IEC 62281

Edition 4.2 2023-02
CONSOLIDATED VERSION

FINAL VERSION

VERSION FINALE

Safety of primary and secondary lithium cells and batteries during transport

Sécurité des piles et des accumulateurs au lithium pendant le transport

IEC 62281:2019-04+AMD1:2021-02+AMD2:2023-02 CSV(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SAFETY OF PRIMARY AND SECONDARY LITHIUM CELLS AND BATTERIES DURING TRANSPORT

FOREWORD

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This consolidated version of the official IEC Standard and its amendments has been prepared for user convenience.

IEC 62281 edition 4.2 contains the fourth edition (2019-04) [documents 35/1416/FDIS and 35/1422/RVD], its amendment 1 (2021-02) [documents 35/1459/FDIS and 35/1463/RVD] and its amendment 2 (2023-02) [documents 35/1511/FDIS and 35/1513/RVD].

This Final version does not show where the technical content is modified by amendments 1 and 2. A separate Redline version with all changes highlighted is available in this publication.

International Standard IEC 62281 has been prepared jointly by IEC technical committee 35: Primary cells and batteries and subcommittee 21A: Secondary cells and batteries containing alkaline or other non-acid electrolytes, of IEC technical committee 21: Secondary cells and batteries.

This fourth edition constitutes a technical revision.

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

a) button cell definition revised, moved to coin (cell or battery);
b) addition of provisions for batteries forming an integral part of equipment (5.4);
c) all tests for secondary cells and batteries now also contain a requirement for 25 charge and recharge cycles prior to the test;
d) addition of alternative tables for Table 1 and Table 2 in Annex B;
e) addition of "forcible" to the rupture criteria;
f) test report 6.8 merged with test certificate 6.9 and replaced with the items listed in [12];
g) addition of an informative Annex B with important deviations from the UN Manual of Tests and Criteria, Chapter 38.3.

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

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

INTRODUCTION

Primary lithium cells and batteries were first introduced in military applications in the 1970s. At that time, little commercial interest and no industrial standards existed. Consequently, the United Nations (UN) Committee of Experts on the Transport of Dangerous Goods, although usually referring to industrial standards for testing and criteria, introduced a sub-section in the Manual of tests and criteria concerning safety tests relevant to transport of primary lithium cells and batteries. Meanwhile, commercial interest in primary and secondary (rechargeable) lithium cells and batteries has grown and several industrial standards exist. However, the existing IEC standards are manifold, not completely harmonized, and not necessarily relevant to transport. They are not suitable to be used as a source of reference in the UN Model Regulations. Therefore this group safety standard has been prepared to harmonize the tests and requirements relevant to transport.

This document applies to primary and secondary (rechargeable) lithium cells and batteries containing lithium in any chemical form: lithium metal, lithium alloy or lithium-ion. Lithium-metal and lithium alloy primary electrochemical systems use metallic lithium and lithium alloy, respectively, as the negative electrode. Lithium-ion secondary electrochemical systems use intercalation compounds (intercalated lithium exists in an ionic or quasi-atomic form within the lattice of the electrode material) in the positive and in the negative electrodes.

This document also applies to lithium polymer cells and batteries, which are considered either as primary lithium-metal cells and batteries or as secondary lithium-ion cells and batteries, depending on the nature of the material used in the negative electrode.

The history of transporting primary and secondary lithium cells and batteries is worth noting. Since the 1970s, over ten billion primary lithium cells and batteries have been transported, and since the early 1990s, over one billion secondary (rechargeable) lithium cells and batteries utilizing a lithium-ion system have been transported. As the number of primary and secondary lithium cells and batteries to be transported is increasing, it is appropriate to also include in this document the safety testing of packaging used for the transportation of these products.

This document specifically addresses the safety of primary and secondary lithium cells and batteries during transport and also the safety of the packaging used.

The UN Manual of Tests and Criteria [12][1] distinguishes between lithium metal and lithium alloy cells and batteries on the one hand, and lithium ion and lithium polymer cells and batteries on the other hand. While it defines that lithium metal and lithium alloy cells and batteries can be either primary (non-rechargeable) or rechargeable, it always considers lithium ion cells and batteries as rechargeable. However, test methods in the UN Manual of Tests and Criteria are the same for both secondary lithium metal and lithium alloy cells and batteries and lithium ion and lithium polymer cells and batteries. The concept is only needed to distinguish between small and large battery assemblies. Battery assemblies assembled from (primary or secondary) lithium metal and lithium alloy batteries are distinguished by the aggregate lithium content of all anodes (measured in grams), while battery assemblies assembled from lithium ion or lithium polymer batteries are distinguished by their "nominal" energy (measured in Watt-hours).

1 Numbers in square brackets refer to the Bibliography.

INTRODUCTION to Amendment 2

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

a) Changes based on amendments to chapter 38.3 of the UN Manual of Tests and Criteria as published in UN document ST/SG/AC.10/11/Rev.7/Amend.1;

b) Addition of "assembled from batteries that have passed all applicable tests" to 5.3.3, based on chapter 38.3.3 g) of the UN Manual of tests and criteria as published in UN document ST/SG/AC.10/11/Rev.7.

SAFETY OF PRIMARY AND SECONDARY LITHIUM CELLS AND BATTERIES DURING TRANSPORT

1 Scope

This International Standard specifies test methods and requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal. Requirements specified in this document do not apply in those cases where special provisions given in the relevant regulations, listed in 7.3, provide exemptions.

NOTE Different standards may apply for lithium-ion traction battery systems used for electrically propelled road vehicles.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
aggregate lithium content
total lithium content of the cells comprising a battery

3.2
battery
one or more cells electrically connected and fitted in a case, with terminals, markings and protective devices etc., as necessary for use

Note 1 to entry: This definition is different from the definition used in the UN Manual of Tests and Criteria [12]. This document was, however, carefully prepared so that the test set-up for each test is harmonized with the UN Manual.

Note 2 to entry: A cell used in equipment where the equipment is providing the functions of a case, terminals, markings and protective devices etc., as necessary for use in the equipment, is, for the purposes of this document, considered to be a battery.

[SOURCE: IEC 60050-482:2004 [1], 482-01-04, modified – Reference to "electrically connected" has been added.]

3.3
battery assembly
battery comprising two or more batteries

3.4
coin cell or battery
lithium button cell or battery
small round cell or battery where the overall height is less than the diameter, containing non-aqueous electrolyte

Note 1 to entry: The nominal voltage of lithium batteries is typically greater than 2 V.

[SOURCE: IEC 60050-482:2004, 482-02-40, modified – The definition "small round cell or battery" replaces the original "cell with a cylindrical shape", "containing non-aqueous electrolyte" was added, the term "lithium button" was added]

3.5
cell
basic functional unit, consisting of an assembly of electrodes, electrolyte, container, terminals and, usually, separators that is a source of electric energy obtained by direct conversion of chemical energy

[SOURCE: IEC 60050-482:2004, 482-01-01]

3.6
component cell
cell contained in a battery

3.7
cycle
<of a secondary (rechargeable) cell or battery> set of operations that is carried out on a secondary (rechargeable) cell or battery and is repeated regularly in the same sequence

Note 1 to entry: These operations may consist of a sequence of a discharge followed by a charge or a charge followed by a discharge under specified conditions. This sequence may include rest periods.

[SOURCE: IEC 60050-482:2004, 482-05-28, modified – The words "secondary (rechargeable)" have been added.]

3.8
cylindrical cell or battery
round cell or battery in which the overall height is equal to or greater than the diameter

[SOURCE: IEC 60050-482:2004, 482-02-39, modified – The words "round cell or battery" replace the original "cell with a cylindrical shape", the term "cylindrical battery" has been added.]

3.9
depth of discharge
DOD
percentage of rated capacity discharged from a battery

Note 1 to entry: This note applies to the French language only.

3.10
first cycle
initial cycle of a secondary (rechargeable) cell or battery following completion of all manufacturing, formation and quality control processes

3.11
fully charged, adj
state of charge of a secondary (rechargeable) cell or battery corresponding to 0 % depth of discharge

3.12
fully discharged, adj
state of charge of a cell or battery corresponding to 100 % depth of discharge

3.13
large battery
battery with a gross mass of more than 12 kg

3.14
large cell
cell with a gross mass of more than 500 g

3.15
lithium cell
<primary or secondary (rechargeable)> cell containing a non-aqueous electrolyte and a negative electrode of lithium or containing lithium

Note 1 to entry: Depending on the design features chosen, a lithium cell may be primary or secondary (rechargeable).

[SOURCE: IEC 60050-482:2004, 482-01-06, modified – The domain "primary or secondary (rechargeable)" has been added.]

3.16
lithium content
mass of lithium in the negative electrode of a lithium metal or lithium alloy cell or battery in the undischarged or fully charged state

3.17
lithium ion cell or battery
rechargeable non-aqueous cell or battery in which the positive and negative electrodes are both intercalation compounds constructed with no metallic lithium in either electrode

Note 1 to entry: Intercalated lithium exists in an ionic or quasi-atomic form with the lattice of the electrode material.

Note 2 to entry: A lithium polymer cell or battery that uses lithium ion chemistries, as described herein, is considered as a lithium ion cell or battery.

3.18
nominal energy
energy value of a cell or battery determined under specified conditions and declared by the manufacturer

Note 1 to entry: The nominal energy is calculated by multiplying the nominal voltage by rated capacity.

Note 2 to entry: The term "rated energy" could be more appropriate.

3.19
nominal voltage
suitable approximate value of the voltage used to designate or identify a cell, a battery or an electrochemical system

[SOURCE: IEC 60050-482:2004, 482-03-31]

3.20
open-circuit voltage
voltage across the terminals of a cell or battery when no external current is flowing

[SOURCE: IEC 60050-482:2004, 482-03-32, modified – "when no external current is flowing" replaces "when the discharge current is zero".]

3.21
primary cell or battery
cell or battery that is not designed to be electrically recharged

[SOURCE: IEC 60050-482:2004, 482-01-02, modified – Addition of "or battery".]

3.22
prismatic cell or battery
cell or battery having rectangular sides and bases

[SOURCE: IEC 60050-482:2004, 482-02-38, modified – Omission of "having the shape of a parallelepiped".]

3.23
protective devices
devices such as fuses, diodes or other electric or electronic current limiters designed to interrupt the current flow, block the current flow in one direction or limit the current flow in an electrical circuit

3.24
rated capacity
capacity value of a cell or battery determined under specified conditions and declared by the manufacturer

Note 1 to entry: The following IEC standards provide guidance and methodology for determining the rated capacity: IEC 61960-3 [5], IEC 62133-2 [6], IEC 62660-1 [7].

[SOURCE: IEC 60050-482:2004, 482-03-15, modified – Inclusion of "a cell or battery", addition of Note 1 to entry.]

3.25
secondary (rechargeable) cell or battery
cell or battery which is designed to be electrically recharged

[SOURCE: IEC 60050-482:2004, 482-01-03, modified – Addition of "rechargeable" and "or battery".]

3.26
small battery
battery with a gross mass of not more than 12 kg

3.27
small cell
cell with a gross mass of not more than 500 g

3.28
type
<for cells or batteries> particular electrochemical system and physical design of cells or batteries

3.29
undischarged, adj
state of charge of a primary cell or battery corresponding to 0 % depth of discharge

4 Requirements for safety

4.1 General considerations

Lithium cells and batteries are categorized by their chemical composition (electrodes, electrolyte) and internal construction (bobbin, spiral, stacked). They are available in various shapes. It is necessary to consider all relevant safety aspects at the battery design stage, recognizing the fact that they may differ considerably, depending on the specific lithium system, power output and battery configuration.

The following design concepts for safety are common to all lithium cells and batteries:

a) To prevent by design an abnormal temperature rise above the critical value defined by the manufacturer.

b) To control by design temperature increases in the cell or battery e.g. by limiting the current flow or by adequate thermal management.

c) To design lithium cells and batteries so as to relieve excessive internal pressure or to preclude a violent rupture under conditions of transport.

d) To design lithium cells and batteries so as to prevent a short-circuit under normal conditions of transport and intended use.

e) To equip primary lithium batteries containing cells or strings of cells connected in parallel with effective means, as may be necessary, to prevent dangerous reverse current flow (e.g. diodes, fuses, etc.).

4.2 Quality plan

The manufacturer shall implement a documented quality plan (i.e. quality reports, inspection records, management structure) defining the procedures for the inspection of materials, components, cells and batteries during the course of manufacture, to be applied to the total process of producing a specific type of battery. Manufacturers should understand their process capabilities and should institute the necessary process controls as they relate to product safety and reliability.

4.3 Packaging

Lithium cells and batteries shall be packaged so as to prevent an external short-circuit under normal transport conditions.

NOTE Additional requirements for packaging of dangerous goods are given in UN Model Regulations:2017 [13], section 6.1. See also regulations mentioned in 7.3.

5 Type testing, sampling and re-testing

5.1 Type testing

Lithium metal and lithium ion cells or batteries which differ from a tested type by

a) for primary cells and batteries, a change of more than 0,1 g or 20 % by mass, whichever is greater, to the electrodes or to the electrolyte, or

b) for rechargeable cells and batteries, a change in nominal energy (in Wh) of more than 20 % or an increase in nominal voltage of more than 20 %, or

c) a change that would lead to failure of any of the tests,

shall be considered a different type and shall be subject to the required tests.

NOTE The type of change that might be considered to differ from a tested type, such that it might lead to failure of any of the test results, may include, but is not limited to

1) a change in the material of the anode, the cathode, the separator or the electrolyte,

2) a change of protective devices, including hardware and software,
3) a change of safety design in cells or batteries, such as a venting valve,
4) a change in the number of component cells, and
5) a change in connecting mode of component cells, and,
6) for batteries which are to be tested according to test T-4 with a peak acceleration less than 150 g_n, a change in the mass which could adversely impact the result of the T-4 test and lead to a failure.

5.2 Overcharge protection

Secondary batteries not equipped with battery overcharge protection that are designed for use only in a battery assembly, vehicle, or in equipment, which affords such protection, are not subject to the requirements of test T-7.

5.3 Battery assemblies

5.3.1 General

Generally, battery assemblies, including battery packs, battery modules, and other units that may be assembled from batteries, are tested like batteries.

5.3.2 Small battery assemblies

When testing a battery assembly in which the aggregate lithium content of all anodes, when fully charged, is not more than 500 g, or in the case of a lithium ion battery, with a nominal energy of not more than 6 200 Wh, assembled from batteries that have passed all applicable tests, one battery assembly in a fully charged state shall be tested under tests T-3, T-4 and T-5, and, in addition, test T-7 in the case of a secondary battery assembly.

NOTE The term "fully charged" is used in [12] although it applies only to secondary battery assemblies. For primary battery assemblies, the term "undischarged" would be more appropriate.

5.3.3 Large battery assemblies

A battery assembly with an aggregate lithium content of more than 500 g, or in the case of a lithium ion battery, with a nominal energy of more than 6 200 Wh, assembled from batteries that have passed all applicable tests, does not need to be tested if it is of a type that has been verified as preventing:

- overcharge, and
- short circuits; and
- over discharge between the batteries.

For an assembled battery not equipped with overcharge protection that is designed for use only as a component in another battery assembly, in equipment, or in a vehicle, which affords such protection:

– the overcharge protection shall be verified at the battery assembly, equipment or vehicle level, as appropriate, and
– the use of charging systems without overcharge protection shall be prevented through a physical system or process controls.

5.4 Batteries forming an integral part of equipment

Cells or batteries that are an integral part of the equipment they are intended to power, and which are transported only when installed in the equipment, may be tested in accordance with the applicable tests when installed in the equipment.

5.5 Sampling

Each different type shall be tested by taking random samples. The number of samples for testing primary cells and batteries is given in Table 1. The number of samples for testing secondary cells and batteries is given in Table 2. The number of samples for testing packages of primary and secondary cells and batteries is given in Table 3.

Table 1 – Number of primary test cells and batteries for type testing

Tests	Discharge state	Cells or single-cell batteries [a]	Multi-cell batteries
Tests T-1 to T-5	Undischarged	10	4
	Fully discharged	10	4
Test T-6	Undischarged	5	5 component cells
	Fully discharged	5	5 component cells
Test T-8	Fully discharged	10	10 component cells
Total for all tests		**40**	**8 batteries and 20 component cells**

[a] Single-cell batteries containing one tested component cell do not require re-testing unless the change could result in a failure of any of the tests.

See also Clause B.2 in Annex B.

Table 2 – Number of secondary test cells and batteries for type testing

Tests	Cycles and discharge state	Cells	Single-cell batteries [a]		Multi-cell batteries	
			Small	Large	Small	Large
Tests T-1 to T-5	At first cycle, fully charged	5	5	5	4	2
	After 25 cycles, fully charged	5	5	5	4	2
Test T-6	At first cycle, at 50 % DOD	5	5	5	5 component cells	5 component cells
	After 25 cycles, at 50 % DOD	5	5	5	5 component cells	5 component cells
Test T-7	At first cycle, fully charged	N/A [b]	4 [c]	2 [c]	4 [c]	2 [c]
	After 25 cycles, fully charged	N/A [b]	4 [c]	2 [c]	4 [c]	2 [c]
Test T-8	At first cycle, fully discharged	10	10	10	10 component cells [d]	10 component cells [d]
	After 25 cycles, fully discharged	10	10	10	10 component cells [d]	10 component cells [d]
Total for all tests		**40**	**48**	**44**	**16 batteries and 30 component cells**	**8 batteries and 30 component cells**

[a] Single-cell batteries containing one tested component cell do not require re-testing unless the change could result in a failure of any of the tests, except for test T-7 where only batteries are tested.

[b] N/A = not applicable.

[c] See 5.2.

[d] Multi-cell batteries are considered to be protected against overdischarge of their component cells. Otherwise they would have to be tested as well.

See also Clause B.3 in Annex B.

Table 3 – Number of packages with primary or secondary test cells and batteries

Number of samples for test P-1	1 package as supplied for transport

5.6 Re-testing

In the event that a primary or secondary lithium cell or battery type does not meet the test requirements, steps shall be taken to correct the deficiency or deficiencies that caused the failure before such a cell or battery type is re-tested.

6 Test methods and requirements

6.1 General

6.1.1 Cautionary notice

WARNING – These tests call for the use of procedures which may result in injury if adequate precautions are not taken.

The execution of these tests shall only be conducted by appropriately qualified and experienced technicians using adequate protection.

6.1.2 Ambient temperature

Unless otherwise specified, the tests shall be carried out in an ambient temperature of 20 °C ± 5 °C.

6.1.3 Parameter measurement tolerances

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

a) ± 1 % for voltage;

b) ± 1 % for current;

c) ± 2 °C for temperature;

d) ± 0,1 % for time;

e) ± 1 % for dimension;

f) ± 1 % for capacity.

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

6.1.4 Pre-discharge and pre-cycling

Where, prior to testing, it is required to discharge primary test cells or test batteries, they shall be discharged to their respective depth of discharge on a resistive load with which the rated capacity is obtained, or at a constant current specified by the manufacturer.

Where, prior to testing, it is required to cycle secondary (rechargeable) test cells or test batteries, they shall be cycled using the charge and discharge conditions specified by the manufacturer for optimum performance and safety.

6.2 Evaluation of test criteria

6.2.1 Shifting

Shifting is considered to have occurred during a test if one or more test cells or batteries are released from the packaging, do not retain their original orientation, or are affected in such a way that the occurrence of an external short-circuit or crushing cannot be excluded.

6.2.2 Distortion

Distortion is considered to have occurred if a physical dimension changes by more than 10 %.

6.2.3 Short-circuit

A short-circuit is considered to have occurred during a test if the open circuit voltage of the cell or battery directly after the test is less than 90 % of its voltage immediately prior to the test. This requirement is not applicable to test cells and batteries at fully discharged states.

6.2.4 Excessive temperature rise

An excessive temperature rise is considered to have occurred during a test if the external case temperature of the test cell or battery rises above 170 °C.

6.2.5 Leakage

Leakage is considered to have occurred during a test if there is visible escape of electrolyte or other material from the test cell or battery or the loss of material (except battery casing, handling devices or labels) from the test cell or battery such that the mass loss exceeds the limits in Table 4.

In order to quantify mass loss $\Delta m / m$, the following equation is provided:

$$\Delta m / m = \frac{m_1 - m_2}{m_1} \times 100\ \%$$

where

m_1 is the mass before a test;

m_2 is the mass after that test.

Table 4 – Mass loss limits

Mass of cell or battery m	Mass loss limit $\Delta m / m$
$m < 1$ g	0,5 %
1 g $\leq m \leq$ 75 g	0,2 %
$m >$ 75 g	0,1 %

6.2.6 Venting

Venting is considered to have occurred during a test if gas has escaped from a cell or battery through a feature designed for this purpose, in order to relieve excessive internal pressure. This gas may include entrapped materials.

6.2.7 Fire

A fire is considered to have occurred if, during a test, flames are emitted from the test cell or battery.

6.2.8 Rupture

A rupture is considered to have occurred if a cell container or battery case has mechanically failed, resulting in expulsion of gas or spillage of liquids but not forcible ejection of solid materials.

6.2.9 Explosion

An explosion is considered to have occurred if a cell container or battery case opens violently and solid components are forcibly expelled.

6.3 Tests and requirements – Overview

Table 5 contains an overview of the tests and requirements for transport, misuse and packaging tests.

Table 5 – Transport and packaging tests and requirements

Test number		**Designation**	**Requirements**
Transport tests	T-1	Altitude	NL, NV, NC, NR, NE, NF
	T-2	Thermal cycling	NL, NV, NC, NR, NE, NF
	T-3	Vibration	NL, NV, NC, NR, NE, NF
	T-4	Shock	NL, NV, NC, NR, NE, NF
	T-5	External short-circuit	NT, NR, NE, NF
	T-6	Impact/crush	NT, NE, NF
Misuse tests	T-7	Overcharge	NE, NF
	T-8	Forced discharge	NE, NF
Packaging tests	P-1	Drop	NS, ND, NL, NV, NC, NT, NR, NE, NF
Tests T-1 to T-5 shall be conducted in sequence on the same cell or battery.			
Key NC: No short-circuit ND: No distortion NE: No explosion NF: No fire NL: No leakage NR: No rupture NS: No shifting NT: No excessive temperature rise NV: No venting See 6.2 for a detailed description of the test criteria.			

6.4 Transport tests

6.4.1 Test T-1: Altitude

a) Purpose

This test simulates air transport under low pressure conditions.

b) Test procedure

Test cells and batteries shall be stored at a pressure of 11,6 kPa or less for at least 6 h at ambient temperature.

c) Requirements

There shall be no leakage, no venting, no short-circuit, no rupture, no explosion and no fire during this test.

6.4.2 Test T-2: Thermal cycling

a) Purpose

This test assesses seal integrity of cells and batteries and internal electrical connections. The test is conducted using temperature cycling.

b) Test procedure

Test cells and batteries shall be stored for at least 6 h at a test temperature of 72 °C, followed by storage for at least 6 h at a test temperature of −40 °C. The maximum time for transfer to each temperature shall be 30 min. Each test cell and battery shall undergo this procedure 10 times. This is then followed by storage for at least 24 h at ambient temperature.

For large cells and batteries the duration of exposure to the test temperatures shall be at least 12 h instead of 6 h.

The test shall be conducted using the test cells and batteries previously subjected to the altitude test.

c) Requirements

There shall be no leakage, no venting, no short-circuit, no rupture, no explosion and no fire during this test.

6.4.3 Test T-3: Vibration

a) Purpose

This test simulates vibration during transport.

b) Test procedure

Test cells and batteries shall be firmly secured to the platform of the vibration machine without distorting them in such a manner as to faithfully transmit the vibration. Test cells and batteries shall be subjected to sinusoidal vibration according to Table 6 which shows a different upper acceleration amplitude for large batteries than it shows for cells and small batteries. This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions. One of the directions shall be perpendicular to the terminal face.

The test shall be conducted using the test cells and batteries previously subjected to the thermal cycling test.

Table 6 – Vibration profile (sinusoidal)

Frequency range		Amplitudes	Duration of logarithmic sweep cycle (7 Hz – 200 Hz – 7 Hz)	Axis	Number of cycles
From	**To**				
f_1 = 7 Hz	f_2	a_1 = 1 g_n	15 min	X	12
f_2	f_3	s = 0,8 mm		Y	12
f_3	f_4 = 200 Hz	a_2		Z	12
and back to f_1 = 7 Hz				Total	36

NOTE 1 Vibration amplitude is the maximum absolute value of displacement or acceleration. For example, a displacement amplitude of 0,8 mm corresponds to a peak-to-peak displacement of 1,6 mm.

NOTE 2 g_n = 9,806 65 m / s^2.

Key

f_1, f_4 lower and upper frequency

f_2, f_3 cross-over frequencies:

f_2 ≈ 17,62 Hz

f_3 ≈ 49,84 Hz for cells and small batteries

f_3 ≈ 24,92 Hz for large batteries

a_1, a_2 acceleration amplitude:

a_2 = 8 g_n for cells and small batteries

a_2 = 2 g_n for large batteries

s displacement amplitude

c) Requirements

There shall be no leakage, no venting, no short-circuit, no rupture, no explosion and no fire during this test.

6.4.4 Test T-4: Shock

a) Purpose

This test simulates rough handling during transport.

b) Test procedure

Test cells and batteries shall be secured to the testing machine by means of a rigid mount which will support all mounting surfaces of each test cell or battery.

Each test cell or single cell battery shall be subjected to a half-sine shock of peak acceleration of 150 g_n and pulse duration of 6 ms. Alternatively, large cells may be subjected to a half-sine shock of peak acceleration of 50 g_n and pulse duration of 11 ms.

Each multi-cell battery shall be subjected to a half-sine shock of peak acceleration depending on the mass of the battery. The pulse duration shall be 6 ms for small batteries and 11 ms for large batteries. The formulas in Table 7 are provided to calculate the appropriate minimum peak accelerations.

Each test cell or battery shall be subjected to 3 shocks in each direction of three mutually perpendicular mounting positions of the cell or battery for a total of 18 shocks.

Table 7 – Shock parameters

Test sample	Wave form	Minimum peak acceleration	Pulse duration	Number of shocks per half axis
Small cells or single-cell batteries	Half sine	$A_1 = 150\ g_n$	6 ms	3
Large cells or single-cell batteries	Half sine	$A_2 = 50\ g_n$	11 ms	3
Small multi-cell batteries	Half sine	$A_3 = \min\left(\sqrt{\frac{100\,850\ \text{kg}}{m}}\ ;\ 150\right) g_n$	6 ms	3
Large multi-cell batteries	Half sine	$A_4 = \min\left(\sqrt{\frac{30\,000\ \text{kg}}{m}}\ ;\ 50\right) g_n$	11 ms	3

NOTE 1 For explanations, see Annex A.

NOTE 2 g_n = 9,806 65 m / s².

Key

A_1, A_2, A_3, A_4 minimum peak acceleration

m test sample mass

The test shall be conducted using the test cells and batteries previously subjected to the vibration test.

c) Requirements

There shall be no leakage, no venting, no short-circuit, no rupture, no explosion and no fire during this test.

6.4.5 Test T-5: External short-circuit

a) Purpose

This test simulates conditions resulting in an external short-circuit.

b) Test procedure

The test cell or battery shall be heated for a period of time necessary to reach a homogeneous stabilized temperature of 57 °C ± 4 °C, measured on the external case. This period of time depends on the size and design of the cell or battery and should be assessed and documented. If this assessment is not feasible, the exposure time shall be at least 6 h for small cells and small batteries, and 12 hours for large cells and large batteries. Then the cell or battery at 57 °C ± 4 °C shall be subjected to a short circuit[2] condition with a total external resistance of less than 0,1 Ω.

This short circuit condition is continued for at least one hour after the cell or battery external case temperature has returned to 57 °C ± 4 °C, or in the case of large multi-cell batteries, has decreased by half of the maximum temperature increase observed during the test and remains below that value.

The short circuit and cooling down phases shall be conducted at least at ambient temperature.

The test shall be conducted using the test samples previously subjected to the shock test.

c) Requirements

There shall be no excessive temperature rise, no rupture, no explosion and no fire during this test and within the 6 h of observation.

2 In [12] the term "one short circuit" is used in order to indicate that each test sample is subjected to only one short-circuit condition. Where the relevant specification indicates that the internal resistance of the test sample is in the order of 0,1 Ω, a lower total external resistance is advisable.

6.4.6 Test T-6: Impact/crush

a) Purpose

This test simulates mechanical abuse from an impact or crush that may result in an internal short-circuit.

b) Test procedure – Impact

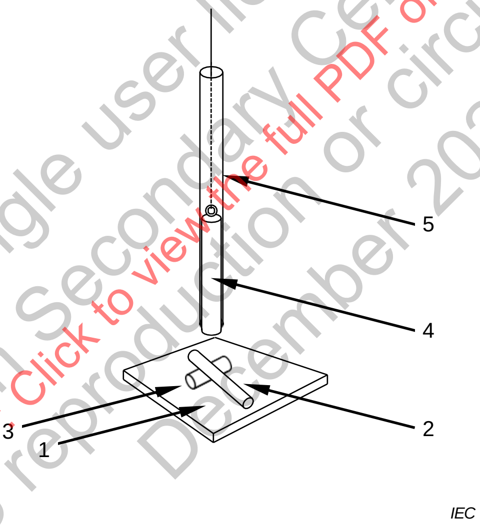
The impact test is applicable to cylindrical cells not less than 18,0 mm in diameter.

NOTE Diameter here refers to the design parameter.

EXAMPLE: The diameter of 18650 cells is 18,0 mm.

The test cell or component cell is placed on a flat smooth surface. A stainless-steel bar (type 316 or equivalent) with a diameter of 15,8 mm ± 0,1 mm and a length of at least 60 mm or of the longest dimension of the cell, whichever is greater, is placed across the centre of the test sample. A mass of 9,1 kg ± 0,1 kg is dropped from a height of 61 cm ± 2,5 cm at the intersection of the bar and the test sample in a controlled manner using a near frictionless, vertical sliding track or channel with minimal drag on the falling mass. The vertical track or channel used to guide the falling mass shall be oriented 90 degrees from the horizontal supporting surface.

The test sample is to be impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the stainless-steel bar lying across the centre of the test sample (see Figure 1).



NOTE Figure 1 shows a flat smooth surface (1) and a stainless-steel bar (2) which is placed across the centre of the test sample (3). A mass (4) is dropped at the intersection in a controlled manner using a vertical sliding channel (5).

Figure 1 – Example of a test set-up for the impact test

Each test cell or component cell shall be subjected to one impact only.

The test sample shall be observed for a further 6 h.

The test shall be conducted using test cells or component cells that have not been previously subjected to other tests.

c) Test procedure – Crush

The crush test is applicable to prismatic, flexible[3], coin/button cells and cylindrical cells less than 18,0 mm in diameter.

[3] The term “flexible cell” is used in this document in place of the term “pouch cell” which was used in Edition 2 (2012) of this document. It is also used in place of the terms “cell with a laminate film case” and “laminate film cell”.

NOTE Here, diameter refers to the design parameter.

EXAMPLE The diameter of 18650 cells is 18,0 mm.

A cell or component cell is to be crushed between two flat surfaces. The crushing is to be gradual with a speed of approximately 1,5 cm/s at the first point of contact. The crushing is to be continued until one of the three conditions below is reached:

1) the applied force reaches 13 kN ± 0,78 kN;

   EXAMPLE The force can be applied by a hydraulic ram with a 32 mm diameter piston until a pressure of 17 MPa is reached on the hydraulic ram.

2) the voltage of the cell drops by at least 100 mV; or

3) the cell is deformed by 50 % or more of its original thickness.

   As soon as one of the above conditions has been obtained, the pressure shall be released.

   A prismatic or flexible cell shall be crushed by applying the force to the widest side. A button/coin cell shall be crushed by applying the force on its flat surfaces. For cylindrical cells, the crush force shall be applied perpendicular to the longitudinal axis.

   Each test cell or component cell is to be subjected to one crush only.

   The test sample shall be observed for a further 6 h.

   The test shall be conducted using test cells or component cells that have not previously been subjected to other tests.

d) Requirements

There shall be no excessive temperature rise, no explosion and no fire during this test and within the 6 h of observation.

6.5 Misuse tests

6.5.1 Test T-7: Overcharge

a) Purpose

This test evaluates the ability of a secondary (rechargeable) battery to withstand an overcharge condition.

b) Test procedure

The charge current shall be twice the manufacturer's recommended maximum continuous charge current. The minimum voltage of the test shall be as follows:

1) when the manufacturer's recommended charge voltage is not more than 18 V, the minimum voltage of the test shall be the lesser of two times the maximum charge voltage of the battery or 22 V;

2) when the manufacturer's recommended charge voltage is more than 18 V, the minimum voltage of the test shall be not less than 1,2 times the maximum charge voltage.

The test shall be conducted at ambient temperature. The charging condition shall be maintained for at least 24 h.

The test may be conducted using undamaged test batteries previously used in tests T-1 to T-5 for purposes of testing on cycled batteries.

c) Requirements

There shall be no explosion and no fire during this test and within 7 days after the test.

6.5.2 Test T-8: Forced discharge

a) Purpose

This test evaluates the ability of a primary or a secondary (rechargeable) cell to withstand a forced discharge condition.

b) Test procedure

Each cell shall be forced discharged at ambient temperature by connecting it in series with a 12 V direct current power supply at an initial current equal to the maximum continuous discharge current specified by the manufacturer.

The specified discharge current is obtained by connecting a resistive load of appropriate size and rating in series with the test cell and the direct current power supply. Each cell shall be forced discharged for a time interval equal to its rated capacity divided by the initial test current.

The test shall be conducted using test cells or component cells that have not previously been subjected to other tests.

c) Requirements

There shall be no explosion and no fire during this test and within 7 days after the test.

6.6 Packaging test – Test P-1: Drop test

a) Purpose

This test assesses the ability of the packaging to prevent damage during rough handling.

NOTE Additional tests for packaging of dangerous goods are given in UN Model Regulations:2017 [13], section 6.1.5. See also the regulations mentioned in 7.3.

b) Test procedure

A package (typically the final outer packaging, not palletized loads) filled with cells or batteries as offered for transport shall be dropped from a height of 1,2 m onto a concrete surface in such a manner that any of its corners first touches the ground.

The test shall be conducted using test cells or batteries that have not been previously subjected to a transport test.

c) Requirements

There shall be no shifting, no distortion, no leakage, no venting, no short-circuit, no excessive temperature rise, no rupture, no explosion and no fire of the test cells or batteries during this test.

6.7 Information to be given in the relevant specification

When this document is referred to in a relevant specification, the following parameters shall be given in so far as they are applicable:

	Clause and/ or subclause
a) (aggregate) lithium content	5.3 6.8 (f)(iii)
b) nominal energy	5.1 5.3
c) Pre-discharge current or resistive load and end-point voltage specified by the manufacturer for primary cells and batteries;	6.1.4
d) Charge and discharge conditions specified by the manufacturer for optimum performance and safety of secondary (rechargeable) cells and batteries;	6.1.4
e) Manufacturer's recommended maximum continuous charge current;	6.5.1
f) Manufacturer's recommended charge voltage;	6.5.1
g) Maximum charge voltage;	6.5.1
h) Maximum continuous discharge current specified by the manufacturer;	6.5.2
i) Rated capacity specified by the manufacturer.	6.5.2

6.8 Test report summary

A test report summary including the following items shall be made available:

a) Name of cell, battery, or product manufacturer, as applicable;

b) Cell, battery, or product manufacturer's contact information to include address, phone number, email address and website for more information;

c) Name of the test laboratory to include address, phone number, email address and website for more information;

d) A unique test report identification number;

e) Date of test report;

f) Description of cell or battery to include at a minimum:

   (i) Lithium ion or lithium metal cell or battery;

   (ii) Mass of cell or battery;

   (iii) Watt-hour rating, or lithium content;

   (iv) Physical description of the cell/battery; and

   (v) Cell or battery model number or, alternatively, if the test summary is established for a product containing a cell or battery, the product model number.

g) List of tests conducted and results (i.e. pass/fail);

h) Reference to assembled battery testing requirements, if applicable (i.e. 5.3.2 and 5.3.3);

i) Reference to the relevant edition of this document; and

j) Name and title of responsible person as an indication of the validity of information provided.

NOTE It is understood that a test report summary may contain data of a range of models, provided they are of the type tested as described in 5.1.

7 Information for safety

7.1 Packaging

The purpose of the packaging is to avoid mechanical damage during transport, handling and stacking. It is particularly important that the packaging prevents crushing of the cells or batteries during rough handling, as well as the development of unintentional electrical short-circuit and corrosion of the terminals. Crushing or external short-circuit can result in leakage, venting, rupture, explosion or fire.

Whenever lithium cells or batteries are transported, it is recommended for safety reasons to use the original packaging or packaging that complies with the requirements listed in 4.3 and 6.6.

7.2 Handling of battery cartons

Battery cartons should be handled with care. Rough handling might result in batteries being short-circuited or damaged. This can cause leakage, rupture, explosion or fire.

7.3 Transport

7.3.1 General

Regulations concerning international transport of lithium batteries are based on the Recommendations on the Transport of Dangerous Goods [12, 13] issued by the United Nations Committee of Experts on the Transport of Dangerous Goods.

Regulations for transport are subject to change. For the transport of lithium batteries, the latest editions of the regulations listed in 7.3.2 to 7.3.5 shall be consulted.

7.3.2 Air transport

Regulations concerning air transport of lithium batteries are specified in the Technical Instructions for the Safe Transport of Dangerous Goods by Air published by the International Civil Aviation Organization (ICAO) and in the Dangerous Goods Regulations published by the International Air Transport Association (IATA) [9].

7.3.3 Sea transport

Regulations concerning sea transport of lithium batteries are specified in the International Maritime Dangerous Goods (IMDG) Code published by the International Maritime Organization (IMO) [11].

7.3.4 Land transport

Regulations concerning road and railroad transport are specified on a national or multilateral basis. While an increasing number of regulators adopt the UN Model Regulations, it is recommended that country-specific transport regulations be consulted before shipping.

7.3.5 Classification

Classification of lithium cells and batteries for transport under the regulations mentioned in 7.3.2 to 7.3.4 is based on the UN Manual of Tests and Criteria, chapter 38.3, basically describing the same tests as this document. Lithium cells and batteries that have not passed all required tests are generally not allowed for transport.

NOTE 1 The UN Model Regulations [13] in 2.9.4.(a) contain requirements regarding retesting of a type after a change of the test methods.

NOTE 2 The UN Model Regulations [13] in 2.9.4.(a) require that multi-cell batteries be of a type proved to meet the test requirements irrespective of whether the component cells of which they are composed are of a tested type.

7.4 Storage

a) Store batteries in well ventilated, dry and cool conditions

   High temperature or high humidity may cause deterioration of the battery performance and/or surface corrosion.

b) Do not stack battery cartons on top of each other exceeding a height specified by the manufacturer

   If too many battery cartons are stacked, batteries in the lowest cartons may be deformed and electrolyte leakage may occur.

c) Avoid storing batteries in direct sun or in places where they get exposed to rain

   When batteries get wet, their insulation resistance may be impaired and self-discharge and corrosion may occur. Heat may cause deterioration.

d) Store batteries in their original packing

   When batteries are unpacked and mixed they may be short-circuited or damaged.

8 Instructions for packaging and handling during transport – Quarantine

Packages that have been crushed, punctured, torn open to reveal contents, or otherwise damaged shall not be transported. Such packages shall be isolated until the shipper has been consulted, has provided instructions and, if appropriate, has arranged to have the product inspected and repacked.

9 Marking

9.1 Marking of primary and secondary (rechargeable) cells and batteries

The marking of primary lithium cells and batteries should comply with IEC 60086-4 [4]. The marking of secondary (rechargeable) lithium cells and batteries should comply with IEC 61960-3 [5].

9.2 Marking of the packaging and shipping documents

Marking of packages and transport documents is regulated. See 7.3.

Annex A
(informative)

Shock test – adjustment of acceleration for large batteries

A.1 General

The adjustment of shock acceleration to the test sample mass is based on proposals made by the UN Informal Working Group on Testing Large Lithium Batteries [14].

Hybrid vehicle traction batteries typically range between 14 kg and 80 kg with full-electric vehicle batteries often exceeding 100 kg mass. Their capacity typically ranges from 300 Wh to 2 500 Wh for hybrid batteries and in excess of 6 200 Wh for full-electric vehicle batteries. Plug-in hybrid electric vehicle (PHEV) batteries occupy any capacity and mass in between.

Constant acceleration conditions are inappropriate for these hybrid or electric vehicle (HEV) battery assemblies as well as other large format batteries, and most importantly, the forces required for HEV battery assemblies during the testing are well beyond any forces that would be encountered during transport.

Therefore, the shock conditions were changed from constant acceleration to constant energy for lithium batteries exceeding a specified mass.

A.2 Shock energy depends on mass, acceleration, and pulse duration

Half-sine shocks are usually specified by a peak acceleration and a duration, for example a half-sine shock with a peak acceleration $A = 50\ g_n$ and a duration of $D = 11$ ms. There is a frequency associated with this duration since it is half of one period of a sine wave with frequency $f = 1 / (2D)$.

$$a(t) = A \sin(2\pi f t) \qquad \text{(A.1)}$$

where

$$f = \frac{1}{2D}.$$

The velocity change during the half sine pulse is very important. Assume zero initial velocity and integrate over the half cycle to get the final velocity, which is the velocity change [3].

$$\Delta V = \frac{A}{\pi f} = \frac{2}{\pi} AD \qquad \text{(A.2)}$$

The energy that acts upon the test sample during such a half-sine shock equals

$$E = ½ m(\Delta V)^2 = 2m(AD)^2/\pi^2 \qquad \text{(A.3)}$$

where

E is the energy acting upon the test sample during a half-sine shock;

m is the mass of the test sample;

V is the velocity change during the half-sine shock pulse;

A is the peak acceleration; and

D is the duration of the half-sine shock pulse.

EXAMPLE If we consider a test sample with a mass m just above 12 kg, then the energy acting upon this sample during a half-sine shock of peak acceleration $A = 50\ g_n$ and duration $D = 11$ ms is $E = 2 \times 12\ \text{kg} \times (50\ g_n \times 11\ \text{ms})^2 / \pi^2 = 70{,}7421$ J with $g_n = 9{,}80665\ \text{m/s}^2$.

In this case, the peak acceleration can also be expressed as $A = \sqrt{\dfrac{E\pi^2}{2mD^2}} = \sqrt{\dfrac{30\,000\ \text{kg}}{m}}\ g_n$.

It may be easier to get a feeling for these figures if the shock energy is expressed in terms of drop height h.

$$E = m \times g_n \times h \qquad \text{(A.4)}$$

Therefore, a test sample with a mass slightly above 12 kg would have to be dropped from a height of approximately 0,6 m in order to generate during 11 ms a shock energy corresponding to a half sine shock of peak acceleration $A = 50\ g_n$.

A.3 The constant acceleration approach

The test method described in Edition 2 (2012) of this document was a constant acceleration approach. A large cell with more than 500 g gross mass and a large battery with more than 12 kg gross mass were both shock tested with a half sine shock of peak acceleration $A = 50\ g_n$ and duration $D = 11$ ms while small ones were tested with a peak acceleration $A = 150\ g_n$ and duration $D = 6$ ms. Figure A.1 shows the peak acceleration A on the left ordinate of the chart and the energy E on its right ordinate over the battery mass. A similar chart would be valid for cells.

NOTE The UN Manual of Tests and Criteria [12] uses a different definition for battery. With this definition, the shock test method for a cell would also apply to a single cell battery. The battery definition is currently under discussion in the UN Informal Working Group on testing large lithium batteries.

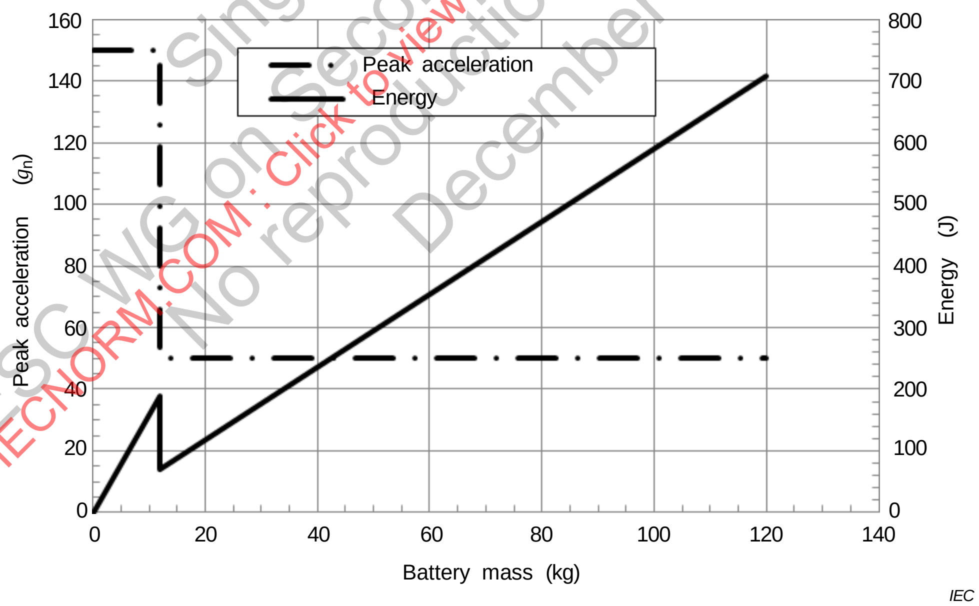


Figure A.1 – Half sine shock for batteries (constant peak acceleration)