PHYSICS EXAM

Eine Batterie wird untersucht. Man hängt nacheinander Widerstandselemente mit festen Widerstandswerten an die Batterie und misst die Spannungen über der Batterie, dem Widerstandselement und die Stromstärke (wie in der Figur angegeben).

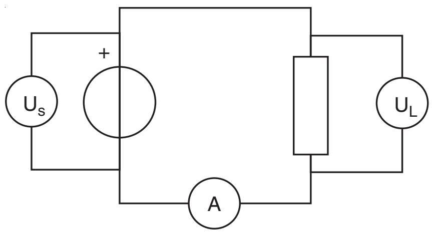


Table 1: Battery Characteristic

U_source / V	U_load / V	I_Q / A
1.257	1.149	2.490
1.470	1.370	2.310
2.250	2.170	1.690
2.720	2.670	1.230
3.240	3.200	0.780
3.690	3.670	0.450
3.990	3.900	0.247
4.190	4.140	0.131
4.290	4.260	0.067
4.350	4.340	0.037
4.380	4.380	0.018

Die Daten sind im unten aufgeführten Diagramm grafisch dargestellt.

a. Sie sehen, dass die beiden gemessenen Spannungen am Anfang der Tabelle nicht gleich sind. Für spätere Werte in der Tabelle sind sie so gut wie gleich. Erklären Sie in Worten, woher diese Erscheinung rührt.

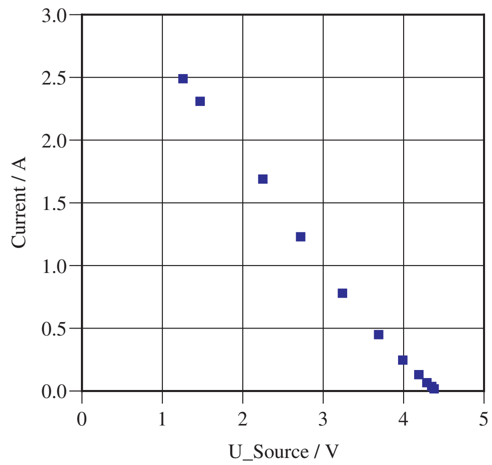
b. Bestimmen Sie den Innenwiderstand des Amperemeters.

c. Bestimmen Sie die Leerlaufspannung und den Innenwiderstand der Batterie. Woran sieht man, dass der Innenwiderstand (ungefähr) konstant ist? [Leerlaufspannung: Spannung über Batterie bei offenem Stromkreis. Sie sollten ungefähr 3.44 V und 1.25 Ω erhalten.]

d. Schliessen Sie ein Widerstandselement mit einem Widerstand von 1.5 Ω an die Batterie an. Wie lange dauert es, bis im Widerstandselement 100 J Energie freigesetzt werden?

e. Wieviel Energie ist in dieser Zeitspanne in der Batterie dissipiert worden?

f. Wieviel Energie hat die Batterie in dieser Zeitspanne durch chemische Reaktionen freigesetzt?



g. Ein Kondensator mit einer (konstanten) Kapazität von 1.0 F wird über ein Widerstandselement mit einem Widerstand von 2.0 Ω an die Batterie angeschlossen. Konstruieren Sie so genau wie möglich die Ladekurve des Kondensators (Kondensatorspannung als Funktion der Zeit). Erklären Sie Ihr Ergebnis.

h. Erläutern Sie den Zusammenhang zwischen der beim ganzen Ladevorgang (1) durch chemische Reaktionen freigesetzten Energie, (2) der in den Widerstandselementen dissipierten Energie und (3) der im Kondensator gespeicherten Energie.

PHYSICS EXAM

We shall investigate a battery. Step by step, different resistors having constant resistances are hooked up to the battery. Voltages and current are measured as indicated in the figure.

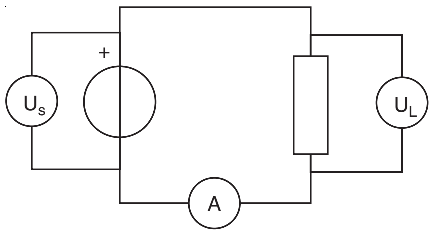


Table 2: Battery Characteristic

U_source / V	U_load / V	I_Q / A
1.257	1.149	2.490
1.470	1.370	2.310
2.250	2.170	1.690
2.720	2.670	1.230
3.240	3.200	0.780
3.690	3.670	0.450
3.990	3.900	0.247
4.190	4.140	0.131
4.290	4.260	0.067
4.350	4.340	0.037
4.380	4.380	0.018

Part of the data set is represented in the graph below.

a. Notice that the voltages U_s and U_L are not the same at the beginning of the table (for later values in the table they are almost equal). Explain (in words) the reason for this phenomenon.

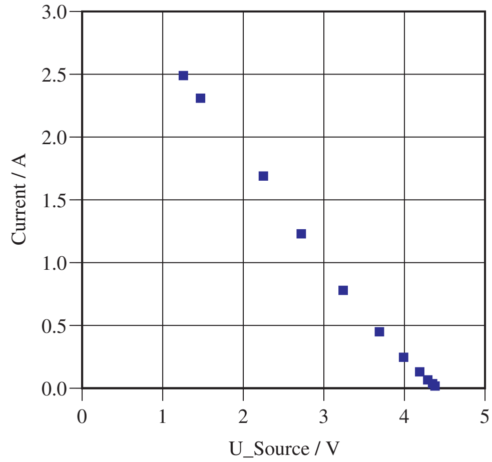
b. Determine the (internal) resistance of the ammeter.

c. Determine the open circuit voltage and the internal resistance of the battery. How can you tell that the internal resistance is (nearly) constant? [You should obtain values of about 3.44 V and 1.25 Ω.]

d. Hook up a resistor having a resistance of 1.5 Ω to the battery. How long will it take for 100 J of energy to be released in the resistor?

e. How much energy has been dissipated during this period in the battery?

f. How much energy has been released by the chemical reactions in the battery in this period?



g. A capacitor having a constant capacitance of 1.0 F is hooked up to the battery together with a resistor having a resistance of 2.0 Ω. Construct as carefully as possible the curve describing charging of the capacitor (voltage across the capacitor as a function of time). Explain you result.

h. Explain the relationship between the following quantities of energy: (1) energy released by chemical reactions during the process of charging; (2) energy dissipated in the resistive elements during charging; and (3) energy stored in the capacitor.

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Solutions

a. If the voltages U_S and U_L are not equal, there must be a voltage across the third element in the circuit, i.e., across the ammeter. If we model the ammeter as having an internal resistance, there will be a voltage proportional to the current through the ammeter.

b. See Question a:

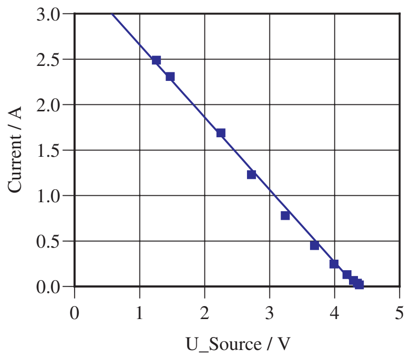
$$U_A = U_S - U_L$$
$$I_Q = \frac{U_A}{R_A}$$
$$\Rightarrow R_A = \frac{U_A}{I_Q} = \frac{U_S - U_L}{I_Q}$$
$$= \frac{1.257 - 1.149}{2.49}\Omega = 0.043\Omega$$

The first few measurements lead to similar results. The smaller the difference between the voltages measured, the less reliable the result will be.

c. Model of the battery with (constant) internal resistance

$$U_S = U_B - U_{Ri} = U_B - R_i I_Q$$

This is a linear relation which corresponds (more or less) to the data in the characteristic diagram:



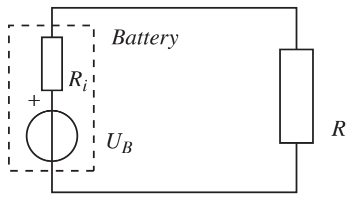
The linear fit is

$$I_Q = -0.797 U_S + 3.46$$

Therefore:

$$I_Q = -0.797 U_S + 3.46$$
$$I_Q = -\frac{1}{R_i} U_S + \frac{1}{R_i} U_B$$
$$R_i = \frac{1}{0.797}\Omega = 1.25\Omega$$
$$\frac{1}{R_i} U_B = 3.46\,\mathrm{A} \quad \Rightarrow \quad U_B = 4.34\,\mathrm{V}$$

d. There are two resistive elements in series:



$$I_Q = \frac{1}{R_i + R} U_B = \frac{4.34}{1.25 + 1.5}\mathrm{A} = 1.58\,\mathrm{A}$$
$$\mathcal{P}_R = U_R I_Q = R I_Q^2 = 1.5 \cdot 1.58^2\,\mathrm{W} = 3.74\,\mathrm{W}$$
$$\Delta t = \frac{W_{el}}{\mathcal{P}_R} = \frac{100}{3.74}\mathrm{s} = 26.8\,\mathrm{s}$$

e. Dissipation in the internal resistor:

$$\mathcal{P}_{Ri} = U_{Ri} I_Q = R_i I_Q^2 = 1.25 \cdot 1.58^2\,\mathrm{W} = 3.12\,\mathrm{W}$$
$$W_{el} = \mathcal{P}_{Ri}\Delta t = 3.12 \cdot 26.8\,\mathrm{J} = 83.6\,\mathrm{J}$$

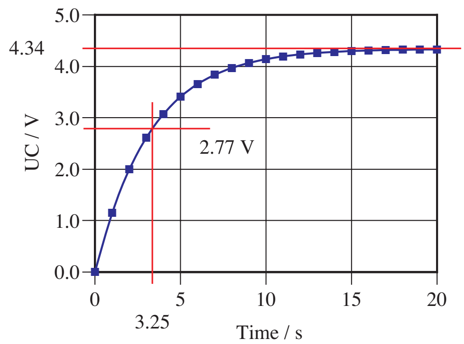
f. Energy released by the chemical reactions:

$$\mathcal{P}_{chem} = U_B I_Q = 4.34 \cdot 1.58\,\mathrm{W} = 6.86\,\mathrm{W}$$
$$W_{chem} = \mathcal{P}_{chem}\Delta t = 6.86 \cdot 26.8\,\mathrm{J} = 184\,\mathrm{J}$$

g. The simple circuit having resistors (R and Ri) with constant resistances and a capacitor having constant capacitance charges according to

$$U_C(t) = U_B\left(1 - \exp\left(-\frac{t}{\tau}\right)\right)$$
$$\tau = (R + R_i)C = (1.25 + 2) \cdot 1.0\,\mathrm{s} = 3.25\,\mathrm{s}$$

Graphical representation:



h. Energy released in battery = Energy dissipated in R_i and R plus energy stored in capacitor.