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INTERNATIONAL STANDARD

colour inside

Secondary lithium-ion cells for the propulsion of electric road vehicles –
Part 1: Performance testing

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Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 1: Performance testing

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SECONDARY LITHIUM-ION CELLS FOR THE PROPULSION OF ELECTRIC ROAD VEHICLES –

Part 1: Performance testing

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 62660-1 has been prepared by IEC technical committee 21: Secondary cells and batteries.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) The purpose of each test has been added.

b) The power test has been revised for clarification, and an informative part of the current-voltage characteristic test has been moved to the new Annex C.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
21/975/FDIS	21/985/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62660 series, published under the general title *Secondary lithium-ion cells for the propulsion of electric road vehicles*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The commercialization of electric road vehicles including battery, hybrid and plug-in hybrid electric vehicles has been accelerated in the global market, responding to the global concerns on CO_2 reduction and energy security. This, in turn, has led to rapidly increasing demand for high-power and high-energy-density traction batteries. Lithium-ion batteries are estimated to be one of the most promising secondary batteries for the propulsion of electric vehicles. In the light of ~~rapidly diffusing~~ the rapid spread of hybrid electric vehicles and the emergence of battery and plug-in hybrid electric vehicles, a standard method for testing performance requirements of lithium-ion batteries is indispensable for securing a basic level of performance and obtaining essential data for the design of vehicle systems and battery packs.

This document specifies performance testing for automobile traction lithium-ion cells that basically differ from the other cells including those for portable and stationary applications specified by other IEC standards. For automobile application, it is important to note the usage specificity; i.e. the design diversity of automobile battery packs and systems, and specific requirements for cells and batteries corresponding to each of such designs. Based on these facts, the purpose of this document is to provide a basic test methodology with general versatility, which serves a function in common primary testing of lithium-ion cells to be used in a variety of battery systems.

This document is associated with ~~ISO 12405-1 and ISO 12405-2~~~~[1]~~ ISO 12405-4 [1][2].

IEC 62660-2 [2] specifies the reliability and abuse testing for lithium-ion cells for electric vehicle application.

IEC 62660-3 [3] specifies the safety requirements of lithium-ion cells for electric vehicle application.

~~1 Under consideration.~~

2 Numbers in square brackets refer to the Bibliography.

SECONDARY LITHIUM-ION CELLS FOR THE PROPULSION OF ELECTRIC ROAD VEHICLES –

Part 1: Performance testing

1 Scope

This part of IEC 62660 specifies performance and life testing of secondary lithium-ion cells used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV).

NOTE 1 Secondary lithium-ion cell used for propulsion of plug-in hybrid electric vehicle (PHEV) can be tested by the procedure either for BEV application or HEV application, according to the battery system design, based on the agreement between the cell manufacturer and the customer.

This document specifies the test procedures to obtain the essential characteristics of lithium-ion cells for vehicle propulsion applications regarding capacity, power density, energy density, storage life and cycle life.

This document provides the standard test procedures and conditions for testing basic performance characteristics of lithium-ion cells for vehicle propulsion applications, which are indispensable for securing a basic level of performance and obtaining essential data on cells for various designs of battery systems and battery packs.

NOTE 2 Based on the agreement between the cell manufacturer and the customer, specific test conditions ~~may~~ can be selected in addition to the conditions specified in this document. Selective test conditions are described in Annex A.

NOTE 3 The performance tests for the electrically connected lithium-ion cells ~~may~~ can be performed with reference to this document.

NOTE 4 The test specification for lithium-ion battery packs and systems is defined in ~~ISO 12405-1 and ISO 12405-2 (under consideration)~~ ISO 12405-4 [1].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60050-482, *International Electrotechnical Vocabulary – Part 482: Primary and secondary cells and batteries*~~

~~IEC 61434, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Guide to the designation of current in alkaline secondary cell and battery standards*~~

ISO/TR 8713, *Electrically propelled road vehicles – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ~~IEC 60050-482~~ ISO/TR 8713 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
battery electric vehicle
BEV
electric vehicle with only a traction battery as power source for vehicle propulsion

3.2
hybrid electric vehicle
HEV
vehicle with both a rechargeable energy storage system and a fuelled power source for propulsion

3.3
rated capacity
C_n
~~quantity of electricity~~ ~~C_3~~ ~~Ah (ampere-hours) for BEV and~~ ~~C_1~~ ~~Ah for HEV declared by the manufacturer~~
capacity value of a cell in ampere hours (Ah) determined under specified conditions and declared by the cell manufacturer

Note 1 to entry: n in C_n is the time base in hours (h). In this document, n = 3 for BEV application and n = 1 for HEV application unless otherwise specified.

3.4
~~**reference test current**~~
I_t
~~current in ampereswhich is expressed as~~

~~I_t (A) = C_n (Ah)/ 1 (h)~~

~~where~~

~~C_n is the rated capacity of the cell ;~~

reference test current in amperes (A) which is expressed as

$I_t = C_n/1$

Note 1 to entry: 1 has a dimension of time in hours (h).

Note 2 to entry: See IEC 61434:1996 [4], Clause 2.

3.5
room temperature
temperature of 25 °C ± 2 K

3.6
secondary lithium-ion cell
cell
secondary single cell whose electric~~al~~ energy is derived from the insertion and extraction reactions of lithium ions between the anode and the cathode

Note 1 to entry: The secondary lithium-ion cell is a basic manufactured unit providing a source of electric~~al~~ energy by direct conversion of chemical energy. It consists of electrodes, separators, electrolyte, container and terminals, and is designed to be charged electrically.

~~NOTE 2 In this standard, cell or secondary cell means the secondary lithium ion cell to be used for the propulsion of electric road vehicles.~~

3.7
state of charge
SOC
~~available~~ capacity in a ~~battery~~ cell expressed as a percentage of rated capacity

3.8
charge retention
ability of a cell to retain capacity on open circuit under specified conditions of storage

4 Test conditions

4.1 General

The details of the instrumentation used shall be provided in any report of results.

Test and measurement shall be conducted with caution to prevent a short circuit.

NOTE Test and measurement can be conducted under fixing condition recommended by the cell manufacturer.

4.2 Measuring instruments

4.2.1 Range of measuring devices

The instruments used shall enable the values of voltage, current and temperature to be measured. The range of these instruments and measuring methods shall be chosen so as to ensure the accuracy specified for each test.

For analogue instruments, this implies that the readings shall be taken in the last third of the graduated scale.

Any other measuring instruments may be used provided they give an equivalent accuracy.

4.2.2 Voltage measurement

The resistance of the voltmeters used shall be at least 1 MΩ/V.

4.2.3 Current measurement

The entire assembly of ammeter, shunt and leads shall be of an accuracy class of 0,5 or better.

4.2.4 Temperature measurements

The cell temperature shall be measured by use of a surface temperature measuring device capable of an equivalent scale definition and accuracy of calibration as specified in 4.2.1. The temperature ~~should~~ shall be measured at a location which most closely reflects the cell temperature. The temperature may be measured at additional appropriate locations, if necessary.

The examples for temperature measurement are shown in Figure 1. The instructions for temperature measurement specified by the cell manufacturer shall be followed.

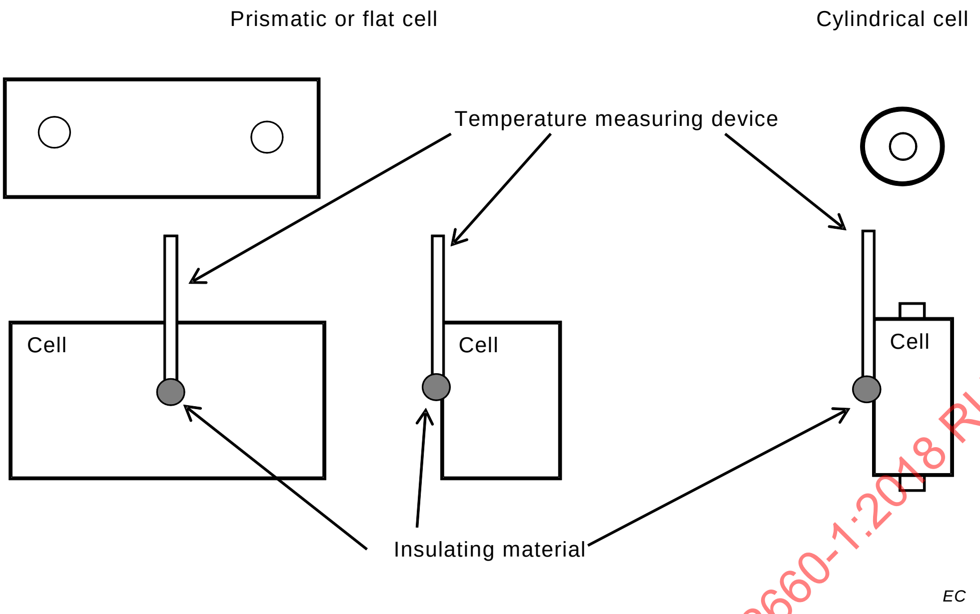


Figure 1 – Example of temperature measurement of cell

4.2.5 Other measurements

Other values ~~including capacity and power~~ may be measured by use of a measuring device, provided that it complies with 4.3.

4.3 Tolerance

The overall accuracy of controlled or measured values, relative to the specified or actual values, shall be within the following tolerances:

a) ± 0,1 % for voltage;

b) ± 1 % for current;

c) ± 2 K for temperature;

d) ± 0,1 % for time;

e) ± 0,1 % for mass;

f) ± 0,1 % for dimensions.

These tolerances comprise the combined accuracy of the measuring instruments, the measurement technique used, and all other sources of error in the test procedure.

~~4.4 Test temperature~~

~~If not otherwise defined, before each test the cell shall be stabilized at the test temperature for a minimum of 12 h. This period can be reduced if thermal stabilization is reached. Thermal stabilization is considered to be reached if after one interval of 1 h, the change of cell temperature is lower than 1 K.~~

~~Unless otherwise stated in this standard, cells shall be tested at room temperature using the method declared by the manufacturer.~~

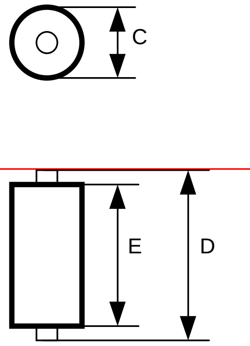
4.4 Thermal stabilization

For the stablization of cell temperature, the cell shall be soaked to a specified ambient temperature for a minimum of 12 h. This period may be reduced if thermal stabilization is reached. Thermal stabilization is considered to be reached if after one interval of 1 h, the change of cell temperature is lower than 1 K.

5 Dimension measurement

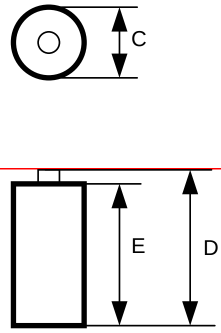
The maximum dimension of the total width, thickness or diameter, and ~~length~~ height of a cell shall be measured at room temperature up to three significant figures in accordance with the tolerances in 4.3.

Examples of maximum dimensions are shown in Figures 2a to 2f.



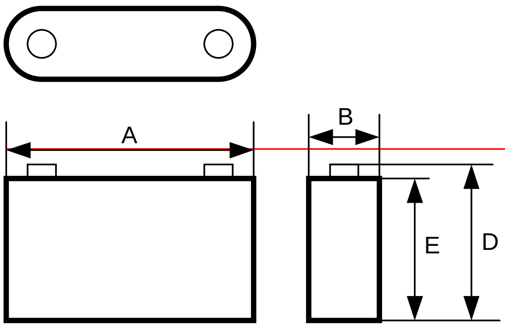
IEC 2862/10

~~**Figure 2a – Cylindrical cell (1)**~~



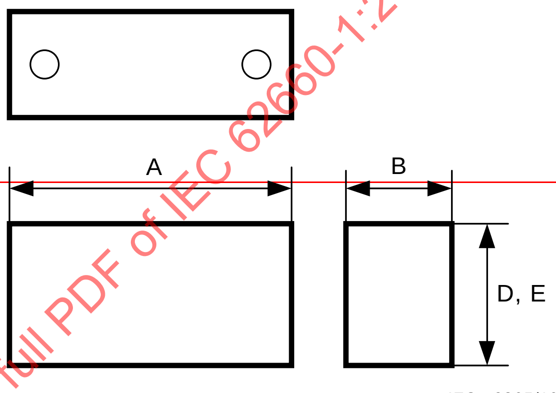
IEC 2863/10

~~**Figure 2b – Cylindrical cell (2)**~~



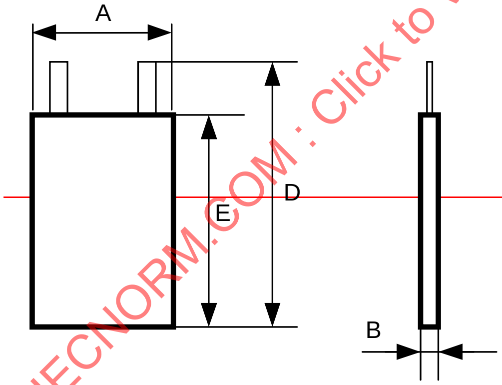
IEC 2864/10

~~**Figure 2c – Prismatic cell (1)**~~



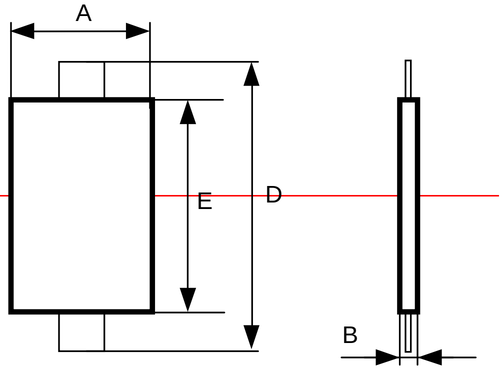
IEC 2865/10

~~**Figure 2d – Prismatic cell (2)**~~



IEC 2866/10

~~**Figure 2e – Flat cell (1)**~~



IEC 2867/10

~~**Figure 2f – Flat cell (2)**~~

~~**Key**~~

~~A total width~~

~~B total thickness~~

~~C diameter~~

~~D total length (including terminals)~~

~~E total length (excluding terminals)~~

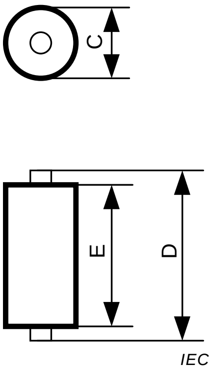


Figure 2a – Cylindrical cell (1)

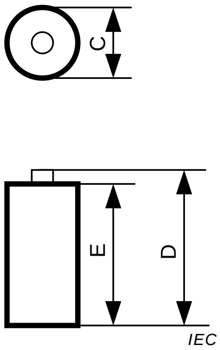


Figure 2b – Cylindrical cell (2)

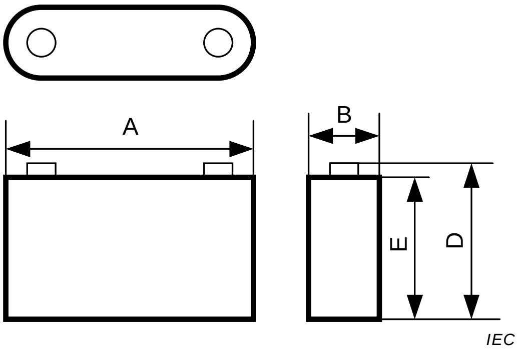


Figure 2c – Prismatic cell (1)

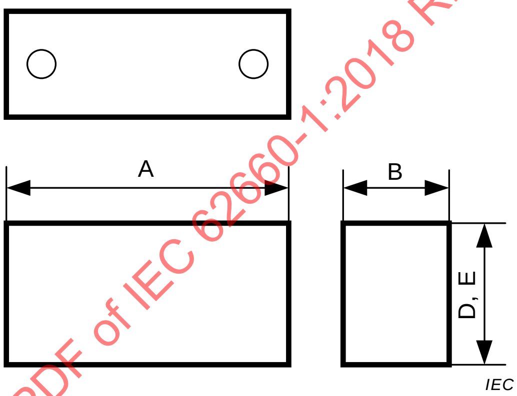


Figure 2d – Prismatic cell (2)

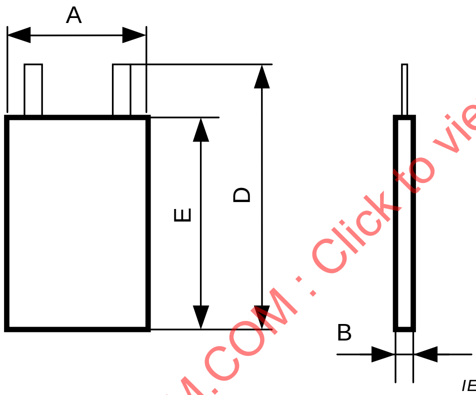


Figure 2e – Prismatic cell with laminate film case (1)

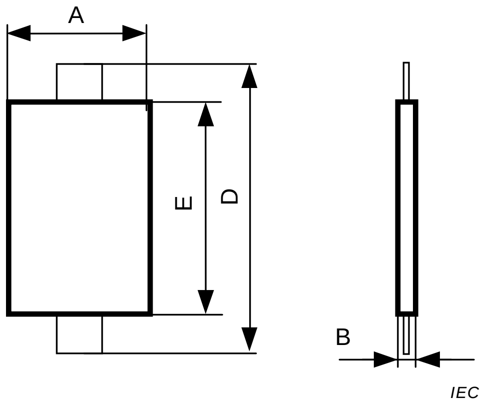


Figure 2f – Prismatic cell with laminate film case (2)

Key

A total width
B total thickness
C diameter
D total height (including terminals)
E total height (excluding terminals)

Figure 2 – Examples of maximum dimensions of cell

NOTE Prismatic cells are provided with either a rigid metal case or flexible laminate film case. A prismatic cell with laminate film case is usually called a pouch cell.

The volume of a prismatic cell is given by the product of its total height excluding terminals, total width, and total thickness, and that of a cylindrical cell is given by the product of the cross section of the cylinder and its total height excluding terminals.

6 Mass measurement

The mass of a cell is measured at room temperature up to three significant figures in accordance with the tolerances in 4.3.

7 Electrical measurement

7.1 General

During each test, voltage, current and temperature shall be recorded.

Before each test, the cell temperature shall be stabilized at room temperature according to 4.4, unless otherwise specified.

The ambient temperature shall be the room temperature unless otherwise specified.

7.2 General charge conditions

Unless otherwise stated in this document, prior to electrical measurement test, the cell shall be charged as follows.

Prior to charging, the cell shall be discharged at room temperature at a constant current described in Table 1 down to an end-of-discharge voltage specified by the cell manufacturer. Then, the cell shall be charged at room temperature according to the charging method declared by the cell manufacturer.

7.3 Capacity

The capacity of a cell shall be measured in accordance with the following phases.

Phase 1 – The cell shall be charged in accordance with 7.2.

After recharge, the cell temperature shall be stabilized in accordance with 4.4.

Phase 2 – The cell shall be discharged at specified temperature at a constant current I_t (A) to the end-of-discharge voltage that is provided by the cell manufacturer. The discharge current and cell temperatures indicated in Table 1 shall be used.

~~NOTE Selective test conditions are shown in Table A.1 in Annex A.~~

~~The method of designation of test current I_t is defined in IEC 61434.~~

In addition to Table 1, specific test conditions may be selected based on the agreement between the cell manufacturer and the customer. Selective test conditions are shown in Table A.1.

Table 1 – Discharge conditions

Cell temperature °C	**Discharge current** A	
	BEV application	**HEV application**
0	1/3 I_t	1 I_t
25		
45		

Phase 3 – Measure the discharge duration until the specified end-of-discharge voltage is reached. Calculate the capacity of cell expressed in Ah up to three significant figures, by multiplying the discharge current (A) with the discharge duration (h).

7.4 SOC adjustment

The test cells shall be charged as specified below, unless otherwise specified. The SOC adjustment is the procedure to be followed for preparing cells to the various SOCs for the tests in this document.

Phase 1 – The cell shall be charged in accordance with 7.2.

Phase 2 – The cell shall be left at rest at room temperature in accordance with 4.4.

Phase 3 – The cell shall be discharged at a constant current according to Table 1 for $(100 - n)/100 \times 3$ h for BEV application and $(100 - n)/100 \times 1$ h for HEV application, where n is SOC (%) to be adjusted for each test.

7.5 Power

7.5.1 General

This test is intended to determine the power characteristics of a cell under the representative usage conditions of BEV and HEV applications.

Based on the current-voltage characteristic test in 7.5.2, the power density and regenerative power density of a cell shall be calculated according to 7.5.3 and 7.5.4, respectively.

The power density and regenerative power density shall be calculated and reported for each combination of SOC and temperature in 7.5.2.

7.5.2 Test method

The test shall be carried out in accordance with the following procedure.

a) Mass measurement

Mass of the cell shall be measured as specified in Clause 6.

b) Dimension measurement

Dimensions of the cell shall be measured as specified in Clause 5.

c) SOC and temperature adjustment

The test in 7.5.2 d) shall be conducted under each combination of SOC and cell temperature at the test commencement as specified in Table 2, according to the procedure specified by the cell manufacturer.

SOC shall be adjusted according to 7.4.

Table 2 – SOC and temperature condition for power test

SOC %	Cell temperature °C			
20	25			
50	−20	0	25	40
80	25			

NOTE Selective test conditions are shown in Table A.2.

d) Current-voltage characteristics test

~~Current-voltage characteristics shall be determined by measuring the voltage at the end of the 10 second pulse, when a constant current is discharged and charged under the conditions specified below.~~

~~1) SOC shall be adjusted to 20 %, 50 %, and 80 % according to the procedure specified in 7.3.~~

~~2) The cell temperature at test commencement shall be set to 40 °C, 25 °C, 0 °C, and −20 °C.~~

~~3) The cell is charged or discharged at each value of the current corresponding to the respective rated capacity level, and the voltage is measured at the end of the 10 s pulse. The range of the charge and discharge current shall be specified by the manufacturer, and the standard measurement interval shall be 1 s. If the voltage after 10 s exceeds the discharge lower limit voltage or charge upper limit voltage, the measurement data shall be omitted.~~

~~NOTE The charge/discharge limits at low temperature specified by the manufacturer should be taken into account.~~

~~Table 2 shows examples of charge and discharge current according to the applications. If it is required, the maximum current for charge and discharge is specified by the cell manufacturer (I_{max}). This value can be reduced according to the agreement with the customer. The maximum charge and discharge current can be applied after the measurement at 5 I_t for BEV application and 10 I_t for HEV application. I_{max} value changes depending on SOC, test temperature and charge or discharge state.~~

~~Table 2 – Examples of charge and discharge current~~

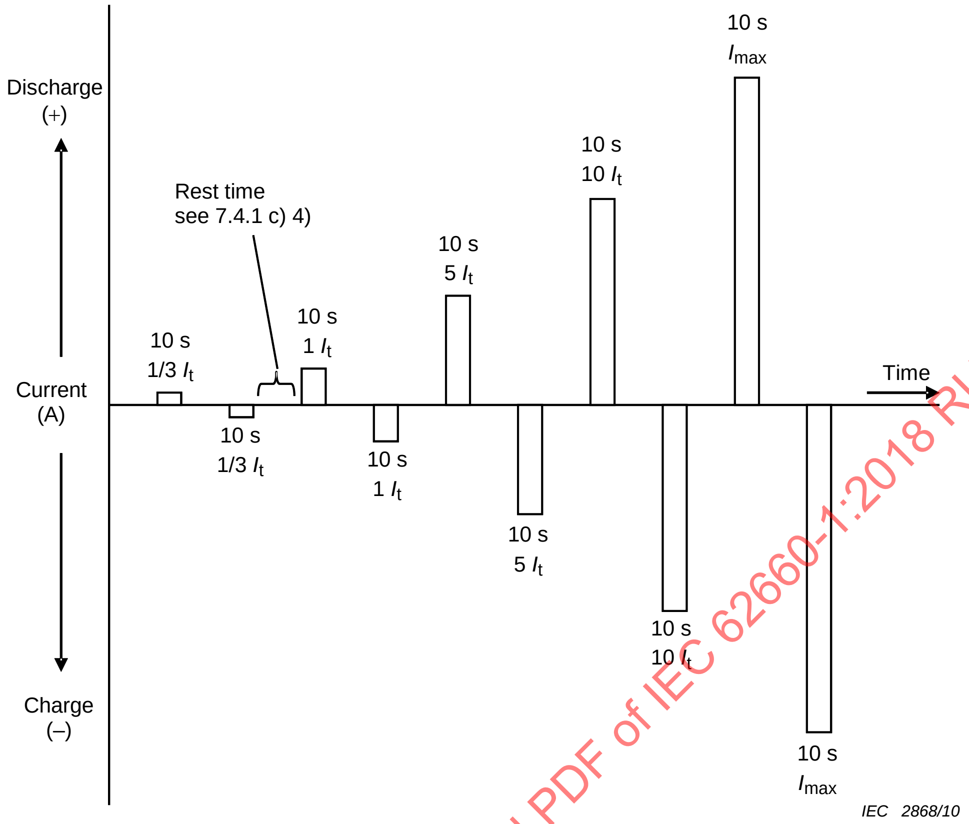
~~Application~~	~~Charge and discharge current~~ ~~A~~				
~~BEV~~	~~1/3 I_t~~	~~1 I_t~~	~~2 I_t~~	~~5 I_t~~	~~I_{max}~~
~~HEV~~	~~1/3 I_t~~	~~1 I_t~~	~~5 I_t~~	~~10 I_t~~	~~I_{max}~~

~~4) 10-min rest time shall be provided between charge and discharge pulses as well as between discharge and charge pulses. However, if the cell temperature after 10 min is not within 2 K of test temperature, it shall be cooled further; alternatively, the rest time duration shall be extended and it shall be inspected whether the cell temperature then settles within 2 K. The next discharging or charging procedure is then proceeded with.~~

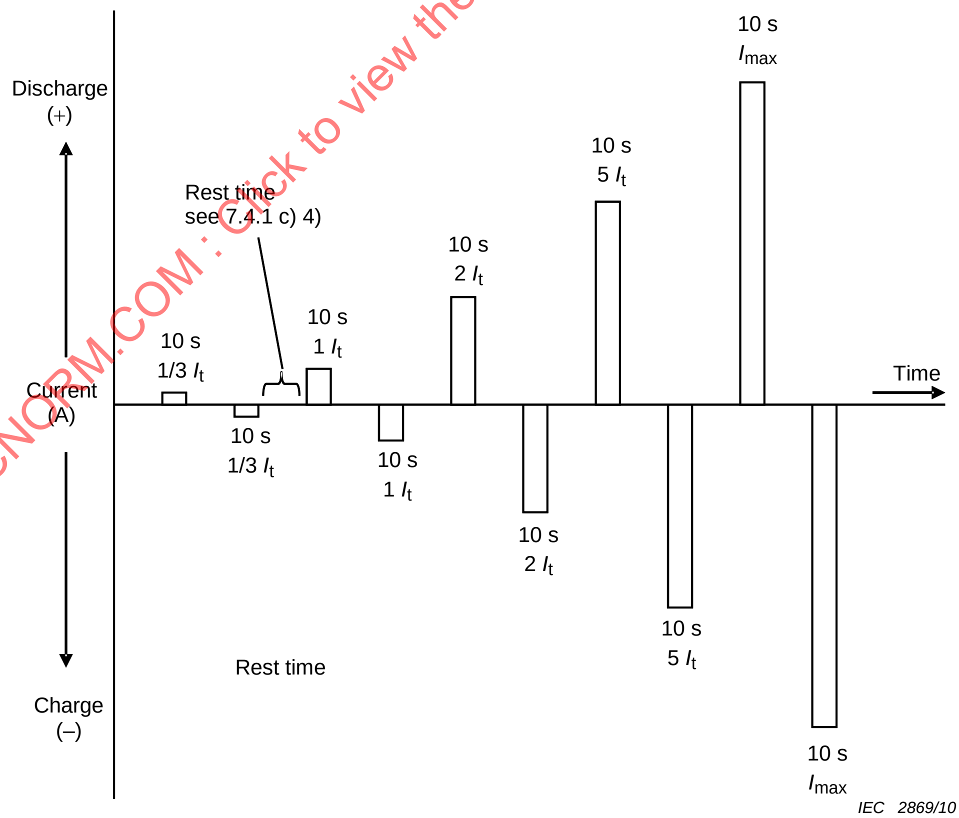
~~5) The test is performed according to the scheme shown in Figure 3a and Figure 3b.~~

~~NOTE 1 Selective test conditions are shown in Table A.2 in Annex A.~~

~~NOTE 2 The current-voltage characteristic line can be obtained by straight-line approximation using the measured values of current and voltage, from which I_{max} and power can be calculated. The slope of this line shows the internal resistance of cell.~~



~~Figure 3a – Test order of the current-voltage characteristic test for HEV application~~



~~Figure 3b – Test order of the current-voltage characteristic test for BEV application~~

~~Figure 3 – Test order of the current-voltage characteristic test~~

Discharge the cell for 10 s at the maximum current for discharge specified by the cell manufacturer (I_{dmax}), and measure the voltage at the end of the 10 s pulse (U_d).

Charge the cell for 10 s at the maximum current for charge specified by the cell manufacturer (I_{cmax}), and measure the voltage at the end of the 10 s pulse (U_c).

The values of I_{dmax} and I_{cmax} change depending on SOC, test temperature and charge or discharge state.

The charge and discharge limits of current and voltage at low temperature specified by the cell manufacturer should be taken into account.

In case that I_{dmax} and I_{cmax} are not available, the value may be obtained according to the test in Annex C.

7.5.3 Calculation of power density

7.5.3.1 Power calculation

The power shall be calculated according to Equation (1) and is rounded to three significant figures.

$$P_d = U_d \times I_{dmax} \quad (1)$$

where

P_d is the power (W);

U_d is the measured voltage at the end of the 10 s pulse of I_{dmax} discharge (V);

I_{dmax} is the maximum discharge current which is specified by the cell manufacturer (A).

If P_d is an estimated value, this shall be stated.

7.5.3.2 Power density per unit mass

Mass power density ~~is~~ shall be calculated from Equation (2), and is rounded to three significant figures.

$$\rho_{pd} = \frac{P_d}{m} \quad (2)$$

where

ρ_{pd} is the power density (W/kg);

P_d is the power (W);

m is the mass of the cell (kg).

7.5.3.3 Power density per unit volume

Volumetric power density shall be calculated from Equation (3), and is rounded to three significant figures.

$$\rho_{pvlm} = \frac{P_d}{V} \quad (3)$$

where

ρ_{pvlm} is the volumetric power density (W/l);

P_d is the power (W);

V is the volume of the cell (l).

~~The volume of a prismatic or a flat cell is given by the product of its total height excluding terminals, width, and length, and that of a cylindrical cell is given by the product of the cross section of the cylinder and its total length excluding terminals.~~

7.5.4 Calculation of regenerative power density

7.5.4.1 Regenerative power

Regenerative power shall be calculated according to Equation (4) and is rounded to three significant figures.

$$P_{\mathrm{c}} = U_{\mathrm{c}} \times I_{\mathrm{cmax}} \tag{4}$$

where

P_{c} is the regenerative power (W);

U_{c} is the measured voltage at the end of the 10 s pulse of I_{cmax} charge (V);

I_{cmax} is the maximum charge current specified by the cell manufacturer (A).

If P_{c} is an estimated value, this shall be stated.

7.5.4.2 Regenerative power density per unit mass

Regenerative power density per unit mass shall be calculated from Equation (5) and is rounded to three significant figures.

$$\rho_{\mathrm{pc}} = \frac{P_{\mathrm{c}}}{m} \tag{5}$$

where

ρ_{pc} is the regenerative power density (W/kg);

P_{c} is the regenerative power (W);

m is the mass of the cell (kg).

7.5.4.3 Regenerative power density per unit volume

Volumetric regenerative power density ~~is~~ shall be calculated from Equation (6) and is rounded to three significant figures.

$$\rho_{\mathrm{pvlmc}} = \frac{P_{\mathrm{c}}}{V} \tag{6}$$

where

ρ_{pvlmc} is the volumetric regenerative power density (W/l);

P_{c} is the regenerative power (W);

V is the volume of the cell (l).

~~The volume of a prismatic or a flat cell is given by the product of its total height excluding terminals, width, and length, and that of a cylindrical battery is given by the product of the cross section of the cylinder and its total length excluding terminals.~~

7.6 Energy

7.6.1 General

This test is intended to determine the energy density that can be derived from a cell under the representative usage conditions of BEV and HEV applications.

Based on the test in 7.6.2, the energy density of a cell shall be calculated according to 7.6.3.

7.6.2 Test method

Mass energy density (Wh/kg) and volumetric energy density (Wh/l) of cells in a certain current discharge of 1/3I_t (A) for BEV application and 1I_t (A) for HEV application shall be determined according to the following procedure.

a) Mass measurement

Mass of the cell shall be measured as specified in Clause 6.

b) Dimension measurement

Dimensions of the cell shall be measured as specified in Clause 5.

c) Capacity measurement

Capacity of the cell shall be determined in accordance with 7.3 at room temperature.

d) Average voltage calculation

The value of the average voltage during discharging in the above capacity test shall be obtained by integrating the discharge voltage over time and dividing the result by the discharge duration. The average voltage is calculated in a simple manner using the following method: Discharge voltages U_1, U_2, ..., U_n are noted every 5 s from the time the discharging starts and voltages that cut off the end-of-discharge voltage in less than 5 s are discarded. The average voltage U_{avr} is then calculated in a simplified manner using Equation (7) up to three significant figures by rounding off the result.

$$U_{avr} = \frac{U_1 + U_2 + \cdots + U_n}{n} \tag{7}$$

~~NOTE Values provided by measurement devices may be used, if sufficient accuracy can be achieved.~~

7.6.3 Calculation of energy density

7.6.3.1 Energy density per unit mass

The mass energy density shall be calculated using Equation (8) and Equation (9) up to three significant figures by rounding off the result.

$$W_{ed} = C_d U_{avr} \tag{8}$$

where

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions;

C_d is the discharge capacity (Ah) at 1/3I_t (A) for BEV or 1I_t (A) for HEV;

U_{avr} is the average voltage during discharging (V).

$$\rho_{ed} = \frac{W_{ed}}{m} \tag{9}$$

where

ρ_{ed} is the mass energy density (Wh/kg);

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions;

m is the mass of the cell (kg).

7.6.3.2 Energy density per unit volume

The volumetric energy density shall be calculated using Equation (10) up to three significant figures by rounding off the result.

$$\rho_{\text{evlmd}} = \frac{W_{\text{ed}}}{V} \tag{10}$$

where

ρ_{evlmd} is the volumetric energy density (Wh/l);

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions;

V is the volume of the cell (l).

~~The volume of prismatic cell shall be given by the product of the total height excluding terminals, width, and length of the cell, and that of cylindrical cells shall be given by the product of the cylindrical cross-sectional area and the total length excluding terminals.~~

7.7 Storage test

7.7.1 General

This test is intended to determine the capacity retaining characteristics of a cell under storage or non-use, and is composed of the charge retention test in 7.7.2 and the storage life test in 7.7.3.

7.7.2 Charge retention test

This test is intended to determine the charge retention characteristics of a cell under storage including transportation.

The charge retention characteristics of the cell at a 50 % SOC shall be determined according to the following procedure.

Phase 1 – The cell shall be charged in accordance with 7.2.

Phase 2 – The cell shall be discharged to 50 % SOC in accordance with the method specified in 7.4. Then, the cell shall be stabilized at ~~test~~ room temperature for 1 h.

NOTE The SOC value can be changed according to the agreement between the customer and the cell manufacturer.

Phase 3 – Discharge the cell to the end-of-discharge voltage at a discharge current of 1/3I_t (A) for BEV application and 1I_t (A) for HEV application and at room temperature. This discharge capacity is C_b.

Phase 4 – Repeat phases 1 and 2 one time.

Phase 5 – The cell shall be stored for 28 days at an ambient temperature of 45 °C ~~± 2 K~~.

Phase 6 – After phase 5, the cell shall be stabilized at room temperature according to 4.4. Then, discharge the cell at a constant current of 1/3I_t (A) for BEV application and 1I_t (A) for HEV application ~~at room temperature~~ until the end-of-discharge voltage, and then measure the capacity of cell. This discharge capacity is C_r.

Charge retention ratio shall be calculated according to Equation (11).

$$R = \frac{C_r}{C_b} \times 100 \tag{11}$$

where

R is the charge retention ratio (%);

C_r is the capacity of the cell after storage (Ah);

C_b is the capacity of the cell before storage (Ah).

7.7.3 Storage life test

This test is intended to determine the degradation characteristics of a cell under the storage or non-use of BEV and HEV applications.

The storage life of a cell shall be determined according to the following procedure.

Phase 1 – Determine the capacity, power density and regenerative power density of the cell in accordance with 7.2, 7.3 and 7.5.

Phase 2 – Adjust the SOC of the cell to 100 % for BEV application, and to 50 % for HEV application in accordance with 7.4. The cell shall then be stored for 42 days at an ambient temperature of 45 °C ~~± 2 K~~.

Phase 3 – Following the storage of phase 2, the cell shall be ~~kept~~ stablized at room temperature according to 4.4 and discharged at a constant current of 1/3I_t (A) for BEV application and 1I_t (A) for HEV application, down to the end-of-discharge voltage specified by the cell manufacturer. Then, measure the capacity of the cell. This discharge capacity is the retained capacity (Ah). The power density and regenerative power density shall also be measured.

Phase 4 – Repeat ~~step1,~~ phase 2 and phase 3 for three times.

The capacity, power density, regenerative power density and retained capacity measured in phase 1 and phase 3 shall be reported.

If the cell is stored at room temperature during the test for rest such as for test timing adjustment, the total time of such rest shall be reported.

7.8 Cycle life test

7.8.1 General

~~The cycle life test shall be performed~~ This test is intended to determine the degradation characteristics of the cell by charge and discharge cycles representing the normal usage conditions of BEV and HEV applications.

The cycle life performance of a cell for BEV application and HEV application shall be determined according to the tests in 7.8.2 and 7.8.3.

~~NOTE~~ The ~~cycle life~~ test sequence is shown in Annex B.

NOTE Selective test conditions are shown in Table A.3.

7.8.2 BEV cycle test

7.8.2.1 Measurement of initial performance

Before the charge and discharge cycle test, measure the capacity, dynamic discharge capacity, and power as the initial performance of the cell.

- Capacity

  The capacity shall be measured as specified in 7.3 at 25 °C ~~± 2 K~~.

- Dynamic discharge capacity C_D

  The dynamic discharge capacity C_D shall be measured at 25 °C ~~± 2 K~~ and 45 °C ~~± 2 K~~.

  The dynamic discharge capacity is defined by the time integrated value of charge and discharge current confirmed by the following test: Discharge the fully charged cell repeatedly by the dynamic discharge profile A specified in Table 3 and Figure 3 until the voltage reaches the lower limit specified by the cell manufacturer.

- Power

  The power shall be measured as specified in 7.5 at 25 °C ~~± 2 K~~ and 50 % SOC.

7.8.2.2 Charge and discharge cycle

The charge and discharge cycle test shall be performed as follows.

~~a) Temperature~~

~~The ambient temperature shall be 45 °C ± 2 K. At the start of charge and discharge cycle, cell temperature shall be 45 °C ± 2 K.~~

~~b) Charge and discharge cycle~~

~~A single cycle is determined as the repetition of the following steps from 1 to 4. The rest time between each step shall be less than 4 h.~~

a) At the start of the test, cell temperature shall be 45 °C. The ambient temperature shall be 45 °C.

b) Test phases

   ~~The cycle~~ The procedure from phase 1 to phase 5 shall be continuously repeated for 28 days. The rest time of less than 4 h can be set between each phase. Then, measure the performance of the cell as specified in 7.8.2.2 c). This procedure shall be repeated until the test termination specified in 7.8.2.2 d).

   Phase 1 – The cell shall be fully discharged by the method specified by the cell manufacturer.

   Phase 2 – The cells shall be fully charged by the method specified by the cell manufacturer. The charge time shall be less than 12 h.

   Phase 3 – Discharge the cell following the dynamic discharge profile A specified in Table 3 and Figure 3 until the discharged capacity reaches equivalent to 50 % ± 5 % of the initial dynamic discharge capacity C_D at 45 °C.

   If the voltage reaches the lower limit specified by the cell manufacturer during phase 3, the test shall be discontinued notwithstanding the stipulation in 7.8.2.2 d), and the cell performance shall be measured at this point as specified in 7.8.2.2 c).

   If the temperature of the cell reaches the upper limit specified by the cell manufacturer during phase 3, the duration of ~~charge/discharge~~ test step 20 in Table 3 ~~can~~ may be extended to an appropriate value. The actual duration time shall be reported.

If the voltage reaches the maximum limit specified by the cell manufacturer during a charge step in Table 3, constant-voltage charge at the maximum voltage shall be applied until the end of duration of this step.

In this profile, the test power shall be calculated using Equation (12):

$$P_{\text{max}} = NW_{\text{ed}} \tag{12}$$

where

P_{max} is the test power (W);

N is ~~a value (1/h) of vehicle required maximum power of cell~~ the required maximum cell power (W) divided by the energy of the cell (Wh) with units of (1/h).

NOTE The value of N = 3/h is an example based on the specifications of commercialized BEVs.

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions.

If the value derived from Equation (12) is larger than the maximum power of the cell specified by the cell manufacturer, the test power shall be defined as 80 % of the maximum power at room temperature and at 20 % SOC specified by the cell manufacturer. The power value actually used shall be reported.

Table 3 – Dynamic discharge profile A for BEV cycle test

~~Charge/discharge~~ **Test step**	**Duration** s	**Ratio to test power** %	**Charge/discharge**
1	16	0,0	–
2	28	+12,5	Discharge
3	12	+25,0	Discharge
4	8	−12,5	Charge
5	16	0,0	–
6	24	+12,5	Discharge
7	12	+25,0	Discharge
8	8	−12,5	Charge
9	16	0,0	–
10	24	+12,5	Discharge
11	12	+25,0	Discharge
12	8	−12,5	Charge
13	16	0,0	–
14	36	+12,5	Discharge
15	8	+100,0	Discharge
16	24	+62,5	Discharge
17	8	−25,0	Charge
18	32	+25,0	Discharge
19	8	−50,0	Charge
20	44	0,0	–

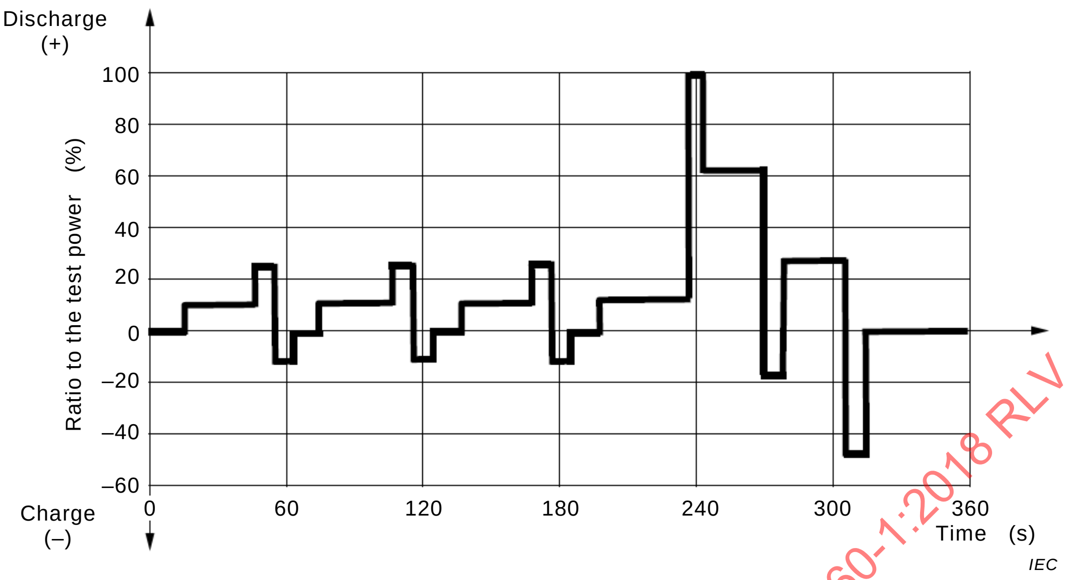


Figure 3 – Dynamic discharge profile A for BEV cycle test

Phase 4 – Discharge the cell following the dynamic discharge profile B (hill climbing profile) specified in Table 4 and Figure 4 for one time. The test power shall be calculated using Equation (12).

If the voltage reaches the lower limit specified by the cell manufacturer during phase 4, the test shall be discontinued notwithstanding the stipulation in 7.8.2.2 d), and the cell performance shall be measured at this point as specified in 7.8.2.2 c).

If the battery voltage frequently reaches the lower limit voltage during ~~charge/discharge~~ test step 16, the discharge power and duration ~~can~~ may be changed appropriately. The actual test values shall be reported accordingly.

Table 4 – Dynamic discharge profile B for BEV cycle test

~~Charge/discharge~~ Test step	Duration s	Ratio to test power %	Charge/discharge
1	16	0,0	–
2	28	+12,5	Discharge
3	12	+25,0	Discharge
4	8	−12,5	Charge
5	16	0,0	–
6	24	+12,5	Discharge
7	12	+25,0	Discharge
8	8	−12,5	Charge
9	16	0,0	–
10	24	+12,5	Discharge
11	12	+25,0	Discharge
12	8	−12,5	Charge
13	16	0,0	–
14	36	+12,5	Discharge
15	8	+100,0	Discharge
16	120	+62,5	Discharge
17	8	−25,0	Charge
18	32	+25,0	Discharge
19	8	−50,0	Charge
20	44	0,0	–

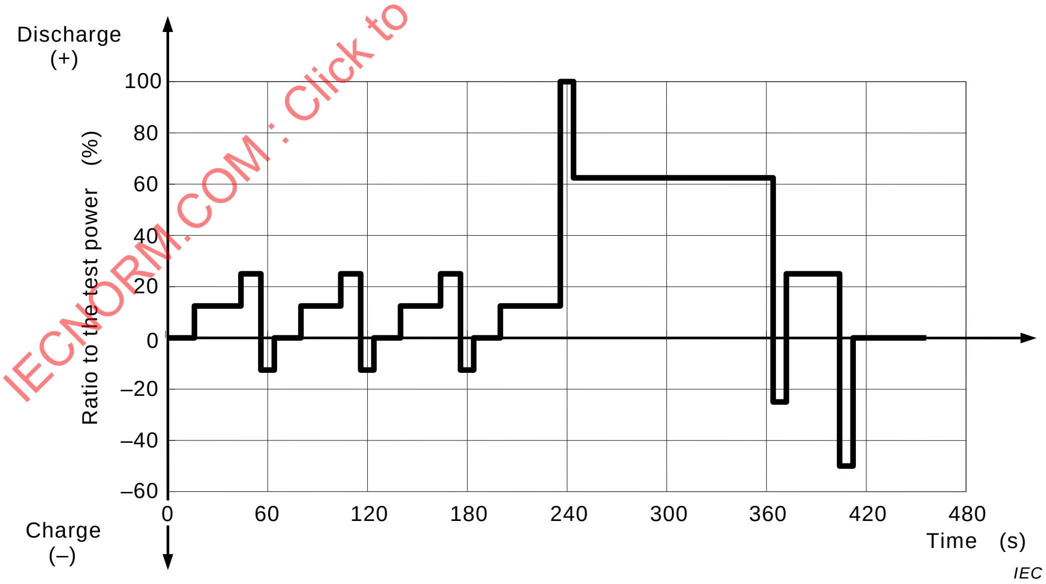


Figure 4 – Dynamic discharge profile B for BEV cycle test

Phase 5 – Discharge the cell following the dynamic discharge profile A specified in Table 3 and Figure 3 until the overall discharge capacity including phase 3 and phase 4 reaches equivalent to 80 % of initial C_D at 45 °C.

If the temperature of the cell reaches the upper limit specified by the cell manufacturer during phase 5, the duration of ~~charge/discharge~~ test step 20 in Table 3 ~~can~~ may be extended to an appropriate value. The actual duration time shall be reported.

If the voltage reaches the lower limit specified by the cell manufacturer during phase 5, the test shall be discontinued notwithstanding the stipulation in 7.8.2.2 d), and the cell performance shall be measured at this point as specified in 7.8.2.2 c).

c) Periodical measurement of performance

After every completion of the repetition from phase 1 to phase 5 for 28 test days, the performance of the cell shall be measured as specified in 7.8.2.1. The accumulated time from phase 1 to phase 4 in 7.8.2.2 b) shall also be reported. The dynamic discharge capacity shall be measured at 25 °C ~~± 2 K~~ only.

d) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise, go back to 7.8.2.2 a) and repeat the test.

Condition A – The test sequence from 7.8.2.2 a) to 7.8.2.2 c) ~~is repeated~~ has been performed six times.

Condition B – ~~When~~ Any of the performance parameters measured in 7.8.2.2 c) is decreased to less than 80 % of the initial value.

Condition C – The temperature of cell reaches the upper limit agreed between the cell manufacturer and the customer during the test.

The number of times that each profile and each cycle are implemented during the test shall be reported.

7.8.3 HEV cycle test

~~The cycle life performance of cell for HEV application shall be determined by the following test methods.~~

7.8.3.1 Measurement of initial performance

Before the charge and discharge cycle test, measure the capacity and power as the initial performance of cell.

- Capacity

  The capacity shall be measured as specified in 7.3 at 25 °C ~~± 2 K~~.

- Power

  The power shall be measured as specified in 7.5 at 25 °C ~~± 2 K~~ and 50 % SOC.

7.8.3.2 Profile switching voltage

Before the cycle life test, set switching voltages at which discharge-rich profile and charge-rich profile specified in 7.8.3.3 c) shall be switched over.

a) Switching voltage from discharge-rich profile to charge-rich profile

Adjust the SOC of the cell to 30 % according to 7.4, and then perform the cycle test with discharge-rich profile at 45 °C for one time. The lowest voltage achieved during this test shall be the switching voltage from discharge-rich profile to charge-rich profile. If the achieved lowest voltage is lower than the cell manufacturer's specified lower limit voltage, the latter shall be the switching voltage. The cell manufacturer's recommended SOC of cell may be used additionally.

b) Switching voltage from charge-rich profile to discharge-rich profile

Adjust the SOC of the cell to 80 % according to 7.4, and then perform the cycle test with charge-rich profile at 45 °C for one time. The highest voltage achieved during this test shall be the switching voltage from charge-rich profile to discharge-rich profile. If the achieved highest voltage is higher than the cell manufacturer's specified upper limit voltage, the latter shall be used as switching voltage. The cell manufacturer's recommended SOC of cell may be used additionally.

7.8.3.3 Charge and discharge cycle

The charge and discharge cycle test shall be performed as follows.

a) Temperature

The ambient temperature shall be maintained at 45 °C ~~± 2 K in accordance with 4.4~~ during the test. At the start of charge and discharge cycle, cell temperature shall be 45 °C ~~± 2 K in accordance with 4.2.4~~.

b) Adjustment of SOC before charge and discharge cycle

The cells shall be left at a temperature of 45 °C ~~± 2 K~~, and be adjusted to 80 % SOC or the SOC agreed between the cell manufacturer and the customer within an interval of 16 h to 24 h, in accordance with 7.4. If 80 % SOC is not used, the used SOC shall be reported.

c) ~~Charge and discharge cycle~~ Test phases

The procedure from phase 1 to phase 4 shall be continuously repeated until the test termination specified in 7.8.3.3 e). During the test, the performance of the cell shall be measured periodically as specified in 7.8.3.3 d).

If the temperature of the cell reaches the upper limit specified by the cell manufacturer during the test, the duration of ~~charge/discharge~~ test step 16 in Table 5 and Table 6 ~~can~~ may be extended to an appropriate duration time. The actual duration time shall be reported.

Phase 1 – The charge and discharge cycle shall be carried out repeatedly through the discharge-rich profile given by Table 5 and Figure 5 until the cell voltage reaches the switching voltage set in 7.8.3.2 a) (see Figure 7).

Phase 2 – The charge and discharge cycle shall be carried out repeatedly through the charge-rich profile given by Table 6 and Figure 6 until the cell voltage reaches the switching voltage set in 7.8.3.2 b) (see Figure 7).

Phase 3 – Repeat phase 1 and phase 2 for 22 h.

Phase 4 – Rest the cell for 2 h.

Table 5 – Discharge-rich profile for HEV cycle test

~~Charge/discharge~~ Test step	Duration s	Current A	Charge/discharge
1	5	20 I_t	Discharge
2	10	10 I_t	Discharge
3	32	5 I_t	Discharge
4	20	0 I_t	–
5	5	−15 I_t	Charge
6	10	−10 I_t	Charge
7	37	−5 I_t	Charge
8	20	0 I_t	–
9	5	15 I_t	Discharge
10	10	10 I_t	Discharge
11	37	5 I_t	Discharge
12	20	0 I_t	–
13	5	−12,5 I_t	Charge
14	7	−7,5 I_t	Charge
15	35	−5 I_t	Charge
16	42	0 I_t	–

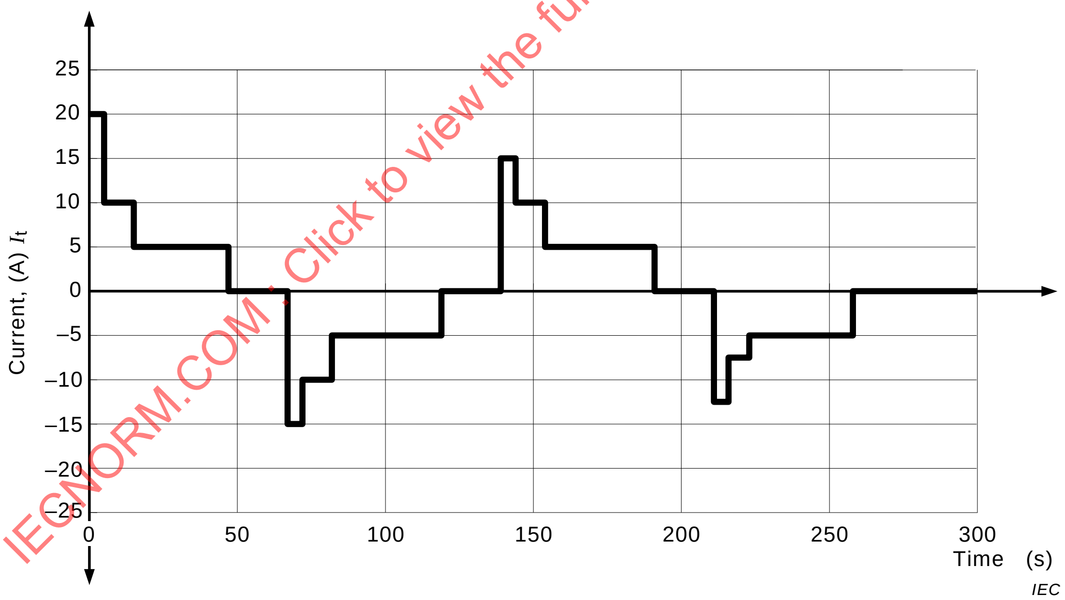


Figure 5 – Discharge-rich profile for HEV cycle test

If the maximum current specified by the cell manufacturer is below 20 I_t, the cell manufacturer's specified maximum current may by used at ~~charge/discharge~~ test step 1, along with replacing the current at ~~charge/discharge~~ test step 6 with 50 % of the cell manufacturer's specified maximum current.

Table 6 – Charge-rich profile for HEV cycle test

~~Charge/discharge~~ Test step	Duration s	Current A	Charge/discharge
1	5	$-15\ I_t$	Charge
2	10	$-10\ I_t$	Charge
3	37	$-5\ I_t$	Charge
4	20	$0\ I_t$	–
5	5	$20\ I_t$	Discharge
6	10	$10\ I_t$	Discharge
7	32	$5\ I_t$	Discharge
8	20	$0\ I_t$	–
9	5	$-12{,}5\ I_t$	Charge
10	7	$-7{,}5\ I_t$	Charge
11	49	$-5\ I_t$	Charge
12	20	$0\ I_t$	–
13	5	$15\ I_t$	Discharge
14	10	$10\ I_t$	Discharge
15	23	$5\ I_t$	Discharge
16	42	$0\ I_t$	–

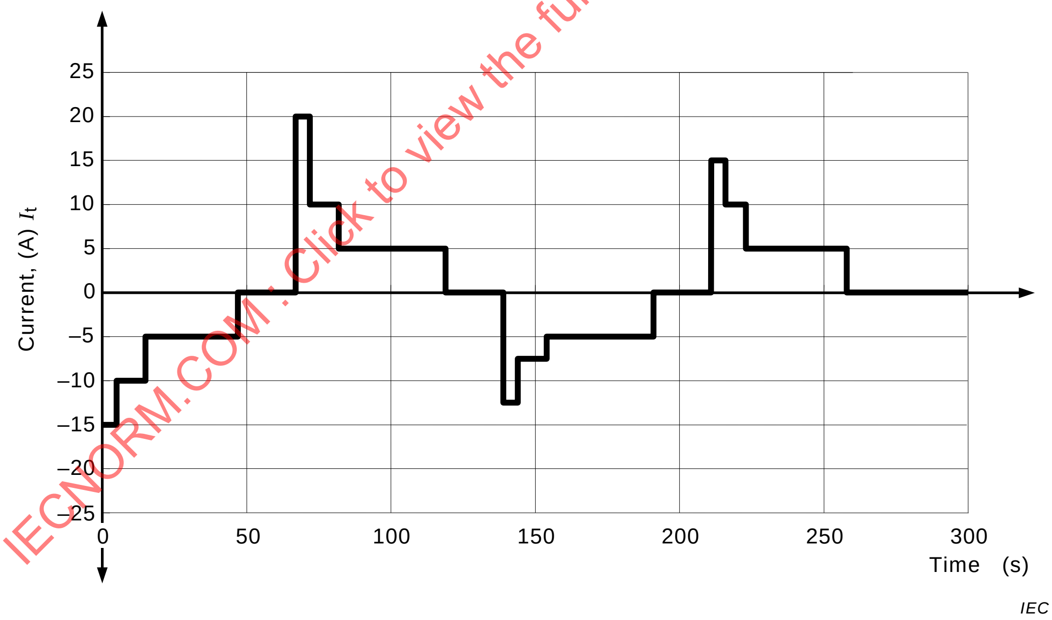


Figure 6 – Charge-rich profile for HEV cycle test

If the maximum current specified by the cell manufacturer is below $20 I_t$, the cell manufacturer's specified maximum current may be used at ~~charge/discharge~~ test step 5, along with replacing the current at ~~charge/discharge~~ test step 2 with 50 % of the cell manufacturer's specified maximum current.

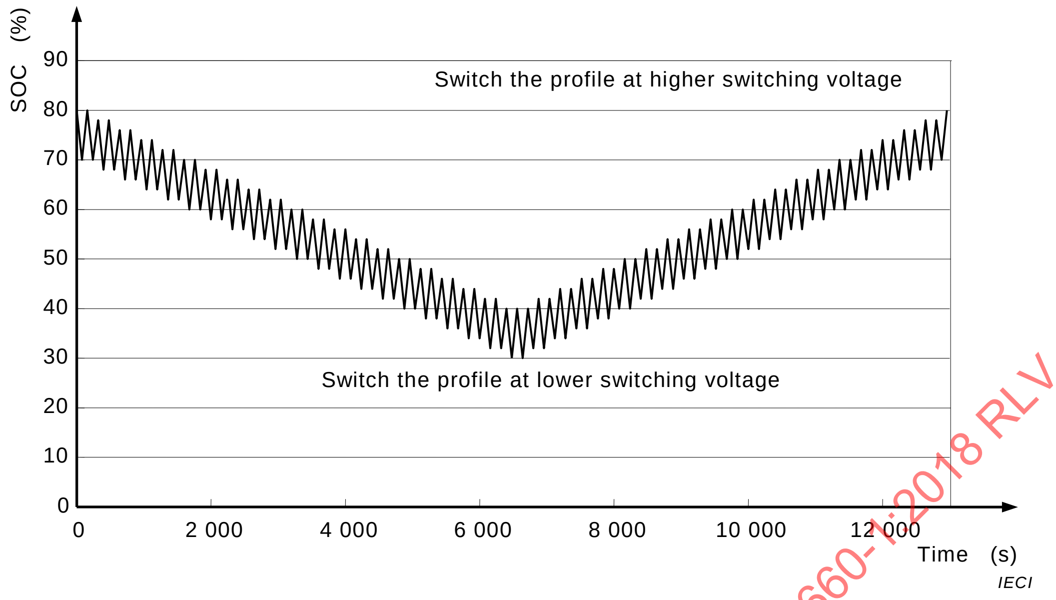


Figure 7 – Typical SOC swing by combination of two profiles for HEV cycle test

d) Periodical measurement of performance

After every completion of the procedure from phase 1 to phase 4 for seven days, the power of the cell shall be measured as specified in 7.8.3.1. The capacity of the cell shall be measured every 14 days as specified in 7.8.3.1.

e) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise, go back to 7.8.3.3 a) and repeat the test.

Condition A – The test in 7.8.3.3 c) is repeated for a total of six months.

Condition B – ~~When~~ Either of the performance parameters measured in 7.8.3.3 d) is decreased to less than 80 % of the initial value.

The number of times that each profile is implemented and that the switching voltages are reached shall be reported.

7.9 Energy efficiency test

7.9.1 General

This test is intended to determine the charging efficiency of a cell under the representative usage conditions of BEV or HEV application.

Energy efficiency of cells shall be determined by two common tests as specified in 7.9.2 and either of tests described in 7.9.3 and 7.9.4.

7.9.2 Common tests for BEV and HEV applications

7.9.2.1 Common test for normal conditions

This test aims to determine the efficiency of a cell in normal charging under the representative usage conditions of BEV and HEV applications.

This test is applicable to cells used in HEVs and BEVs. The test shall be carried out in accordance with the following procedure.

a) The cell shall be left at rest at room temperature for a minimum of 1 h and a maximum of 4 h after full charge. The test shall then be commenced.

b) Discharge the cell by the method specified in 7.3 at room temperature.

c) Energy efficiency test at 100 % SOC:

1) leave the cell at rest for 4 h, and then charge it to 100 % SOC by the method recommended by the cell manufacturer;

2) leave the cell at rest for 4 h, and then discharge it by the method specified in 7.3 at room temperature.

d) Energy efficiency test at 70 % SOC:

1) leave the cell at rest for 4 h, and then charge it to 70 % SOC by the method recommended by the cell manufacturer;

2) leave the cell at rest for 4 h, and then discharge it by the method specified in 7.3 at room temperature.

e) Calculation of the discharge electric quantity and charge electric quantity

The electric quantity during the discharge and charge can be calculated using the following method: read the discharge and charge currents I at intervals of s seconds ($s \leq 30$) from the start of the discharge; then, calculate the discharge electric quantity Q_d and charge electric quantity Q_c using Equation (13).

$$Q = \frac{I_1 + I_2 + \cdots + I_n}{\dfrac{3600}{s}} \tag{13}$$

where

Q is the discharge electric quantity or charge electric quantity (Ah);

I_n is the discharge current value or charge current value at point n of measured intervals (A).

f) Calculation of the discharge electric energy and charge electric energy.

The electric energy during the discharge and charge can be calculated using the following method: read the discharge currents I and the discharge voltages ~~V~~ U at intervals of s seconds ($s \leq 30$) from the start of discharge; then, calculate the discharge electric energy W_d and charge electric energy W_c using Equation (14).

$$W = \frac{I_1 U_1 + I_2 U_2 + \cdots + I_n U_n}{\dfrac{3600}{s}} \tag{14}$$

where

W is the discharge electric energy or charge electric energy (Wh);

I_n is the charge current value or discharge current value at point n of measured intervals (A);

U_n is the discharge voltage value at point n of measured intervals (V).

g) Calculation of energy efficiency

Determine the coulomb efficiency using Equation (15) and the energy efficiency using Equation (16).

$$\eta_c = \frac{Q_d}{Q_c} \times 100 \tag{15}$$

where

η_c is the coulomb efficiency (%);

Q_d is the discharge electric quantity in 7.9.2.1 e) (Ah);

Q_c is the charge electric quantity in 7.9.2.1 e) (Ah).

$$\eta_e = \frac{W_d}{W_c} \times 100 \quad (16)$$

where

η_e is the energy efficiency (%);

W_d is the discharge electric energy in 7.9.2.1 f) (Wh);

W_c is the charge electric energy in 7.9.2.1 f) (Wh).

~~NOTE Values provided by measurement devices may be used, if sufficient accuracy can be achieved.~~

7.9.2.2 Test by temperature

This test is intended to determine the energy efficiency of a cell in normal charging at different temperature conditions.

This test is applicable to cells used in HEVs and BEVs.

The test shall be carried out in accordance with the following procedure at the test temperatures of −20 °C ~~± 2 K~~, 0 °C ~~± 2 K~~, and 45 °C ~~± 2 K~~.

a) Full charge at room temperature.
b) Thermal equilibration of the cell at the test temperature, and start testing after a minimum of 16 h and a maximum 24 h.
c) Discharge the cell by the method specified in 7.3 at each test temperature.
d) Energy efficiency test at 100 % SOC:
   1) at each test temperature, leave the cell at rest for 4 h, and then charge it to 100 % SOC by the method recommended by the cell manufacturer;
   2) leave the battery at rest for 4 h, and then discharge it by the method specified in 7.3.
e) Calculate discharge electric quantity and charge electric quantity using Equation (13).
f) Calculate discharge electric energy and charge electric energy using Equation (14).
g) Calculate coulomb efficiency and energy efficiency using Equation (15) and Equation (16).

~~NOTE~~ The charge/discharge limits at low temperature specified by the cell manufacturer should be taken into account.

7.9.3 Test for cells of BEV application

This test is applicable to cells used in BEVs, and intended to determine the energy efficiency of a cell under fast charging conditions.

The test shall be carried out in accordance with the following procedure.

a) The cell shall be left at rest at room temperature for a minimum of 1 h and a maximum of 4 h after full charge. The test shall then be commenced.
b) Discharge the cell by the method specified in 7.3.
c) Energy efficiency test at 80 % SOC:
   1) leave the cell at rest for 4 h, and then charge it to 80 % SOC at $2I_t$. If the voltage reached the upper limit voltage specified by the cell manufacturer, charging shall be terminated;

      NOTE Selective test conditions are shown in Table A.4.

   2) leave the cell at rest for more than 4 h until the cell has attained the test temperature, and then discharge it by the method specified in 7.3.
d) Calculate discharge electric quantity and charge electric quantity using Equation (13).

e) Calculate discharge electric energy and charge electric energy using Equation (14).

f) Calculation of energy efficiency

Determine the coulomb efficiency using Equation (17) and the energy efficiency using Equation (18).

$$\eta_{c1} = \frac{Q_{d1}}{Q_{c1}} \times 100 \tag{17}$$

where

η_{c1} is the coulomb efficiency (%);

Q_{d1} is the discharge electric quantity in 7.9.3 d) (Ah);

Q_{c1} is the charge electric quantity in 7.9.3 d) (Ah).

$$\eta_{e1} = \frac{W_{d1}}{W_{c1}} \times 100 \tag{18}$$

where

η_{e1} is the energy efficiency (%);

W_{d1} is the discharge electric energy in 7.9.3 e) (Wh);

W_{c1} is the charge electric energy in 7.9.3 e) (Wh).

7.9.4 Energy efficiency calculation for cells of HEV application

This test is applicable to cells used in HEVs, and intended to determine the energy efficiency of a cell under representative usage conditions of HEV application.

a) Calculation of the charge electric energy and discharge electric energy

Calculate the charge and discharge electric energy from the results of the test specified in 7.5 using Equation (19) and Equation (20). Round off the resulting values to three significant figures.

Read current values and voltage values at regular intervals from the current and voltage data collected during the charge and discharge cycles, which correspond to the charge and discharge patterns of duration $10 I_t$ × 10 s. Use the standard measurement interval of 1 s. When the battery voltage after 10 s exceeds the discharge lower limit voltage or the charge upper limit voltage, perform the test using the current value in the lower stage of Table 1, and report the current value that was actually observed.

$$W_{c2} = \frac{I_{c1}U_{c1} + I_{c2}U_{c2} + \cdots + I_{cn}U_{cn}}{3\,600} \tag{19}$$

where

W_{c2} is the charge electric energy (Wh);

I_{cn} is the charge current value at point n of measured intervals (A);

U_{cn} is the charge voltage value at point n of measured intervals (V).

$$W_{d2} = \frac{I_{d1}U_{d1} + I_{d2}U_{d2} + \cdots + I_{dn}U_{dn}}{3\,600} \tag{20}$$

where

W_{d2} is the discharge electric energy (Wh);

I_{dn} is the discharge current value at point n of measured intervals (A);

U_{dn} is the discharge voltage value at point n of measured intervals (V).

b) Calculation of energy efficiency

Determine the energy efficiency using Equation (21).

$$\eta_{e2} = \frac{W_{d2}}{W_{c2}} \times 100 \qquad (21)$$

where

η_{e2} is the energy efficiency (%);

W_{d2} is the discharge electric energy (Wh);

W_{c2} is the charge electric energy (Wh).

Annex A
(informative)

Selective test conditions

Annex A provides additional and selective conditions for the capacity test specified in 7.3, the power tests in 7.5, the cycle life test in 7.8, and the energy efficiency test in 7.9.3.

The test conditions "r" in Table A.1, Table A.2, Table A.3 and Table A.4 are specified in this document. In addition, the test conditions "a" may be selected based on the agreement between the cell manufacturer and the customer.

Table A.1 – Capacity test conditions

Application	Discharge current	Cell temperature			
		−20 °C	0 °C	25 °C	45 °C
BEV	0,2 I_t	a	a	a	a
	1/3 I_t	a	r	r	r
	1 I_t	a	a	a	a
	5 I_t	a	a	a	a
HEV	0,2 I_t	a	a	a	a
	1/3 I_t	a	a	a	a
	1 I_t	a	r	r	r
	10 I_t	a	a	a	a
	I_{dmax}	a	a	a	a

If the data deviation is larger than that of 1 I_t and 1/3 I_t, it shall be indicated.

Table A.2 – Power test conditions

Application	SOC	Cell temperature			
		−20 °C	0 °C	25 °C	40 °C
BEV	20 %	a	a	r	a
	50 %	r	r	r	r
	80 %	a	a	r	a
HEV	20 %	a	a	r	a
	50 %	r	r	r	r
	80 %	a	a	r	a

Table A.3 – Cycle life test conditions

Application	Ambient and cell temperature	
	25 °C	45 °C
BEV	a	r
HEV	a	r

Table A.4 – Conditions for energy efficiency test for BEV application

SOC	Charge current	Test condition
80 %	2 I_t	r
Manufacturer's recommended SOC	Manufacturer's recommended current	a

Annex B
(informative)

Cycle life test sequence

Annex B provides the test sequences of cycle life tests specified in 7.8. The test sequence and concept of BEV cycle are shown in Figure B.1 and Figure B.2. The test sequence of HEV cycle test is shown in Table B.1.

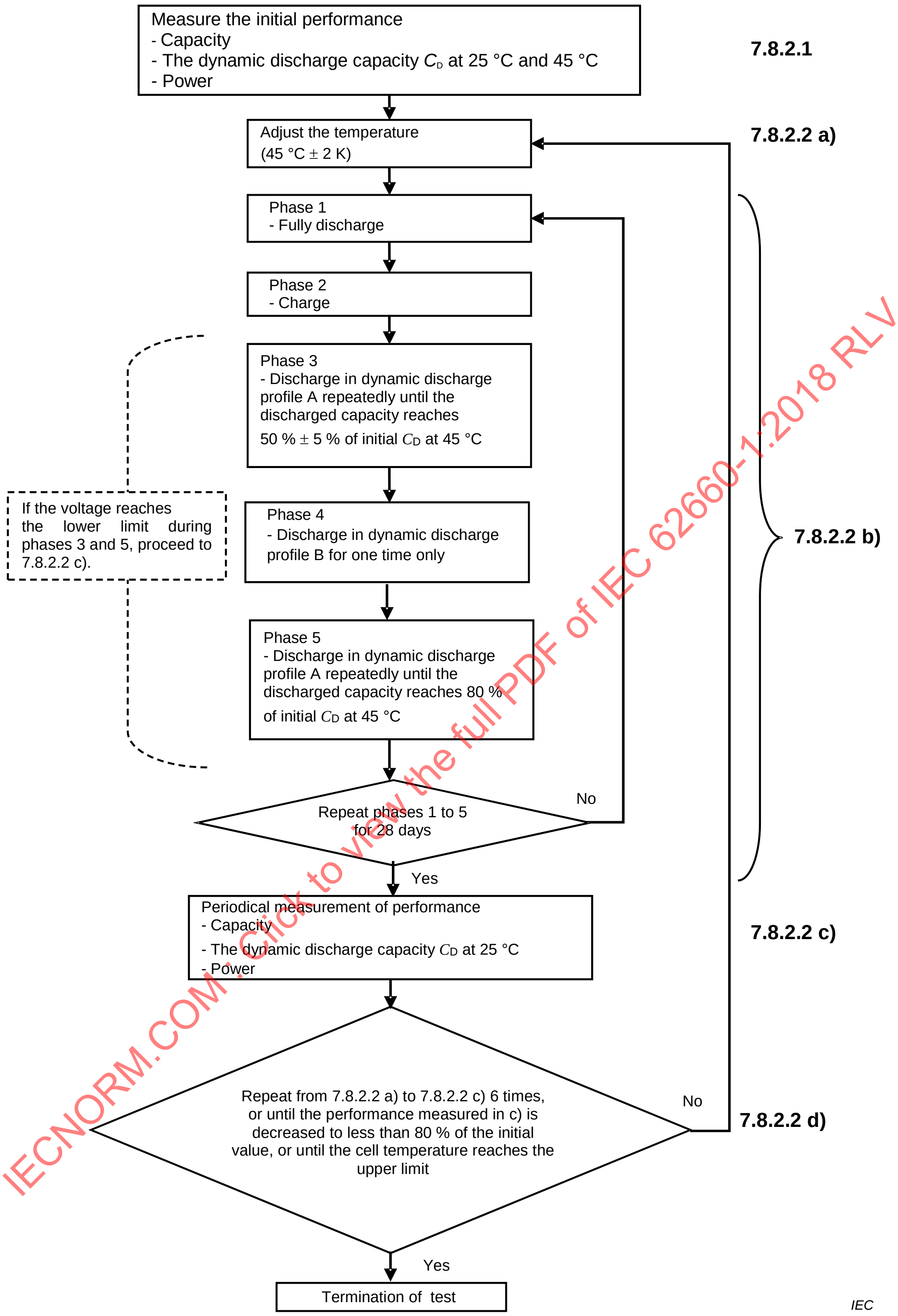


Figure B.1 – Test sequence of BEV cycle test

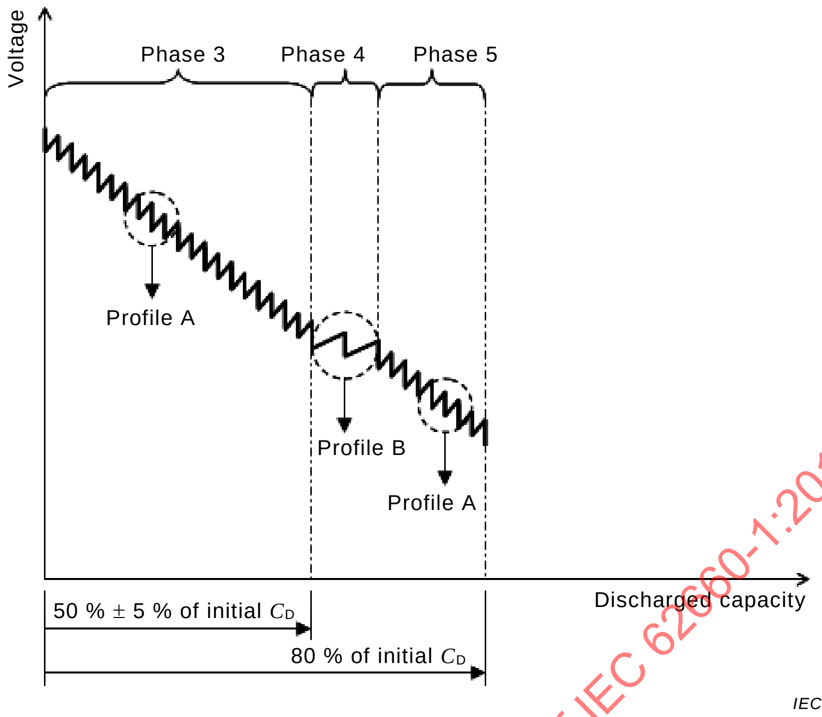


Figure B.2 – Concept of BEV cycle test

Table B.1 – Test sequence of HEV cycle test

<table>
<tr><th colspan="2"></th><th>Test procedure</th><th>Temperature</th></tr>
<tr><td colspan="2">7.8.3.1</td><td>Measure the initial performance
– Capacity
– Power</td><td>Room temperature</td></tr>
<tr><td colspan="2">7.8.3.2 a)</td><td>Set the switching voltage from discharge-rich profile to charge-rich profile</td><td rowspan="2">45 °C ~~± 2 K~~</td></tr>
<tr><td colspan="2">7.8.3.2 b)</td><td>Set the switching voltage from charge-rich profile to discharge-rich profile</td></tr>
<tr><td colspan="2">7.8.3.3 a)</td><td>Adjust the temperature to 45 °C ~~± 2 K~~</td><td rowspan="7">45 °C ~~± 2 K~~</td></tr>
<tr><td colspan="2">7.8.3.3 b)</td><td>Adjust the SOC to 80 %</td></tr>
<tr><td rowspan="5">7.8.3.3 c)</td><td>Phase 1</td><td>Repeat the cycle in discharge-rich profile until the switching voltage set in 7.8.3.2 a)</td></tr>
<tr><td>Phase 2</td><td>Repeat the cycle in charge-rich profile until the switching voltage set in 7.8.3.2 b)</td></tr>
<tr><td>Phase 3</td><td>Repeat phase 1 and phase 2 for 22 h</td></tr>
<tr><td>Phase 4</td><td>Rest for 2 h</td></tr>
<tr><td></td><td>Repeat the procedure from phase 1 to phase 4</td></tr>
<tr><td colspan="2">7.8.3.3 d)</td><td>Periodical measurement of performance
– Capacity (every 14 days)
– Power (every 7 days)</td><td>Room temperature</td></tr>
<tr><td colspan="2">7.8.3.3 e)</td><td>Terminate the test when either of the following conditions is satisfied. If not satisfied, go back to 7.8.3.3 a)
– Repeat 7.8.3.3 c) for 6 months
– Either of the performance parameters measured in 7.8.3.3 d) is decreased to less than 80 % of the initial value</td><td>-</td></tr>
</table>

Annex C
(informative)

Current-voltage characteristic test

C.1 General

Annex C describes the test method to determine the current-voltage characteristics of a cell, when the maximum current values for charge and discharge are not available for the power test in 7.5.

C.2 Test method

The test shall be conducted under each combination of SOC and cell temperature at the test commencement as specified in Table 2, according to the procedure specified by the cell manufacturer.

The test shall be performed according to the scheme shown in Figure C.1.

Charge and discharge the cell at the constant test currents in Table C.1, and measure the voltage at the end of the 10 s pulse of each test current. The range of the charge and discharge current shall be specified by the cell manufacturer, and the standard measurement interval shall be 1 s. If the voltage after 10 s exceeds the discharge lower limit voltage or charge upper limit voltage, the measurement data shall be omitted.

The charge/discharge limits at low temperature specified by the cell manufacturer should be taken into account.

Table C.1 – Charge and discharge current for the current-voltage characteristic test

Application	Charge and discharge current A			
BEV	1/3 I_t	1 I_t	2 I_t	5 I_t
HEV	1/3 I_t	1 I_t	5 I_t	10 I_t

10-min rest time shall be provided between charge and discharge pulses as well as between discharge and charge pulses. However, if the cell temperature after 10 min is not within 2 K of test temperature, it shall be cooled further. Alternatively, the rest time duration shall be extended and it shall be inspected whether the cell temperature then settles within 2 K. The next discharging or charging procedure is then performed.

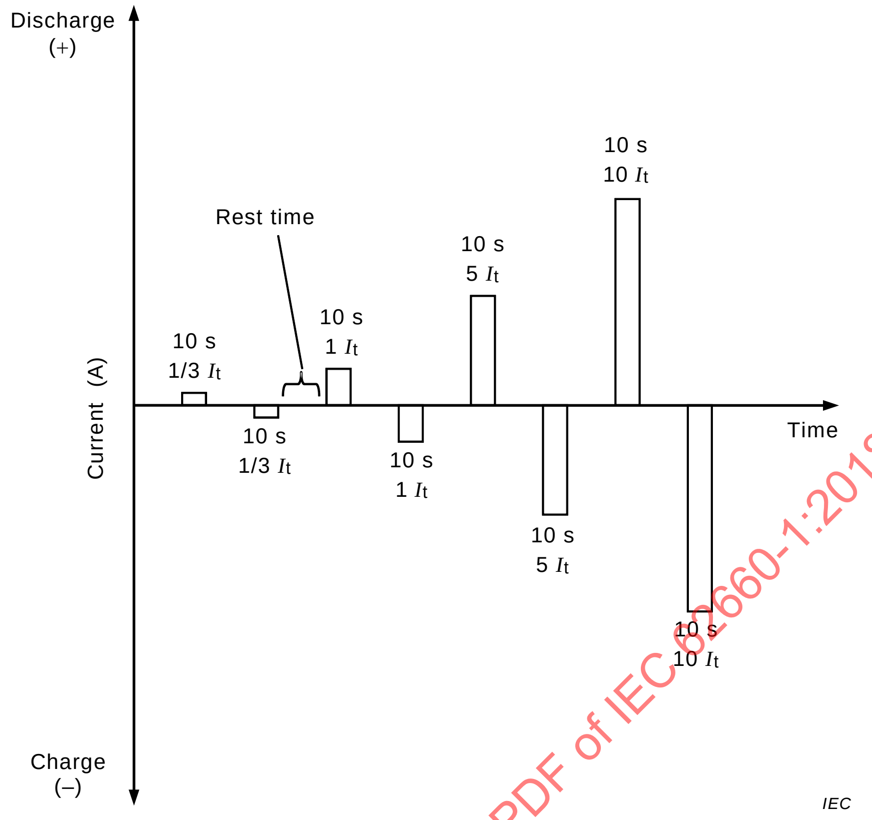


Figure C.1a – Test order of the current-voltage characteristic test for HEV application

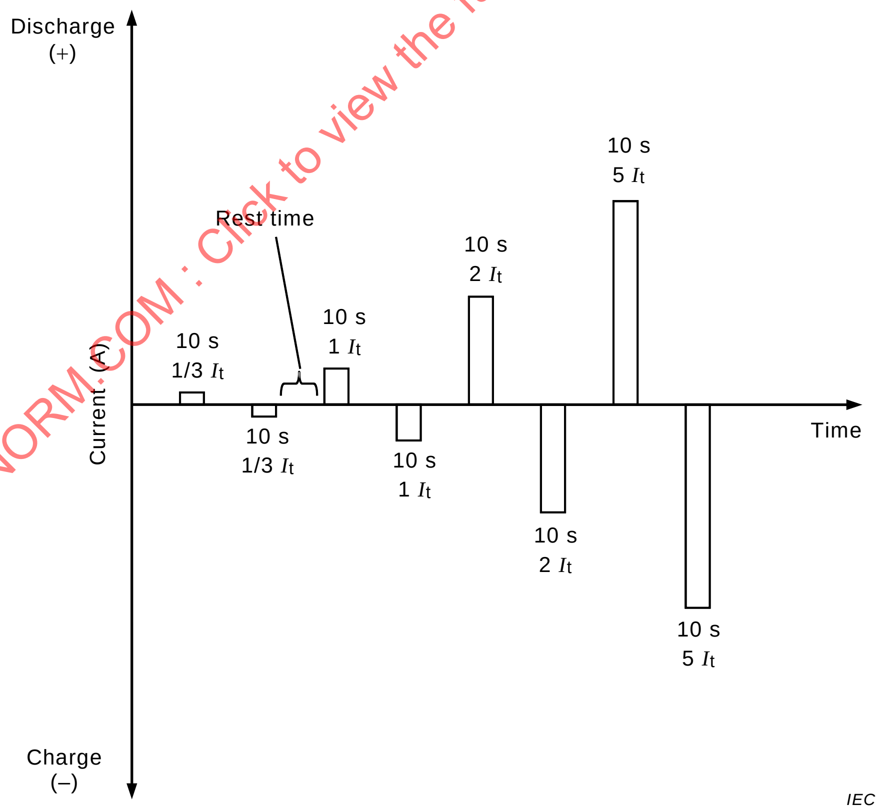


Figure C.1b – Test order of the current-voltage characteristic test for BEV application

Figure C.1 – Test order of the current-voltage characteristic test

Using the measured values of current and voltage, the current-voltage characteristic line shall be obtained by straight-line approximation, and the maximum current for charge and discharge (I_{dmax}, I_{cmax}) and power shall be calculated. The slope of this line shows the internal resistance of the cell.

Bibliography

~~ISO 12405-1, *Road vehicles – Electrically propelled road vehicles – Test specification for lithium-ion battery packs and systems – Part 1: High power application*~~ [3]

~~ISO 12405-2, *Road vehicles – Electrically propelled road vehicles – Test specification for lithium-ion battery packs and systems – Part 2: High energy application that defines tests and related requirements for battery systems*~~ [4]

[1] ISO 12405-4, *Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems – Part 4: Performance testing*

[2] IEC 62660-2, *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing* [5]

[3] IEC 62660-3, *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 3: Safety requirements*

[4] IEC 61434:1996, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Guide to the designation of current in alkaline secondary cell and battery standards*

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[3] ~~Under consideration.~~

[4] ~~Under consideration.~~

[5] ~~To be published.~~

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Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 1: Performance testing

Éléments d'accumulateurs lithium-ion pour la propulsion des véhicules routiers électriques – Partie 1: Essais de performance

IEC 62660-1:2018-12(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SECONDARY LITHIUM-ION CELLS FOR THE PROPULSION OF ELECTRIC ROAD VEHICLES –

Part 1: Performance testing

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62660-1 has been prepared by IEC technical committee 21: Secondary cells and batteries.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) The purpose of each test has been added.
b) The power test has been revised for clarification, and an informative part of the current-voltage characteristic test has been moved to the new Annex C.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
21/975/FDIS	21/985/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62660 series, published under the general title *Secondary lithium-ion cells for the propulsion of electric road vehicles*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The commercialization of electric road vehicles including battery, hybrid and plug-in hybrid electric vehicles has been accelerated in the global market, responding to the global concerns on CO_2 reduction and energy security. This, in turn, has led to rapidly increasing demand for high-power and high-energy-density traction batteries. Lithium-ion batteries are estimated to be one of the most promising secondary batteries for the propulsion of electric vehicles. In the light of the rapid spread of hybrid electric vehicles and the emergence of battery and plug-in hybrid electric vehicles, a standard method for testing performance requirements of lithium-ion batteries is indispensable for securing a basic level of performance and obtaining essential data for the design of vehicle systems and battery packs.

This document specifies performance testing for automobile traction lithium-ion cells that basically differ from the other cells including those for portable and stationary applications specified by other IEC standards. For automobile application, it is important to note the usage specificity; i.e. the design diversity of automobile battery packs and systems, and specific requirements for cells and batteries corresponding to each of such designs. Based on these facts, the purpose of this document is to provide a basic test methodology with general versatility, which serves a function in common primary testing of lithium-ion cells to be used in a variety of battery systems.

This document is associated with ISO 12405-4 [1][1].

IEC 62660-2 [2] specifies the reliability and abuse testing for lithium-ion cells for electric vehicle application.

IEC 62660-3 [3] specifies the safety requirements of lithium-ion cells for electric vehicle application.

1 Numbers in square brackets refer to the Bibliography.

SECONDARY LITHIUM-ION CELLS FOR THE PROPULSION OF ELECTRIC ROAD VEHICLES –

Part 1: Performance testing

1 Scope

This part of IEC 62660 specifies performance and life testing of secondary lithium-ion cells used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV).

NOTE 1 Secondary lithium-ion cell used for propulsion of plug-in hybrid electric vehicle (PHEV) can be tested by the procedure either for BEV application or HEV application, according to the battery system design, based on the agreement between the cell manufacturer and the customer.

This document specifies the test procedures to obtain the essential characteristics of lithium-ion cells for vehicle propulsion applications regarding capacity, power density, energy density, storage life and cycle life.

This document provides the standard test procedures and conditions for testing basic performance characteristics of lithium-ion cells for vehicle propulsion applications, which are indispensable for securing a basic level of performance and obtaining essential data on cells for various designs of battery systems and battery packs.

NOTE 2 Based on the agreement between the cell manufacturer and the customer, specific test conditions can be selected in addition to the conditions specified in this document. Selective test conditions are described in Annex A.

NOTE 3 The performance tests for the electrically connected lithium-ion cells can be performed with reference to this document.

NOTE 4 The test specification for lithium-ion battery packs and systems is defined in ISO 12405-4 [1].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 8713, *Electrically propelled road vehicles – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 8713 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
battery electric vehicle
BEV
electric vehicle with only a traction battery as power source for vehicle propulsion

3.2
hybrid electric vehicle
HEV
vehicle with both a rechargeable energy storage system and a fuelled power source for propulsion

3.3
rated capacity
C_n
capacity value of a cell in ampere hours (Ah) determined under specified conditions and declared by the cell manufacturer

Note 1 to entry: n in C_n is the time base in hours (h). In this document, n = 3 for BEV application and n = 1 for HEV application unless otherwise specified.

3.4
I_t
reference test current in amperes (A) which is expressed as

$$I_t = C_n / 1$$

Note 1 to entry: 1 has a dimension of time in hours (h).

Note 2 to entry: See IEC 61434:1996 [4], Clause 2.

3.5
room temperature
temperature of 25 °C ± 2 K

3.6
secondary lithium-ion cell
cell
secondary single cell whose electric energy is derived from the insertion and extraction reactions of lithium ions between the anode and the cathode

Note 1 to entry: The secondary lithium-ion cell is a basic manufactured unit providing a source of electric energy by direct conversion of chemical energy. It consists of electrodes, separators, electrolyte, container and terminals, and is designed to be charged electrically.

3.7
state of charge
SOC
capacity in a cell expressed as a percentage of rated capacity

3.8
charge retention
ability of a cell to retain capacity on open circuit under specified conditions of storage

4 Test conditions

4.1 General

The details of the instrumentation used shall be provided in any report of results.

Test and measurement shall be conducted with caution to prevent a short circuit.

NOTE Test and measurement can be conducted under fixing condition recommended by the cell manufacturer.

4.2 Measuring instruments

4.2.1 Range of measuring devices

The instruments used shall enable the values of voltage, current and temperature to be measured. The range of these instruments and measuring methods shall be chosen so as to ensure the accuracy specified for each test.

For analogue instruments, this implies that the readings shall be taken in the last third of the graduated scale.

Any other measuring instruments may be used provided they give an equivalent accuracy.

4.2.2 Voltage measurement

The resistance of the voltmeters used shall be at least 1 MΩ/V.

4.2.3 Current measurement

The entire assembly of ammeter, shunt and leads shall be of an accuracy class of 0,5 or better.

4.2.4 Temperature measurements

The cell temperature shall be measured by use of a surface temperature measuring device capable of an equivalent scale definition and accuracy of calibration as specified in 4.2.1. The temperature shall be measured at a location which most closely reflects the cell temperature. The temperature may be measured at additional appropriate locations, if necessary.

The examples for temperature measurement are shown in Figure 1. The instructions for temperature measurement specified by the cell manufacturer shall be followed.

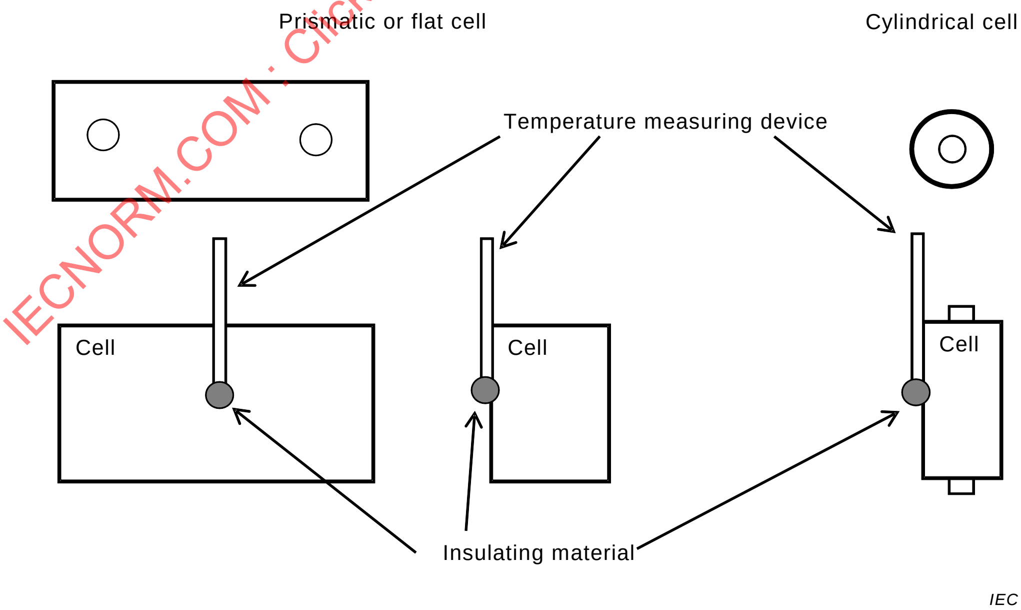

Figure 1 – Example of temperature measurement of cell

4.2.5 Other measurements

Other values may be measured by use of a measuring device, provided that it complies with 4.3.

4.3 Tolerance

The overall accuracy of controlled or measured values, relative to the specified or actual values, shall be within the following tolerances:

a) ± 0,1 % for voltage;

b) ± 1 % for current;

c) ± 2 K for temperature;

d) ± 0,1 % for time;

e) ± 0,1 % for mass;

f) ± 0,1 % for dimensions.

These tolerances comprise the combined accuracy of the measuring instruments, the measurement technique used, and all other sources of error in the test procedure.

4.4 Thermal stabilization

For the stablization of cell temperature, the cell shall be soaked to a specified ambient temperature for a minimum of 12 h. This period may be reduced if thermal stabilization is reached. Thermal stabilization is considered to be reached if after one interval of 1 h, the change of cell temperature is lower than 1 K.

5 Dimension measurement

The maximum dimension of the total width, thickness or diameter, and height of a cell shall be measured at room temperature up to three significant figures in accordance with the tolerances in 4.3.

Examples of maximum dimensions are shown in Figures 2a to 2f.

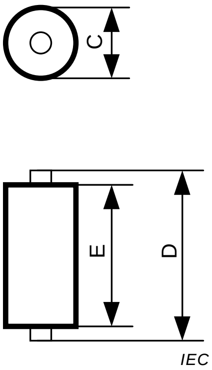

Figure 2a – Cylindrical cell (1)

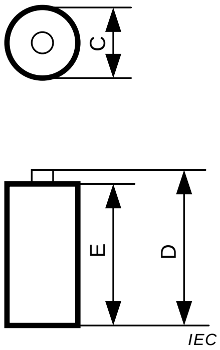

Figure 2b – Cylindrical cell (2)

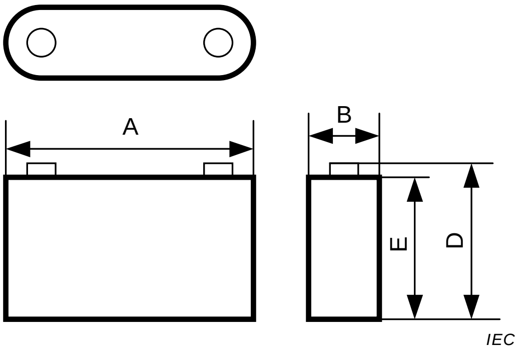

Figure 2c – Prismatic cell (1)

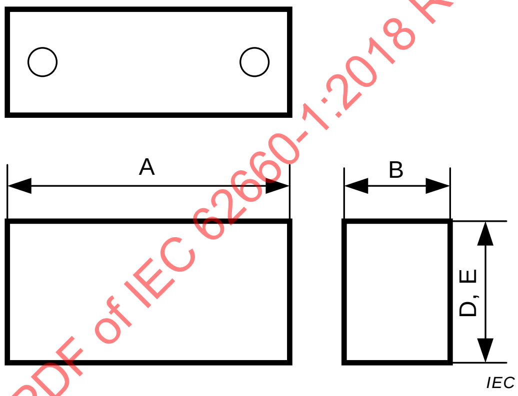

Figure 2d – Prismatic cell (2)

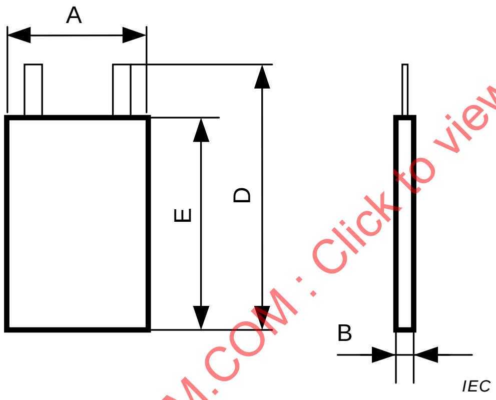

Figure 2e – Prismatic cell with laminate film case (1)

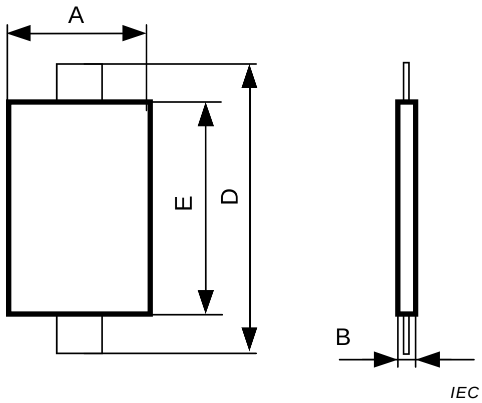

Figure 2f – Prismatic cell with laminate film case (2)

Key

A total width

B total thickness

C diameter

D total height (including terminals)

E total height (excluding terminals)

Figure 2 – Examples of maximum dimensions of cell

NOTE Prismatic cells are provided with either a rigid metal case or flexible laminate film case. A prismatic cell with laminate film case is usually called a pouch cell.

The volume of a prismatic cell is given by the product of its total height excluding terminals, total width, and total thickness, and that of a cylindrical cell is given by the product of the cross section of the cylinder and its total height excluding terminals.

6 Mass measurement

The mass of a cell is measured at room temperature up to three significant figures in accordance with the tolerances in 4.3.

7 Electrical measurement

7.1 General

During each test, voltage, current and temperature shall be recorded.

Before each test, the cell temperature shall be stabilized at room temperature according to 4.4, unless otherwise specified.

The ambient temperature shall be the room temperature unless otherwise specified.

7.2 General charge conditions

Unless otherwise stated in this document, prior to electrical measurement test, the cell shall be charged as follows.

Prior to charging, the cell shall be discharged at room temperature at a constant current described in Table 1 down to an end-of-discharge voltage specified by the cell manufacturer. Then, the cell shall be charged at room temperature according to the charging method declared by the cell manufacturer.

7.3 Capacity

The capacity of a cell shall be measured in accordance with the following phases.

Phase 1 – The cell shall be charged in accordance with 7.2.

After recharge, the cell temperature shall be stabilized in accordance with 4.4.

Phase 2 – The cell shall be discharged at specified temperature at a constant current I_t (A) to the end-of-discharge voltage that is provided by the cell manufacturer. The discharge current and cell temperatures indicated in Table 1 shall be used.

In addition to Table 1, specific test conditions may be selected based on the agreement between the cell manufacturer and the customer. Selective test conditions are shown in Table A.1.

Table 1 – Discharge conditions

Cell temperature °C	**Discharge current** A	
	BEV application	**HEV application**
0	1/3 I_t	1 I_t
25		
45		

Phase 3 – Measure the discharge duration until the specified end-of-discharge voltage is reached. Calculate the capacity of cell expressed in Ah up to three significant figures, by multiplying the discharge current (A) with the discharge duration (h).

7.4 SOC adjustment

The test cells shall be charged as specified below, unless otherwise specified. The SOC adjustment is the procedure to be followed for preparing cells to the various SOCs for the tests in this document.

Phase 1 – The cell shall be charged in accordance with 7.2.

Phase 2 – The cell shall be left at rest at room temperature in accordance with 4.4.

Phase 3 – The cell shall be discharged at a constant current according to Table 1 for $(100 - n)/100 \times 3$ h for BEV application and $(100 - n)/100 \times 1$ h for HEV application, where n is SOC (%) to be adjusted for each test.

7.5 Power

7.5.1 General

This test is intended to determine the power characteristics of a cell under the representative usage conditions of BEV and HEV applications.

Based on the current-voltage characteristic test in 7.5.2, the power density and regenerative power density of a cell shall be calculated according to 7.5.3 and 7.5.4, respectively.

The power density and regenerative power density shall be calculated and reported for each combination of SOC and temperature in 7.5.2.

7.5.2 Test method

The test shall be carried out in accordance with the following procedure.

a) Mass measurement

Mass of the cell shall be measured as specified in Clause 6.

b) Dimension measurement

Dimensions of the cell shall be measured as specified in Clause 5.

c) SOC and temperature adjustment

The test in 7.5.2 d) shall be conducted under each combination of SOC and cell temperature at the test commencement as specified in Table 2, according to the procedure specified by the cell manufacturer.

SOC shall be adjusted according to 7.4.

Table 2 – SOC and temperature condition for power test

SOC %	Cell temperature °C			
20	25			
50	−20	0	25	40
80	25			

NOTE Selective test conditions are shown in Table A.2.

d) Current-voltage characteristics test

Discharge the cell for 10 s at the maximum current for discharge specified by the cell manufacturer (I_{dmax}), and measure the voltage at the end of the 10 s pulse (U_d).

Charge the cell for 10 s at the maximum current for charge specified by the cell manufacturer (I_{cmax}), and measure the voltage at the end of the 10 s pulse (U_c).

The values of I_{dmax} and I_{cmax} change depending on SOC, test temperature and charge or discharge state.

The charge and discharge limits of current and voltage at low temperature specified by the cell manufacturer should be taken into account.

In case that I_{dmax} and I_{cmax} are not available, the value may be obtained according to the test in Annex C.

7.5.3 Calculation of power density

7.5.3.1 Power calculation

The power shall be calculated according to Equation (1) and is rounded to three significant figures.

$$P_d = U_d \times I_{dmax} \quad (1)$$

where

P_d is the power (W);

U_d is the measured voltage at the end of the 10 s pulse of I_{dmax} discharge (V);

I_{dmax} is the maximum discharge current which is specified by the cell manufacturer (A).

If P_d is an estimated value, this shall be stated.

7.5.3.2 Power density per unit mass

Mass power density shall be calculated from Equation (2), and is rounded to three significant figures.

$$\rho_{pd} = \frac{P_d}{m} \quad (2)$$

where

ρ_{pd} is the power density (W/kg);

P_d is the power (W);

m is the mass of the cell (kg).

7.5.3.3 Power density per unit volume

Volumetric power density shall be calculated from Equation (3), and is rounded to three significant figures.

$$\rho_{pvlm} = \frac{P_d}{V} \quad (3)$$

where

ρ_{pvlm} is the volumetric power density (W/l);

P_d is the power (W);

V is the volume of the cell (l).

7.5.4 Calculation of regenerative power density

7.5.4.1 Regenerative power

Regenerative power shall be calculated according to Equation (4) and is rounded to three significant figures.

$$P_{\mathrm{c}} = U_{\mathrm{c}} \times I_{\mathrm{cmax}} \tag{4}$$

where

P_{c} is the regenerative power (W);

U_{c} is the measured voltage at the end of the 10 s pulse of I_{cmax} charge (V);

I_{cmax} is the maximum charge current specified by the cell manufacturer (A).

If P_{c} is an estimated value, this shall be stated.

7.5.4.2 Regenerative power density per unit mass

Regenerative power density per unit mass shall be calculated from Equation (5) and is rounded to three significant figures.

$$\rho_{\mathrm{pc}} = \frac{P_{\mathrm{c}}}{m} \tag{5}$$

where

ρ_{pc} is the regenerative power density (W/kg);

P_{c} is the regenerative power (W);

m is the mass of the cell (kg).

7.5.4.3 Regenerative power density per unit volume

Volumetric regenerative power density shall be calculated from Equation (6) and is rounded to three significant figures.

$$\rho_{\mathrm{pvlmc}} = \frac{P_{\mathrm{c}}}{V} \tag{6}$$

where

ρ_{pvlmc} is the volumetric regenerative power density (W/l);

P_{c} is the regenerative power (W);

V is the volume of the cell (l).

7.6 Energy

7.6.1 General

This test is intended to determine the energy density that can be derived from a cell under the representative usage conditions of BEV and HEV applications.

Based on the test in 7.6.2, the energy density of a cell shall be calculated according to 7.6.3.

7.6.2 Test method

Mass energy density (Wh/kg) and volumetric energy density (Wh/l) of cells in a certain current discharge of 1/3 I_t (A) for BEV application and 1 I_t (A) for HEV application shall be determined according to the following procedure.

a) Mass measurement

Mass of the cell shall be measured as specified in Clause 6.

b) Dimension measurement

Dimensions of the cell shall be measured as specified in Clause 5.

c) Capacity measurement

Capacity of the cell shall be determined in accordance with 7.3 at room temperature.

d) Average voltage calculation

The value of the average voltage during discharging in the above capacity test shall be obtained by integrating the discharge voltage over time and dividing the result by the discharge duration. The average voltage is calculated in a simple manner using the following method: Discharge voltages U_1, U_2, ..., U_n are noted every 5 s from the time the discharging starts and voltages that cut off the end-of-discharge voltage in less than 5 s are discarded. The average voltage U_{avr} is then calculated in a simplified manner using Equation (7) up to three significant figures by rounding off the result.

$$U_{\text{avr}} = \frac{U_1 + U_2 + \cdots + U_n}{n} \tag{7}$$

7.6.3 Calculation of energy density

7.6.3.1 Energy density per unit mass

The mass energy density shall be calculated using Equation (8) and Equation (9) up to three significant figures by rounding off the result.

$$W_{\text{ed}} = C_{\text{d}} U_{\text{avr}} \tag{8}$$

where

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions;

C_d is the discharge capacity (Ah) at 1/3 I_t (A) for BEV or 1 I_t (A) for HEV;

U_{avr} is the average voltage during discharging (V).

$$\rho_{\text{ed}} = \frac{W_{\text{ed}}}{m} \tag{9}$$

where

ρ_{ed} is the mass energy density (Wh/kg);

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions;

m is the mass of the cell (kg).

7.6.3.2 Energy density per unit volume

The volumetric energy density shall be calculated using Equation (10) up to three significant figures by rounding off the result.

$$\rho_{\text{evlmd}} = \frac{W_{\text{ed}}}{V} \qquad (10)$$

where

ρ_{evlmd} is the volumetric energy density (Wh/l);

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions;

V is the volume of the cell (l).

7.7 Storage test

7.7.1 General

This test is intended to determine the capacity retaining characteristics of a cell under storage or non-use, and is composed of the charge retention test in 7.7.2 and the storage life test in 7.7.3.

7.7.2 Charge retention test

This test is intended to determine the charge retention characteristics of a cell under storage including transportation.

The charge retention characteristics of the cell at a 50 % SOC shall be determined according to the following procedure.

Phase 1 – The cell shall be charged in accordance with 7.2.

Phase 2 – The cell shall be discharged to 50 % SOC in accordance with the method specified in 7.4. Then, the cell shall be stabilized at room temperature for 1 h.

NOTE The SOC value can be changed according to the agreement between the customer and the cell manufacturer.

Phase 3 – Discharge the cell to the end-of-discharge voltage at a discharge current of 1/3I_t (A) for BEV application and 1I_t (A) for HEV application and at room temperature. This discharge capacity is C_b.

Phase 4 – Repeat phases 1 and 2 one time.

Phase 5 – The cell shall be stored for 28 days at an ambient temperature of 45 °C.

Phase 6 – After phase 5, the cell shall be stabilized at room temperature according to 4.4. Then, discharge the cell at a constant current of 1/3I_t (A) for BEV application and 1I_t (A) for HEV application until the end-of-discharge voltage, and then measure the capacity of cell. This discharge capacity is C_r.

Charge retention ratio shall be calculated according to Equation (11).

$$R = \frac{C_r}{C_b} \times 100 \qquad (11)$$

where

R is the charge retention ratio (%);

C_r is the capacity of the cell after storage (Ah);

C_b is the capacity of the cell before storage (Ah).

7.7.3 Storage life test

This test is intended to determine the degradation characteristics of a cell under the storage or non-use of BEV and HEV applications.

The storage life of a cell shall be determined according to the following procedure.

Phase 1 – Determine the capacity, power density and regenerative power density of the cell in accordance with 7.2, 7.3 and 7.5.

Phase 2 – Adjust the SOC of the cell to 100 % for BEV application, and to 50 % for HEV application in accordance with 7.4. The cell shall then be stored for 42 days at an ambient temperature of 45 °C.

Phase 3 – Following the storage of phase 2, the cell shall be stablized at room temperature according to 4.4 and discharged at a constant current of $1/3 I_t$ (A) for BEV application and $1 I_t$ (A) for HEV application, down to the end-of-discharge voltage specified by the cell manufacturer. Then, measure the capacity of the cell. This discharge capacity is the retained capacity (Ah). The power density and regenerative power density shall also be measured.

Phase 4 – Repeat phase 2 and phase 3 for three times.

The capacity, power density, regenerative power density and retained capacity measured in phase 1 and phase 3 shall be reported.

If the cell is stored at room temperature during the test for rest such as for test timing adjustment, the total time of such rest shall be reported.

7.8 Cycle life test

7.8.1 General

This test is intended to determine the degradation characteristics of the cell by charge and discharge cycles representing the normal usage conditions of BEV and HEV applications.

The cycle life performance of a cell for BEV application and HEV application shall be determined according to the tests in 7.8.2 and 7.8.3.

The test sequence is shown in Annex B.

NOTE Selective test conditions are shown in Table A.3.

7.8.2 BEV cycle test

7.8.2.1 Measurement of initial performance

Before the charge and discharge cycle test, measure the capacity, dynamic discharge capacity, and power as the initial performance of the cell.

- Capacity

  The capacity shall be measured as specified in 7.3 at 25 °C.

- Dynamic discharge capacity C_D

The dynamic discharge capacity C_D shall be measured at 25 °C and 45 °C.

The dynamic discharge capacity is defined by the time integrated value of charge and discharge current confirmed by the following test: Discharge the fully charged cell repeatedly by the dynamic discharge profile A specified in Table 3 and Figure 3 until the voltage reaches the lower limit specified by the cell manufacturer.

- Power

The power shall be measured as specified in 7.5 at 25 °C and 50 % SOC.

7.8.2.2 Charge and discharge cycle

The charge and discharge cycle test shall be performed as follows.

a) At the start of the test, cell temperature shall be 45 °C. The ambient temperature shall be 45 °C.

b) Test phases

The procedure from phase 1 to phase 5 shall be continuously repeated for 28 days. The rest time of less than 4 h can be set between each phase. Then, measure the performance of the cell as specified in 7.8.2.2 c). This procedure shall be repeated until the test termination specified in 7.8.2.2 d).

Phase 1 – The cell shall be fully discharged by the method specified by the cell manufacturer.

Phase 2 – The cells shall be fully charged by the method specified by the cell manufacturer. The charge time shall be less than 12 h.

Phase 3 – Discharge the cell following the dynamic discharge profile A specified in Table 3 and Figure 3 until the discharged capacity reaches equivalent to 50 % ± 5 % of the initial dynamic discharge capacity C_D at 45 °C.

If the voltage reaches the lower limit specified by the cell manufacturer during phase 3, the test shall be discontinued notwithstanding the stipulation in 7.8.2.2 d), and the cell performance shall be measured at this point as specified in 7.8.2.2 c).

If the temperature of the cell reaches the upper limit specified by the cell manufacturer during phase 3, the duration of test step 20 in Table 3 may be extended to an appropriate value. The actual duration time shall be reported.

If the voltage reaches the maximum limit specified by the cell manufacturer during a charge step in Table 3, constant-voltage charge at the maximum voltage shall be applied until the end of duration of this step.

In this profile, the test power shall be calculated using Equation (12):

$$P_{max} = NW_{ed} \tag{12}$$

where

P_{max} is the test power (W);

N is the required maximum cell power (W) divided by the energy of the cell (Wh) with units of (1/h).

NOTE The value of N = 3/h is an example based on the specifications of commercialized BEVs.

W_{ed} is the electric energy of the cell at room temperature (Wh) when discharged under specified conditions.

If the value derived from Equation (12) is larger than the maximum power of the cell specified by the cell manufacturer, the test power shall be defined as 80 % of the maximum power at room temperature and at 20 % SOC specified by the cell manufacturer. The power value actually used shall be reported.

Table 3 – Dynamic discharge profile A for BEV cycle test

Test step	Duration s	Ratio to test power %	Charge/discharge
1	16	0,0	–
2	28	+12,5	Discharge
3	12	+25,0	Discharge
4	8	−12,5	Charge
5	16	0,0	–
6	24	+12,5	Discharge
7	12	+25,0	Discharge
8	8	−12,5	Charge
9	16	0,0	–
10	24	+12,5	Discharge
11	12	+25,0	Discharge
12	8	−12,5	Charge
13	16	0,0	–
14	36	+12,5	Discharge
15	8	+100,0	Discharge
16	24	+62,5	Discharge
17	8	−25,0	Charge
18	32	+25,0	Discharge
19	8	−50,0	Charge
20	44	0,0	–

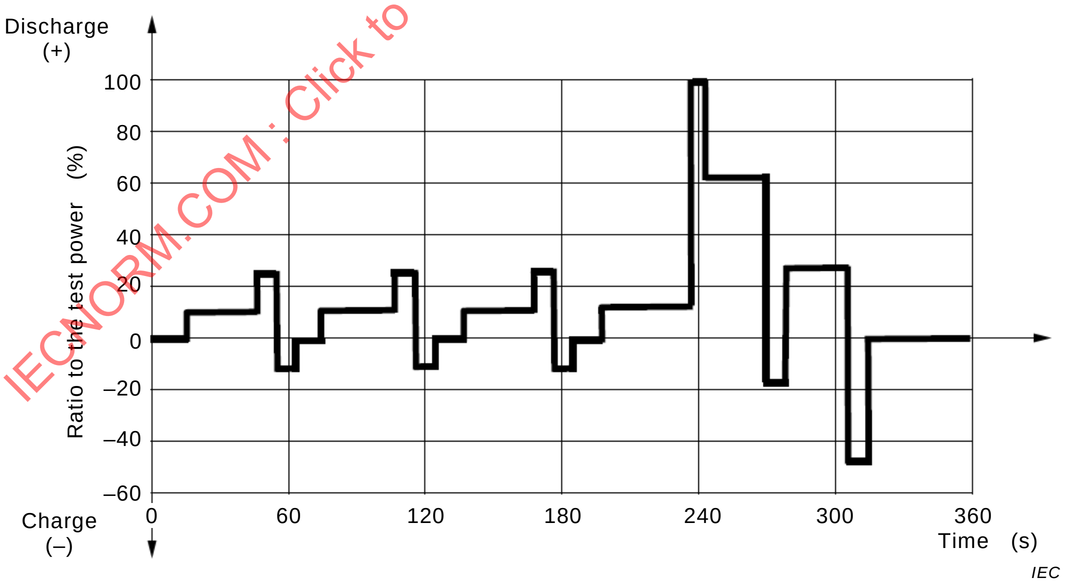

Figure 3 – Dynamic discharge profile A for BEV cycle test

Phase 4 – Discharge the cell following the dynamic discharge profile B (hill climbing profile) specified in Table 4 and Figure 4 for one time. The test power shall be calculated using Equation (12).

If the voltage reaches the lower limit specified by the cell manufacturer during phase 4, the test shall be discontinued notwithstanding the stipulation in 7.8.2.2 d), and the cell performance shall be measured at this point as specified in 7.8.2.2 c).

If the battery voltage frequently reaches the lower limit voltage during test step 16, the discharge power and duration may be changed appropriately. The actual test values shall be reported accordingly.

Table 4 – Dynamic discharge profile B for BEV cycle test

Test step	Duration s	Ratio to test power %	Charge/discharge
1	16	0,0	–
2	28	+12,5	Discharge
3	12	+25,0	Discharge
4	8	−12,5	Charge
5	16	0,0	–
6	24	+12,5	Discharge
7	12	+25,0	Discharge
8	8	−12,5	Charge
9	16	0,0	–
10	24	+12,5	Discharge
11	12	+25,0	Discharge
12	8	−12,5	Charge
13	16	0,0	–
14	36	+12,5	Discharge
15	8	+100,0	Discharge
16	120	+62,5	Discharge
17	8	−25,0	Charge
18	32	+25,0	Discharge
19	8	−50,0	Charge
20	44	0,0	–

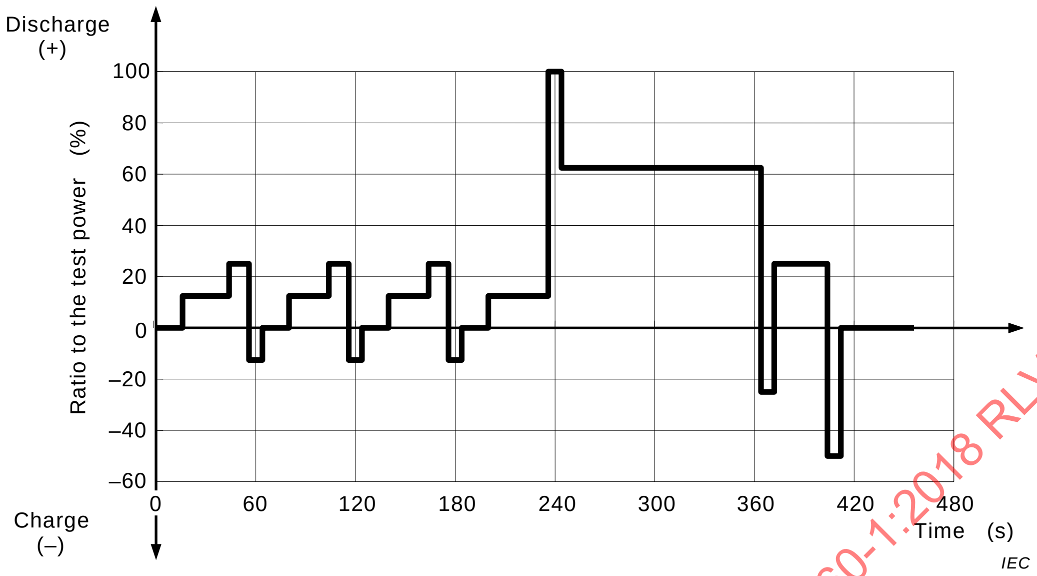

Figure 4 – Dynamic discharge profile B for BEV cycle test

Phase 5 – Discharge the cell following the dynamic discharge profile A specified in Table 3 and Figure 3 until the overall discharge capacity including phase 3 and phase 4 reaches equivalent to 80 % of initial C_D at 45 °C.

If the temperature of the cell reaches the upper limit specified by the cell manufacturer during phase 5, the duration of test step 20 in Table 3 may be extended to an appropriate value. The actual duration time shall be reported.

If the voltage reaches the lower limit specified by the cell manufacturer during phase 5, the test shall be discontinued notwithstanding the stipulation in 7.8.2.2 d), and the cell performance shall be measured at this point as specified in 7.8.2.2 c).

c) Periodical measurement of performance

After every completion of the repetition from phase 1 to phase 5 for 28 test days, the performance of the cell shall be measured as specified in 7.8.2.1. The accumulated time from phase 1 to phase 4 in 7.8.2.2 b) shall also be reported. The dynamic discharge capacity shall be measured at 25 °C only.

d) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise, go back to 7.8.2.2 a) and repeat the test.

Condition A – The test sequence from 7.8.2.2 a) to 7.8.2.2 c) has been performed six times.

Condition B – Any of the performance parameters measured in 7.8.2.2 c) is decreased to less than 80 % of the initial value.

Condition C – The temperature of cell reaches the upper limit agreed between the cell manufacturer and the customer during the test.

The number of times that each profile and each cycle are implemented during the test shall be reported.

7.8.3 HEV cycle test

7.8.3.1 Measurement of initial performance

Before the charge and discharge cycle test, measure the capacity and power as the initial performance of cell.

- Capacity

  The capacity shall be measured as specified in 7.3 at 25 °C.

- Power

  The power shall be measured as specified in 7.5 at 25 °C and 50 % SOC.

7.8.3.2 Profile switching voltage

Before the cycle life test, set switching voltages at which discharge-rich profile and charge-rich profile specified in 7.8.3.3 c) shall be switched over.

a) Switching voltage from discharge-rich profile to charge-rich profile

   Adjust the SOC of the cell to 30 % according to 7.4, and then perform the cycle test with discharge-rich profile at 45 °C for one time. The lowest voltage achieved during this test shall be the switching voltage from discharge-rich profile to charge-rich profile. If the achieved lowest voltage is lower than the cell manufacturer’s specified lower limit voltage, the latter shall be the switching voltage. The cell manufacturer's recommended SOC of cell may be used additionally.

b) Switching voltage from charge-rich profile to discharge-rich profile

   Adjust the SOC of the cell to 80 % according to 7.4, and then perform the cycle test with charge-rich profile at 45 °C for one time. The highest voltage achieved during this test shall be the switching voltage from charge-rich profile to discharge-rich profile. If the achieved highest voltage is higher than the cell manufacturer’s specified upper limit voltage, the latter shall be used as switching voltage. The cell manufacturer's recommended SOC of cell may be used additionally.

7.8.3.3 Charge and discharge cycle

The charge and discharge cycle test shall be performed as follows.

a) Temperature

   The ambient temperature shall be maintained at 45 °C during the test. At the start of charge and discharge cycle, cell temperature shall be 45 °C.

b) Adjustment of SOC before charge and discharge cycle

   The cells shall be left at a temperature of 45 °C, and be adjusted to 80 % SOC or the SOC agreed between the cell manufacturer and the customer within an interval of 16 h to 24 h, in accordance with 7.4. If 80 % SOC is not used, the used SOC shall be reported.

c) Test phases

   The procedure from phase 1 to phase 4 shall be continuously repeated until the test termination specified in 7.8.3.3 e). During the test, the performance of the cell shall be measured periodically as specified in 7.8.3.3 d).

   If the temperature of the cell reaches the upper limit specified by the cell manufacturer during the test, the duration of test step 16 in Table 5 and Table 6 may be extended to an appropriate duration time. The actual duration time shall be reported.

   Phase 1 – The charge and discharge cycle shall be carried out repeatedly through the discharge-rich profile given by Table 5 and Figure 5 until the cell voltage reaches the switching voltage set in 7.8.3.2 a) (see Figure 7).

   Phase 2 – The charge and discharge cycle shall be carried out repeatedly through the charge-rich profile given by Table 6 and Figure 6 until the cell voltage reaches the switching voltage set in 7.8.3.2 b) (see Figure 7).

   Phase 3 – Repeat phase 1 and phase 2 for 22 h.

   Phase 4 – Rest the cell for 2 h.

Table 5 – Discharge-rich profile for HEV cycle test

Test step	Duration s	Current A	Charge/discharge
1	5	20 I_t	Discharge
2	10	10 I_t	Discharge
3	32	5 I_t	Discharge
4	20	0 I_t	–
5	5	−15 I_t	Charge
6	10	−10 I_t	Charge
7	37	−5 I_t	Charge
8	20	0 I_t	–
9	5	15 I_t	Discharge
10	10	10 I_t	Discharge
11	37	5 I_t	Discharge
12	20	0 I_t	–
13	5	−12,5 I_t	Charge
14	7	−7,5 I_t	Charge
15	35	−5 I_t	Charge
16	42	0 I_t	–

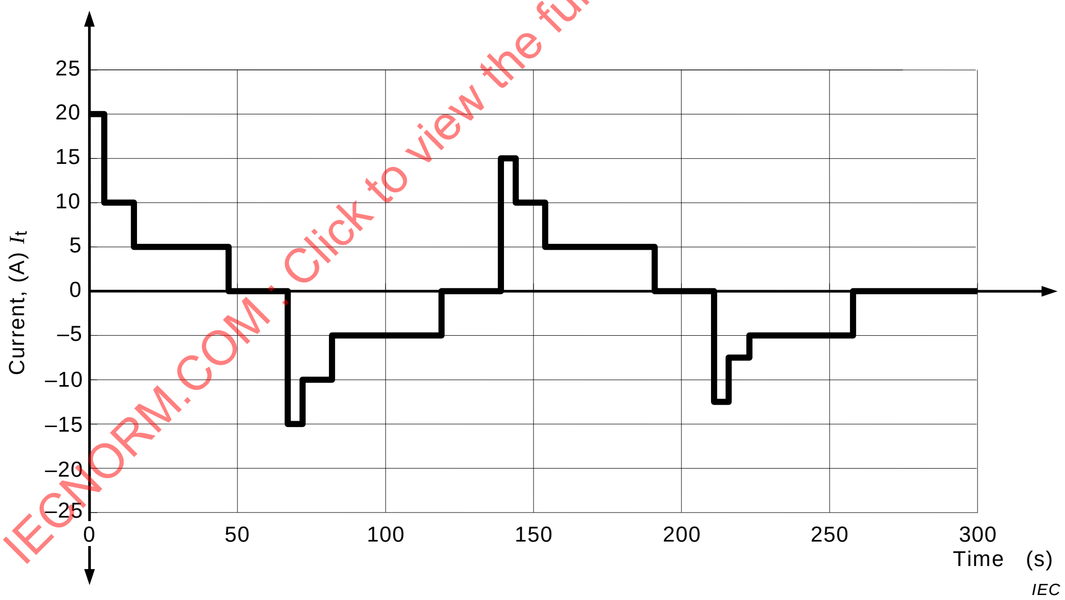

Figure 5 – Discharge-rich profile for HEV cycle test

If the maximum current specified by the cell manufacturer is below 20I_t, the cell manufacturer's specified maximum current may by used at test step 1, along with replacing the current at test step 6 with 50 % of the cell manufacturer's specified maximum current.

Table 6 – Charge-rich profile for HEV cycle test

Test step	Duration s	Current A	Charge/discharge
1	5	−15 I_t	Charge
2	10	−10 I_t	Charge
3	37	−5 I_t	Charge
4	20	0 I_t	–
5	5	20 I_t	Discharge
6	10	10 I_t	Discharge
7	32	5 I_t	Discharge
8	20	0 I_t	–
9	5	−12,5 I_t	Charge
10	7	−7,5 I_t	Charge
11	49	−5 I_t	Charge
12	20	0 I_t	–
13	5	15 I_t	Discharge
14	10	10 I_t	Discharge
15	23	5 I_t	Discharge
16	42	0 I_t	–

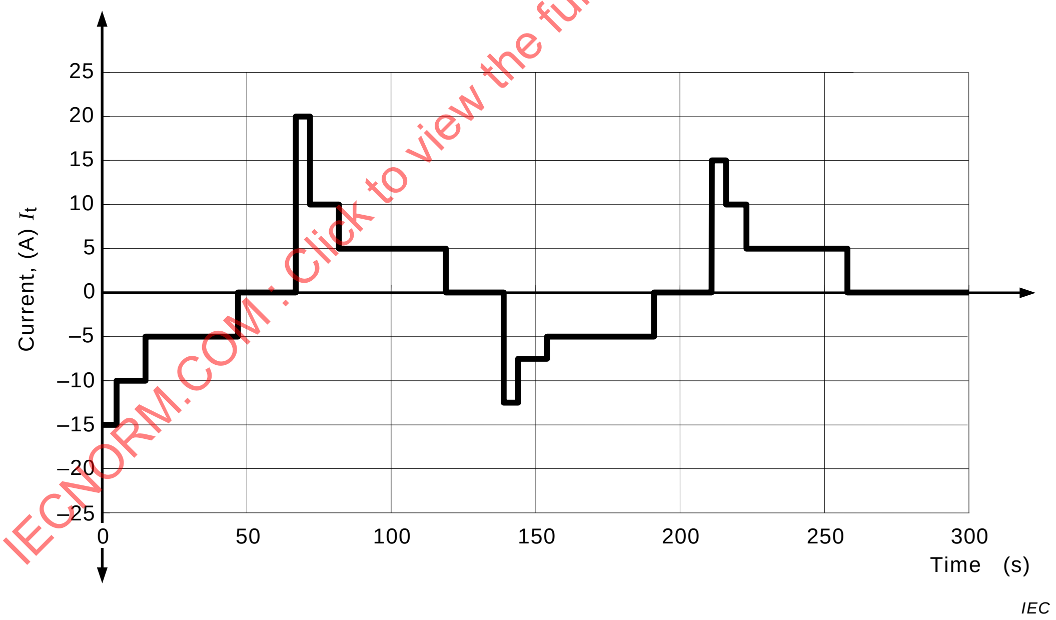

Figure 6 – Charge-rich profile for HEV cycle test

If the maximum current specified by the cell manufacturer is below 20 I_t, the cell manufacturer's specified maximum current may be used at test step 5, along with replacing the current at test step 2 with 50 % of the cell manufacturer's specified maximum current.

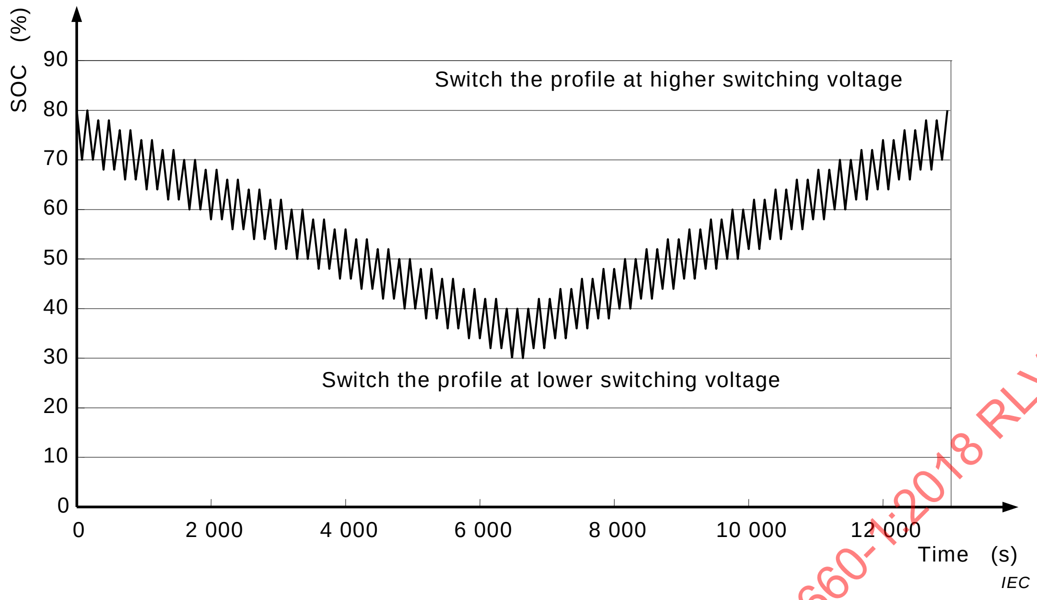

Figure 7 – Typical SOC swing by combination of two profiles for HEV cycle test

d) Periodical measurement of performance

After every completion of the procedure from phase 1 to phase 4 for seven days, the power of the cell shall be measured as specified in 7.8.3.1. The capacity of the cell shall be measured every 14 days as specified in 7.8.3.1.

e) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise, go back to 7.8.3.3 a) and repeat the test.

Condition A – The test in 7.8.3.3 c) is repeated for a total of six months.

Condition B – Either of the performance parameters measured in 7.8.3.3 d) is decreased to less than 80 % of the initial value.

The number of times that each profile is implemented and that the switching voltages are reached shall be reported.

7.9 Energy efficiency test

7.9.1 General

This test is intended to determine the charging efficiency of a cell under the representative usage conditions of BEV or HEV application.

Energy efficiency of cells shall be determined by two common tests as specified in 7.9.2 and either of tests described in 7.9.3 and 7.9.4.

7.9.2 Common tests for BEV and HEV applications

7.9.2.1 Common test for normal conditions

This test aims to determine the efficiency of a cell in normal charging under the representative usage conditions of BEV and HEV applications.

This test is applicable to cells used in HEVs and BEVs. The test shall be carried out in accordance with the following procedure.

a) The cell shall be left at rest at room temperature for a minimum of 1 h and a maximum of 4 h after full charge. The test shall then be commenced.

b) Discharge the cell by the method specified in 7.3 at room temperature.

c) Energy efficiency test at 100 % SOC:

1) leave the cell at rest for 4 h, and then charge it to 100 % SOC by the method recommended by the cell manufacturer;

2) leave the cell at rest for 4 h, and then discharge it by the method specified in 7.3 at room temperature.

d) Energy efficiency test at 70 % SOC:

1) leave the cell at rest for 4 h, and then charge it to 70 % SOC by the method recommended by the cell manufacturer;

2) leave the cell at rest for 4 h, and then discharge it by the method specified in 7.3 at room temperature.

e) Calculation of the discharge electric quantity and charge electric quantity

The electric quantity during the discharge and charge can be calculated using the following method: read the discharge and charge currents I at intervals of s seconds ($s \leq 30$) from the start of the discharge; then, calculate the discharge electric quantity Q_d and charge electric quantity Q_c using Equation (13).

$$Q = \frac{I_1 + I_2 + \cdots + I_n}{\frac{3600}{s}} \tag{13}$$

where

Q is the discharge electric quantity or charge electric quantity (Ah);

I_n is the discharge current value or charge current value at point n of measured intervals (A).

f) Calculation of the discharge electric energy and charge electric energy.

The electric energy during the discharge and charge can be calculated using the following method: read the discharge currents I and the discharge voltages U at intervals of s seconds ($s \leq 30$) from the start of discharge; then, calculate the discharge electric energy W_d and charge electric energy W_c using Equation (14).

$$W = \frac{I_1 U_1 + I_2 U_2 + \cdots + I_n U_n}{\frac{3600}{s}} \tag{14}$$

where

W is the discharge electric energy or charge electric energy (Wh);

I_n is the charge current value or discharge current value at point n of measured intervals (A);

U_n is the discharge voltage value at point n of measured intervals (V).

g) Calculation of energy efficiency

Determine the coulomb efficiency using Equation (15) and the energy efficiency using Equation (16).

$$\eta_c = \frac{Q_d}{Q_c} \times 100 \tag{15}$$

where

η_c is the coulomb efficiency (%);

Q_d is the discharge electric quantity in 7.9.2.1 e) (Ah);

Q_c is the charge electric quantity in 7.9.2.1 e) (Ah).

$$\eta_e = \frac{W_d}{W_c} \times 100 \tag{16}$$

where

η_e is the energy efficiency (%);

W_d is the discharge electric energy in 7.9.2.1 f) (Wh);

W_c is the charge electric energy in 7.9.2.1 f) (Wh).

7.9.2.2 Test by temperature

This test is intended to determine the energy efficiency of a cell in normal charging at different temperature conditions.

This test is applicable to cells used in HEVs and BEVs.

The test shall be carried out in accordance with the following procedure at the test temperatures of −20 °C, 0 °C, and 45 °C.

a) Full charge at room temperature.
b) Thermal equilibration of the cell at the test temperature, and start testing after a minimum of 16 h and a maximum 24 h.
c) Discharge the cell by the method specified in 7.3 at each test temperature.
d) Energy efficiency test at 100 % SOC:
   1) at each test temperature, leave the cell at rest for 4 h, and then charge it to 100 % SOC by the method recommended by the cell manufacturer;
   2) leave the battery at rest for 4 h, and then discharge it by the method specified in 7.3.
e) Calculate discharge electric quantity and charge electric quantity using Equation (13).
f) Calculate discharge electric energy and charge electric energy using Equation (14).
g) Calculate coulomb efficiency and energy efficiency using Equation (15) and Equation (16).

The charge/discharge limits at low temperature specified by the cell manufacturer should be taken into account.

7.9.3 Test for cells of BEV application

This test is applicable to cells used in BEVs, and intended to determine the energy efficiency of a cell under fast charging conditions.

The test shall be carried out in accordance with the following procedure.

a) The cell shall be left at rest at room temperature for a minimum of 1 h and a maximum of 4 h after full charge. The test shall then be commenced.
b) Discharge the cell by the method specified in 7.3.
c) Energy efficiency test at 80 % SOC:
   1) leave the cell at rest for 4 h, and then charge it to 80 % SOC at $2I_t$. If the voltage reached the upper limit voltage specified by the cell manufacturer, charging shall be terminated;

      NOTE Selective test conditions are shown in Table A.4.

   2) leave the cell at rest for more than 4 h until the cell has attained the test temperature, and then discharge it by the method specified in 7.3.
d) Calculate discharge electric quantity and charge electric quantity using Equation (13).
e) Calculate discharge electric energy and charge electric energy using Equation (14).

f) Calculation of energy efficiency

Determine the coulomb efficiency using Equation (17) and the energy efficiency using Equation (18).

$$\eta_{c1} = \frac{Q_{d1}}{Q_{c1}} \times 100 \tag{17}$$

where

η_{c1} is the coulomb efficiency (%);

Q_{d1} is the discharge electric quantity in 7.9.3 d) (Ah);

Q_{c1} is the charge electric quantity in 7.9.3 d) (Ah).

$$\eta_{e1} = \frac{W_{d1}}{W_{c1}} \times 100 \tag{18}$$

where

η_{e1} is the energy efficiency (%);

W_{d1} is the discharge electric energy in 7.9.3 e) (Wh);

W_{c1} is the charge electric energy in 7.9.3 e) (Wh).

7.9.4 Energy efficiency calculation for cells of HEV application

This test is applicable to cells used in HEVs, and intended to determine the energy efficiency of a cell under representative usage conditions of HEV application.

a) Calculation of the charge electric energy and discharge electric energy

Calculate the charge and discharge electric energy from the results of the test specified in 7.5 using Equation (19) and Equation (20). Round off the resulting values to three significant figures.

Read current values and voltage values at regular intervals from the current and voltage data collected during the charge and discharge cycles, which correspond to the charge and discharge patterns of duration $10 I_t$ × 10 s. Use the standard measurement interval of 1 s. When the battery voltage after 10 s exceeds the discharge lower limit voltage or the charge upper limit voltage, perform the test using the current value in the lower stage of Table 1, and report the current value that was actually observed.

$$W_{c2} = \frac{I_{c1}U_{c1} + I_{c2}U_{c2} + \cdots + I_{cn}U_{cn}}{3\,600} \tag{19}$$

where

W_{c2} is the charge electric energy (Wh);

I_{cn} is the charge current value at point n of measured intervals (A);

U_{cn} is the charge voltage value at point n of measured intervals (V).

$$W_{d2} = \frac{I_{d1}U_{d1} + I_{d2}U_{d2} + \cdots + I_{dn}U_{dn}}{3\,600} \tag{20}$$

where

W_{d2} is the discharge electric energy (Wh);

I_{dn} is the discharge current value at point n of measured intervals (A);

U_{dn} is the discharge voltage value at point n of measured intervals (V).

b) Calculation of energy efficiency

Determine the energy efficiency using Equation (21).

$$\eta_{e2} = \frac{W_{d2}}{W_{c2}} \times 100 \tag{21}$$

where

η_{e2} is the energy efficiency (%);

W_{d2} is the discharge electric energy (Wh);

W_{c2} is the charge electric energy (Wh).

Annex A
(informative)

Selective test conditions

Annex A provides additional and selective conditions for the capacity test specified in 7.3, the power tests in 7.5, the cycle life test in 7.8, and the energy efficiency test in 7.9.3.

The test conditions "r" in Table A.1, Table A.2, Table A.3 and Table A.4 are specified in this document. In addition, the test conditions "a" may be selected based on the agreement between the cell manufacturer and the customer.

Table A.1 – Capacity test conditions

Application	Discharge current	Cell temperature			
		−20 °C	0 °C	25 °C	45 °C
BEV	0,2 I_t	a	a	a	a
	1/3 I_t	a	r	r	r
	1 I_t	a	a	a	a
	5 I_t	a	a	a	a
HEV	0,2 I_t	a	a	a	a
	1/3 I_t	a	a	a	a
	1 I_t	a	r	r	r
	10 I_t	a	a	a	a
	I_{dmax}	a	a	a	a

If the data deviation is larger than that of 1 I_t and 1/3 I_t, it shall be indicated.

Table A.2 – Power test conditions

Application	SOC	Cell temperature			
		−20 °C	0 °C	25 °C	40 °C
BEV	20 %	a	a	r	a
	50 %	r	r	r	r
	80 %	a	a	r	a
HEV	20 %	a	a	r	a
	50 %	r	r	r	r
	80 %	a	a	r	a

Table A.3 – Cycle life test conditions

Application	Ambient and cell temperature	
	25 °C	45 °C
BEV	a	r
HEV	a	r

Table A.4 – Conditions for energy efficiency test for BEV application

SOC	Charge current	Test condition
80 %	2 I_t	r
Manufacturer's recommended SOC	Manufacturer's recommended current	a

Annex B
(informative)

Cycle life test sequence

Annex B provides the test sequences of cycle life tests specified in 7.8. The test sequence and concept of BEV cycle are shown in Figure B.1 and Figure B.2. The test sequence of HEV cycle test is shown in Table B.1.

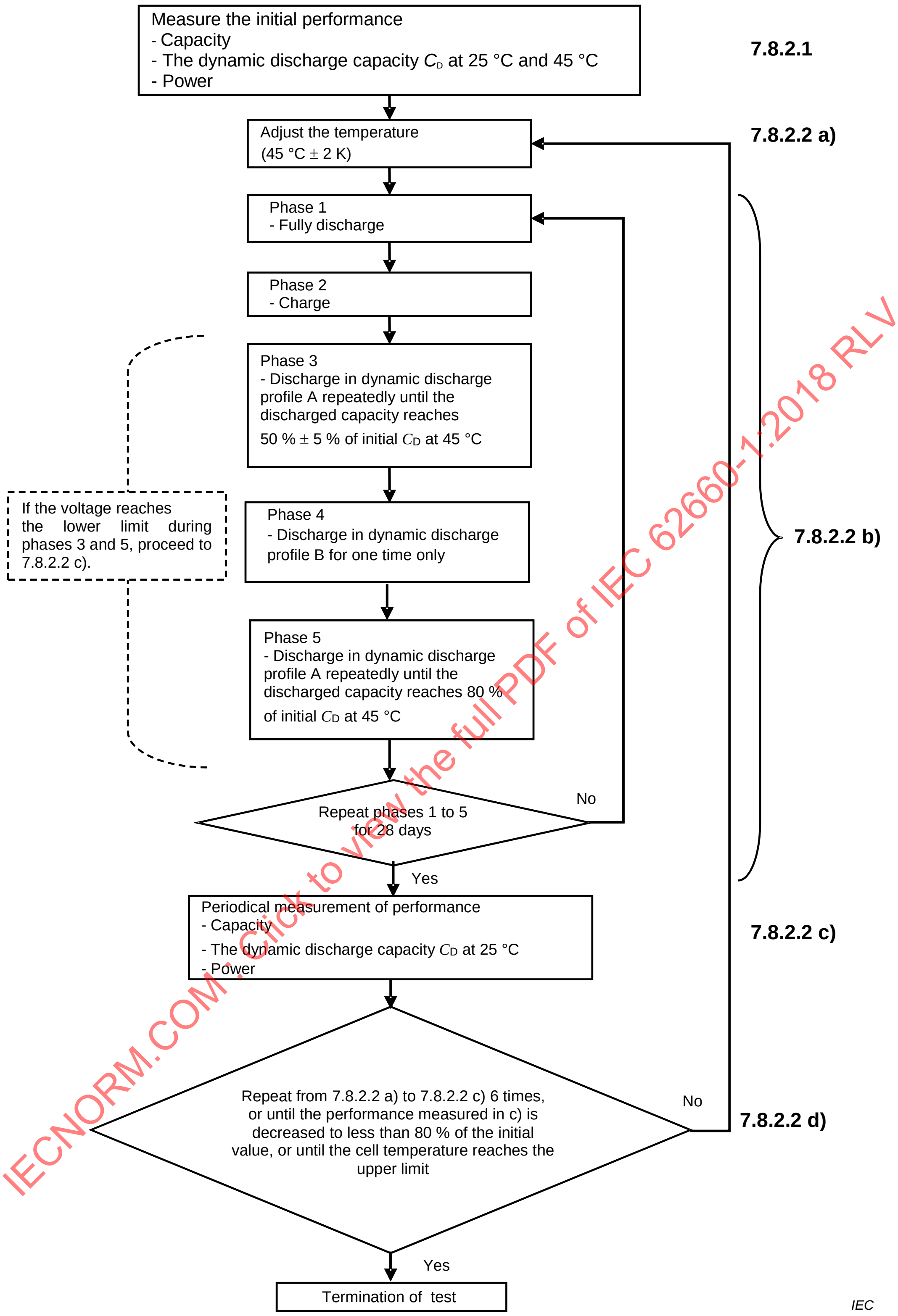

Figure B.1 – Test sequence of BEV cycle test

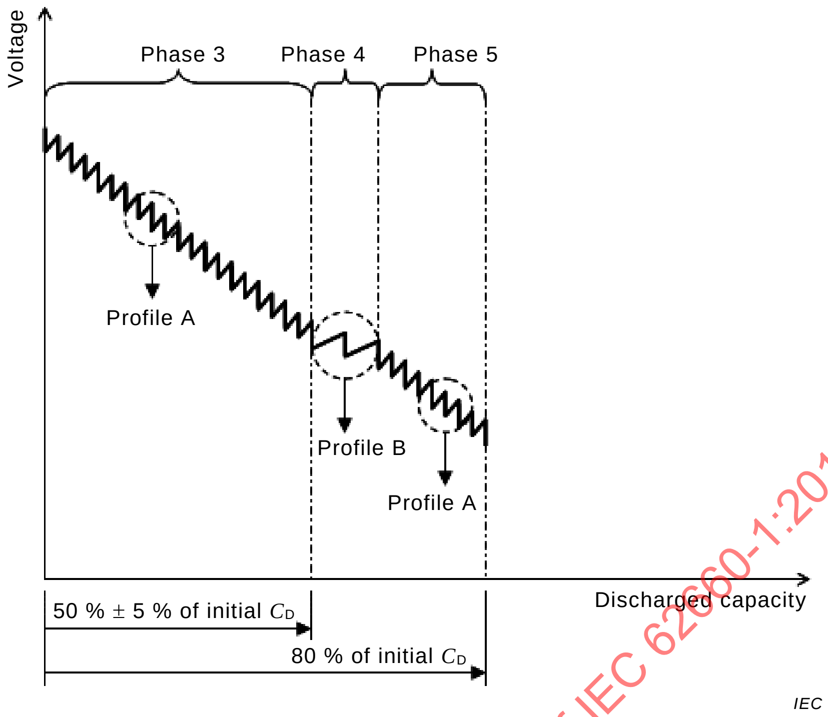

Figure B.2 – Concept of BEV cycle test

Table B.1 – Test sequence of HEV cycle test

		Test procedure	Temperature
7.8.3.1		Measure the initial performance – Capacity – Power	Room temperature
7.8.3.2 a)		Set the switching voltage from discharge-rich profile to charge-rich profile	45 °C
7.8.3.2 b)		Set the switching voltage from charge-rich profile to discharge-rich profile	
7.8.3.3 a)		Adjust the temperature to 45 °C	45 °C
7.8.3.3 b)		Adjust the SOC to 80 %	
7.8.3.3 c)	Phase 1	Repeat the cycle in discharge-rich profile until the switching voltage set in 7.8.3.2 a)	
	Phase 2	Repeat the cycle in charge-rich profile until the switching voltage set in 7.8.3.2 b)	
	Phase 3	Repeat phase 1 and phase 2 for 22 h	
	Phase 4	Rest for 2 h	
		Repeat the procedure from phase 1 to phase 4	
7.8.3.3 d)		Periodical measurement of performance – Capacity (every 14 days) – Power (every 7 days)	Room temperature
7.8.3.3 e)		Terminate the test when either of the following conditions is satisfied. If not satisfied, go back to 7.8.3.3 a) – Repeat 7.8.3.3 c) for 6 months – Either of the performance parameters measured in 7.8.3.3 d) is decreased to less than 80 % of the initial value	-

Annex C
(informative)

Current-voltage characteristic test

C.1 General

Annex C describes the test method to determine the current-voltage characteristics of a cell, when the maximum current values for charge and discharge are not available for the power test in 7.5.

C.2 Test method

The test shall be conducted under each combination of SOC and cell temperature at the test commencement as specified in Table 2, according to the procedure specified by the cell manufacturer.

The test shall be performed according to the scheme shown in Figure C.1.

Charge and discharge the cell at the constant test currents in Table C.1, and measure the voltage at the end of the 10 s pulse of each test current. The range of the charge and discharge current shall be specified by the cell manufacturer, and the standard measurement interval shall be 1 s. If the voltage after 10 s exceeds the discharge lower limit voltage or charge upper limit voltage, the measurement data shall be omitted.

The charge/discharge limits at low temperature specified by the cell manufacturer should be taken into account.

Table C.1 – Charge and discharge current for the current-voltage characteristic test

Application	Charge and discharge current A			
BEV	1/3 I_t	1 I_t	2 I_t	5 I_t
HEV	1/3 I_t	1 I_t	5 I_t	10 I_t

10-min rest time shall be provided between charge and discharge pulses as well as between discharge and charge pulses. However, if the cell temperature after 10 min is not within 2 K of test temperature, it shall be cooled further. Alternatively, the rest time duration shall be extended and it shall be inspected whether the cell temperature then settles within 2 K. The next discharging or charging procedure is then performed.

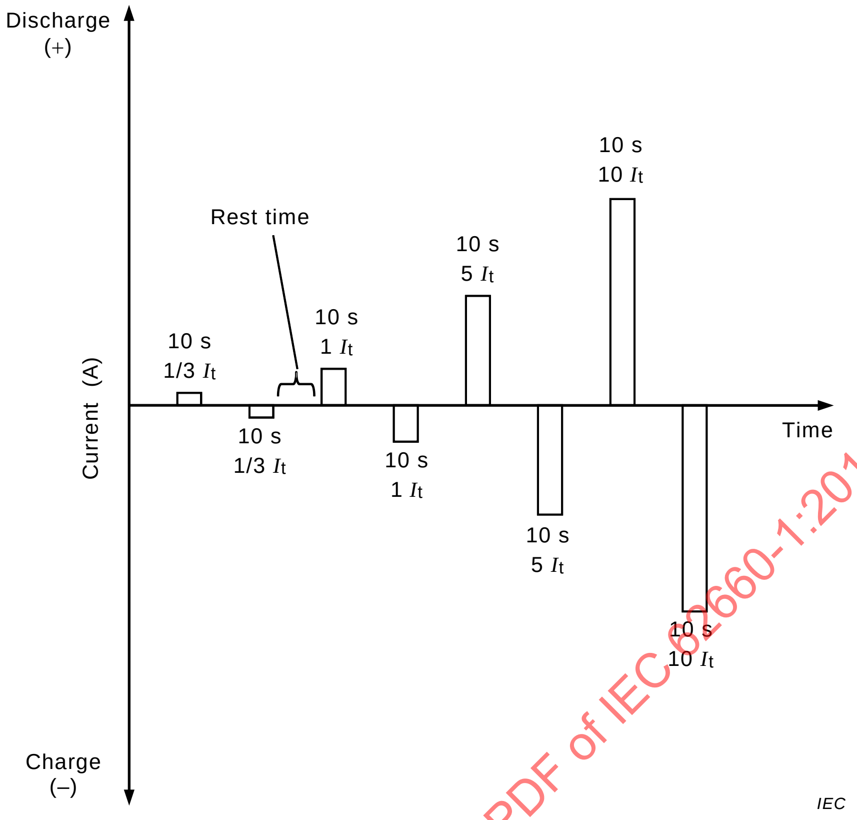

Figure C.1a – Test order of the current-voltage characteristic test for HEV application

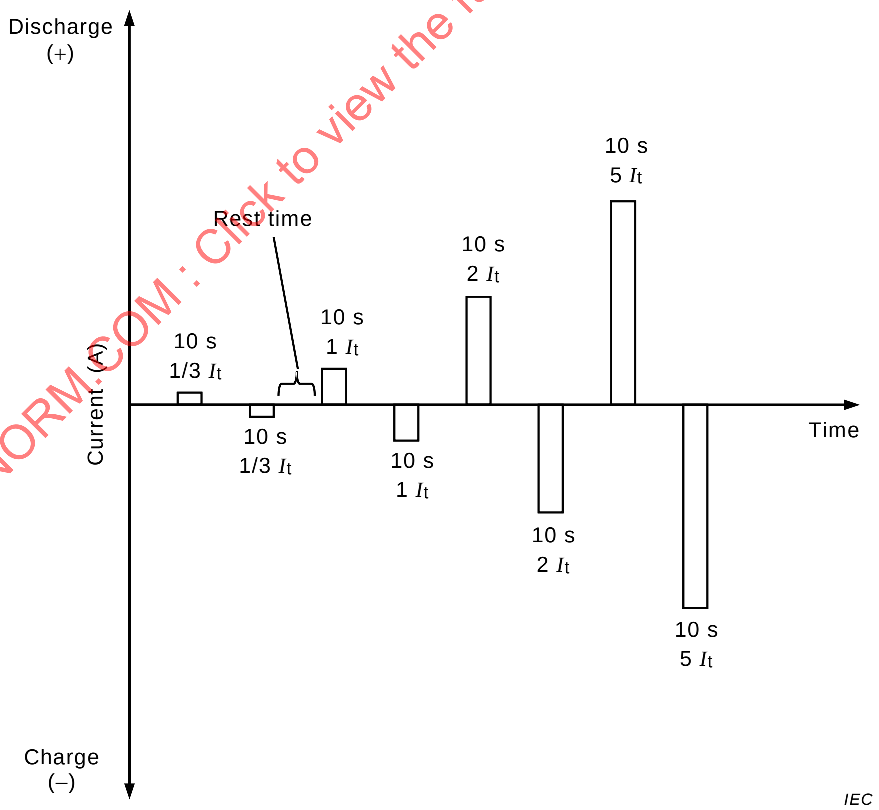

Figure C.1b – Test order of the current-voltage characteristic test for BEV application

Figure C.1 – Test order of the current-voltage characteristic test

Using the measured values of current and voltage, the current-voltage characteristic line shall be obtained by straight-line approximation, and the maximum current for charge and discharge (I_{dmax}, I_{cmax}) and power shall be calculated. The slope of this line shows the internal resistance of the cell.

Bibliography

[1] ISO 12405-4, *Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems – Part 4: Performance testing*

[2] IEC 62660-2, *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing*

[3] IEC 62660-3, *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 3: Safety requirements*

[4] IEC 61434:1996, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Guide to the designation of current in alkaline secondary cell and battery standards*

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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ÉLÉMENTS D’ACCUMULATEURS LITHIUM-ION POUR LA PROPULSION DES VÉHICULES ROUTIERS ÉLECTRIQUES –

Partie 1: Essais de performance

AVANT-PROPOS

1) La Commission Électrotechnique Internationale (IEC) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de l’IEC). L’IEC a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. À cet effet, l’IEC – entre autres activités – publie des Normes internationales, des Spécifications techniques, des Rapports techniques, des Spécifications accessibles au public (PAS) et des Guides (ci-après dénommés "Publication(s) de l’IEC"). Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec l’IEC, participent également aux travaux. L’IEC collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.

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8) L'attention est attirée sur les références normatives citées dans cette publication. L'utilisation de publications référencées est obligatoire pour une application correcte de la présente publication.

9) L’attention est attirée sur le fait que certains des éléments de la présente Publication de l’IEC peuvent faire l’objet de droits de brevet. L’IEC ne saurait être tenue pour responsable de ne pas avoir identifié de tels droits de brevets et de ne pas avoir signalé leur existence.

La Norme internationale IEC 62660-1 a été établie par le comité d’études 21 de l’IEC: Accumulateurs.

Cette deuxième édition annule et remplace la première édition parue en 2010. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) L’objet de chaque essai a été ajouté.

b) L’essai de puissance a été révisé pour clarification, et une partie informative de l'essai des caractéristiques courant-tension a été transférée à la nouvelle Annexe C.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
21/975/FDIS	21/985/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 62660, publiées sous le titre général *Éléments d'accumulateurs lithium-ion pour la propulsion des véhicules routiers électriques*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

La commercialisation des véhicules routiers électriques, comprenant les véhicules électriques à batterie, les véhicules électriques hybrides et les véhicules électriques hybrides rechargeables, a été accélérée sur le marché international, répondant ainsi aux préoccupations mondiales concernant la réduction du CO_2 et la sécurité en matière d'énergie. Par voie de conséquence, cela a conduit à une demande rapidement croissante de batteries de traction de forte puissance et de grande densité énergétique. Il est estimé que les batteries lithium-ion sont les accumulateurs les plus prometteurs pour la propulsion des véhicules électriques. Du fait de la diffusion rapide des véhicules électriques hybrides et de l'émergence des véhicules électriques à batterie et hybrides rechargeables, une méthode normalisée d'essai relative aux exigences de performance des batteries lithium-ion est indispensable pour fixer un niveau de performance de base et obtenir des données essentielles pour la conception des systèmes des véhicules et des packs de batteries.

Le présent document spécifie les essais de performance des éléments lithium-ion destinés à la traction automobile qui diffèrent fondamentalement des autres éléments y compris ceux destinés aux applications portatives et fixes spécifiées par d'autres normes IEC. Dans le cas d'une application automobile, il est important de tenir compte de la spécificité d'usage, c'est-à-dire la diversité de conception des packs et des systèmes de batteries pour automobile, ainsi que de la diversité des exigences spécifiques relatives aux éléments et aux batteries correspondant à chacune de ces conceptions. Basé sur ces faits, le but du présent document est de fournir une méthodologie fondamentale d'essai ayant une polyvalence générale, remplissant une fonction d'essais préliminaires communs pour les éléments lithium-ion destinés à être utilisés dans divers systèmes de batteries.

Le présent document est associé à l'ISO 12405-4 [1][1].

L'IEC 62660-2 [2] spécifie les essais de fiabilité et de traitement abusif des éléments lithium-ion pour application aux véhicules électriques.

L'IEC 62660-3 [3] spécifie les exigences de sécurité des éléments lithium-ion pour application aux véhicules électriques.

1 Les chiffres entre crochets se réfèrent à la Bibliographie.

ÉLÉMENTS D'ACCUMULATEURS LITHIUM-ION POUR LA PROPULSION DES VÉHICULES ROUTIERS ÉLECTRIQUES –

Partie 1: Essais de performance

1 Domaine d'application

La présente partie de l'IEC 62660 spécifie les essais de performance et de durée de vie des accumulateurs lithium-ion utilisés pour la propulsion des véhicules électriques, incluant les véhicules électriques à batterie (BEV) et les véhicules électriques hybrides (HEV).

NOTE 1 Les éléments d'accumulateurs lithium-ion pour la propulsion des véhicules électriques hybrides rechargeables (PHEV) peuvent être soumis à l'essai avec la procédure pour application BEV ou pour application HEV, selon la conception des systèmes de batteries, sur la base de l'accord entre le fabricant de l'élément et le client.

Le présent document spécifie les procédures d'essai afin d'obtenir les caractéristiques essentielles des éléments lithium-ion destinés aux applications de propulsion de véhicules; ces caractéristiques concernent la capacité, la densité de puissance, la densité d'énergie, la durée de stockage et la durée de vie.

Le présent document spécifie les procédures d'essai et les conditions normalisées pour effectuer les essais des caractéristiques de performance fondamentales des éléments lithium-ion destinés aux applications de propulsion de véhicules; ces caractéristiques sont indispensables pour fixer un niveau de performance de base et obtenir des données essentielles pour différentes conceptions de systèmes de batteries et de packs de batteries.

NOTE 2 En plus des conditions spécifiées dans le présent document, des conditions d'essai spécifiques, basées sur un accord entre le fabricant de l'élément et le client, peuvent être choisies. Des conditions d'essai sélectives sont décrites à l'Annexe A.

NOTE 3 Les essais de performance des éléments lithium-ion connectés électriquement peuvent être effectués en faisant référence au présent document.

NOTE 4 La spécification d'essai pour les packs et systèmes de batteries est définie dans l'ISO 12405-4 [1].

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

ISO/TR 8713, *Véhicules routiers électriques – Vocabulaire*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'ISO/TR 8713, ainsi que les suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
véhicule électrique à batterie
BEV
véhicule électrique comportant seulement une batterie d’accumulateurs de traction comme source d'énergie pour sa propulsion

Note 1 à l'article: L’abréviation "BEV" est dérivée du terme anglais développé correspondant "battery electric vehicle".

3.2
véhicule électrique hybride
HEV
véhicule comportant à la fois un système de stockage d'énergie électrique rechargeable et une source d'énergie à carburant pour sa propulsion

Note 1 à l'article: L’abréviation "HEV" est dérivée du terme anglais développé correspondant "hybrid electric vehicle".

3.3
capacité assignée
C_n
valeur de la capacité d’un élément en ampères-heures (Ah) déterminée dans des conditions spécifiées et déclarée par le fabricant de l’élément

Note 1 à l'article: n dans C_n est le temps de base en heures (h). Dans le présent document, n = 3 pour l’application BEV et n = 1 pour l’application HEV, sauf spécification contraire.

3.4
I_t
courant d’essai de référence en ampères (A), exprimé comme

$$I_t = C_n / 1$$

Note 1 à l’article: 1 a une dimension temporelle exprimée en heures (h).

Note 2 à l'article: Voir l’Article 2 de l’IEC 61434:1996 [4].

3.5
température ambiante
température de 25 °C ± 2 K

3.6
accumulateur lithium-ion
élément d’accumulateur
accumulateur unitaire dont l'énergie électrique provient des réactions d'insertion et d'extraction d'ions lithium entre l'anode et la cathode

Note 1 à l'article: L’accumulateur lithium-ion est un dispositif unitaire manufacturé élémentaire fournissant une source d'énergie électrique par conversion directe de l'énergie chimique. Il est constitué d'électrodes, de séparateurs, d'électrolyte, du conteneur et des bornes; il est conçu pour être chargé électriquement.

3.7
état de charge
SOC
capacité d'un élément, exprimée en pourcentage de la capacité assignée

Note 1 à l'article: L’abréviation "SOC" est dérivée du terme anglais développé correspondant "state of charge".

3.8
conservation de charge
aptitude d’un élément à conserver sa capacité en circuit ouvert dans des conditions spécifiées de stockage

4 Conditions d’essai

4.1 Généralités

Les caractéristiques des instruments de mesure utilisés doivent être données dans tous les rapports de résultats.

L’essai et les mesures doivent être effectués avec soin pour éviter tout court-circuit.

NOTE L’essai et les mesures peuvent être effectués dans des conditions de fixation recommandées par le fabricant de l’élément.

4.2 Instruments de mesure

4.2.1 Amplitude des dispositifs de mesure

Les appareils utilisés doivent permettre de mesurer les valeurs de tension, de courant et de température. L’amplitude et les méthodes de mesure de ces instruments doivent être choisies de façon à garantir la précision spécifiée pour chaque essai.

Pour des instruments analogiques, cela implique que les lectures doivent être effectuées sur le dernier tiers de l’échelle graduée.

Tout autre instrument de mesure peut être utilisé dans la mesure où il donne une précision équivalente.

4.2.2 Mesure de la tension

La résistance des voltmètres utilisés doit être d’au moins 1 MΩ/V.

4.2.3 Mesure du courant

L'ensemble complet ampèremètre, shunt et fils doit être d’une classe de précision supérieure ou égale à 0,5.

4.2.4 Mesure de la température

La température de l’élément doit être mesurée à l’aide d’un dispositif de mesure de la température de surface permettant une définition d’échelle et une précision d’étalonnage équivalentes à celles spécifiées en 4.2.1. La température doit être mesurée à l’endroit qui reflète le mieux la température de l'élément. La température peut être mesurée à d’autres endroits appropriés, si nécessaire.

La Figure 1 donne des exemples de mesure de la température. Les instructions de mesure de la température spécifiées par le fabricant de l’élément doivent être respectées.

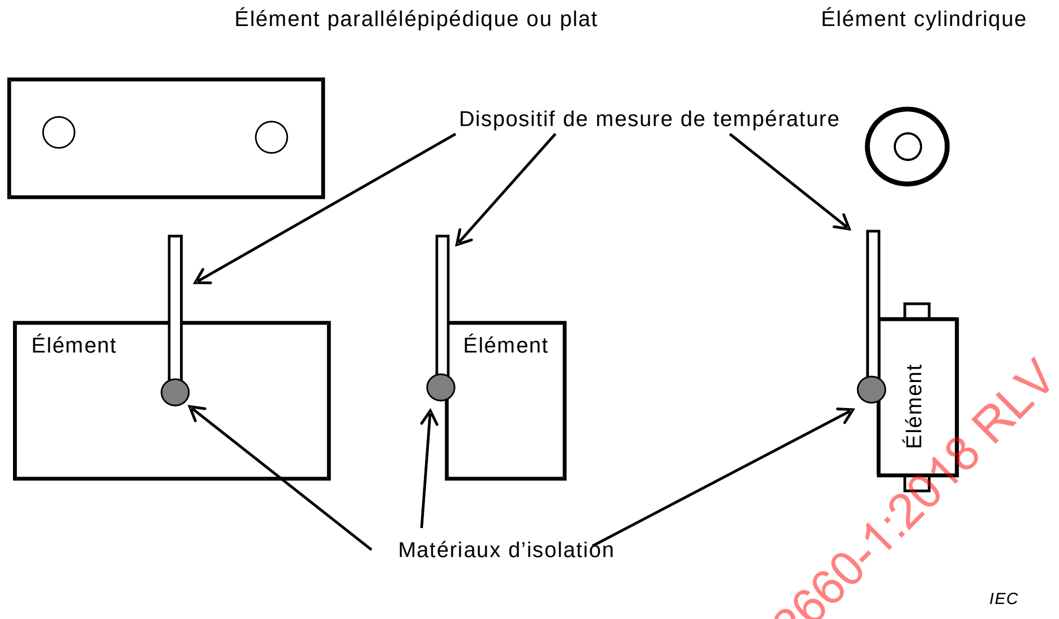

Figure 1 – Exemple de mesure de la température d'un élément

4.2.5 Autres mesures

D'autres valeurs peuvent être mesurées au moyen d'un appareil de mesure, à condition qu'il satisfasse à 4.3.

4.3 Tolérance

La précision globale des valeurs contrôlées ou mesurées, relatives aux valeurs spécifiées ou réelles, doit être comprise dans les tolérances suivantes:

a) ± 0,1 % pour la tension;

b) ± 1 % pour le courant;

c) ± 2 K pour la température;

d) ± 0,1 % pour le temps;

e) ± 0,1 % pour la masse;

f) ± 0,1 % pour les dimensions.

Ces tolérances comprennent la précision combinée des instruments de mesure, de la technique de mesure utilisée, et de toutes les autres sources d'erreur de la procédure d'essai.

4.4 Stabilisation thermique

Pour stabiliser la température de l'élément, celui-ci doit être trempé à une température ambiante spécifiée pendant au moins 12 h. Cette durée peut être réduite si la stabilisation thermique est atteinte. La stabilisation thermique est considérée comme étant atteinte si, dans un intervalle de temps de 1 h, la variation de température de l'élément est inférieure à 1 K.

5 Mesure des dimensions

La dimension maximale de largeur totale, d'épaisseur totale ou de diamètre, et de hauteur totale d'un élément doit être mesurée à la température ambiante avec trois chiffres significatifs, selon les tolérances de 4.3.

Des exemples de dimensions maximales sont donnés aux Figures 2a à 2f.

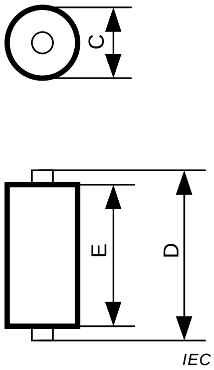

Figure 2a – Élément cylindrique (1)

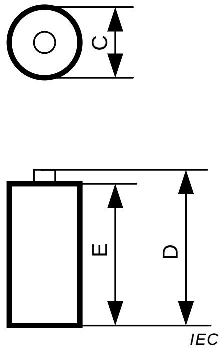

Figure 2 b – Élément cylindrique (2)

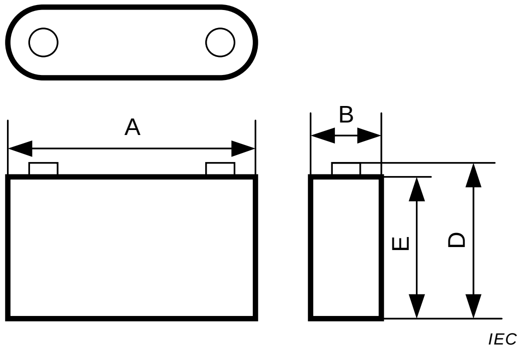

Figure 2c – Élément parallélépipédique (1)

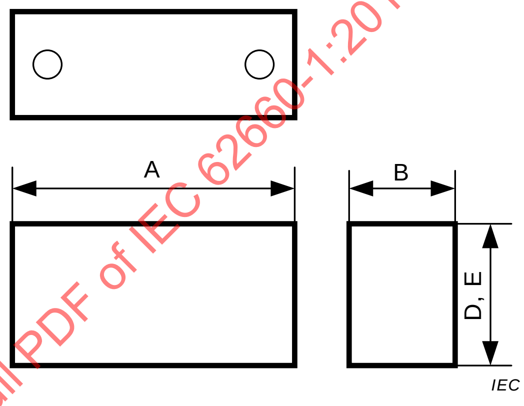

Figure 2d – Élément parallélépipédique (2)

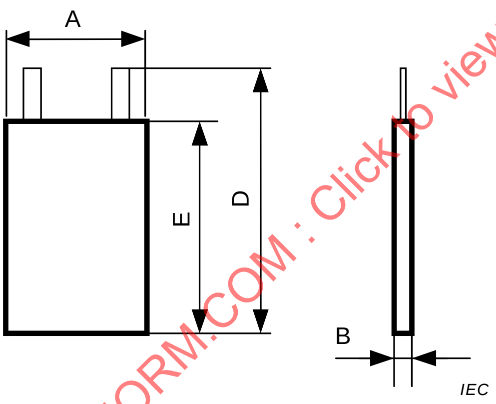

Figure 2e – Élément parallélépipédique en pochette laminée (1)

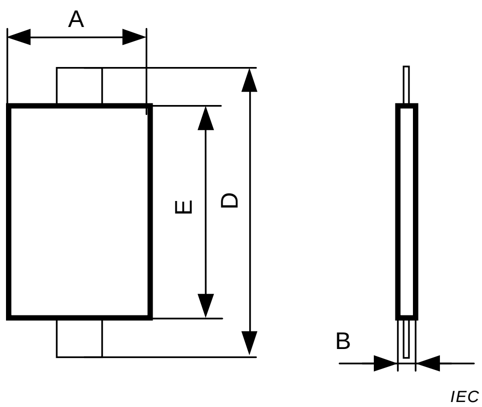

Figure 2f – Élément parallélépipédique en pochette laminée (2)

Légende

A largeur totale

B épaisseur totale

C diamètre

D hauteur totale (bornes comprises)

E hauteur totale (bornes non comprises)

Figure 2 – Exemples de dimensions maximales de l'élément

NOTE Les éléments parallélépipédiques sont fournis avec soit un étui métallique rigide soit une pochette souple laminée. L'élément parallélépipédique en pochette laminée est habituellement appelé "élément en pochette".

Le volume d'un élément parallélépipédique est donné par le produit de sa hauteur totale (bornes non comprises), de sa largeur totale et de son épaisseur totale, et celui d'un élément cylindrique est donné par le produit de la section transversale cylindrique et de sa hauteur totale (bornes non comprises).

6 Mesure de la masse

La masse d'un élément est mesurée à la température ambiante avec trois chiffres significatifs, selon les tolérances de 4.3.

7 Mesures électriques

7.1 Généralités

Durant chaque essai, la tension, le courant et la température doivent être enregistrés.

Avant chaque essai, la température de l'élément doit être stabilisée à la température ambiante selon 4.4, sauf spécification contraire.

La température ambiante doit être la température de la pièce, sauf spécification contraire.

7.2 Conditions générales de charge

Sauf indication contraire dans le présent document, avant l'essai de mesures électriques, l'élément doit être chargé comme indiqué ci-après.

Avant la charge, l'élément doit être déchargé à la température ambiante à un courant constant donné dans le Tableau 1 jusqu'à une tension finale spécifiée par le fabricant de l'élément. Puis l'élément doit être chargé à la température ambiante conformément à la méthode de charge préconisée par le fabricant de l'élément, à la température ambiante.

7.3 Capacité

La capacité d'un élément doit être mesurée conformément aux étapes suivantes.

Étape 1 – L'élément doit être chargé conformément à 7.2.

Après la recharge, la température de l'élément doit être stabilisée conformément à 4.4.

Étape 2 – L'élément doit être déchargé à la température spécifiée, à un courant constant I_t (A), jusqu'à la tension finale donnée par le fabricant de l'élément. Les courants de décharge et les températures de l'élément indiqués dans le Tableau 1 doivent être utilisés.

En complément des conditions du Tableau 1, des conditions d'essai spécifiques peuvent être sélectionnées sur la base d'un accord entre le fabricant de l'élément et le client. Des conditions d'essai sélectives sont présentées dans le Tableau A.1.

Tableau 1 – Conditions de décharge

Température de l'élément °C	Courant de décharge A	
	Application BEV	Application HEV
0		
25	1/3 I_t	1 I_t
45		

Étape 3 – Mesurer la durée de décharge jusqu'à atteindre la tension finale spécifiée. Calculer la capacité de l'élément, exprimée en Ah, avec trois chiffres significatifs, en multipliant le courant de décharge (A) par la durée de décharge (h).

7.4 Ajustement de l'état de charge (SOC)

Les éléments d'essai doivent être chargés comme indiqué ci-dessous, sauf spécification contraire. L'ajustement de l'état de charge (SOC) est la procédure à suivre pour préparer les éléments aux différents états de charge (SOC) destinés aux essais du présent document.

Étape 1 – L'élément doit être chargé conformément à 7.2.

Étape 2 – L'élément doit être laissé au repos, à la température ambiante, conformément à 4.4.

Étape 3 – L'élément doit être déchargé à un courant constant conformément au Tableau 1, c'est-à-dire au $(100 - n)/100 \times 3$ h pour une application BEV et $(100 - n)/100 \times 1$ h pour une application HEV, où n est le SOC (%) à ajuster à chaque essai.

7.5 Puissance

7.5.1 Généralités

Cet essai a pour objet de déterminer les caractéristiques de puissance d'un élément dans les conditions d'utilisation représentatives des applications BEV et HEV.

En se fondant sur l'essai des caractéristiques courant-tension en 7.5.2, la densité de puissance et la densité de puissance régénérative d'un élément doivent être calculées conformément à 7.5.3 et 7.5.4, respectivement.

La densité de puissance et la densité de puissance régénérative doivent être calculées et consignées pour chaque combinaison de SOC et de température en 7.5.2.

7.5.2 Méthode d'essai

L'essai doit être effectué conformément à la procédure suivante.

a) Mesure de la masse

La masse de l'élément doit être mesurée comme indiqué à l'Article 6.

b) Mesure des dimensions

Les dimensions de l'élément doivent être mesurées comme indiqué à l'Article 5.

c) Ajustement du SOC et de la température

L'essai en 7.5.2 d) doit être réalisé pour chaque combinaison de SOC et de température de l'élément au début de l'essai, tels que spécifiés dans le Tableau 2, conformément à la procédure définie par le fabricant de l'élément.

Le SOC doit être ajusté conformément à 7.4.

Tableau 2 – SOC et température pour l'essai de puissance

SOC %	Température de l'élément °C			
20	25			
50	−20	0	25	40
80	25			

NOTE Des conditions d'essai sélectives sont présentées dans le Tableau A.2.

d) Essai des caractéristiques courant-tension

Décharger l'élément pendant 10 s au courant de décharge maximal spécifié par le fabricant de l'élément (I_{dmax}), et mesurer la tension à la fin de l'impulsion de 10 s (U_d).

Charger l'élément pendant 10 s au courant de charge maximal spécifié par le fabricant de l'élément (I_{cmax}), et mesurer la tension à la fin de l'impulsion de 10 s (U_c).

Les valeurs de I_{dmax} et I_{cmax} varient en fonction du SOC, de la température d'essai et de l'état de charge ou de décharge.

Il convient de prendre en considération les limites de charge et de décharge du courant et de la tension à basse température spécifiées par le fabricant.

En l'absence de I_{dmax} et I_{cmax} les valeurs peuvent être obtenues à partir de l'essai spécifié à l'Annexe C.

7.5.3 Calcul de la densité de puissance

7.5.3.1 Calcul de la puissance

La puissance doit être calculée conformément à l'Équation (1) et est arrondie à trois chiffres significatifs.

$$P_d = U_d \times I_{dmax} \tag{1}$$

où

P_d est la puissance (W);

U_d est la tension mesurée à la fin de l'impulsion de décharge I_{dmax} de 10 s (V);

I_{dmax} est le courant de décharge maximal spécifié par le fabricant de l'élément (A).

Si P_d est une valeur estimée, cela doit être indiqué.

7.5.3.2 Densité de puissance par unité de masse

La densité de puissance massique doit être calculée à partir de l'Équation (2), et est arrondie à trois chiffres significatifs.

$$\rho_{pd} = \frac{P_d}{m} \tag{2}$$

où

ρ_{pd} est la densité de puissance massique (W/kg);

P_d est la puissance (W);

m est la masse de l'élément (kg).

7.5.3.3 Densité de puissance par unité de volume

La densité de puissance volumique doit être calculée à partir de l'Équation (3), et est arrondie à trois chiffres significatifs.

$$\rho_{pvlm} = \frac{P_d}{V} \tag{3}$$

où

ρ_{pvlm} est la densité de puissance volumique (W/l);

P_d est la puissance (W);

V est le volume de l'élément (l).

7.5.4 Calcul de la densité de puissance régénérative

7.5.4.1 Puissance régénérative

La puissance régénérative doit être calculée conformément à l'Équation (4) et est arrondie à trois chiffres significatifs.

$$P_{\mathrm{c}} = U_{\mathrm{c}} \times I_{\mathrm{cmax}} \tag{4}$$

où

P_{c} est la puissance régénérative (W);

U_{c} est la tension mesurée à la fin de l'impulsion de la charge I_{cmax} de 10 s (V);

I_{cmax} est le courant de charge maximal spécifié par le fabricant de l'élément (A).

Si P_{c} est une valeur estimée, cela doit être indiqué.

7.5.4.2 Densité de puissance régénérative par unité de masse

La densité de puissance régénérative massique doit être calculée à partir de l'Équation (5), et est arrondie à trois chiffres significatifs.

$$\rho_{\mathrm{pc}} = \frac{P_{\mathrm{c}}}{m} \tag{5}$$

où

ρ_{pc} est la densité de puissance régénérative massique (W/kg);

P_{c} est la puissance régénérative (W);

m est la masse de l'élément (kg).

7.5.4.3 Densité de puissance régénérative par unité de volume

La densité de puissance régénérative volumique doit être calculée à partir de l'Équation (6), et est arrondie à trois chiffres significatifs.

$$\rho_{\mathrm{pvlmc}} = \frac{P_{\mathrm{c}}}{V} \tag{6}$$

où

ρ_{pvlmc} est la densité de puissance régénérative volumique (W/l);

P_{c} est la puissance régénérative (W);

V est le volume de l'élément (l).

7.6 Énergie

7.6.1 Généralités

Cet essai a pour objet de déterminer la densité d'énergie qui peut provenir d'un élément dans les conditions d'utilisation représentatives des applications BEV et HEV.

En se fondant sur l'essai spécifié en 7.6.2, la densité d'énergie d'un élément doit être calculée conformément à 7.6.3.

7.6.2 Méthode d'essai

La densité d'énergie massique (Wh/kg) et la densité d'énergie volumique (Wh/l) des éléments sous une décharge de courant de $1/3 I_t$ (A) pour une application BEV et de $1 I_t$ (A) pour une application HEV doivent être déterminées conformément à la procédure suivante.

a) Mesure de la masse

La masse de l'élément doit être mesurée comme indiqué à l'Article 6.

b) Mesures des dimensions

Les dimensions de l'élément doivent être mesurées comme indiqué à l'Article 5.

c) Mesure de la capacité

La capacité de l'élément doit être déterminée à la température ambiante, conformément à 7.3.

d) Calcul de la tension moyenne

La valeur de la tension moyenne pendant la décharge, lors de l'essai de capacité ci-dessus, doit être obtenue en intégrant la tension de décharge dans le temps et en divisant le résultat par la durée de décharge. La tension moyenne est calculée d'une façon simple, en utilisant la méthode suivante: Les tensions de décharge U_1, U_2, ..., U_n sont notées toutes les 5 s à partir du début de la décharge et les tensions atteignant la tension finale en moins de 5 s sont écartées. La tension moyenne U_{avr} est alors calculée de manière simplifiée à l'aide de l'Équation (7) avec trois chiffres significatifs en arrondissant le résultat.

$$U_{avr} = \frac{U_1 + U_2 + \cdots + U_n}{n} \tag{7}$$

7.6.3 Calcul de la densité d'énergie

7.6.3.1 Densité d'énergie par unité de masse

La densité d'énergie massique doit être calculée à l'aide des Équations (8) et (9) avec trois chiffres significatifs en arrondissant le résultat.

$$W_{ed} = C_d U_{avr} \tag{8}$$

où

W_{ed} est l'énergie électrique de l'élément à la température ambiante (Wh) lorsqu'il est déchargé dans des conditions spécifiées;

C_d est la capacité de décharge (Ah) à $1/3 I_t$ (A) pour BEV ou à $1 I_t$ (A) pour HEV;

U_{avr} est la tension moyenne pendant la décharge (V).

$$\rho_{ed} = \frac{W_{ed}}{m} \tag{9}$$

où

ρ_{ed} est la densité d'énergie massique (Wh/kg);

W_{ed} est l'énergie électrique de l'élément à la température ambiante (Wh) lorsqu'il est déchargé dans des conditions spécifiées;

m est la masse de l'élément (kg).