ABYC E-13 July 2022

Electrical Division Standard

Electrical Project Technical Committee

The ABYC Standards and Technical Information Reports for Small Craft are the product of a consensus of representatives of government, industry, and public sectors. It is intended solely as a guide to aid manufacturers and the marine community in the design, construction, equipage, and maintenance of small craft.

ABYC reviews each standard at least every five years at which time it may be reaffirmed, revised, or withdrawn. ABYC welcomes any written comments on the standards and technical information reports.

ABYC E-13

LITHIUM ION BATTERIES

Origin and Development

E-13, *Lithium Ion Batteries* was first published in 2020 as the technical information report, TE-13. The document was converted to a standard in this 2022 revision. It is the work of the Electrical Project Technical Committee.

Electrical Project Technical Committee

This list represents the membership at the time the committee was balloted.

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Membership on a committee shall not in and of itself constitute an endorsement of ABYC or any document developed by the committee on which the member serves.

This standard, which is the result of extended and careful consideration of available knowledge and experience on the subject, was developed under procedures accredited as meeting the criteria for American National Standards and is intended to provide minimum performance requirements. The Project Technical Committee that approved the standard was balanced to ensure that individuals from competent and concerned interests have had an opportunity to participate.

ABYC's Project Technical Committee (PTC) meetings are open to the public. All inquiries regarding standards activity, interpretations, or meeting attendance should be directed to the ABYC Technical Department at comments@abycinc.org.

ABYC and its committees do not "approve" or "endorse" any item, construction, or proprietary device.

Request for Interpretations

Upon written request, the Electrical PTC will render an interpretation of any requirement of the standard. The request for interpretation should be clear and unambiguous. Requests should be presented to the PTC in a manner in which they may be answered in a "Yes" or "No" fashion.

The committee reserves the right to reconsider any interpretation when or if additional information that might affect it becomes available to the PTC. Persons aggrieved by an interpretation may appeal to the committee for reinterpretation.

Summary of Revisions

This list indicates revisions to the standard when compared with the previously published version. It is not intended to be used independently of the standard. It shall be used for informational purposes and as a guide to the official recommendations contained in this standard. It is the responsibility of the user to read and understand the complete standard.

This is the first edition of E-13, *Lithium Ion Batteries*. This standard supersedes the Technical Information Report, TE-13, *Lithium Ion Batteries*.

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E-13 LITHIUM ION BATTERIES

Based on ABYC's assessment of the existing technology and the problems associated with achieving the goals of this standard, ABYC recommends compliance with this standard for all systems and associated equipment manufactured and/or installed after July 31, 2023.

13.1 *SCOPE*

13.1.1 This standard addresses selection and installation of lithium ion batteries on boats, lithium ion battery system design (e.g., house battery bank, cranking, propulsion), and manufacturer safety information.

13.1.2 This standard applies to installed boat battery systems over 600 watt-hours (Wh).

NOTE: Lithium ion batteries used in direct current (DC) electrical systems on boats that operate at potentials of 60 V or higher may have additional safety requirements not addressed by this standard and should be installed in accordance with the manufacturer's recommendations.

13.2 *UNITS OF MEASURE*

Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate.

13.3 *REFERENCES*

The following references form a part of this standard. Unless otherwise noted, the latest version of the referenced standards shall apply.

13.3.1 ABYC - American Boat & Yacht Council, Inc., 613 Third Street, Suite 10, Annapolis, MD 21403. Phone: (410) 990-4460. Fax: (410) 990-4466. Website: www.abycinc.org

ABYC C-7, *Battery Switches for Use on Boats*
ABYC E-10, *Storage Batteries*
ABYC E-11, *AC & DC Electrical Systems on Boats*
ABYC E-30, *Electric Propulsion Systems*

13.3.2 CFR - Code of Federal Regulations and other government publications. Obtain from the Superintendent of Documents, United States Government Information, PO Box 371954, Pittsburgh, PA 15250-7954. Phone: (202) 512-1800. Fax: (202) 512-2104. Website: www.ecfr.gov An excerpted edition of the CFR is also available from ABYC, Inc.

33 CFR

13.3.3 IEC - International Electrotechnical Commission, 3 rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland, Phone: +41 22 919 02 11. Website: www.iec.ch

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*
IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications*
IEC 62133, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications*
IEC 62620, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications*

13.3.4 SAE - SAE International, 400 Commonwealth Drive, Warrendale, PA 15096. Phone: (724) 776-4841. Fax: (724) 776-0790. Website: www.sae.org

SAE J2929, *Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells*

13.3.5 UL - Underwriters Laboratories Marine Department, PO Box 13995, 12 Laboratory Drive, Research Triangle Park, NC 27709. Phone: (919) 549-1400. Website: www.ul.com

UL 1642, *Lithium Batteries*

UL 1973, *Batteries for Use in Stationary and Motive Auxiliary Power Applications*
UL 2054, *Standard for Household and Commercial Batteries*

13.4 ***DEFINITIONS***

For the purposes of this standard, the following definitions apply.

13.4.1 Ampere Interrupting Capacity (AIC) - the maximum short-circuit current that an overcurrent protective device can safely interrupt under standard test conditions.

13.4.2 Battery - a collection of cells (or blocks) wired in series (or series/parallel) and constituting a single physical unit.

13.4.3 Battery Bank - two or more batteries connected in series to provide higher voltage, or in parallel to provide increased capacity.

13.4.4 Battery Capacity - the capacity of the battery, expressed in ampere-hours (Ah) at a nominal voltage or in watt-hours (Wh), from the manufacturer's specified fully charged to discharged voltage levels.

NOTE: Capacity ratings should include a discharge rate or time, and temperature, typically 25C / 77F.

13.4.5 Battery Cell – a single unit device which converts chemical energy into electric energy that is the fundamental building block of a lithium ion battery.

NOTE: A battery cell is designed to be rechargeable by way of a reversible chemical reaction.

13.4.6 Battery Management System (BMS) - a system designed to protect a lithium ion battery or battery bank from hazardous situations such as overcharging or overdischarging, charging or discharging in high and low temperatures, etc.

13.4.7 Battery Switch - a device rated to disconnect or connect a battery or battery bank to a load or another battery or battery bank.

13.4.8 Battery System - battery (or batteries) and all ancillary components.

13.4.9 High Temperature Cutoff (HTC) - a BMS's response to a high temperature event (HTE).

13.4.10 High Temperature Event (HTE) - the condition where a cell, parallel string, or bank has a temperature above the manufacturer's maximum cell temperature limit.

13.4.11 High Voltage Cutoff (HVC) - a BMS's response to a high voltage event (HVE) that protects the battery from overcharging.

13.4.12 High Voltage Event (HVE) - the condition where a cell, parallel string, or bank has been charged to a voltage above the manufacturer's maximum cell voltage limit.

13.4.13 Low Temperature Cutoff (LTC) - a BMS's response to a low temperature event (LTE).

13.4.14 Low Temperature Event (LTE) - the condition where a cell, parallel string, or bank has a temperature below the manufacturer's minimum cell temperature limit.

13.4.15 Low Voltage Cutoff (LVC) - a BMS's response to a low voltage event (LVE) that protects the battery from overdischarging.

13.4.16 Low Voltage Event (LVE) - the condition where a cell, parallel string, or bank has been discharged to a voltage below the manufacturer's minimum cell voltage limit.

13.4.17 Output Disconnect Device - a switch controlled by the BMS which disconnects a battery or battery bank from charge and discharge sources, and other batteries or battery banks.

13.4.18 Overcharging - charging a battery or cell above the manufacturer's maximum cell voltage limit.

NOTE: Overcharging may result in thermal runaway or damage to the battery or cells.

13.4.19 Overdischarging - discharging a battery or cell below the manufacturer's minimum cell voltage limit.

NOTES:
1. *Overdischarging may result in damage to the battery or cells and may include cell polarity reversal.*
2. *Subsequent charging after overdischarging may result in thermal runaway.*

13.4.20 Readily Accessible - capable of being reached quickly and safely for effective use under emergency conditions without the use of tools.

13.4.21 Safe Operating Envelope (SOE) - a set of limits specified by the cell or battery manufacturer within which the battery and all constituent battery cells and components should be operated to ensure the safety of the system. (e.g., high and low voltage limits, charging and discharging current limits, charging and discharging temperature limits, etc.).

NOTE: BMS may cut off power or provide an alarm for other reasons (e.g., the excessive difference in cell voltages (weak cell), currents over the rated discharge level, communication failures between modules, sensor failure, etc.).

13.4.22 Thermal Runaway - a potentially dangerous, self-propagating battery heating condition that can occur within a cell or cells.

13.4.23 Watertight - constructed so that water will not enter the enclosure under the test conditions specified in NEMA Standard 250, Type 6P or IEC Standard 60529, Code IP 67 or UL 50E, Type 6P.

13.4.24 Weatherproof - constructed or protected so that exposure to the weather will not interfere with successful operation under the test conditions specified in NEMA standard 250, Type 3 or IEC Standard 60529 Type IP 54 or UL 50E, Type 3.

13.5 ***GENERAL REQUIREMENTS***

13.5.1 Lithium ion batteries and their systems shall be installed in accordance with the requirements of ABYC E-11, *AC & DC Electrical Systems on Boats*, and, if applicable, ABYC E-10, *Storage Batteries*, and, ABYC E-30, *Electric Propulsion Systems*.

NOTE: Lithium ion batteries are not subject to routine electrolyte leakage or routine release of gas, therefore requirements regarding electrolyte containment and routine gas ventilation may not apply to lithium ion battery installations.

13.5.2 Lithium ion battery systems shall be installed, commissioned, and maintained in accordance with the manufacturer's recommendations.

NOTE: Lithium ion battery systems should be used (i.e., operated) in accordance with the battery manufacturer's recommendations.

13.5.3 SOE parameters shall be adhered to for determining the system design, installation, storage, and operation of a lithium ion battery.

NOTES:
1. *All lithium ion batteries lose capacity through cycling and over time. Loss of capacity can be exacerbated due to charge/discharge cycling, high temperature, overcharging, undercharging, and high charge/ discharge currents.*
2. *Lithium ion batteries have very strict temperature operating limits established by the cell or battery manufacturers. Hot and cold temperatures could damage battery cells and cause safety hazards.*
3. *For boats in long term storage, battery installation should follow manufacturer-recommended battery storage procedures based on ambient temperature, connected charging sources, and parasitic loads.*
4. *Expected peak loads should not exceed the manufacturer's maximum allowed discharge rate for the battery or battery bank.*

13.5.4 Batteries or cells shall meet the testing requirements of at least one of the following standards:

13.5.4.1 IEC 62133, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications*,

13.5.4.2 IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications,*

13.5.4.3 IEC 62620, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications,*

13.5.4.4 SAE J2929, *Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells*,

13.5.4.5 UL 1642, *Lithium Batteries,*

13.5.4.6 UL 1973, *Batteries for Use in Stationary and Motive Auxiliary Power Applications,* or

13.5.4.7 UL 2054, *Standard for Household and Commercial Batteries*.

13.6 *SYSTEM DESIGN AND INSTALLATION*

13.6.1 *Battery Management System (BMS) Installation*

13.6.1.1 All battery systems shall have a BMS to provide for battery cutoff if hazardous conditions exist.

NOTES:
1. *A BMS can be external or internal to the battery.*
2. *In the event of an individual BMS that disconnects, battery bank capacity may be reduced with no notification to the vessel operator.*

13.6.1.2 No electrical connections shall be made directly to a battery that would bypass a BMS or any battery protection circuits.

EXCEPTION: Connections made specifically per the battery manufacturer's instructions.

NOTE: Consideration should be given to providing power for critical systems (e.g., engine starting, propulsion, navigation lights, etc.) if a BMS shuts down the battery or a battery bank. The power source can be another lithium ion battery.

13.6.2 *Charging Sources*

13.6.2.1 Charging sources shall be operated and controlled to meet the charging profile recommendations provided by the battery or cell manufacturer.

13.6.3 *Ambient Temperature*

13.6.3.1 Batteries shall not be installed in locations where temperatures outside acceptable parameters (high or low), specified by the cell or battery manufacturer, can be expected to occur.

NOTES:
1. *Thermal management systems (e.g., forced ventilation or liquid cooled heat exchangers) may be required to keep all cells within the manufacturer's safe operating envelope (SOE).*
2. *Consideration should be given to avoiding potential external heat sources.*
3. *The temperature in battery storage locations should not exceed the manufacturer's recommended storage temperature range.*
4. *The BMS may disconnect the battery bank at manufacturer specific temperature limits.*

13.6.4 *Shock and Vibration*

13.6.4.1 Batteries shall be installed in locations and restrained in such a manner that they will be protected from shock, vibration, or movement according to the battery manufacturer's recommendations.

NOTE: Lithium ion battery manufacturers may have stricter battery restraining requirements than those specified in ABYC E-10, Storage Batteries, and 33 CFR 183.420 for lead acid batteries.

13.6.4.2 In the absence of the battery manufacturer's recommendations, batteries and battery banks shall be restrained to prevent any visible movement in the conditions under which the vessel is intended to be operated.

NOTE: For offshore vessels, the conditions under which the vessel is intended to be operated should include knockdowns and slamming loads.

13.6.5 ***Water Ingress Protection***

13.6.5.1 Lithium ion batteries and their system components (e.g., BMS) shall be constructed or installed to provide adequate water ingress protection during normal vessel operation.

13.6.5.2 Lithium ion batteries and their system components installed in locations subject to rain, spray, or splash shall be weatherproof.

13.6.5.3 Lithium ion batteries and their system components installed in locations subject to flooding or momentary submersion shall be watertight.

NOTE: Lithium ion batteries, their system components, and their electrical connections should be protected from corrosion.

13.6.6 ***Overcurrent Protection***

13.6.6.1 Conductors shall be provided with overcurrent protection device(s) as per ABYC E-11, *AC & DC Electrical Systems on Boats*.

13.6.6.2 If necessary, a battery bank shall be subdivided into units such that the ampere interrupting capacity (AIC) of the overcurrent protection device is not exceeded.

13.6.7 ***Battery Switches***

13.6.7.1 A battery switch or other means of disconnection independent from a BMS shall be installed for each battery or battery bank in addition to an output disconnect device.

13.6.7.2 A battery switch shall be mounted in a readily accessible location as close as practicable to the battery.

13.6.7.3 A battery switch or other means of disconnection shall comply with requirements of ABYC C-7, *Battery Switches for Use on Boats* if applicable, and be installed in accordance with ABYC E-11, *AC & DC Electrical Systems on Boats* or ABYC E-30, *Electric Propulsion Systems* if applicable.

13.6.8 ***Battery Banks***

13.6.8.1 Series and paralleling installations for battery banks shall comply with the battery manufacturer's recommendations.

13.6.8.2 If a battery manufacturer specifies a voltage deviation limit between individual battery voltages, it shall be met before the batteries are paralleled or connected in series to prevent excessive battery to battery current.

NOTES:
1. *If batteries are paralleled in an unbalanced state, extremely high paralleling currents can flow. If used, automatic paralleling devices should have an appropriate current-limiting capability. Manual switches, (e.g., a 1, 2, both switch or on/off switch) and automatic paralleling devices may not be appropriate.*
2. *Special attention to balancing is very important in larger battery banks.*
3. *Mixed battery chemistries are not suited for installation in the same battery bank.*

13.6.9 ***Fire Protection and Cell Venting***

13.6.9.1 The battery manufacturer's recommendation(s) shall be followed to protect against fire hazards, including ventilation and specific fire suppression requirements (e.g., specific fire extinguishing medium).

NOTES:
1. *Lithium ion battery technologies have unique fire characteristics (see APPENDIX for more information).*
2. *Lithium ion batteries can emit toxic, flammable, or explosive gases during a thermal runaway event.*

13.7 *BATTERY MANAGEMENT SYSTEM*

13.7.1 A BMS shall protect a battery from overcharging or overdischarging, charging or discharging in high or low temperatures, or in any way operating outside the SOE specified by the battery or cell manufacturer.

13.7.2 A BMS shall be able to perform HVC, LVC, HTC, and LTC actions in response to an HVE, LVE, HTE, or LTE independent from the programmed functions of the charging sources, regulators, inverters, or inverter/chargers, etc.

13.7.2.1 A BMS shall respond to any conditions outside the SOE by activating the output disconnect device.

13.7.3 A BMS shall have a voltage rating not less than the system voltage and a current rating not less than the total of the ampacities of the main overcurrent protection devices immediately downstream of the battery or battery bank.

13.7.4 An output disconnect device shall be capable of disconnecting the output immediately when operating under the battery's or the battery system's maximum specified rate of discharge.

NOTES:
1. *An alternative power source is recommended for critical systems (e.g., engine starting, propulsion, navigation lights, etc.) that may be affected if a BMS shuts down the battery. The alternative power source can be another lithium ion battery.*
2. *If a shutdown condition is approaching, a battery system should notify the operator with a visual and/or audible alarm before disconnecting the battery from the DC system.*
3. *BMS(s) may suddenly and unexpectedly disconnect a battery from loads and charging sources.*

13.8 *OWNER'S MANUAL AND COLLATERAL LITERATURE*

13.8.1 The battery manufacturer shall provide safety information regarding the owner/operator's responsibility and proper installation and maintenance of the batteries, including:

13.8.1.1 cell chemistry and design;

13.8.1.2 documentation of the safety hazards that are specific to the battery;

13.8.1.3 a description of the primary features of the battery concerning safety;

13.8.1.4 a detailed description of operating requirements necessary to ensure safe operation, with details of the safe operating envelope (SOE), including relevant charge and discharge characteristics and temperature limits, and any external relays and other features necessary to ensure operation within the SOE;

13.8.1.5 requirements, if any, for the control of charging sources;

13.8.1.6 the effects of an external fire or excessive external heating, together with a description of measures to be taken, if any, to guard against external hazards such as fire and impact, including any ventilation and specific fire suppression requirements (e.g., specific fire extinguishing medium);

13.8.1.7 information about the toxic, flammable, or explosive gases that might be released given a thermal runaway event;

13.8.1.8 a description of the limits to connecting batteries in series and parallel, and a description of a safe means of making the connections up to the specified limits, including overcurrent and other required protective mechanisms; and

13.8.1.9 a description of the hazard, if any, that occurs with submersion in freshwater and saltwater;

13.8.1.10 battery short circuit current; and

13.8.1.11 battery restraining requirements.

13.8.2 The battery manufacturer shall provide information regarding the recycling and/or disposal of lithium ion batteries.

APPENDIX - Thermal Runaway

Lithium ion batteries are unlike lead acid batteries in two important respects:

1. The electrolyte within most lithium ion batteries is ignitable.
2. Under certain fault conditions lithium ion batteries can enter a condition known as a thermal runaway (see AP FIGURE 1), which results in rapid internal heating. Once initiated, it is a self-perpetuating and exothermic reaction that can be difficult to halt.

The rate of temperature rise during thermal runaway and the peak temperature reached vary widely depending on the particular chemistry used in the battery (e.g., lithium phosphate [LFP], nickel-manganese-cobalt [NMC], or some other chemistry) and numerous construction features (e.g., cylindrical cells versus flat plate; different separator materials; chemical doping; etc.).

Given thermal runaway, some batteries can reach high enough temperatures to ignite the battery's electrolyte whereas others will not. In all cases, internal cell pressures will rise, which may result in the venting of gases and electrolytes from the cell(s) experiencing thermal runaway. The flammability of the vented materials varies widely depending on the chemistry, cell doping, and other features.

Given thermal runaway, even if the internal temperature is not high enough to cause ignition, electrical arcing, flames, or other heat sources could result in ignition. Once ignited, because of the exothermic and self-perpetuating nature of the chemical reaction fueling the thermal runaway, a lithium ion battery fire is difficult to extinguish. Typically, the best approach is to remove heat as quickly as possible, which is most effectively done by flooding the battery with water, although this may have serious consequences for the boat's electrical systems, machinery, buoyancy, etc.

Lithium ion batteries should be constructed and installed in boats such that a thermal runaway event never occurs under reasonably foreseeable fault conditions. Toward this goal, some thought should be given to:

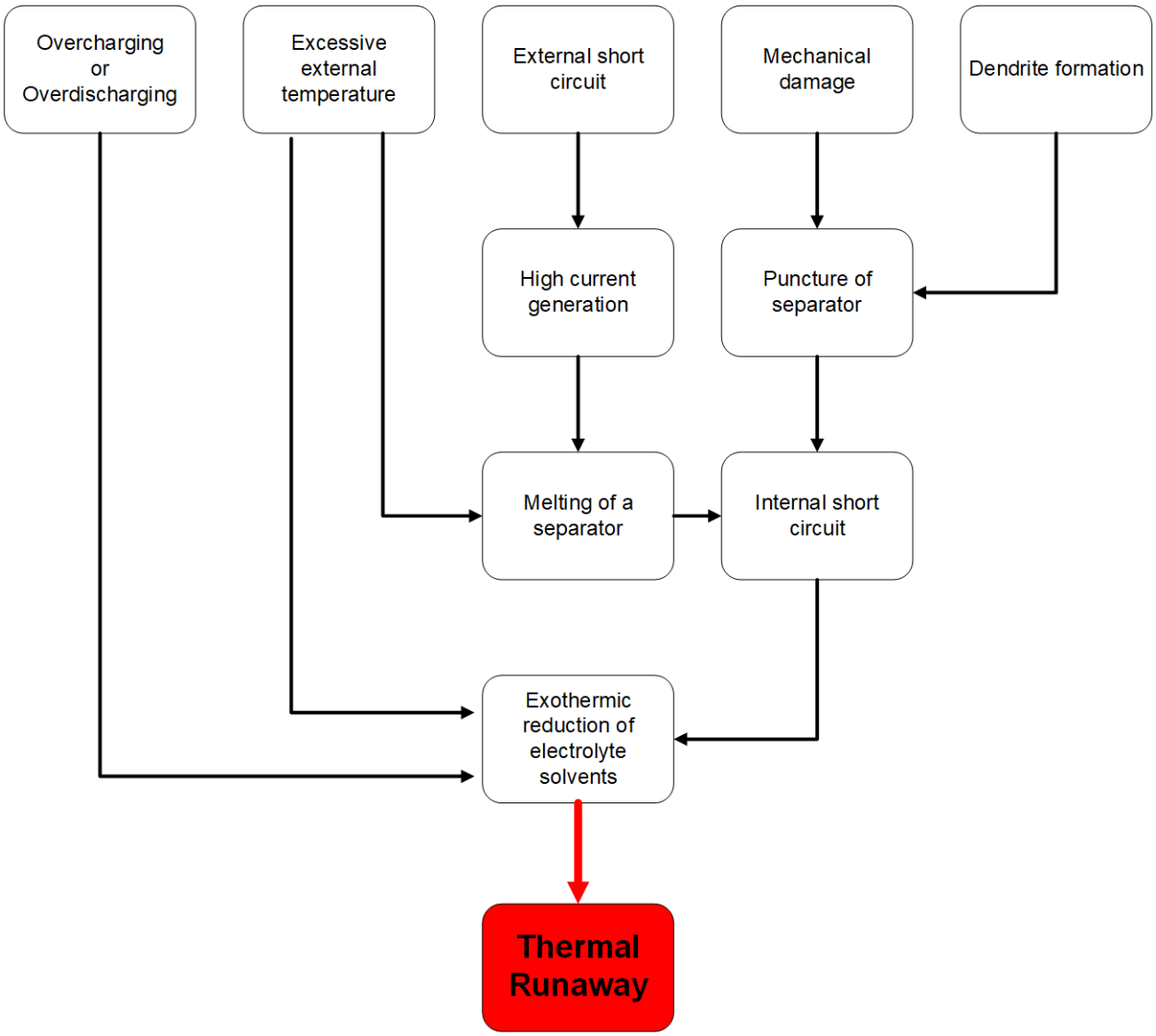
1. additional protection for the boat in the event the various battery protection mechanisms fail and a thermal runaway event occurs, and
2. external heat sources that have the potential to initiate thermal runaway in the battery.

Some batteries are assembled inside metal cases that are designed to contain any thermal runaway event. Some of these cases are hermetically sealed and designed to prevent venting, while others have vents. Some batteries consist of multiple small cylindrical cells with each cell designed to contain a thermal event and to shut the battery down so that the event does not propagate. Other batteries have the cells assembled inside a plastic housing that will not contain a serious thermal runaway event. The level of resistance to fire of plastic cases varies. Regardless of construction, in all thermal runaway events, in the absence of a sealed metal case, the venting of gases is likely. These gases vary significantly in their volatility, flammability, specific gravity (e.g., lighter or heavier than air), and level of hazard.

Because of the wide variations in terms of battery chemistries, construction, volatility, and responses to a thermal runaway event, it is not possible to issue a generic prescription for battery compartment design and ventilation. It is incumbent on the boat builder and battery installer to consult with the battery manufacturer and supplier to determine an appropriate compartment design and venting mechanism, and appropriate fire containment and firefighting mechanisms if these are considered necessary.

Battery compartment design and construction, including venting and the level of fire protection, must comply with the battery manufacturer's specifications.

AP FIGURE 1 Examples of Typical Causes of Thermal Runaway



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