Measuring the Remaining State-of-Charge of an Alkaline, Primary, Battery with Arduino and hand-made Instrument

Mauro Tomassetti, Francesca Pagnanelli, Maria Pia Sammartino, Angela Marchetti, Mauro Castrucci, Giovanni Visco and Enrico Bodo

Chemistry Department, "La Sapienza" University, p.le A. Moro 5, 00185, Rome, Italy

Abstract

In 1800, an Italian scientist named Conte Alessandro Giuseppe Antonio Anastasio Volta invented the "Voltaic battery", then called the "Voltaic column", which consisted of alternating discs of silver and zinc separated by a card soaked in salt water [1].

Imagine a world without batteries: everything from a modern car to an old quartz watch would stop working. Among the many methods of generating direct current (DC) electricity for use in portable devices are batteries (primary battery), accumulators (secondary battery) and now supercapacitors, which can also be used for energy storage [2].

On 2024 European Portable Battery Association reports 295,000 tonnes, 570 g per capita in 2021. In unit terms, around 23 portable batteries per capita were placed on the market in 2020 [3].

According to a recent Eurostat report, Recycling of batteries and accumulators, around 244,000 tonnes (or an estimated 12 billion units) of portable batteries were placed on the market in the EEA plus Switzerland in 2022 [4].

Given the amount of non-rechargeable batteries on the market, a tool is needed to measure the residual charge and then, if possible, define a re-charging method.

Arduino has all the features to a data acquisition instrument [5], some our previous work use Arduino to build electrochemistry instrument [6] as well as the circuit presented here.

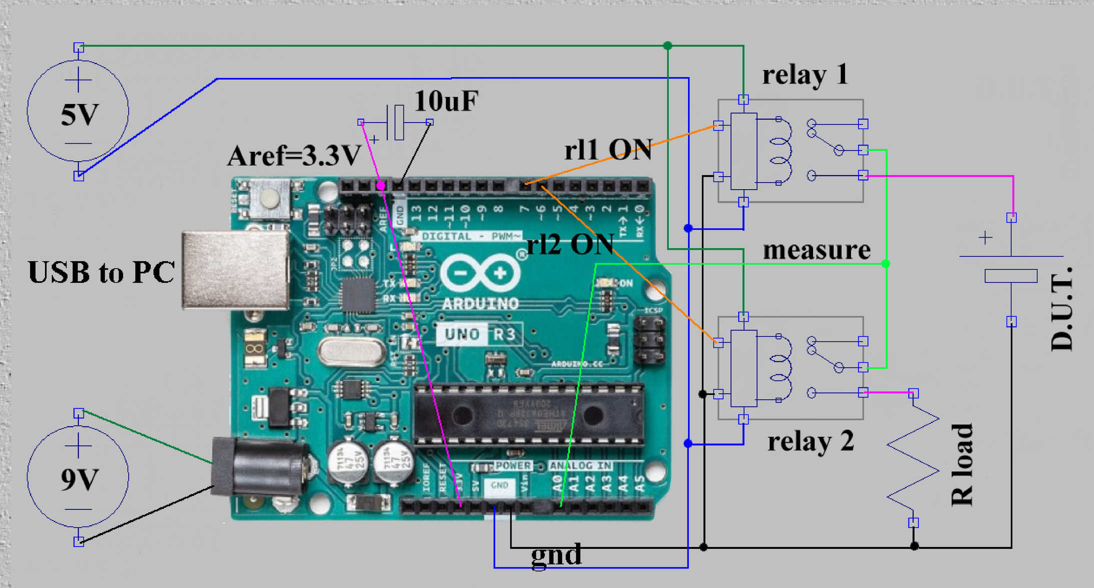


Fig.1 Drawing of the instrument. The circuit: from the left the 2 power supply; the Arduino UNO R3 with violet bridge to reduce AREF; the 2 relays to connect the battery (DUT) to Arduino and load; in orange the digital signal to switch relays in On-Off; in green the voltage measure wires; next the Rload and finally the DUT into an AA holder

Introduction

Primary batteries convert chemical energy produced by internal (irreversible) redox reactions into a flow of electrons in the external circuit. In contrast, secondary batteries and supercapacitors use reversible chemical-physical processes and can be returned to a 'charged' state by appropriate charging methods.

Of the various primary batteries that have gradually appeared on the market, alkaline zinc-manganese dioxide batteries are the most commonly used for portable equipment. These are not rechargeable, as is clearly stated on the label of any battery; *All batteries listed in this bulletin are of the primary type and are not designed to be recharged.*

Attempts to recharge an alkaline battery may cause an imbalance within the cell, leading to gassing and possibly explosion on either charge or discharge cycles [8].

However, if an attempt is made to reverse the chemical reactions of a primary battery, a careful measurement of the remaining capacity is required to determine whether the battery can be recharged.

The simple circuit described here, based on the Arduino UNO R3, allows the residual charge of an alkaline battery to be measured and plotted.

Aim of the project

Accurate measurement of residual charge is a complex task. The aim of this work is to construct a simple instrument, as shown in Fig.1, which estimate the state of charge of an alkaline battery, here of the AA/LR06 type, to be estimated in three steps. The IEC 60086-1 to IEC 60086-6 standards should be used as a guide, as well as the manufacturers' data sheets and bibliography. The graph in Fig.2 shows a typical discharge behaviour of a battery [7], where we should identify the point at which the battery under test (DUT) falls.

The first step is to measure the voltage with a high impedance voltmeter (Atmel declare >100Mohm) with 10 steps of 1sec simulating no-load. The second step involves a relay connecting the battery to a 100 Ohm resistive load, double the value of blue curve of Fig.3 from [8], and the voltage is measured in 10 steps of 1sec. The third step includes a relaxation period of 5s to allow the battery to recovery, after which the voltage is measured again in 10 steps of 1s at no load.

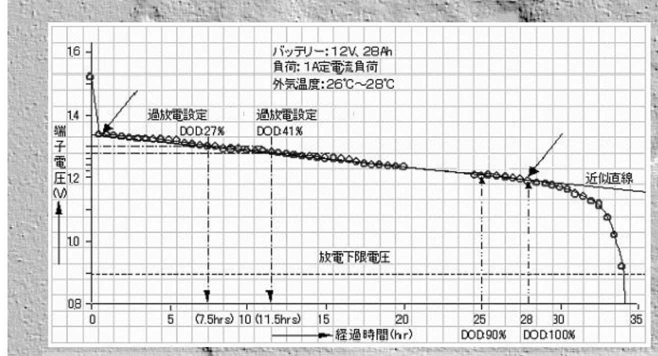


Fig.2, a typical discharge curve of Alkaline battery [7]

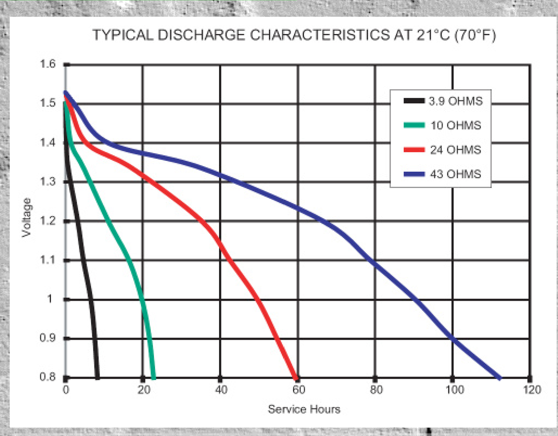


Fig.3, discharge curve with constant load, see ohm, from this we select the Rload [8]

Material & Methods

Spent batteries were collected through representative availability sampling (convenience sampling) by selecting those that were easily accessible in the collection bins found in many electronics stores and shopping centres, taking approximately 20 batteries per sampling.

In the laboratory, the first selection was made to eliminate clearly or partially damaged batteries, as shown in Fig.4. This selection produced 158 batteries in perfect condition and shape, some even looking as good as new

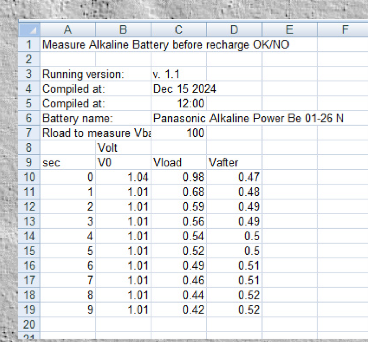
At the end of the study, all batteries were disposed of in the municipality's ecological islands.

The instrument was build following the 3Rs paradigm using parts already available in the lab, only the Arduino and the relays were purchased.

The software (skecth) has been hand-written from scratch, with comment in every line of code thinking to an educational use in electrochemistry lab. No external libraries are used that are not included in the Arduino IDE 1.8.9.

The sketch produces a text on the serial-monitor of the IDE which must be copied into a .txt file. The txt file is structured so that it can be easily read by any Excel to produce tables (Fig.5) and graphs like the one in Fig.6.

Fig.4, disposed battery not suitable to check the remaining charge … to waste and recycle metals



	A	B	C	D	E	F
1	Measure Alkaline Battery before recharge OK/NO					
2						
3	Running version:		v. 1.1			
4	Compiled at:		Dec 15 2024			
5	Compiled at:		12:00			
6	Battery name:		Panasonic Alkaline Power Be 01-26 N			
7	Rload to measure Vba		100			
8		Volt				
9	sec	V0	Vload	Vafter		
10	0	1.04	0.98	0.47		
11	1	1.01	0.68	0.48		
12	2	1.01	0.59	0.49		
13	3	1.01	0.56	0.49		
14	4	1.01	0.54	0.5		
15	5	1.01	0.52	0.5		
16	6	1.01	0.49	0.51		
17	7	1.01	0.46	0.51		
18	8	1.01	0.44	0.52		
19	9	1.01	0.42	0.52		
20						

Fig.5, the output text from our sketch that produce charts of fig.6 and fig.7, d) in this case

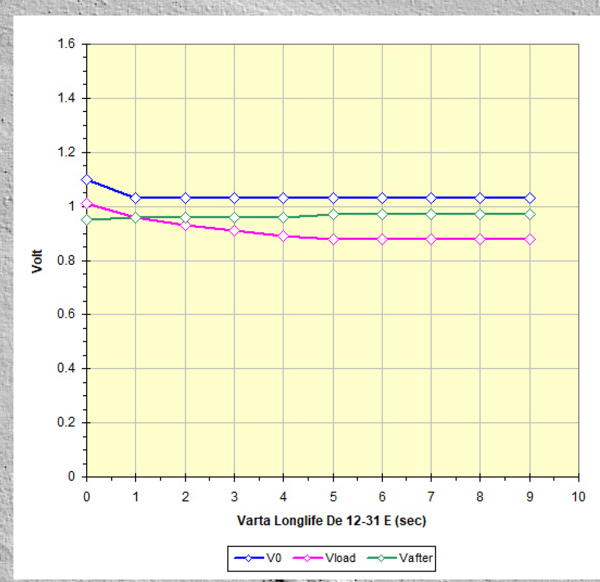


Fig.6, curves obtained using instrument of Fig.1; first the blue with no-load, 5sec of delay, the violet with 100ohm load, 5sec of delay, the green with no-load. The last point of violet produce the fig.8

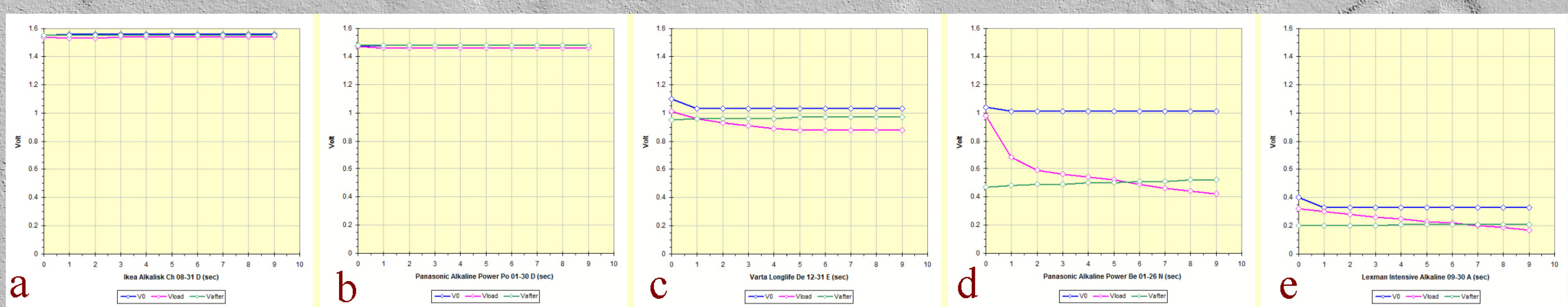


Fig. 7, five different AA alkaline battery (find in a waste-thank ready for dismantle) measured with instrument of fig.1. The a) is a better than new!; the b) is a like-new; the c) show a limit of discharge for IEC standard 0.9V; the d) show a battery with a few residue charge; the e) is a battery near empty. More battery show 0V when measured.

Results

The graph in Figure 6 shows a typical, expected trend for a battery with residual charge. The blue curve shows the battery voltage measured every 1 second at high impedance, which in this case remains constant at about 1V.

The violet curve shows the battery voltage when connected to an R-load of 100 ohms, again in 1 sec. increments.

In green is the voltage produced by the battery still at high impedance after the recovery period.

The kinetics of the internal redox reactions, also demonstrated in other studies, causes the voltage of the battery not connected to a load to rise, which is why there is a delay of 5 seconds after each series of measurements.

Of all the possible curves, Fig.6 is "typical", a constant voltage at no load, a slow discharge when current is requested, recovery and the green curve, perhaps left for a long time, would reach the blue curve.

Each battery behaves differently, maintaining a pattern as in Fig.6, but with different slopes and values, perhaps related to the different chemical composition and the different discharge process undergone.

The five batteries in Fig. 7 show a sample of the 158 batteries measured: a) a new but (unfortunately) discarded battery, b) a used battery but with a lot of residual charge, c) almost discharged but with a typical trend, d) a battery that appears to be still charged from the blue curve but collapses as soon as you ask it for current, e) a battery with a very low residual charge.

For completeness, there are several batteries that show a blue curve close to zero.

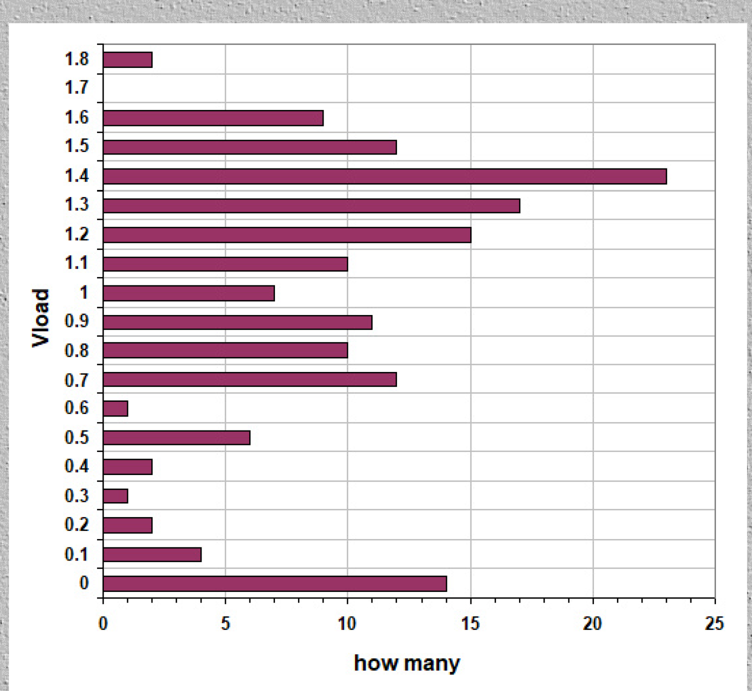


Fig.8, after measure 158 disposed AA battery we obtain the above histogram using the last point of violet curve of fig.6.

Counting, 48% of the measured batteries show a voltage from 1.2 to 1.6V.

Accounting the IEC 60086 norms stated 0.9V as lower limit, 65.8% of our battery stay from 0.9 to 1.6V.

Conclusions

Bearing in mind that standards and manufacturers define an alkaline battery as discharged when it drops to 0.9V [8], let us make some observations about the results.

The number of batteries is still too small for statistics and the study is still in progress, but from the data obtained, shown in Fig. 8, we can already see several practically new batteries at 1.6V, a group of batteries with a lot of residual charge with voltages between 1.5 and 1.2V.

Then there is a group with a voltage between 1.1 and 0.9V.

The instrument probably disconnects the battery when it drops below 0.9V, which would explain the small number of batteries between 0.6 and 0.1V, and finally a large number of batteries with no voltage.

A recharging test, which will be the subject of a later paper, could use this graph to identify the batteries that are the best candidates for regeneration.

In the light of these data, a word of advice to users is in order: buy a passive battery tester, such as the BT-168, the IBT-Tester4 or the BAT-393, which will cost you a few euros but will allow you to recycle 40% of the batteries you would otherwise throw away, for example in a wall clock or a mouse.

Acknowledgment

All brands and models mentioned are used for reference only, the authors do NOT receive any direct or indirect financial compensation from the companies mentioned.

Instead, thanks are due to the inventors of Arduino, Fig.9

Fig.9, All of makers and electronics users, also teachers must thank to the Team that developed the Arduino board widely used in didactics.

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1st Joint Conference of "Gruppo Interdivisionale di Chimica per l'Accumulo e la Conversione Elettrochimica dell'Energia" (ACee-GISEL). 21st–23rd July 2025 - Padova, Italy