relevant terminals.
- Set the selector knob to EXTERN.

Measurement of charging time t_C

- Set the function switch to CHARGE – STOP.
- Set the reference level selector to the required voltage.
- Briefly press the the RESET button to reset the digital counter to zero.
- Set the function switch to CHARGE – START, to start charging and measurement of time.
- Make a note of the time measured as soon as the counter stops.

Measurement of discharging time t_{DC}

- Follow a similar procedure as for the charging curve, except that the function switch should be set to DISCHARGE – STOP and then DISCHARGE – START.

Determination of time $t_{5\%}$

The time $t_{5\%}$ can be determined by measuring either charging or discharging (see explanation of equation (4)). Better precision can be obtained by forming an average from the measurements of both:

- Measure time $t_{C,\,5\%}$ to charge to 9.5 V.
- Measure time $t_{DC,\,5\%}$ to discharge to 0.5 V.
- Take the average of the two $(t_{C,\,5\%} + t_{DC,\,5\%}) / 2 = t_{5\%}$.

Plotting of charging curve

- Set the level selector switch for the reference voltage to 0.5 V and measure the discharging time as described under “Measurement of discharging time”.
- To measure the time for the next value, turn the selector switch up to the next level and repeat each step of the procedure.

Plotting of discharging curve

- Set the level selector switch for the reference voltage to 9.5 V and measure the discharging time as described under “Measurement of discharging time”.
- To measure the time for the next value, turn the selector switch up to the next level and repeat each step of the procedure.

Determination of internal and external capacitances and internal resistances

- Set the selector switch for the R/C pair to INTERN 1, INTERN 2 and INTERN 3 in sequence and, for each setting, measure times $t_{C,\,5\%}$ and $t_{DC,\,5\%}$ three times as described above. Enter the values into Table 5 and determine the time $t_{5\%}$.
- Connect the external capacitor. Set the selector switch for the R/C pair to INTERN 3, for example, and make three measurements of the times $t_{C,\,5\%}$ and $t_{DC,\,5\%}$ as described above. Enter the values into Table 5 and determine the time $t_{5\%}$.
- Also plug in the external resistor. Set the selector switch for the R/C pair to EXTERN and make three measurements of the times $t_{C,\,5\%}$ and $t_{DC,\,5\%}$ as described above. Enter the values into Table 5 and determine the time $t_{5\%}$.

SAMPLE MEASUREMENT

Tab. 1: Charge and discharge times for internal R/C pair 1.

U_C / V	t_C / s	t_{DC} / s
0.5	0.3	14.1
1.0	0.5	10.7
2.0	1.0	7.5
3.0	1.6	5.6
4.0	2.3	4.3
5.0	3.1	3.2
6.0	4.1	2.4
7.0	5.5	1.7
8.0	7.3	1.1
9.0	10.6	0.5
9.5	13.8	0.3

Tab. 2: Charge and discharge times for internal R/C pair 2.

U_C / V	t_C / s	t_{DC} / s
0.5	0.5	32.6
1.0	1.2	24.8
2.0	2.3	17.3
3.0	3.8	12.9
4.0	5.3	9.8
5.0	7.2	7.4
6.0	9.6	5.5
7.0	12.7	3.9
8.0	17.0	2.5
9.0	24.6	1.3
9.5	32.4	0.7

Tab. 3: Charge and discharge times for internal R/C pair 3.

U_C / V	t_C / s	t_{DC} / s
0.5	1.1	63.8
1.0	2.2	48.6
2.0	4.6	33.8
3.0	7.3	25.2
4.0	10.4	19.2
5.0	14.2	14.6
6.0	18.9	10.7
7.0	24.9	7.7
8.0	33.6	4.8
9.0	49.1	2.4
9.5	65.8	1.3

Tab. 4: Charge and discharge times for external R/C pair.

U_C / V	t_C / s	t_{DC} / s
0.5	0.6	33.7
1.0	1.1	25.8
2.0	2.4	17.8
3.0	3.7	13.3
4.0	5.5	10.1
5.0	7.4	7.6
6.0	9.8	5.7
7.0	13.0	3.9
8.0	17.7	2.5
9.0	26.5	1.3
9.5	37.8	0.7

Tab. 5: Charging and discharging times $t_{C,5\%}$ and $t_{DC,5\%}$ for the three internal R/C pairs, for internal R/C pair 3 connected in parallel with an external capacitor and for the external RC pair plus times $t_{5\%}$ obtained from the averages.

Mode	$t_{C,\,5\%}$ / s			$t_{DC,\,5\%}$ / s			$t_{5\%}$ / s
INTERN 1	13.8	14.0	13.8	14.1	14.1	13.9	14.0
INTERN 2	32.4	32.4	32.1	32.6	32.6	32.4	32.4
INTERN 3	65.8	63.9	63.4	63.8	64.5	63.5	64.1
INTERN 3 + C_{EXT}	100.3	99.9	99.7	97.1	97.0	97.0	98.5
EXTERN	37.8	37.4	36.6	33.7	33.5	33.6	35.4

EVALUATION

Recording of charging and discharging curves

- Plot the selected voltages U_C against the measured charging and discharging times t_C and t_{DC} (tables 1 – 4).

Figs. 2 and 3 show examples of the charging and discharging curves for internal R/C pair 3. The exponential progressions expected from equations (1) and (2) are verified.

Determination of external and internal capacitance and internal resistances

For a known external resistance R_{ext} = 10 kΩ (5% tolerance) the external capacitance C_{ext} can be calculated from the time $t_{5\%} = t_{5\%,\,ext}$ (Table 5) by means of equation (4):

$$(5)\quad C_{ext} = \frac{t_{5\%,\,ext}}{3 \cdot R_{ext}} = \frac{35.4\ \text{s}}{3 \cdot 10\ \text{k}\Omega} = 1180\ \mu\text{F}\,.$$

This value is in agreement with the nominal value 1000 µF to within the specified tolerance of 20%.

According to equation (4), the following relationships are true of the times $t_{5\%}$ determined for internal R/C pair 3 with and without the external capacitor plugged in:

$$(6)\quad t_{5\%,\,3} = 3 \cdot R_{int,\,3} \cdot C_{int}$$

and

$$(7)\quad t_{5\%,\,3ext} = 3 \cdot R_{int,\,3} \cdot \left(C_{int} + C_{ext}\right)\,.$$

Dividing equation (7) by equation (6) and substituting the times from Table 5 yields:

$$(8)\quad C_{int} = C_{ext} \cdot \frac{t_{5\%,\,3}}{t_{5\%,\,3ext} - t_{5\%,\,3}} = 1180\ \mu\text{F} \cdot \frac{64.1\ \text{s}}{98.5\ \text{s} - 64.1\ \text{s}}\,.$$
$$= 2199\ \mu\text{F}$$

This value is in agreement with the nominal value 2000 µF to within the specified tolerance of 10%.

Finally, the three remaining unknown internal resistances $R_{int,\,i}$ can be found from the corresponding charging and discharging times (Table 5) and the previously determined internal capacitance C_{int}:

$$(9)\quad R_{int,\,i} = \frac{t_{5\%,\,i}}{3 \cdot C_{int}} \quad \text{mit } i = 1, 2, 3$$

The results are as follows:

$$(10)\quad R_{int,\,1} = \frac{14.0\ \text{s}}{3 \cdot 2199\ \mu\text{F}} = 2122\ \Omega\,.$$

$$(11)\quad R_{int,\,2} = \frac{32.4\ \text{s}}{3 \cdot 2199\ \mu\text{F}} = 4911\ \Omega\,.$$

$$(12)\quad R_{int,\,3} = \frac{64.1\ \text{s}}{3 \cdot 2199\ \mu\text{F}} = 9717\ \Omega\,.$$

These values are in good agreement with the nominal values of 2.2 kΩ, 5.1 kΩ and 10 kΩ.

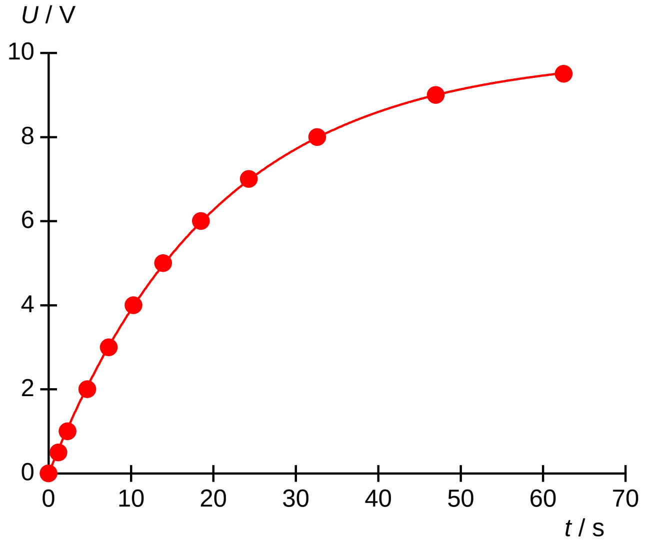

Fig. 2: Charging curve for internal RC pair no. 3.

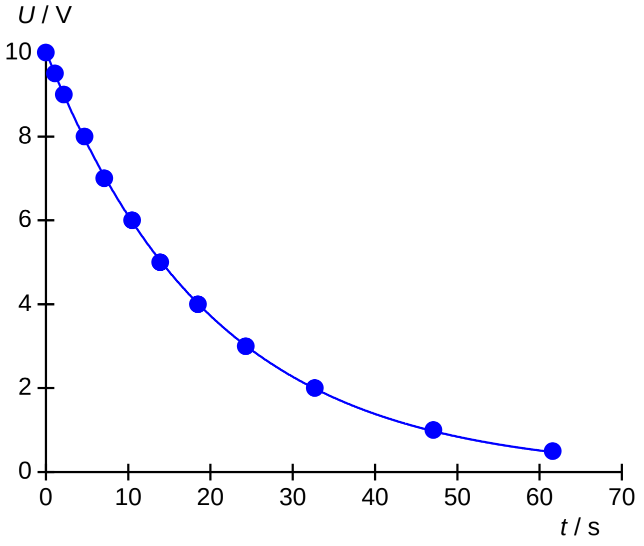

Fig. 3: Discharging curve for internal RC pair no. 3.