APLUXOR MARINE ELECTRICAL LIBRARY · PART III. ENERGY: HOW MUCH YOU HAVE AND WHERE IT COMES FROM

Chapter 11. Lithium: What Changes on Your Boat — Before You Buy and After

Decide on a lithium bank before you buy, and check a lithium system that is already aboard

A lithium bank changes what the voltmeter tells you, what the fuse at the battery has to withstand, what the alternator and the charger must do, and what goes dark when the battery protects itself. This chapter introduces no new part: it says what changes, against Chapters 4 to 10, when the bank is lithium, so that you can decide on a change to lithium before you buy, or check the system you already have and fix it without rebuilding it.

AFTER THIS CHAPTER YOU CAN

- tell why the voltage of a lithium battery says almost nothing about how full it is, and set the battery monitor for it;
- read the main protection of a lithium bank and the fuses beside it against the current the bank can push into a short;
- say what charges your lithium bank, what its battery maker's numbers are, and what keeps the alternator on a battery when the BMS opens;
- tell which kind of BMS your battery has, what it takes with it when it disconnects, and how the bank comes back;
- find out whether your battery may take a charge in the cold, and what stops a charge there;
- audit a lithium system already aboard in one evening, and know what to fix first;

- go through the checklist before you buy, and keep the papers your insurer may ask for.

Read first: → 1.7, → 4.4, → 6.1, → 7.6, → 8.3, → 9.1, → 9.3, → 12.2

11.1 How LiFePO4 differs for you
11.2 Protecting the bank
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11.6 Lithium already aboard: a one-evening audit
11.7 The standard and your insurer
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11.1. How LiFePO4 differs for you

What changes for you when the bank is lithium? The lithium batteries this chapter is about are lithium iron phosphate batteries, marked LiFePO4 on the label (→ 2.2). Inside the case, cells are joined in series, and a battery management system (BMS) monitors each cell and can switch the cells off from the terminals; on some batteries the BMS is a separate unit that the battery must be connected to (→ 11.4 · p. 25). Five things change for you at once: what the voltage tells you, how much of the label you can use, the weight, how long the battery lasts, and what a mistake costs. This section takes them in turn and ends with the battery monitor; protection, charging, the BMS and the cold have their own sections.

The voltage curve: the voltmeter is no longer a fuel gauge

A lead-acid battery's resting voltage falls steadily as it discharges, which is why → 3.5 can read its state of charge off a table. A LiFePO4 battery holds a nearly flat voltage through most of its discharge. One maker writes that a battery at 80% state of charge may show nearly the same voltage as one at 30%, and that a battery monitor is the most accurate

way to follow it; a second writes that on such a battery a small voltage change can represent a large capacity difference (→ Fig. 11.1 · p. 3).

PRACTICE

A third maker answers its owners that a typical lead-acid, voltage-based battery gauge will not show the state of charge of its lithium batteries, and that a lithium battery gauge is needed. A MFR voltage reading in the flat part of the curve does not tell you how full the bank is. The state of charge comes from a count of the current in and out: a battery monitor with a shunt (→ 7.6), or the battery's own BMS, where its maker's app shows one. A normal-looking voltage does not even show that the cells are connected to the loads: a BMS that has switched them off can leave the terminals at almost any reading (→ 11.4 · p. 25).

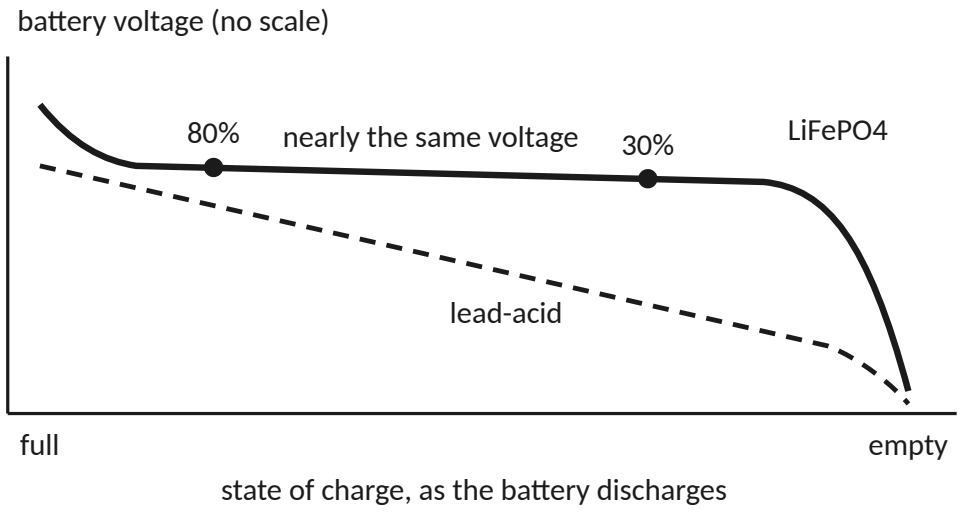


Fig. 11.1. How the voltage of a LiFePO4 battery and of a lead-acid battery changes as each discharges, drawn from the makers' words, not measured. The LiFePO4 line stays nearly flat through most of the discharge: one maker writes that 80% and 30% can show nearly the same voltage. The voltage axis has no scale; a voltage table for a lead-acid battery is in → 3.5.

Usable capacity, rate and cold

On a lead-acid battery the share of the label you can use is the maker's depth of discharge — 50% on the battery of → 7.2. Lithium makers set other limits. One writes that its batteries can be discharged up to 100% without risk of damage, that a battery is charged right after such a discharge, and recommends limiting the discharge to 80–90% so that

the BMS does not disconnect the battery; a second system's BMS switches the loads off with a reserve of about 1 Ah for each 100 Ah of capacity left in the battery; a third maker's battery disables power at 12.0 V or 10% state of charge, whichever comes first. The depth your battery allows is in its own manual. Plan the budget of → 7.1 on it: past it, the BMS takes the whole bank away at one moment, with everything on it (→ 11.4 · p. 25). MFR

> **WORKED EXAMPLE: TWO BANKS WITH THE SAME LABEL**
>
> Suppose two banks of 200 Ah on the label: a lead-acid bank whose maker allows 50%, and a lithium bank whose maker recommends stopping at 80%. The lead-acid bank gives 200 × 0.5 = 100 Ah; the lithium bank gives 200 × 0.8 = 160 Ah. For a night that takes 100 Ah, the lithium bank has 60 Ah left over, and a lithium bank of 125 Ah on its label would give the same 100 Ah (125 × 0.8 = 100). What the numbers mean: compare banks by the amp-hours their makers let you take, not by the numbers on their labels.

The rate matters less. One lithium maker writes that the rate of discharge has virtually no effect on the capacity its batteries deliver, and contrasts that with lead-acid batteries, which lose capacity as the rate rises (→ 7.2). One monitor maker sets its Peukert exponent at 1.01 for a lithium battery whose exponent is unknown (→ 7.6). MFR

In the cold, three lithium makers' data give discharge down to −4 °F; one writes that cold temperatures reduce performance, as with all batteries, and that its batteries keep significantly more capacity and voltage in the cold than lead-acid batteries, without a number. Neither these three makers' documents nor a fourth maker's manual gives the capacity at a temperature. Charging in the cold is another matter, with limits of its own (→ 11.5 · p. 38). MFR

Weight, life and storage

One maker's 100 Ah lithium battery weighs 31 lb, and a second maker's, 29.8 lb. The weight of the lead-acid battery it would replace is on that battery's own data sheet; set the two side by side for your boat. MFR

One maker rates its LiFePO4 batteries at 3,500 cycles at 100% depth of discharge, and writes that the actual life depends on several variables of your own use. The same maker writes that, unlike lead-acid batteries, a partial state of charge does not harm lithium batteries. The battery may not need a full charge, but a battery monitor does: it sets its count right only at full (→ 7.6, and the monitor below). MFR



For storage, the makers differ. One gives a storage range of 23 °F to 95 °F, and for longer than three months 32 °F to 77 °F, in which it is safe to store its batteries at a 50% state of charge; a second recommends bringing its batteries to a 100% charge and then disconnecting them completely; a third, storing them well charged between 40 °F and 95 °F. Store yours as its own manual says. A bank disconnected for the winter takes with it everything it fed: on a boat left on the water, the bilge pump's automatic switch, the high-water alarm and the CO alarm on that bank stay dark for those months unless another source feeds them (→ 11.4 · p. 25). MFR

A lithium battery also has a draw of its own. One maker's battery with Bluetooth inside draws about 10 mA all the time for it — 0.24 Ah a day, about 7 Ah in a month at the dock. That current flows inside the battery, so a monitor's shunt never sees it (→ 7.6). MFR

The cost of a mistake

A lead-acid battery pays for some mistakes slowly, by losing capacity. A lithium battery can be damaged by some of them in a short time, or for good. Left empty, it is damaged in a time its maker gives: one maker's manual asks that its battery be woken within 24 hours of entering low-voltage disconnect, or you risk damaging it and voiding its warranty, whereas the same maker's article gives five days; a second maker writes that its battery, left deeply discharged without immediate charging after its reserve is used, becomes permanently damaged; a third requires immediate recharging after a low-cell-voltage disconnect. The time that counts is the one your battery's manual gives — and a MFR

boat left at the dock with a draw (→ 7.3) can pass it without anyone seeing.

The other mistakes have their own sections. Charged below its maker's charging temperature, the battery can be damaged for good (→ 11.5 · p. 38). When its BMS disconnects, the whole bank goes dark at one moment, the bilge pump and the CO alarm with it where they are fed from it (→ 11.4 · p. 25). An alternator that is charging when the BMS opens loses its battery (→ 11.3 · p. 15). And a short across a lithium bank draws a current from which only the right fuse protects the cable (→ 11.2 · p. 7).

The monitor on a lithium bank

A monitor counts a lithium bank the way it counts a lead-acid one (→ 7.6): from a full battery as its fixed point, against the capacity you typed in. A lithium battery's BMS can count the same way: one maker writes that the system counts amps going into and out of the battery, then calculates the remaining amp-hours from a known reference point. What changes are the settings (Table 7.7, → 7.6), and each comes from the battery maker's numbers and the monitor maker's manual: MFR

- **Battery capacity:** the amp-hours on the lithium battery's label, for the whole bank — the batteries in parallel added together.
- **Charged voltage and tail current:** set against what your charging sources do at the end of a lithium charge (→ 11.3 · p. 15). One monitor maker writes that some lithium battery chargers stop charging when the current drops below a set threshold, and that the tail current must then be set higher. A tail current below the current at which your charger stops is never reached, and the monitor never sets itself to full. MFR
- **Peukert exponent:** the battery maker's figure; where it gives none, the monitor maker's figure for lithium — 1.01 for the monitor maker of the tail-current item.
- **Charge efficiency:** the battery maker's figure where it gives one; where it gives none, the monitor maker's figure for lithium — 98% for the monitor maker of the tail-current item, whose own default is 95%. MFR

- **Discharge floor:** the depth your battery's manual allows, so that the time remaining on the screen ends before the BMS does.


HOT BATTERY

Then the check is the same as on a lead-acid bank: charge the bank fully from a source set to its battery maker's numbers, until that source shows the charge complete, and look at the monitor — it sets itself to 100% on its own. If it does not, compare its charged voltage and tail current with what that source did at the end of its charge, as the procedure "Bringing the monitor back to the truth" does (→ 7.6), and write every setting into field 12 of the Boat Passport. On a battery whose app shows its own state of charge, the app's count and the monitor's can drift apart between full charges; the monitor's is set right by that full charge.

11.2. Protecting the bank

What must the protection at a lithium bank withstand, and what does its BMS do for the cable? A lithium battery's internal resistance is low, so a short across its terminals, or across any cable that leaves it, draws a very large current, and the protection where that cable starts has to stop it (→ 4.4). The BMS does not do that job for it. This section says how large the current is, what the fuses at the bank must interrupt at the bank's voltage, what the battery makers ask, and how you read what your boat has.

The bank's short-circuit current

Only the battery's maker can give the current one battery pushes into a short, and most do not: the manuals, data sheets and articles of six lithium makers in Sources give none. One maker gives it for its 320 Ah battery as a bolted fault current at nominal voltage of 5,818 A, worked out by the method of NFPA 70E from an impedance at the terminals of 2.20 mΩ or less at 12.8 V (12.8 ÷ 0.0022 = 5,818). Both conditions of MFR that figure count. "Or less" makes 5,818 A the least that battery pushes into a short, not the most. And 12.8 V is its nominal voltage: its maker

recommends charging the same battery at 14.4 V, and at 14.4 V the same resistance gives 14.4 ÷ 0.0022 = 6,545 A. Where a maker gives the internal resistance only, it gives the order of the current, as the worked example of → 4.4 shows, not the figure.

A maker's figure is for one battery. Batteries in parallel push their currents into a short together, so the bank's short-circuit current at its terminals is that figure times the number of batteries in parallel, less what the jumpers between them take. Batteries in series add their voltages and their resistances alike, so a string of them pushes about the current of one of its batteries. PRACTICE

Suppose two batteries whose maker gives 5,818 A for each are joined in parallel. Together they push 2 × 5,818 = 11,636 A into a short before the jumpers — more than the 10,000 A one terminal fuse interrupts at 14 V (Table 4.4, → 4.4).

> **WHY IT WORKS**
>
> The current a short draws is the battery's voltage divided by the resistance of the whole loop: the cells, the battery's own terminals and connections, the jumpers, the cable to the short and the short itself. A lithium battery's part of that loop is a few thousandths of an ohm, so the cable and its joints decide a large share of the current. That is why the current that counts for a fuse is the current where that fuse stands. A fuse with a few inches of cable between it and the batteries meets nearly all of the bank's short-circuit current when its own output is shorted; every foot of cable before it lowers that current a little. How much, for a given fuse, takes the resistance of every joint and cable in the loop: a pro's arithmetic, not a guess. PRACTICE

The interrupting rating, at the bank's voltage

A fuse's interrupting rating holds at the voltage its maker gives, and it falls as the voltage rises (→ 4.4). One maker's terminal fuse interrupts 10,000 A at 14 V, 5,000 A at 32 V and 2,000 A at 58 V. One maker's Class T fuse interrupts 20,000 A at 125 V DC; a second maker's Class T fuses interrupt 20,000 A DC in their 15–600 A sizes, at 160 V DC, and 100,000 A in their 700–1,200 A sizes; the 200,000 A on the same sheet is

an AC rating, which does not carry over to DC. So the figure you compare is the one the fuse maker gives at your bank's voltage or above it: on a 12 V bank, at 14 V or more; on a 24 V bank, at 32 V or more. A rating printed with no voltage, or an AC rating only, gives you nothing to compare. MFR

The fuse sits in a holder, and the holder's own data count too: its voltage rating and, where it sits in a space that asks for it, whether it is ignition protected. One maker sells two Class T holders, one listed as not ignition protected and one as ignition protected (→ 4.6). MFR

What the battery makers ask

Battery makers do not agree on the main protection, and some do not agree with themselves (→ Table 11.1 · p. 10). One names only its Class T fuse and forbids an ANL, a MIDI or another type in its place. A second names "a T-fuse or an MRBF fuse" with an interrupting rating of 15,000 A, which no terminal fuse in Table 4.4 reaches at 12 V (→ 4.4). A third supplies its own DC breaker with its battery, and writes that any other breaker voids the system's UL listing. A fourth names ANL fuses in its manual, with no interrupting rating, whereas the same maker's article asks for a Class T fuse at the bank's main positive. A system maker asks that at least one fuse in the DC line have an interrupting rating equal to or greater than the bank's prospective short-circuit current, calls it a mandatory safety requirement, and allows other fuse types whose current, voltage and interrupting ratings match the system. A Class T fuse is the type that four of these five makers name or allow; it is not the only one, and the manual of your battery decides the type. Where two documents of one maker name different types, as maker 4's do, a protection of either of those types is a type its maker names, as long as its interrupting rating at the bank's voltage meets the bank's short-circuit current. MFR

Table 11.1. What five lithium makers ask of the main protection, as printed; the makers are numbered within this table MFR

Maker	Main protection named	Figure given	In its place
Maker 1, a 460 Ah battery (article on its technical bulletin, 2026)	A 400 A Class T fuse of one named part number, 160 V DC	20,000 A interrupting rating at 160 V DC for that fuse; no short-circuit current of the battery	No ANL, MIDI or other type
Maker 2, a 12 V battery system (manual, 2022)	"A T-fuse or an MRBF fuse and a fuse holder"	Interrupting rating 15,000 A; no short-circuit current of the battery	—
Maker 3, a 320 Ah battery (manual RevG)	Its own DC breaker, included with the battery	Bolted fault current 5,818 A at 12.8 V, from an impedance of 2.20 mΩ or less, for one battery	Any other breaker voids the system's UL listing
Maker 4, a 100 Ah battery (manual, 2026; article, 2024)	Manual: ANL fuses; article: a Class T fuse at the bank's main positive	Neither an interrupting rating nor a short-circuit current	—
Maker 5, a system maker (wiring guide, 2026)	At least one fuse in the DC line, rated to interrupt the bank's prospective short-circuit current	None for its batteries; how to find the current is not given	Other types with matching current, voltage and interrupting ratings

A bank of several batteries in parallel can need a fuse on each battery as well. One system maker asks for each battery to be fused on the positive side, and the bank's main positive cable too; a second maker always recommends a fuse block between each battery when they are wired in parallel; a third maker's manual allows its batteries in parallel with no limit on their number and says nothing about fuses between them. The jumpers between the batteries of one bank are part of the bank, not positives that leave it (→ 4.2); whether your bank needs a MFR

fuse on each battery is a question for its battery maker and a pro, and the answer goes into the Boat Passport (→ 6.4).

The main protection of a lithium bank

The main protection of a lithium bank has an interrupting rating, at the bank's voltage, at least equal to the bank's short-circuit current — the battery maker's figure for one battery, times the batteries joined in parallel — and is the type the battery's maker names, where it names one; in practice, a Class T fuse. The BMS is not overcurrent protection. Where the maker gives no short-circuit figure, or the protection on the bank is not the type the maker names, or its interrupting rating cannot be read, a pro sizes it. It is replaced only with the same rating, and with a type and an interrupting rating that meet this — never with a lower interrupting rating. Until a pro has done it, the bank stays in use while the cable it protects has its insulation whole, nothing chafing it and nothing wet on it, and the finding is the first line of the Boat Passport (→ 2.3). PRACTICE

The main protection is the fuse or breaker where the bank's positive cable leaves the bank. The battery maker's figure counts with the conditions it is given under: a figure worked out at nominal voltage from a resistance "or less" is the least that battery pushes into a short, and at its charging voltage it pushes more (→ "The bank's short-circuit current" · p. 7). Fitting or replacing the main protection is work at the battery terminal, a pro's (→ 1.8).

WHY IT WORKS

The BMS opens its circuit to save the cells, not the cable. One maker writes that the short-circuit protection of its BMS protects the battery's cells, and that a short can still produce a spark and damage the cable or the bolt; a second, that its BMS protects the battery internally and that fuses protect against external faults; a third, that a BMS is no substitute for properly rated overcurrent protection; a system maker, that it is essential that all electrical connections to the battery are fused. A BMS inside the battery guards what lies behind its own switch; the cable outside is guarded only by the fuse or breaker at its start. A battery with an external BMS has no switch inside at all: one system maker's battery must be connected to a separate BMS that switches loads and chargers off (→ 11.4 · p. 25). And some BMSs are fast. One maker's BMS opens on a short in 200 to 600 µs, and on a discharge overcurrent of 1,000 A (±100 A) within 2.2 ms (±1 ms); a second maker's at 600 A within 500 µs; a third maker writes that its BMS turns the battery off when a short lasts more than a few seconds, though not in every case. A BMS that opens in millionths of a second can open before a fuse melts: the bank goes dark and the fuse stays whole. That case — a short the BMS caught — and how it is told from an empty bank are in → 11.4 · p. 25.

MFR

The other fuses at a lithium bank

Every positive that leaves a bank has its own fuse at its start, except the starter cable traced to the starter (→ 4.2): the charger's lead, the charge controller's (→ 10.4), a wind generator's (→ 10.5), a DC-DC charger's, an inverter's, a circuit wired around the battery switch (→ Fig. 11.2 · p. 13). On a lithium bank each of these fuses stands about as close to the batteries as the main protection does, and a short at its output draws nearly the bank's short-circuit current through it, less only what the cable before it takes. Its interrupting rating is read against that current, at the bank's voltage, from its body or its maker's data, as the main protection's is. A blade fuse interrupts 1,000 A at 32 V (Table 4.4, → 4.4); at a lithium bank it can stand where a short draws thousands of amps.

A Class T fuse upstream does not change that. In a short at a branch's output, the branch fuse and the main protection carry the same current at the same moment; where the branch fuse opens first, as the smaller

of the two is meant to, it has to break that current. If its interrupting rating is below it, its arc can keep burning until its body ruptures (→ 4.4). The system maker of → Table 11.1 · p. 10 asks this of at least one fuse in the line; the physics holds for each fuse at the bank. Read each one and write its type, rating and interrupting rating into the Boat Passport — field 9 for a charger, a DC-DC charger or an inverter, field 10 for a circuit wired around the battery switch — and give a pro every fuse whose interrupting rating is below the bank's short-circuit current, or cannot be read, to work out the current at its place (→ 11.9 · p. 61).

PRACTICE

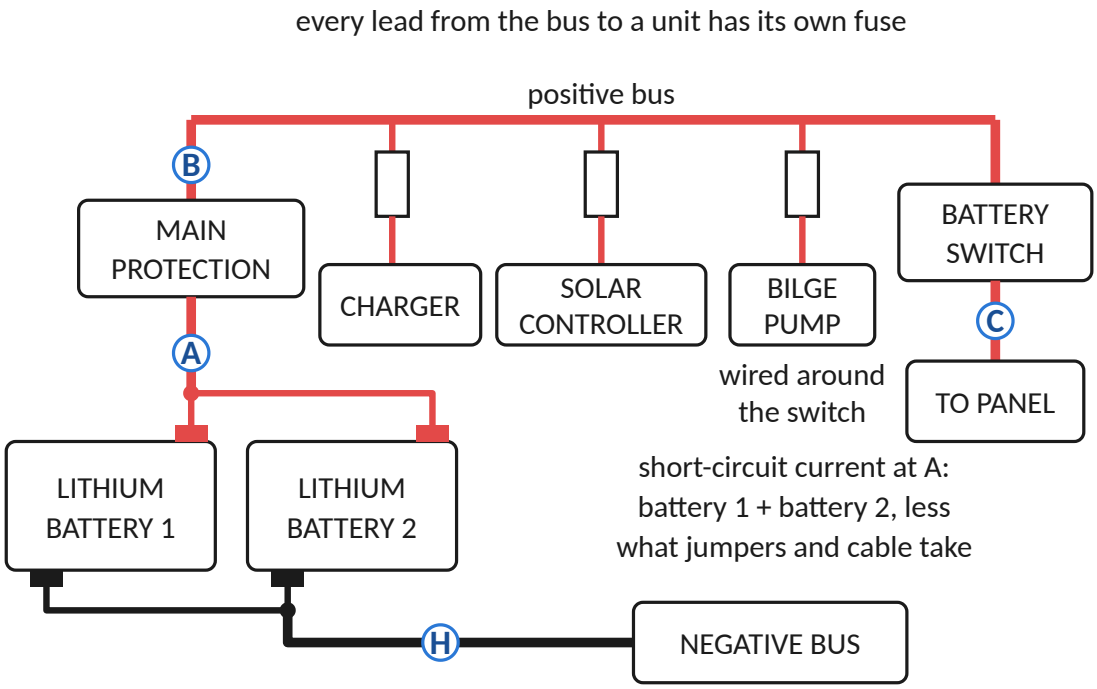


Fig. 11.2. A lithium bank of two batteries in parallel: the main protection between A and B, which also protects the bank's cable on to the battery switch, and a fuse at the start of every lead from the bus to a unit. A short at the output of any of these fuses draws nearly the bank's whole short-circuit current through it; only the jumpers and the cable before it lower that current. C is the battery switch's panel-side terminal, H the bank's negative. One typical arrangement: your boat can be wired differently, and a lead can also land at the battery itself.

Procedure: Reading the main protection of a lithium bank

For any lithium bank — one battery, several in parallel, or batteries in series — to find out what protects its positive cable and whether it meets → "The main protection of a lithium bank" · p. 11. You need a

flashlight, the battery's manual or data sheet, the fuse maker's data where you can find them, and the Boat Passport. No tool goes on the holder or its studs.

 **SHORT CIRCUIT**  **BLOWN FUSE**

1. Write down the battery's maker and model from its label, how many batteries the bank has in parallel and in series, and the bank's voltage. In the battery's manual or data sheet, find the main protection its maker names and the short-circuit current it gives for one battery; write both down, or "none given".
2. Follow the bank's positive cable from the battery by eye, without touching it, to the first fuse or breaker it meets — A to B on → Fig. 11.2 · p. 13. A fuse or breaker within reach of the battery: step 3. None that you can find along the cable, and the cable is not one you traced to the starter: write "not found" on the first line of the Boat Passport; the cable goes to a pro to trace (→ 4.2), and the entry of the BLOWN FUSE sign says what that cable may carry until then.
3. Read what is printed on the fuse or breaker: its type, by the name on the part (Class T, MRBF, ANL, MEGA, a breaker), its rating in amps, and its interrupting rating with the voltage printed beside it. A cover that hides the marking and lifts off by hand: lift it, read, and put it back on as it came off; a cover held by a nut stays on, and what it hides is read by a pro.
4. An interrupting rating not printed on the part: find the part number on its body and the interrupting rating in its maker's data, at your bank's voltage or above (→ 4.4). No part number, or no data: write "interrupting rating unknown".
5. Work out the bank's short-circuit current: the figure for one battery times the number of batteries in parallel — on a bank in series, times the number of its strings in parallel — taken with the conditions its maker gives it under (→ "The bank's short-circuit current" · p. 7). Compare the type on the bank with the type the battery maker names — either type, where

two of its documents differ — and the interrupting rating at your bank's voltage with that current.

6. Write the type, the rating, the interrupting rating with its voltage, and the bank's short-circuit current into field 7 of the Boat Passport. Where the battery maker gives no figure, where the type is not one its maker names, where the interrupting rating is unknown, or where it is below the bank's short-circuit current, write that on the first line of the Boat Passport as well, and order the work in the words of "What to tell the pro" (→ 11.9 · p. 61); until then the bank is used as →
"The main protection of a lithium bank" · p. 11 says. The fuse found blown or the breaker tripped, with the panel dark: the card "The panel went dark — no lights, no electronics" (→ emergency card).

PUT THE BOAT BACK IN SERVICE

- A cover you lifted in step 3: back on, seated as it came off.
- The flashlight, the manuals and the readings put away with the Boat Passport.

11.3. Charging with lithium — the full treatment

What in your charging system has to change when the bank is lithium? Every source that charges it — the alternator, the shore charger, a DC-DC charger, solar panels, a wind generator — has to charge it by its battery maker's numbers, has to be stopped when the battery cannot take a charge, and has to survive the moment the BMS opens. This section takes the numbers first, then each source, then the outboard's start battery, then a lithium bank joined to a lead-acid one.

The numbers are the battery maker's

This book gives no charge numbers for lithium, only each battery maker's (→ Table 11.2 · p. 16). The makers of that table give a charge voltage between 14 V and 14.8 V for a 12 V battery, and differ on the float voltage, on the largest charge current and on whether a float is wanted

at all. One of them asks that equalization and temperature compensation be disabled for its batteries; another lithium maker writes that equalization and desulfation modes are to be disabled unless the battery's maker specifically approves them, and that the temperature adjustment of many lead-acid chargers may not suit LiFePO4. Your battery's own manual gives its numbers; a source is set to them, and they go into field 12 of the Boat Passport. MFR

Table 11.2. Six lithium makers' charge numbers for a 12 V battery, as printed; the makers are numbered within this table MFR

Maker	Charge (absorption) voltage	Float	Charge current
Maker 1, a 100 Ah battery	14.2–14.6 V; absorption time 1 hour for a 200 Ah bank of two batteries	13.4–13.8 V	Largest 50 A; equalization and temperature compensation disabled
Maker 2, a 12.8 V battery with an external BMS	14.2 V	13.5 V	—
Maker 3, its batteries (answers to owners); one model's data sheet	14–14.6 V; one model: 14.4–14.8 V recommended	13.8 V	One model: 5–50 A continuous, 165 A for up to 1 minute
Maker 4, a 320 Ah battery	14.4 V recommended; 14.8 V at most, at 200 A	—	150 A standard; charge ends at 10 A
Maker 5, a 105 Ah battery	14.6 V at most	—	100 A at most
Maker 6, its batteries	14.4 V; the charger disconnected after charging	Float charging and maintainers are not good for its batteries	—

A lithium bank charges in another way than the lead-acid bank of → 9.4. One maker writes that lithium batteries can be charged faster than wet or AGM lead-acid batteries, and that lithium iron phosphate batteries can be charged in as fast as 1 hour; a second gives an absorption time of

1 hour for a bank of two of its batteries; a third ends the charge when the current falls to 10 A. So the current that goes in is what the sources give, and the battery maker's largest charge current is the limit the sources together are held under (→ 9.2). On a bank of several batteries in parallel, their limits add only as far as the batteries share the current; one system maker's wiring example gives each battery a cable of the same length. MFR

Whether a charger may stay connected is the battery maker's to say, and the makers differ: one writes that the charger can stay connected to its lithium batteries indefinitely without harm; another, that float charging and maintainers are not good for its batteries, and that the charger is disconnected after charging. MFR

The alternator: a long, full current

A lead-acid bank near full takes less and less, and the alternator's current falls with it (→ 9.4). A lithium bank can hold an alternator at a high current for much longer, and its makers write about what that does to the alternator. One writes that a DC-DC charger can help protect the alternator from sustained high current demand; a second, that its BMS is not designed to protect the alternator from working too hard; a system maker, that a regulator with a temperature sensor on the alternator prevents it from overheating, and that a current-limiting device such as a DC-DC charger can be used. The regulator maker of → 9.2 asks that the alternator not be able to exceed the battery's largest continuous charge current, and writes that its lithium profile is no replacement for a BMS. MFR

The makers also differ on whether an alternator may charge their battery straight. One writes that its batteries can be charged with most alternators, that low-quality alternators with poor voltage regulation can make the BMS disconnect the batteries, and that a compatible high-quality alternator or a voltage regulator is used; another writes that a DC-DC charger is required to charge its battery from an engine's alternator, and that an output above 14.8 V may make its BMS turn the battery off. Your battery's manual decides which applies to your bank. MFR

> **⚠ COSTLY DAMAGE · AN ALTERNATOR THAT LOSES ITS BATTERY WHEN THE BMS OPENS**
>
> An alternator pushes its current into a battery, and the battery holds the voltage down. When the BMS opens its switch while the alternator charges, the alternator loses that battery in an instant — as if a cable had come loose, or a battery switch had been turned with the engine running — and the voltage jumps: the load dump of → 1.7 and → 9.1. One maker of alternators and regulators writes that running an alternator without a battery will damage the alternator and may damage any attached system, and that the only safe way to shut the alternator down is to turn off its regulator; a lithium battery maker answers its owners that if the BMS disconnects the batteries, the alternator could be damaged; a third maker writes that a disconnection while it runs causes a massive spike in the alternator which can easily destroy the alternator regulator. So what matters on a lithium bank is what keeps the alternator on a battery, or stops its regulator, when the BMS opens (→ Table 11.3 · p. 20). Where your boat has none of these, the cure is one of them, installed by a pro (→ 11.9 · p. 61). MFR

What keeps the alternator safe: the makers' ways

Makers of regulators, BMSs and DC-DC chargers each offer their own answer, and each works only on its own conditions (→ Table 11.3 · p. 20, → Fig. 11.3 · p. 22). Three let the BMS warn a charging source before a charge limit is reached. One regulator's manual lists the messages it takes from a battery's BMS over a data link, among them that the battery has reached its upper limit but is not yet disconnecting, and a request that the battery bus be disconnected for high voltage; one battery system triggers its "Stop Charge" event before the battery reaches its limits, and that event must be configured for each charging device; one BMS sends a "charge disconnect" signal to turn the chargers off. Each of these warnings concerns the charge. A disconnect on the discharge side comes with none: one maker's battery disconnects power when its voltage, current or temperature limits are exceeded during discharging, and two makers' BMSs open on a MFR

discharge overcurrent or a short within a few thousandths of a second (→ 11.2 · p. 7). An alternator that is charging at that moment loses its battery, link or no link, so a link keeps the alternator safe at the end of a charge, not at every opening; the protection module, the DC-DC charger and the other ways below each cover what their own makers say they cover. On a BMS of kind 1, 2 or 3 (→ 11.4 · p. 25), a source that the BMS cannot reach by such a link is stopped only by the BMS opening, with the load dump that follows (→ 9.1). On a BMS of kind 4, which only sends signals, nothing opens between the cells and the terminals: a source its signal does not reach is stopped by nothing, and that system's maker, in its steps for an imbalanced battery, writes that dangerous cell overvoltage can occur if the BMS does not control the charger.

One maker of alternators sells a protection module that it writes can protect alternators from lithium battery BMS disconnects, among other surges, and it gives the module's limits in the same sheet: no surge protection device can protect against unlimited surges in amplitude, power or duration, and if the nuts that hold the cables to the alternator loosen, the module cannot protect it. MFR

Table 11.3. How a lithium bank is charged from the engine, and what keeps the alternator on a battery when the BMS opens

Path	What it is	When the BMS opens	Whose manual decides
Alternator straight to the lithium bank, its own regulator	One maker allows most alternators; another requires a DC-DC charger	The alternator loses the bank; nothing stops it unless another battery stays on its output	The battery's and the alternator's
An external regulator with a lithium program, linked to the BMS	The BMS tells the regulator to stop before a charge limit makes it open, by a data link or a signal wire	At the end of a charge, the regulator has already stopped, where the link is set up as both manuals say; at a disconnect on the discharge side, which comes with no warning, the alternator loses the bank	The regulator's and the battery's
A protection module on the alternator	A unit that takes the voltage spike	Takes the spike within its limits	The module's sheet
A DC-DC charger from a lead-acid start battery (→ 8.3)	The alternator charges the start battery; the DC-DC charger charges the lithium bank on its own settings	The alternator keeps the start battery; the DC-DC charger loses its output	The DC-DC charger's and the battery's

Path	What it is	When the BMS opens	Whose manual decides
A BMS with an alternator port	One maker writes that its port controls and current-limits the alternator	As that BMS's manual says	The BMS's
A charging relay (ACR) between a lead-acid battery and the lithium bank	Joins the two banks while it senses a charge (→ 8.3)	While the relay stays closed, the lead-acid battery stays on the alternator	The lithium battery's maker: → "Lithium joined to lead-acid" · p. 21
An outboard's own isolator or charging lead	The engine maker's unit (→ 9.1)	As the engine's manual says	The engine's and the battery's

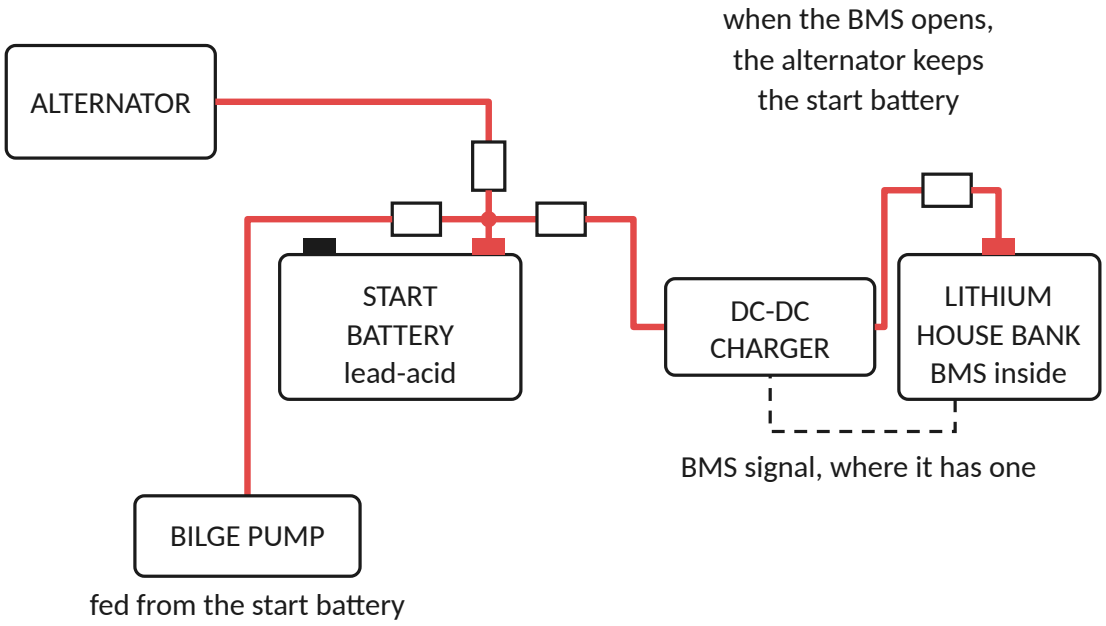


Fig. 11.3. One way to charge a lithium house bank from an inboard engine: the alternator charges the lead-acid start battery, and a DC-DC charger charges the house bank from it. When the house bank's BMS opens, the alternator keeps its battery, and a bilge pump fed from the start battery keeps its power. Every lead drawn from a battery has its own fuse at that battery; the starter cable is not drawn. One typical arrangement: your boat can be wired differently.

The shore charger and its profiles

A charger is set for a lithium battery by its battery maker's numbers (→ 9.3). One marine charger offers a LiFePO4 setting for approved lithium batteries only, and in that setting its DC terminals are powered whenever AC is present (Table 9.2, → 9.3). On a lead-acid charger, the lithium makers differ. One writes that many existing lead-acid chargers will still charge its lithium batteries but that it discourages this: such chargers may end up in a fault code, which can damage other system electronics and even the charger itself; and that where you charge with one anyway, its AGM, gel or sealed profile is the best choice. A second writes that lead-acid chargers do not damage its batteries. A third writes that a charger is not necessarily compatible simply because it turns on or begins delivering current. So a charger with no profile MFR its battery's maker allows — one that maker names for its battery, as the first choice or as a fallback — is not that battery's charger (→ 9.3), and

its equalization or desulfation mode, where it has one, stays off unless the battery's maker approves it.

A charger can also fail to see a lithium battery that its BMS has switched off. One maker writes that some chargers may not sense a battery in low-voltage disconnect; a second, that a charger cannot detect or wake a battery in protection mode, and that you check whether yours can. How the bank comes back then is in → 11.4 · p. 25. MFR

A factory charger built for lead-acid that charges every bank

A boat can come with one charger whose outputs charge every bank. One lithium maker asks you to confirm that every charging bank of such a charger supports LiFePO4 batteries, and writes that a multibank charger designed for lead-acid batteries may use a charging profile that cannot be changed. A charger with one setting for all its outputs charges every bank on it by that one setting (→ 9.3). A lithium bank on one of its outputs and a lead-acid bank on another need a charger whose manual lets each output be set apart, or a charger for each; until then that charger runs only on a setting that every bank on it allows, by its manual and the battery makers' numbers, and otherwise stays off, as step 6 of the route in → 9.3 says. Whether its outputs are isolated from one another is in its manual; a charger whose manual does not say so counts as tying the banks it charges (→ 1.8). MFR

Solar panels, a wind generator, and a signal from the BMS

A solar charge controller is set to the battery maker's numbers like a charger, and how a lithium battery's charge is stopped in the cold — by its own BMS, by the BMS's signal to the controller, or by the controller's own low-temperature cut-off — is in → 10.2. A wind generator's regulator is set as its own manual says: one turbine maker's manual carries a technical bulletin for lithium batteries, and a turning turbine needs a load when the BMS disconnects the bank (→ 10.5).

The same holds for every source: a source the BMS can stop by a signal — a charger's remote on/off port, a controller's remote input, a

regulator's data link — is stopped before a charge limit makes the BMS open, where the link is wired and set up as both manuals say; at a disconnect on the discharge side it loses the battery all the same. A source with no such link keeps charging until a BMS of kind 1, 2 or 3 opens, and then loses the battery; on a BMS of kind 4 nothing stops it (→ "What keeps the alternator safe" · p. 18). The links your boat has, and those it lacks, go into field 12 of the Boat Passport.

The outboard's start battery

An outboard's charging system meets the same physics as an inboard's, and the start battery it charges is set by the engine's own documents:

An outboard's charging output charges the start battery its engine's manual or bulletin allows — a lead-acid battery unless that manual or bulletin allows a lithium one, on the conditions it gives — and charges a house bank only through a unit between them: the engine maker's own isolator or accessory charging lead, as its manual says; a charging relay (ACR); or a DC-DC charger. An inboard with an external regulator may charge the house bank directly (→ 9.1). PRACTICE

A start battery with a BMS can take itself out of the circuit while the outboard charges it; what one outboard maker's numbered statement asks of a lithium start battery is in → 9.1. Which of the three units reaches your lithium house bank, and whether its maker allows it, is in → Table 11.3 · p. 20 and → "Lithium joined to lead-acid" · p. 21.

Lithium joined to lead-acid

 **HOT BATTERY**

A lithium bank and a lead-acid bank rest at different voltages and take a charge in different ways. Joined directly — by a battery switch at BOTH, ALL, 1+2 or COMBINE, a parallel switch ON, or a charging relay that has closed — they become one battery for every source and every load. One lithium maker writes that when batteries are not at the same voltage, or discharge at mismatched rates, the power flows quickly between them. The current that flows is limited only by the two batteries' internal resistances and the cables between them, and the lithium MFR

bank's BMS can disconnect the whole bank on that current or on a starter's (→ 8.5).

The lithium makers set their own limits. One maker's manual says not to operate its battery in series or in parallel with any other type of battery, and the same maker's article names, as the only method it recommends for joining its lithium batteries to lead-acid batteries, an isolator or a DC-to-DC charger in line between the two; another of its articles writes that an emergency parallel switch between a lithium house bank and a start battery is not recommended and is replaced by another means, such as a DC-to-DC charger. A second maker, asked whether a starting battery may be joined in parallel to one of its lithium trolling-motor batteries, answers yes, with a switch to isolate each battery, so that they can be charged separately with a multi-bank charger. A system maker sells a relay that will join a lead-acid starter battery and a LiFePO4 battery only while its BMS's charge-disconnect output allows it and it senses 13.4 V or more, and that parts them at once on a signal of cell overvoltage or overtemperature, or below 13.2 V. Whether your lithium bank may be joined to a lead-acid bank at all, and by which means, is set out in the entry of the HOT BATTERY sign; the means your boat has goes into the Boat Passport — a switch into field 6, a relay or a DC-DC charger into field 9. MFR

Designing a lithium system as one — the bank, its BMS, the charging sources and the links between them — and putting it into service are the subject of → module "Lithium".

11.4. The BMS

What does the battery management system disconnect, when, and what happens then on your boat? A BMS protects the cells: it opens a switch, or tells other units to switch off, when a cell is too low, too high, too cold or too hot to charge or discharge, or when the current is too large. How it does that differs from battery to battery, and so does what goes dark, what the terminals read afterwards and how the bank comes back. This section takes the four kinds in turn, then what a disconnect takes with it, then the route for a bank that went dark.

Four kinds of BMS

The makers' documents in Sources describe four kinds (→ Fig. 11.4 · p. 28, → Table 11.4 · p. 27). In the first, the BMS sits inside the battery case and opens an electronic switch between the cells and the terminals: one maker writes that if a cell falls below its threshold during discharge, the BMS prevents further discharge but still allows a charging current, and that if a cell exceeds its threshold during charging, the BMS stops the charge while discharge is always allowed; a second writes that in protection mode its BMS disconnects the battery from the terminals. In the second, the BMS inside the case works a relay and has a power button of its own: one maker's battery disconnects power when its voltage, current or temperature limits are exceeded, during charging or discharging; a second maker's built-in battery switch also disconnects the battery from the charger. In the third, the BMS is a separate unit with a contactor in the DC system: one system maker's BMS first sends signals that turn the loads and the chargers off, and keeps its contactor as a fallback that opens if the batteries are discharged or overcharged further, disconnecting the DC system. In the fourth, the BMS is a separate unit that only sends signals: it disables the loads by a signal to the load or to the device that disconnects it, and turns the chargers off by a "charge disconnect" signal. MFR

Which kind yours is, is in its manual and goes into field 4 of the Boat Passport, with where the BMS is (→ 2.2). Where you cannot tell yet, assume the widest case: the BMS can take everything on the bank away, charge and discharge alike, and can give it back by itself.

Table 11.4. The four kinds of BMS: what goes dark and what the terminals read, by their makers' documents MFR

Kind	What it disconnects	The battery's terminals afterwards	How the bank comes back
1. Inside the case, an electronic switch	Discharge, charge, or both, by the cause: a low cell stops the discharge and still allows a charge; a high cell stops the charge and still allows a discharge	One maker: 0 to 4 V; a second: under 1 V; a third: above 12 V in its protection mode	By a charge, by itself, or by the method its manual gives
2. Inside the case, a relay and a power button	Charge and discharge, the charger included	As its manual says	By its power button, or by itself, as its manual says
3. A separate unit with a contactor	First the loads and the chargers by signals; then, as a fallback, the whole DC system	Full battery voltage: the contactor opens after them	As that unit's manual says
4. A separate unit that sends signals only	Only what its signal reaches — a device that disconnects the loads, and the chargers it can switch off	Full battery voltage: nothing opens between the cells and the terminals	When the cells recover, as its manual says

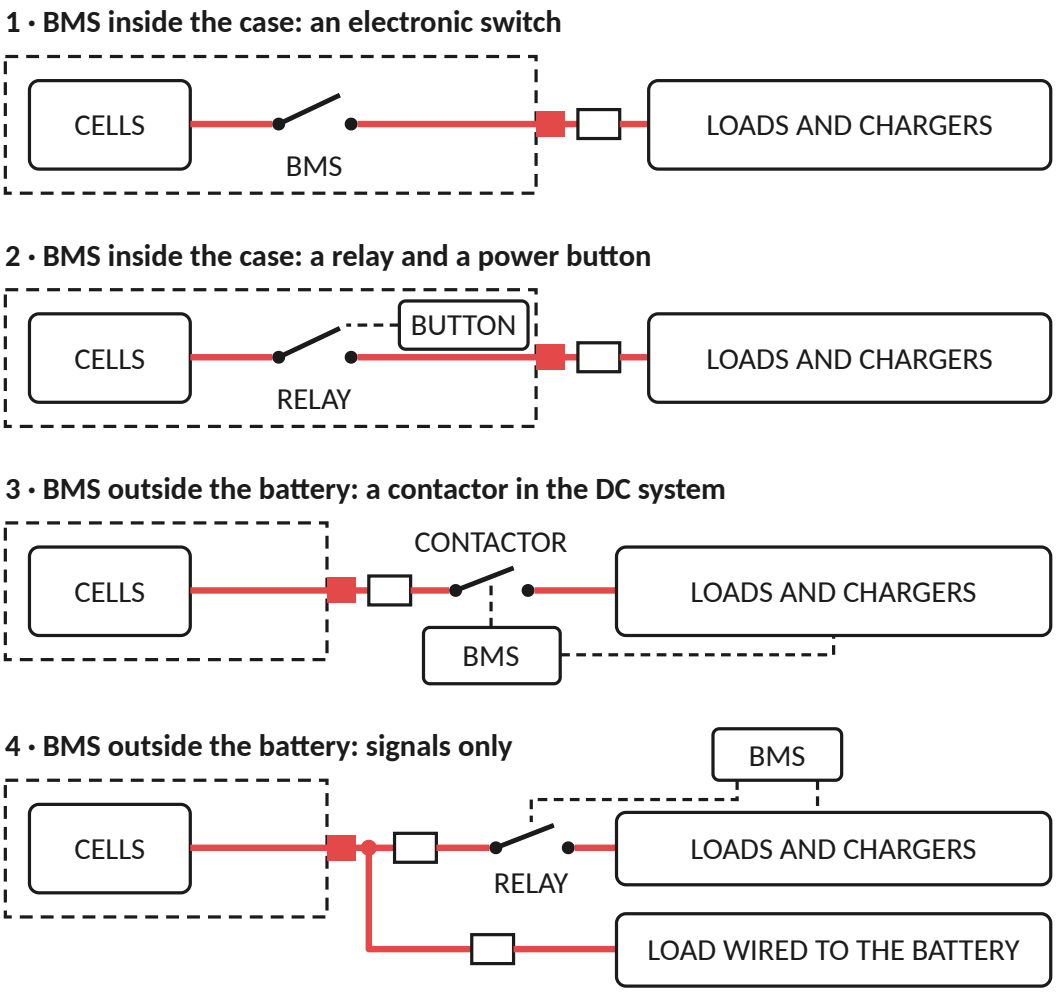


Fig. 11.4. The four kinds of BMS. In 1 and 2 a switch inside the battery case opens between the cells and the terminals. In 3 a contactor outside the battery opens the whole DC system as a fallback, if the signals have not stopped the discharge or the charge. In 4 nothing opens between the cells and the terminals: only what the BMS's signals reach goes off, and a load wired straight to the battery stays on. Every lead from the battery has its own fuse at the battery. Dashed lines are signal wires; the dashed outline is the battery case.

When it disconnects

Each maker sets its own thresholds, and some print more than one in one document. One maker's data sheet gives a charge cut-off at 15.4 V with a reconnect at 14.6 V, a discharge cut-off at 9.2 V, a high-temperature cut-off at 176 °F, and recommends that the loads be disconnected at 11.0 V, before its BMS does it; a second maker's battery cuts off at 10.0 V and reconnects at 12.0 V, and stops a charge at 14.6 V;

one external BMS turns the loads back on only when every cell is at 3.2 V or higher. The thresholds of your battery are in its own manual. Two of the causes come from the charge: a cell too high at the end of a charge, which is how a bank can disconnect itself just after charging (→ 2.7), and a charge in the cold (→ 11.5 · p. 38). One comes from the night: a bank drawn down to its BMS's low limit (→ 7.4). One comes from heat. And one comes from current: a short, or a load larger than the BMS allows. MFR

The makers give that load limit as a continuous current and a surge for some seconds: one maker's 100 Ah battery, 100 A continuous and a 200 A surge for 30 seconds; a second maker's heated 105 Ah battery, 105 A continuous and 200 A for up to 10 seconds; a third maker's larger 12 V battery, 200 A continuous and 500 A for 10 seconds; a fourth writes that the battery's maximum discharge specifications are not to be exceeded. The largest loads on a bank — a windlass, a thruster, an inverter, an engine start — are the ones that can pass it; your battery's own limits are in its manual or data sheet (→ 11.8 · p. 57). MFR

What the terminals read afterwards: 0 V proves nothing

A lithium battery whose BMS has switched it off does not read one voltage. One maker writes that in protection mode its battery reads between 0 and 4 V; a second, that less than 1 V is evidence that its BMS has been triggered; a third, that its battery can read above 12 V in its protection mode (→ 3.5); a battery with a separate BMS of kind 3 or 4 reads its full voltage at its terminals, because nothing opens inside it. So a reading at the terminals does not tell you whether the bank is connected, and a low reading does not tell you that the terminals are dead. MFR

WHY IT WORKS

The cells behind the switch stay charged whatever the switch does: one maker writes that its battery's internal cells remain charged after all power is disconnected, and a system maker, that the terminals of a lithium battery are always live. The switch is also not a switch you hold open. One maker writes that its built-in protection resets after five seconds in most fault conditions; a second maker's battery reconnects by itself at 12.0 V; a third maker's switches itself back on once its cell voltages and temperatures have been within their safe range for at least 30 seconds. A reading of 0 V at the terminals of such a battery shows the switch open at that moment, or a meter whose leads, jacks or fuse have failed (→ 3.7); it says nothing about the next minute. That is why a lithium bank's terminals are live in the source map of → 1.7 whatever its BMS shows, and why no planned job counts a BMS disconnect as proof that a terminal is dead (→ 11.6 · p. 41). MFR

What goes dark with it

 BILGE PUMP  CARBON MONOXIDE

With a BMS of kind 1, 2 or 3, a disconnect takes away everything on that bank at the same moment, wired around the battery switch or after it: one maker writes that its BMS disconnects the battery and shuts down all functions. The electronics go dark and restart when the bank comes back; the bilge pump's automatic switch, the high-water alarm and the CO alarm go dark with it, where they are fed from that bank (→ 12.2, → 12.5, → 8.2). With a BMS of kind 4, what goes dark is what its signal reaches: a load wired to the battery around the device the BMS controls keeps its power, and keeps drawing the cells down. MFR

No battery maker's document in Sources says how to keep the pump and the alarms powered through a disconnect. The physics does. A pump fed from another bank, one that this BMS does not control, keeps working through it (→ 12.2, → Fig. 11.3 · p. 22); a CO alarm can run on its own battery, or be fed from the battery side of a switch on a bank the BMS does not control (→ 8.2). Where they stay on the lithium bank, they go dark at every cause of → "When it disconnects" · p. 28 that takes the whole bank on your kind of BMS (→ Table 11.4 · p. 27). On any kind,

that is a bank drawn down to its BMS's low limit, a short, a load larger than the BMS allows, or cold below the battery's discharge range. On kind 2 it is also a limit of voltage, current or temperature exceeded while the bank charges, and on kind 3 a charge carried on past what its signals stop: a boat left at the dock on shore power, with nobody aboard, can lose them at the end of a charge. What you watch is the bank itself: its state of charge on the monitor before you leave the boat, worked out in days by → 7.4; every charging source's setting against the battery maker's numbers (→ 11.3 · p. 15); a charge in the cold (→ 11.5 · p. 38); and a warning from the BMS where it gives one. What feeds each of them on your boat is traced and written into fields 10, 11 and 15 of the Boat Passport.

A warning can come first. One system maker's BMS gives a pre-alarm to warn that it is about to turn the loads off, at least 30 seconds before it does. A warning keeps nothing powered, and it helps only someone who hears or sees it in time. What ABYC E-13 says of such a warning is in → 11.7 · p. 55. MFR

The alternator, and the battery's own switch, button or app

 GASOLINE VAPOR  BILGE PUMP  CARBON MONOXIDE

A disconnect while the alternator charges is the load dump of → 11.3 · p. 15. A lithium battery's own power switch, button or app setting does to the bank what its BMS does, and to a running alternator what a battery switch turned with the engine running does: the order of → 1.7 for a battery switch holds for it as well. One maker's battery is turned OFF by its power switch and gives its reserve back by a short press of that switch; a second maker's has a built-in battery switch that also disconnects the battery from the charger. Turned OFF, such a switch takes the bilge pump and the CO alarm on that bank with it, just as the BMS does; where your battery has one, it goes into field 6 of the Boat Passport beside the battery switches. MFR

A short the BMS caught before the fuse



Some BMSs open on a short in a few hundred millionths of a second; another maker writes that its BMS turns the battery off when a short lasts more than a few seconds, though not in every case (→ 11.2 · p. 7). Where the BMS opens first, a short on a lithium bank leaves the bank dark and its main protection whole. On the panel this looks like an empty bank: everything dark at once, the switch and the protection looking intact. A Class T fuse or an MRBF that blew can look intact too, with nothing to see, and so can a lug that came loose at the battery: step 4 of the route below tells those apart first. Three things then tell a short from an empty bank. The monitor, where its count is one you trust (→ 7.6): an empty bank was near empty before it went dark; one that went dark with charge on the screen was not. The moment: a bank drawn down goes dark in the night or under a steady load; a short takes it the moment a load is switched on or a cable is worked on, and can come with a bang, a smell or smoke; a load above the BMS's discharge limit takes it each time that load starts (→ "When it disconnects" · p. 28). The battery's app or display, where it has one, names the cause. One maker writes that repeated short circuits, or a sustained one, will damage the battery; a second, that if a battery repeatedly disconnects while charging, you do not keep forcing it back online without understanding why. Whether a bank its BMS disconnected on a short may be woken once, and by what method, is set out in the entry of the BLOWN FUSE sign; the card "The panel went dark — no lights, no electronics" (→ emergency card) holds the same branch in short form.

MFR

How the bank comes back: each maker's way

The makers' methods fall into four kinds. By a charge: one maker names a charge from its own charger as the way its BMS is reset, though not in every case; a system maker has a charger or power supply set to 13.8 V for its 12 V battery; one maker's BMS in low-voltage disconnect still allows a charging current. By its button or app: one maker's battery gives its remaining reserve back through its power switch, held for 1 second. By its loads: one maker writes that disconnecting the battery

from its loads also resets its BMS. By its cables: that same maker has the battery cables disconnected, the voltage read, and the cables reconnected above 10 V, and its article has a battery in low-voltage disconnect jumped with another 12 V source; another maker writes that its battery's voltage returns when the battery cables are disconnected and reconnected. When a charge may go on in the cold is in → 11.5 · p. 38. These makers give the cable method and the jump to the owner; this book counts both as work at a battery terminal (→ 1.8), since the cables come off, and another battery's clamps go on, a terminal that stays live. And the time matters: a battery left in low-voltage disconnect is woken within the time its manual gives (→ "The cost of a mistake" · p. 5). MFR

What the BMS means for a battery test, and for planned work at a lithium battery's terminals, is in → 11.6 · p. 41.

Route: the lithium bank went dark, or stopped taking a charge

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → a new load or a cable worked on, and the bank went dark at that moment: steps 1 to 4 in order; step 5 reads that moment
- after charging → a bank that went dark at the end of a charge, or a source above its setting: steps 1 to 4 in order; step 5 reads which
- after rain or washing the boat → water at the battery: step 1
- after the boat sat unused → a draw that took the bank down (→ 7.3): steps 1 to 4 in order; step 5 reads it
- after switching sources (shore power, generator, inverter) → which source charges the bank now: steps 1 to 4 in order; step 5 reads it
- nothing you noticed → step 1

ROUTE: THE LITHIUM BANK WENT DARK, OR STOPPED TAKING A CHARGE — THE FOUR KINDS ON → FIG. 11.4 · P. 28

 HOT BATTERY  BLOWN FUSE  BILGE PUMP  CARBON MONOXIDE
 SHORT CIRCUIT  METER LEADS  GASOLINE VAPOR

1. From outside its compartment, smell and listen at the battery, and look at it where you can see it without reaching in.

   You will see: Hissing, venting or a case that swells fast: the card “Battery smells, is swollen, or is hot” (→ emergency card), its first action. Hot or swollen, with no hiss or vent: the same card, its lithium branch. Smoke or a burning smell: the card “Smoke, a burning smell, or an overheated wire” (→ emergency card). Water in the boat at its terminals: the card “Water in the boat — the pump can’t keep up or is silent” (→ emergency card), then step 2; what may charge or wake that bank afterwards is in the entry of the HOT BATTERY sign. Water on its case, its terminals dry: wipe the case dry with a cloth; step 2. None of these: step 2. You cannot see the battery: what you smell and hear decides; none of these signs, step 2.

2. Under way, get to safe water or anchor first. Look at the bilge pump and the alarms on this bank, from your Boat Passport (fields 10, 11 and 15).

   You will see: They are dark with the bank: watch the water, and bail if it rises, until the bank is back; the entries of the BILGE PUMP and CARBON MONOXIDE signs say what applies meanwhile. They are fed from another bank and still work: step 3. You do not know what feeds them: treat them as dark.

3. After the boat is safe, stop the engine; turn off every other charging source on this bank — the charger at its own switch, a DC-DC charger at its own control, the solar panels covered or their solar disconnect switch OFF, a wind generator stopped at the control its manual names (→ 10.5) — and turn the loads on this bank off at their own switches, the bilge pump’s switch and the alarms left as they are.

   You will see: With the sources and the loads off, a bank that its BMS switches back on by itself comes back neither under a charge nor onto the load that took it down: one maker’s BMS resets after five seconds in most fault conditions, and a second maker’s switches itself back on after at least 30 seconds within its safe range (→ “What the terminals read afterwards” · p. 29). It comes back by itself: its loads stay off, and the route goes on to step 4 — step 5 still reads why it went dark. A wind generator turning with the bank dark has no load; stop it right

away, as its manual names. A battery whose heater runs only on the charge current cannot warm with every source off: step 8 says when one source goes back on for it.

4 Look at the battery switch, the main panel breaker and the main protection at the battery, and at the lugs on the battery's terminals and on the main protection, without touching them (→ Fig. 11.2 · p. 13). Where the main protection shows nothing by eye — a Class T fuse or an MRBF has no window — and has no indicator its maker names, read from the bank's negative, H on → Fig. 11.2 · p. 13, to each of its two studs, A and then B.

You will see: The battery switch at OFF, the main panel breaker tripped, or the main protection blown or tripped — by eye, by its indicator, or with A at about the bank's voltage and B at about 0 V: the card "The panel went dark — no lights, no electronics" (→ emergency card), from its tree. A lug that looks loose or discolored: the route ends here — the same card, its branches "Still dark" and "A lug is loose". Insulation melted or blistered at a lug: the card "Smoke, a burning smell, or an overheated wire" (→ emergency card). A main protection whole by eye, or A and B at about the same reading, whatever it is, with the switch and the breaker as they should be: the main protection is not open — step 5. Its studs out of reach under a cover held by a nut: step 5; if the bank does not come back there, the main protection goes to a pro with your readings. You cannot find the main protection: the same card, its branch "I don't know / can't see / can't reach it".

5 Read the cause: the battery's app or display, as its manual explains it; the monitor's state of charge and what it showed before the bank went dark — where the monitor went dark with the bank, the battery's own charge indicator, or a charging source's display that shows the battery's state of charge, in its place; and when it went dark and what happened at that moment.

You will see: A short circuit or an overcurrent named — whatever the monitor shows — or a bank not near empty that went dark as a load was switched on or a cable was worked on, with a bang, a smell or smoke: what you do is in the entry of the BLOWN FUSE sign, and with smoke or a burning smell, the card "Smoke, a burning smell, or an overheated wire" (→ emergency card); a bank that came back by itself after step 3 and went dark again has disconnected again. A bank that went dark as one large load started — a windlass, a thruster,

an inverter, an engine start — can be past its BMS's discharge limit rather than shorted (→ "When it disconnects" · p. 28): that load goes to the pro with your readings. Otherwise: low cell or low voltage, or the bank near empty before it went dark — the bank was drawn down, step 6. High cell or high voltage named, or a bank of kind 2 or 3 that went dark at the end of a charge: a source above the battery's numbers, or one cell that reached its limit before the others — step 7. A BMS of kind 1 stops only the charge at a high cell, and its loads stay on: a bank of kind 1 that went dark at the end of a charge went dark for another cause — what its app names, or, with nothing named, the card "The panel went dark — no lights, no electronics", its lithium branch (→ emergency card). Low temperature — step 8. High temperature — the card "Battery smells, is swollen, or is hot" (→ emergency card). No app, no display, no monitor and no other reading of the state of charge, or none of them names a cause: the card "The panel went dark — no lights, no electronics", its lithium branch (→ emergency card). A switch, button or app of the battery's own found OFF: turn it back ON by the method its manual gives, with the engine stopped — the bank has power again: who or what turned it OFF goes into field 15, and the restore follows.

6 Drawn down: charge it from a source set to its battery maker's numbers — the charger, a DC-DC charger with the engine running (→ Table 11.3 · p. 20), the solar panels — by the method its manual gives for a battery in low-voltage disconnect, and within the time it gives.

You will see: The bank comes back and takes a charge: the restore follows, and the budget of → 7.4 says why it went down. The charger does not see it: the method its manual gives the owner — a portable charger its manual names, its clamps on the terminals as the entry of the SHORT CIRCUIT sign says; a method that takes cables off the battery, or puts another battery on its terminals, is work at a battery terminal (→ 1.8). The only source at hand is the engine, run at rest to charge, while the CO alarm is dark with the bank: the entry of the CARBON MONOXIDE sign governs that run; until it can go ahead, step 2 stays in force, with a portable light where the boat needs its lights, and a call for help where it needs help. It does not come back by its manual's method: the readings and the manual to a pro, and the bank stays dark until then, with step 2 in force.

7 A source above the battery's numbers: find which source was charging when it went dark, and read its setting against the battery maker's numbers (→ Table 11.2 · p. 16): the regulator (→ 9.2), the charger (→ 9.3), the charge controller (→ 10.2), a wind

generator's regulator (→ 10.5).

You will see: A setting above the battery's numbers that its manual lets you change: change it as that manual says and write it into field 12; until it is changed, that source stays off. A setting above the numbers that its manual does not let you change — an alternator's own built-in regulator, a charger with one fixed profile: that source stays off this bank until a pro has dealt with it; where it is the alternator, the engine is not run to charge this bank, and still is when you need it to reach safety. A battery of kind 1 whose BMS stopped only the charge still feeds its loads and can reconnect by itself when its voltage falls — one maker's at 14.6 V: the restore follows. No setting above the numbers: one cell that reached its limit before the others, or the source and its link to the BMS — the cell voltages from the app and the settings to a pro.

8 Low temperature: let the battery warm, and read its own temperature again in its app or on its display; on a battery whose heater runs only on the charge current, a source set to its battery maker's numbers goes back on for it as its manual says, and its BMS holds the cells from charge until they are warm. When, and at what current, a source may charge it meanwhile is in → 11.5 · p. 38.

You will see: A battery of kind 1 stopped only from charging still feeds its loads within its discharge range. The whole bank dark in the cold: step 2 stays in force until it is back.

PUT THE BOAT BACK IN SERVICE

- With the bank back, the loads you turned off in step 3 on again, one at a time; the electronics that restarted, set again where they lost their settings.
- The charging sources you turned off in step 3, back on only after the bank is back and the cause of steps 5 to 8 is dealt with — one put back on for a heater in step 8 stays on: the charger at its own switch, a DC-DC charger at its own control, the panels uncovered or the solar disconnect switch back ON, a wind generator released last, as its manual says. A source whose setting waits for a change or a pro stays off; where that source is the alternator, the engine runs only when you need it to reach safety.
- A switch, button or app of the battery's own that you turned: at its working position, with the engine stopped.

- The CO alarm on this bank lost its power while the bank was dark; the entry of the CARBON MONOXIDE sign says how you see that it is working again.
- Check that the bilge pump's automatic switch has power, by the procedure "The check that the automatic switch has power" (→ 12.2).
- What you found — the cause, the readings, the time — written into field 15 of the Boat Passport.

11.5. Cold: charging below your battery's charging temperature, and where on a boat it gets that cold

When may your lithium battery take a charge in the cold, and how cold does it get where it sits? A lithium battery's maker gives a range of temperatures for the charge — and on some batteries a current that falls with the temperature. Below that range, a charge can damage the battery for good; one maker calls charging below 32 °F unsafe and writes that it will drastically and permanently reduce the capacity, and another that a current that is not reduced below freezing can cause irreversible damage to its battery. MFR



HOT BATTERY

The makers set different limits (→ Table 11.5 · p. 39). One maker's BMS will not allow a charging current under 32 °F, and keeps discharging down to −4 °F; the same manual's table for its heated model gives a charge temperature of 25 °F to 135 °F. A system maker gives its battery a charging range of 5 °C to 50 °C (41 °F to 122 °F) and asks that every charger be switched off when the lowest charging temperature is reached, best by a remote on/off port that its BMS controls. One maker allows a charge from −4 °F to 130 °F on one model, but at no more than a tenth of its capacity in amps (0.1C — 10 A on that 100 Ah battery) from 14 °F to 32 °F, and no more than a twentieth (0.05C, 5 A) from −4 °F to 14 °F. One maker's heated battery disables charging at 32 °F and resumes it by itself at 41 °F, and charges from −4 °F with its heater. One

maker gives 32 °F to 131 °F as its charging range. One number does not fit them all: 32 °F is the limit of several, 41 °F of one, and another allows a reduced current below freezing. MFR

Table 11.5. Charging in the cold: six lithium makers' limits, as printed; the makers are numbered within this table MFR

Maker	Charging range	Below 32 °F	What stops or limits a cold charge
Maker 1, a 100 Ah battery and its heated model	From 32 °F up to 131 °F, internal temperature; discharge down to −4 °F. The heated model's own table in the same manual: 25 °F to 135 °F	No charging current, in the manual's section on the BMS	Its BMS, by itself; the heated model heats at an internal temperature of about 35 °F, with its heat function enabled
Maker 2, a battery with an external BMS	5 °C to 50 °C (41 °F to 122 °F)	No charge	Every charger switched off at that temperature, best by a remote on/off port its BMS controls
Maker 3, its batteries (manual)	Not below 32 °F, unless the battery has internal heating	Unsafe; capacity drastically and permanently reduced	—
Maker 4, one 100 Ah model; a heated series	−4 °F to 130 °F	At most 0.1C (10 A) from 14 °F to 32 °F; 0.05C (5 A) from −4 °F to 14 °F	The charging source held to that current; its heated series heats with the charging current before it allows a charge
Maker 5, a heated 105 Ah battery	−4 °F to 131 °F, with heating	Charging disabled at 32 °F; resumes by itself at 41 °F	Its heater, powered only by an incoming charge current of at least 0.5 A
Maker 6, a 320 Ah battery	32 °F to 131 °F	No charge	—

Who stops a cold charge on your boat

On some batteries the BMS stops a cold charge by itself. On others, a charging source has to be stopped, or held to the maker's reduced current, from outside: by the BMS's signal, by a low-temperature cut-off of the source itself that reads the battery's temperature, where its manual has one and it is set up (→ 10.2), or not at all. A regulator maker writes that its regulator cannot prevent charging at low temperatures (→ 9.2), so on a bank whose BMS does not stop a cold charge itself, the alternator's charge needs a stop from outside: a BMS link, or a DC-DC charger that one is wired to (→ Table 11.3 · p. 20). On a bank whose BMS does stop it, the alternator needs something else: the BMS stops that charge while the alternator may be charging, and an alternator that charges only that bank then loses its battery, as at any opening of the BMS (→ "What keeps the alternator safe" · p. 18). Which way your battery works is in its manual; where no source on your boat can be stopped or held, the entry of the HOT BATTERY sign says what then, and so it does where you cannot read the battery's range at all.

A heater warms the battery from somewhere. One maker's heater draws only on an incoming charge current, never on the battery's own energy; a second maker's heated series uses the charging current to heat the battery before it allows a charge, and its heater engages only during charging, below 32 °F; a third maker's battery turns its heater on by itself below 32 °F, until 41 °F is reached or the charger is disconnected. On all three, no source charging means no heat: a heated battery on a boat with every source off is as cold as the air around it. The heater of your battery, what powers it and when it runs, is in its manual. MFR

A battery that has just warmed can still refuse a charge. The heated battery of → Table 11.5 · p. 39 that stops at 32 °F resumes only at 41 °F, so between the two, on the way up after a cold night, it takes no charge and is not faulty. And the temperature that counts is the battery's own: one maker writes of the internal temperature of its battery. MFR

Where on a boat it gets that cold

No battery maker's document in Sources gives the temperature of a boat's compartments, and this book gives none. What you read is the battery itself: its temperature in its app, on its BMS's display, or on a battery monitor whose temperature sensor sits on the battery. A thermometer in the compartment reads the air, not the cells. A battery is a heavy block: after hours in cold air, or against a cold hull, it comes to their temperature, and it warms again more slowly than the air. On a cold morning the air in the cabin can be warm while the battery below is still cold, and its BMS still holds the charge back. PRACTICE

Four scenes bring the cold to a lithium bank. A boat that lives on the water in winter, with the bank charging from shore. A boat stored ashore or on a trailer, with solar panels or a charger left on it. The first sunny morning after a frost, when solar panels start charging before the battery has warmed (→ 10.2). And an engine started on a cold morning, whose alternator charges the bank the moment it runs. In each, the battery's own temperature against its maker's range decides. For a battery that gives no reading of its own temperature, its manual says whether its BMS stops a cold charge by itself; where it does not, or where you cannot read its range, the entry of the HOT BATTERY sign says what then (→ "Who stops a cold charge on your boat" · p. 40).

Storage is another matter. The makers give storage ranges of their own — one from 23 °F to 95 °F, a second from 40 °F to 95 °F (→ "Weight, life and storage" · p. 4).

11.6. Lithium already aboard: a one-evening audit

A lithium bank is already on your boat: is it protected, charged and wired so that it fails safely? Most of the answer can be read in one evening with the engine stopped, by eye, from labels and settings, in the battery's app and with a meter. The procedure "The one-evening audit of a lithium system" goes through it in the order of what burns first, then what floods, then what breaks; after it come what to fix first

and what you can live with until then, how a lithium battery is tested, and the planned work you can do on one.

Procedure: The one-evening audit of a lithium system

For a boat with a lithium bank of any kind, not under way, with the engine stopped for the whole audit. You need a flashlight, a multimeter, a bucket of tap water or of the water around the boat for the check of 12.2, the battery's manual, the manuals of the charger, the regulator, the DC-DC charger and the charge controller, the battery's app where it has one, and the Boat Passport. Nothing in this audit takes a cable off or puts a tool on a terminal.



1. Read the battery's label and find its manual by the model printed there: the maker, the model, the revision of the manual, how many batteries the bank has in parallel or in series, and which of the four kinds of BMS it has (→ Table 11.4 · p. 27). Write them into field 4 of the Boat Passport. No model on the label: the maker's support asked in writing, and the answer into field 15.
2. Read the main protection, by the procedure "Reading the main protection of a lithium bank" (→ 11.2 · p. 7), and write what you read into field 7.
3. Follow every positive lead that leaves the bank by eye, without touching it, to its first fuse or breaker, and read each one's type, rating and interrupting rating as step 3 of that procedure does. A positive with no fuse at its start, other than the starter cable traced to the starter: write it on the first line of the Boat Passport; the entry of the BLOWN FUSE sign says what that lead may carry until a pro protects it. A lead you cannot follow: "not traced" in field 15.
4. Find everything that can join this bank to a lead-acid bank — a battery switch with BOTH, ALL, 1+2 or COMBINE, a parallel switch, a charging relay, a DC-DC charger — by its label and its place (→ 8.3), and look at its position without turning it. Write each switch into field 6 and each relay or DC-DC charger into field 9, with what

the lithium battery's manual says about it (→ "Lithium joined to lead-acid" · p. 21).

5. Read the charger's setting for each of its outputs on its display or switches, against the battery maker's numbers (→ Table 11.2 · p. 16): its profile, an equalization or desulfation mode, a temperature sensor, and whether its manual lets each output be set apart and calls its outputs isolated (→ 11.3 · p. 15). Write the settings into field 12. Change nothing in this step.
6. Find how the engine charges this bank, by → Table 11.3 · p. 20: where the alternator's output lands, whether a regulator, a DC-DC charger, a charging relay or an outboard's own lead stands between, and what keeps the alternator on a battery when the BMS opens. Write it into fields 9 and 15; "not known" where you cannot trace it.
7. Read the charge controller's setting, its low-temperature cut-off and its link to the BMS (→ 10.2), and a wind generator's regulator setting (→ 10.5), into field 12.
8. From the battery's manual and the sources' manuals, write into field 15 what stops a charge on this bank in the cold: its BMS by itself, a signal, a cut-off at each source, or nothing you can find (→ 11.5 · p. 38).
9. Trace by eye what feeds the bilge pump's automatic switch, the high-water alarm and the CO alarm, and whether it is this bank — at the battery, wired around the battery switch, or after it (→ 8.2, → 12.2). Write each into fields 10 and 11. A wire you cannot follow by eye: "not traced", and it counts as fed from this bank.
10. Not under way, and at anchor only by day, where the battery's manual gives the owner a way to turn it OFF and back ON — its power button, its switch or its app: first every charging source off — the charger at its own switch, a DC-DC charger at its own control, the solar panels covered or their solar disconnect switch OFF, a wind generator stopped at the control its manual names; then turn the battery OFF by that way, and see what goes dark — the panel and the electronics. With the battery still OFF, press the test button of the CO alarm, and of the high-water alarm where it

has one, and take the check that the bilge pump's automatic switch has power (→ 12.2): an alarm that sounds, or a pump that starts, has its power from elsewhere. Then turn the battery back ON the same way. Write into field 15 what went dark and what kept its power. A battery with no such way: what step 9 found on this bank is what its BMS takes with it.

11. Open the battery's app, where it has one, and read what its manual explains there: the cell voltages, the temperature, the state of charge and any alarm or event it has stored. Write anything its manual calls a fault into field 15.
12. Read the battery monitor's settings against → "The monitor on a lithium bank" · p. 6, and write them into field 12.
13. With the flashlight, look at every terminal and lug of the bank without touching metal: a lug that is discolored, insulation that has melted or blistered, a smell; then lay the back of your hand on each cable's insulation a few inches from its terminal. A terminal, a lug or a cable that is hot, or a battery case that is hot or swollen: the audit ends here, and the card "Battery smells, is swollen, or is hot" takes over (→ emergency card). A lug that looks loose: write it on the first line of the Boat Passport; the planned job of → "Planned work on a drop-in battery" · p. 44 tightens it where that job is yours, and a pro where it is not.
14. Read the voltage at the bank's terminals, the meter set as the entry of the METER LEADS sign says, the red probe on the positive terminal and the black on the negative, for the record in field 4 — not as proof of anything (→ 11.4 · p. 25).
15. Write the list: every finding, in the order of → "What to fix first" · p. 44, the first ones on the first line of the Boat Passport, with the date.

PUT THE BOAT BACK IN SERVICE

- A cover you lifted in step 2: back on, seated as it came off.
- The battery turned OFF in step 10: back ON by the way its manual gives. It does not come back ON: the card "The panel went dark — no lights, no electronics" (→ emergency card), its lithium branch.

- The charging sources you turned off in step 10: back as you found them, the panels uncovered or the solar disconnect switch back ON, the charger and the DC-DC charger at their own controls, a wind generator released last, as its manual says — except a source that step 5 or 7 found with no setting the battery maker allows, which stays off until it has one (→ "What to fix first" · p. 44), and one that step 8 found with nothing to stop it in the cold, which the entry of the HOT BATTERY sign governs.
- Where step 10 turned the battery OFF: the CO alarm on this bank lost its power for that time; the entry of the CARBON MONOXIDE sign says how you see that it is working again. Check that the bilge pump's automatic switch has power, by the procedure "The check that the automatic switch has power" (→ 12.2).
- The meter's dial at OFF.

What to fix first

Fix in the order of what harms most, and live with the rest on the terms the book gives for each:

- **A positive with no fuse, or a main protection that does not meet the bank's short-circuit current or cannot be read.** These can start a fire. A pro protects the lead or sizes the main protection (→ 11.9 · p. 61). Until then, the main protection's terms are in → "The main protection of a lithium bank" · p. 11, and an unprotected lead's in the entry of the BLOWN FUSE sign.
- **A bilge pump, a high-water alarm or a CO alarm that the BMS takes with it.** A pro can feed them from a source this BMS does not control (→ 11.4 · p. 25). Until then, they go dark at each cause that takes the whole bank on your kind of BMS — on kinds 2 and 3, the end of a charge as well — and both those causes and what you watch are in → "What goes dark with it" · p. 30.
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A lithium bank joined to a lead-acid bank by a means its battery maker does not name. A pro replaces the means with one the maker names (→ "Lithium joined to lead-acid" · p. 21). Until then, the two banks are kept apart by that means's own

controls, as its manual gives them: a battery switch at a position that joins neither bank to the other, turned with the engine stopped; a parallel switch OFF; a charging relay at the position its maker gives for holding it open, where it has one, or else with its own fuse at one bank out, as the entry of the SHORT CIRCUIT sign says. The start battery then takes its charge on its own, as its manual and its charging source's manual say.

- **An alternator with nothing to keep it on a battery, or to stop it, when the BMS opens.** This one costs equipment: the alternator, its regulator and what is attached to them. A pro adds one of the ways of → Table 11.3 · p. 20. Until then, the engine is run as the alternator's maker and the battery's maker allow, and it is run whenever you need it to reach safety; an alternator whose own regulator charges above the battery maker's numbers and cannot be set down is not run to charge this bank, except on the way to safety (step 7 of the route in → 11.4 · p. 25).
- **A source with no setting the battery maker allows, or nothing that stops it in the cold.** A source with no such setting does not charge this bank until it has one, and the bank takes its charge another way meanwhile (→ 11.3 · p. 15); a source with nothing to stop it in the cold is governed by the entry of the HOT BATTERY sign (→ 11.5 · p. 38).
-  HOT BATTERY **Settings, the monitor and the Boat Passport.** Yours to put right the same evening, each by its own manual.

Testing a lithium battery

The tests of → 3.6 and → 6.6 belong to lead-acid batteries. The load test's numbers come from lead-acid battery makers, for their batteries; one conductance tester lists flooded, AGM and gel batteries as the ones it tests (→ 3.6). A lithium battery is tested as its own maker's MFR manual says, and what an owner can read without a tester is what this audit reads: its cells, its temperature and its alarms in its app, and what the battery monitor counts between full charges — the amp-hours the bank gives from full to the depth you use, against what its label promises. A capacity test that takes the bank down to its BMS's limit, for the amp-hours it still holds, is for its maker to describe, or for a pro.

A hot or swollen lithium battery



HOT BATTERY

A lithium cell that fails inside heats itself, and its gases burn and are toxic (→ 1.1). The card "Battery smells, is swollen, or is hot" (→ emergency card) takes a lithium battery that hisses, vents or swells fast first, and has its own branch for one that is hot or swollen but does not hiss or vent. One maker writes that a visibly damaged, dented, bulging or punctured battery is neither charged nor operated; a second, that a battery with any sign of physical damage is not installed; a third, that a terminal that feels hot, looks discolored or smells unusual is a reason to stop the charge and look at the system. The cells behind the terminals stay charged whatever its switch or its BMS does (→ 11.4 · p. 25), which is why that branch keeps metal away from them. MFR

Planned work on a drop-in battery

Some lithium batteries are made to take a lead-acid battery's place, with their BMS inside the case — a drop-in battery. Where its maker's manual speaks to the owner, it gives the torque of the terminal hardware: one maker asks that its hardware be torqued to 9 to 11 ft-lb, not finger-tightened, writes that failing to meet that may result in system damage or failure, and that its battery is not operated with loose connections; a second gives 10 ft-lb at most, and writes that more can damage the terminal. A U.S. Coast Guard safety alert reports a lithium battery fire on an inspected vessel that began when loosely crimped lugs overheated (→ 11.7 · p. 55). A lug that is loose, or a battery that comes out and goes back — also a drop-in that takes a lead-acid battery's place — is the planned job on a drop-in battery, the procedure below. The BMS and the chemistry change three things, and the procedure takes each: a BMS that has disconnected the battery proves nothing about its terminals (→ 11.4 · p. 25); the terminal hardware and its torque are the battery maker's; and batteries at different voltages, joined together, push current between them (→ "Lithium joined to lead-acid" · p. 21). What a drop-in in a lead-acid battery's place asks of the rest of the boat — the settings of the charger MFR

and the alternator, the main protection, the joins — is in → 11.3 · p. 15, → 11.2 · p. 7 and the checklist of → 11.8 · p. 57.

Not every such manual speaks to the owner. Two makers of batteries with their BMS inside write that work on them is for qualified personnel, and so does a maker of batteries that need an external BMS; their manuals speak to such people, not to the owner. What stays a pro's on a lithium bank, and what is yours, is set out in → "Do it yourself or hire a pro" · p. 48. MFR

Procedure: A planned job on a drop-in battery

For a 12 V lithium battery with its BMS inside its case — a drop-in — whose maker's manual speaks to the owner: one on its own, or one of a bank of such batteries joined in parallel, where its manual and its product specification allow parallel connection and only with the batteries they allow with it; and for a drop-in that takes the place of a 12 V flooded, AGM or gel battery. The battery is not hot, swollen or gassing, water in the boat has not reached its terminals, and its positive terminal carries no fuse bolted to it. The job: taking it out and putting it or a new one back in, both in one session — before you leave the boat, or, on a boat out of the water, later by this procedure from step 1, before the boat goes back in the water (step 15) — or cleaning or tightening its terminals. A battery in trouble goes to the card "Battery smells, is swollen, or is hot" (→ emergency card); a battery whose terminals water in the boat reached, to the card "Water in the boat — the pump can't keep up or is silent" (→ emergency card). A battery with an external BMS, a battery in a system its maker reserves to qualified personnel, a fuse holder bolted to the positive terminal, a battery cable replaced, a new lug crimped on a cable, a battery of a bank in series, and a battery whose bank is tied on the positive side to a bank in series are a pro's (→ 1.8). On someone else's boat this job is not yours: tools — no (→ 2.6).

You need: the battery's manual, with the terminal hardware and the torque it gives; a torque wrench with insulated handles that covers that torque — without one, the job waits; the gloves and the eye protection that the entry of the SHORT CIRCUIT sign names, and, where a lead-

acid battery comes out, those of the BATTERY ACID sign; your meter; tape, a marker and cable ties; insulating tape or boots for the lugs you lift off; a terminal brush and a clean cloth; the battery's own handles or a lifting strap. The points A, B and C are those of the battery procedure in → 6.5; steps 11 and 12 name them.



1. If the boat needs its engine running, or its navigation or anchor lights, its radio or its electronics, from this bank or from a bank tied to it (step 10) — under way, or at anchor after dark — while the job lasts, or before a pro could come if the battery cannot go back in (step 15), stop here until it does not. Nothing the boat needs before then runs from this bank, from a bank tied to it or from the engine.
2. If a new battery goes in, it is on board before the job starts: the battery that comes out, or the new one, goes back in during this session, before you leave the boat, or — on a boat out of the water — later, as step 15 says. If a battery will join others in a bank, charge each battery of the bank before the day of the job, and each new one as well, fully, as its manual says, on a charger set to its maker's numbers (→ 11.3 · p. 15), until the charger shows the charge complete. A drop-in that takes a lead-acid battery's place goes in only after the checklist of → 11.8 · p. 57 has been gone through for it and its findings written into the Boat Passport. Any new battery is on board, and each charger has shown the charge complete.
3. Read each battery's label and the manual of its model, and follow each jumper on its terminals by eye to the terminal at its other end (→ 6.4); do the same on every bank tied to its bank, by the ties step 10 names. Look, listen and smell first, without touching the battery; then lay the back of your hand on the side of its case, away from the terminals. A drop-in whose maker's manual speaks to the owner — or a 12 V flooded, AGM or gel battery that comes out for one — on its own or joined to the others of its bank only positive to positive and negative to negative, with batteries the drop-in's manual and specification allow with it — after the job, no lead-acid

battery stays in the same bank with a drop-in — whose bank is tied to no bank in series, cool, not swollen, with no hiss and no smell, no water in the boat at its terminals and no fuse holder bolted to its positive terminal: continue. Anything else: this procedure stops here, and the paragraph above says where the battery goes.

4. With the engine stopped, open the battery compartment to the air. In a compartment with a gasoline engine or tank, the entry of the GASOLINE VAPOR sign says what comes first; nothing is switched off yet, so the blower still has power. Leave the compartment open for the time the entry of the SHORT CIRCUIT sign gives for this job before you continue. The time has passed on your watch.
5. Stop every other source that can charge the battery: the charger and any inverter/charger at its own switch or at its breaker on the AC panel; a DC-DC charger at its own switch, or at the DC breaker or isolation switch that feeds it; the solar panels at their disconnect switch, or covered; a wind generator stopped as its manual says; a generator stopped, with its automatic start OFF. The charger's light or display shows no charging.
6. Switch every load off: each at its own switch or at its breaker on the DC panel, and the inverter at its own switch. Nothing you switched runs.
7. With the engine stopped, turn the battery switch of this bank OFF; a selector that joins two banks — BOTH, ALL, 1+2 or COMBINE — goes to OFF. On a boat with no battery switch, step 6 has already switched every load off. What this switch fed is dark. What still works now is wired around the battery switch (→ 1.7): a bilge pump's automatic switch, a CO alarm or an electronics memory loses its power when the negatives of its bank come off in step 10, and the restore below gives it back. A drop-in's own switch, button or app stays where it is: the battery switch is what this job turns.
8. Get ready as the entry of the SHORT CIRCUIT sign says for this job — and, where a lead-acid battery comes out, the entry of the BATTERY ACID sign: what comes off your hands, wrists, neck and belt, what you put on, and the torque wrench of the list above. Nothing on those lists is missing.

9. Mark each cable before anything comes off: a piece of tape on each lead and each jumper, with the battery it is on and + or −, and a photograph of the whole bank. Every lead and jumper carries its tape.
10. Take off the negative leads one at a time, starting with the bank's main negative cable — to the negative bus or to the shunt: loosen its nut with the wrench and lift its lug off the battery's negative terminal; cover the lug at once with insulating tape or a boot, and tie the lead back so that it cannot touch a terminal, another lead or other metal. Then, the same way, every other negative lead on every battery of the bank — the charger's, and those of circuits wired around the battery switch. The jumpers that join positive to positive and negative to negative stay; a jumper's lug under the same nut stays on the terminal. Then the same on every bank tied to this one on the positive side, its main negative cable first, then its other negative leads: a bank tied by a battery switch at BOTH, ALL, 1+2 or COMBINE, a parallel switch ON, a charging relay (ACR) whether or not it seems closed, a DC-DC charger, or a charger — a charger with an output for each bank whose manual says those outputs are isolated from one another is no such tie (→ 1.8). No lead is left on a negative terminal of these banks but a jumper that joins two negatives, and every lug you lifted is covered and tied back.
11. Set the meter as the entry of the METER LEADS sign says, and put the probes on A and B: A, the bank's positive terminal — the one its positive cable leaves from — and B, the same battery's negative terminal. The meter reads that battery's voltage. This proves the meter and its leads on a known live source. A battery that reads far less — a flat one, or one whose BMS has disconnected it (→ 11.4 · p. 25) — proves nothing: prove the meter on a known live source instead, across the two terminals of a charged battery of another bank or of a charged spare battery, and use the same source in steps 13 and 14. With no such source, the job waits: put back what step 10 took off, as step 18 says, then the restore below.
12. Keep the red probe on A and move the black probe to C: bare metal of the negative bus — for a bank kept apart from the boat's other

negatives (→ 6.4), of that bank's own negative cable at the lug you took off, its tape opened for the probe and closed after it. It reads 0 V: nothing joins this bank's positive to a battery any more — continue. Any voltage: something still does — a negative lead still on, a charging source still on, a bank tied to this one — and the job is a pro's. No tool touches a positive lug or terminal: take step 5 again, then put back what step 10 took off, as step 18 says, then the restore below.

13. Put the probes back where step 11 proved the meter. The meter reads that voltage again: it was working through the 0 V reading. If it does not, the 0 V proved nothing: find why the meter failed (→ 3.7) and take steps 11 to 13 again; with no working meter today, put back what step 10 took off, as step 18 says, then the restore below.
14. Read each positive terminal you will work on that is not A — each drop-in's own positive terminal among them, whatever its BMS shows (→ 11.4 · p. 25): the red probe on it, the black probe on C as in step 12, and then both probes back on the source of step 11. It reads 0 V, and the source its voltage again: continue. Any voltage on the terminal: the job is a pro's, and no tool touches a positive lug or terminal — take step 5 again, then put back what step 10 took off, as step 18 says, then the restore below. A source that no longer reads its voltage: the 0 V proved nothing — find why the meter failed (→ 3.7) and take steps 11 to 14 again; with no working meter today, put back what step 10 took off, as step 18 says, then the restore below. Each positive terminal you will work on has read 0 V.
15. Do the job:
    - to take a battery out: loosen every positive lead and every jumper still on its terminals, one at a time, and lift their lugs off; cover each one and tie it back as step 10 does, the free end of a jumper whose other end stays on a battery of the bank as well; unfasten the hold-down; and lift the battery out by its handles, or by a strap under it — never by its terminals;
    - to put a drop-in in: set it in its tray or box with its terminals the way the photograph of step 9 shows, or the way its manual shows where it takes a lead-acid battery's place, on the terminal

hardware its manual names, and fasten the hold-down until the battery does not move when you push it;

- to clean a terminal: loosen its lead and lift the lug off the battery's terminal, then clean the terminal and the inside of the lug with the terminal brush, as the battery's manual says, until both are bright metal, and wipe them dry with the clean cloth;
- to tighten a loose lug: it goes back on, tightened, in step 16 for a positive lead or a jumper, step 18 for a negative lead.

Every terminal and lug you cleaned is bright metal and dry; every lug that is off is covered and tied back; a battery that came out stands outside the compartment, and the battery that goes back in stands in its tray or box with its hold-down fastened. If neither the battery that came out nor a new one goes in during this session, this bank stays as it is, every lug covered and tied back: on a boat out of the water until a battery goes back by this procedure from step 1, before the boat goes back in the water; elsewhere the job is a pro's. A bank tied to this one comes back only where every tie between it and this bank is set apart, with the engine still stopped: a selector set to that bank alone, or a dual-circuit switch set to ON, where each bank feeds only its own circuit; a parallel switch OFF; a charging relay (ACR) with its own fuse at one of the two banks taken out, where that fuse sits in a holder that opens by hand — its hold-open position alone is not enough, because contacts that have welded keep the banks joined there; a DC-DC charger between the two banks, either way, stopped at the DC breaker or isolation switch that feeds it; a charger whose manual says its outputs, one for each bank, are isolated from one another is no tie (step 10) and needs nothing here, and any other charger that reaches both banks is a tie you cannot set apart. Then put back that bank's negative leads, each the same way as in step 18. A bank whose tie you cannot set apart, or cannot tell, stays down with this one; the restore below says what then.

16. Put each positive lead back on its terminal, stacked on the terminal hardware as the battery's manual shows, and each nut tightened to the torque its manual gives, with the torque wrench. A loose lug is

tightened the same way. Then put back each jumper that joins positive to positive or negative to negative, the same way. Pushed by hand, no lug turns on its terminal.

17. Put the positive terminal's cover (boot) back over the terminal and its lug. No metal of the positive terminal or of its lug shows; where the lid of a battery box is the only cover, it goes on at the end of step 18.
18. Put back every negative lead step 10 took off, each the same way as in step 16, the tape that covered it taken off: first those of a bank tied to this one; then this bank's other negative leads — the charger's, and those of circuits wired around the battery switch — and, last of all, this bank's main negative cable. Every lead is where its tape and the photograph of step 9 put it, none turns when you push it, and a battery box's lid is closed.

PUT THE BOAT BACK IN SERVICE

- After step 18, or after a stop at step 11, 12, 13 or 14 with the leads of step 10 put back as step 18 says: with the engine still stopped, the battery switch of this bank back to its working position.
- After a stop at step 15, this bank stays as that step left it until a pro has finished the job, or, on a boat out of the water, until a battery goes back by this procedure from step 1, before the boat goes back in the water: every lug covered and tied back, no tool touches its lugs or terminals, its battery switch stays OFF, and every charging source you stopped stays stopped. A bank tied to it that step 15 did not put back stays down with it. Until then, no charge reaches the banks left down, and what they feed has no power — the bilge pump's automatic switch, the high-water alarm and the CO alarm among them, where they are wired that way: the entries of the CARBON MONOXIDE and BILGE PUMP signs say what you do meanwhile. The items below go only to a bank that step 15 put back.

- Every charging source you stopped, back as you found it — the charger and any inverter/charger, the DC-DC charger and the breaker or switch that feeds it, the solar disconnect switch or the cover, the wind generator, the generator and its automatic start — but only where its setting suits the battery now in place: a drop-in that took a lead-acid battery's place gets its maker's charging settings on every source that has a setting (→ 11.3 · p. 15) before that source charges it, and a source with no setting its maker allows stays off this bank (→ "What to fix first" · p. 44).
- Every load you switched off, and the inverter, back as you found them.
- A CO alarm wired to this bank or to a bank tied to it lost its power with the negatives; the entry of the CARBON MONOXIDE sign says how you see that it is working again. The high-water alarm sounds when you press its test button, where it has one.
- Electronics that lost their clock or settings are set again by their manuals; the meter's dial goes to OFF.
- Check that every bilge pump's automatic switch has power, by the procedure "The check that the automatic switch has power" (→ 12.2).

11.7. The standard and your insurer

What does the standard say about lithium on a boat, and what will your insurer want to see? ABYC's standard for lithium batteries on boats is E-13, "Lithium Ion Batteries". ABYC wrote in August 2025 that its supplement of that year updates 14 standards, among them E-11, AC and DC Electrical Systems on Boats, and E-13, Lithium Ion Batteries; its news of August 2026 names neither. ABYC's standards are voluntary, not law (→ 1.9), and ABYC's own list of standards gives E-13's title, not its text; this chapter quotes it only as others quote it.

One battery maker, on a page dated July 2023 — before that 2025 supplement — quotes three of its items word for word. Item 13.5.2: "Lithium-ion battery systems shall be installed, commissioned, and maintained in accordance with the manufacturer's recommendations." Item 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 discharge rate." And a NOTE: "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." The first is the reason to keep the battery maker's manual aboard and to follow it; the NOTE is the warning of → "What goes dark with it" · p. 30. VERIFY

The U.S. Coast Guard published a Marine Safety Alert on lithium-ion battery system installations in July 2025. It is written for inspected vessels, not for recreational boats; it reports a fire that began when loosely crimped lugs overheated, and recommends that batteries be inspected visually for signs of deterioration and that a record of the maintenance done be kept.

Insurers. No published requirement of a US insurer for lithium batteries on a recreational boat is in Sources: one boat-insurance program's published questions and answers say nothing about lithium batteries. A broker writing in 2024 about insurance for superyachts and mega yachts reports that insurers are writing conditions into yacht policies and asking for loss-control surveys, and that there is no standard approach to policy language for lithium-ion battery risks. So the question goes to your own insurer, in writing, before the change — whether the policy covers a lithium bank, on which conditions, and whether it asks for an installer of a particular certification — and the answer goes into the Boat Passport with its date (field 15). PRACTICE

Keep these papers with the Boat Passport: the battery maker's manual and data sheet, with their revision; the main protection's type, rating and interrupting rating, and the battery maker's short-circuit figure (field 7); who installed the system, when, what was installed and what was measured (field 16); the settings of every charging source and of the battery monitor (field 12); and the insurer's written answer. PRACTICE

11.8. Compatibility checklist: before you buy, not after

Will a lithium bank work on your boat as it is, and what will it take? "Drop-in" describes a battery that fits a lead-acid battery's place: one maker answers the question with the standard sizes it offers, Group 24, Group 27 and Group 31. It says nothing about the charger, the alternator, the fuse, the pump or the cold. The checklist of this section asks those questions before you buy; each answer comes from the battery maker's manual and data sheet, read for the model you mean to buy, and from your own Boat Passport. MFR

- ☐ Every charging source on the bank: the charger's outputs and their settings, the alternator's path and what keeps it on a battery when the BMS opens, the charge controller, a wind generator — each with a setting the battery maker allows (→ 11.3 · p. 15). One lithium maker asks you to check the onboard chargers, the alternators, the solar controllers and the shore-power equipment.
- ☐ The outboard's start battery, if the boat has an outboard: lead-acid unless the engine's manual or bulletin allows a lithium one (→ 9.1).
- ☐ What the bank will feed — the bilge pump, the high-water alarm, the CO alarm — and how each will keep its power, or be watched, when the BMS takes the bank away (→ 11.4 · p. 25).
- ☐ The largest continuous and surge discharge current its BMS allows, from the model's manual or data sheet, against the largest loads the bank will feed — a windlass, a thruster, an inverter, an engine start (→ "When it disconnects" · p. 28).
- ☐ The main protection: the type the battery maker names, and its short-circuit figure for one battery; with no figure, the choice of the main protection is part of a pro's job (→ 11.2 · p. 7).
- ☐ Every way the bank can be joined to a lead-acid bank — a battery switch at BOTH, a parallel switch, a charging relay — and whether this battery's maker allows it, by which means (→ 11.3 · p. 15).

- ☐ The cold where the boat spends the winter, against the battery's charging range, its current below freezing and what stops a cold charge (→ 11.5 · p. 38).
- ☐ Which kind of BMS it has, what it disconnects, whether it warns first, and whether it has its own switch, button or app (→ Table 11.4 · p. 27).
- ☐ Its limits in series and in parallel, for that model (→ Table 11.6 · p. 59), and the batteries it may be joined with.
- ☐ Its protection against water, and the positions it may be mounted in. One maker gives one model IP67; a second calls another battery dust-protected and splash-resistant but not submersible; a third recommends mounting its batteries upright in marine applications, although they will operate on their side. MFR
- ☐ Its terminals, their hardware and torque, its size, its weight and where it will sit (→ "Weight, life and storage" · p. 4).
- ☐ Your insurer's answer, in writing (→ 11.7 · p. 55).

Table 11.6. Six lithium makers' limits in series and in parallel, as printed; the makers are numbered within this table MFR

Maker	In series	In parallel	Also printed
Maker 1, a 100 Ah battery	Up to 48 V	No limit	Not in series or in parallel with any other type of battery
Maker 2, one 100 Ah model; its heated series	That model: 12 V systems only; the heated series: no series connection	That model's page: one battery only; the maker's answers to owners: in parallel is fine	The page and the answers disagree
Maker 3, its 12 V batteries	Four at most (48 V)	Matching batteries only	No batteries of a different voltage or amp-hour rating in series
Maker 4, a 12.8 V battery with an external BMS	Four at most	20 at most	—
Maker 5, a 105 Ah battery	Four at most	Four at most	—
Maker 6, a battery system	A cluster up to 48 V	Up to 24 devices in one cluster, in total	—

Where two documents of one maker disagree, as the page and the answers of maker 2 do, the stricter of the two stands until the maker answers you in writing, and the answer goes into field 15. PRACTICE

A system whose maker lists it with its own parts — one maker writes that its included breaker is one of the components that make its system UL 1973 listed, and that any other breaker voids the listing — stays that system only with those parts. MFR

MARINE-GRADE OR NOT? · A LITHIUM BATTERY SOLD FOR A CAMPER, A CART OR A SOLAR SHED

A LiFePO4 battery whose manual is written for a camper, a golf cart or a cabin. Its cells can be the same kind as a marine battery's; what changes is what its manual covers. Read it for water — its protection rating, and whether it may stand where bilge water or spray can reach it — for the positions it may be mounted in, for vibration, and for its charge numbers, its cold limits, its short-circuit figure and the main protection it names. A manual that says nothing on these points gives you nothing to go on for a boat: the questions go to its maker, in writing, before you buy.

Verdict: read its manual

LOOKS LIKE THE FIX	FIND OUT FIRST	WHAT FIXES IT
A drop-in lithium battery in the lead-acid battery's place, on the wires and the charger already there.	Each item of the checklist of 11.8, for the model you mean to buy: the charging sources and their settings, the alternator, the outboard's start battery, the pump and the alarms, the main protection, the joins, the cold.	The battery, together with what the checklist calls for on your boat — a setting changed, a DC-DC charger, a main protection of the named type, a pump fed from another bank — or the lead-acid bank kept, where the list costs more than lithium gives you back.

Choosing among the makers' models, their limits and their links to chargers and regulators, battery by battery, is the subject of → module "Lithium".

11.9. On board

What your lithium bank does, what protects it and what it takes with it when it protects itself is something you can find, read and write down. This section turns what you notice into a first check, says which of this work is yours, gives you the words for a pro, and says what to plan for far from help.

ON BOARD: GOLDEN RULE

On a lithium bank the battery maker's manual gives every number — the charge, the cold, the depth, the fuse — and the BMS protects the cells, not the boat. Protect every lead from the bank against the current the whole bank can push into a short, keep the alternator on a battery or stopped when the BMS opens, and know what the BMS takes with it before it takes it.

What it means

Each first check below names the procedure or route that carries it out; the signs at the start of that procedure go with it.

Table 11.7. What it means

What you notice	What is happening	First check	Yourself or a pro
Everything on the lithium bank went dark at once, with no hiss, heat or swelling	Among the causes: the bank drawn down to its BMS's limit, a cell high at the end of a charge, the cold, heat, a short the BMS caught, or the battery's own switch, button or app	The route "The lithium bank went dark, or stopped taking a charge" (→ 11.4 · p. 25)	**Do it yourself, if... you can do that route, with its signs**
It went dark the moment a load was switched on or a cable was worked on, with a bang or a smell, and the monitor showed charge	A short the BMS caught before the fuse could melt, or a load above the BMS's discharge limit; a main fuse that blew with nothing to see, or a loose lug at the battery, looks the same	Steps 4 and 5 of that route; the entry of the BLOWN FUSE sign	**Do it yourself, if... that route and that entry let you**
The voltage looks normal, but nothing on the bank works	A BMS that has switched the cells off can leave almost any reading; a separate BMS that only signals leaves the terminals at full voltage	"What the terminals read afterwards" (→ 11.4 · p. 25); step 4 of that route	**Do it yourself**
The meter reads about 0 V at the lithium battery's terminals	Its BMS switch is open at this moment, or the meter, its leads or its fuse failed; it says nothing about the next minute	The meter proven on another battery (→ 3.7); → 11.4 · p. 25	**Do it yourself**
The monitor never shows 100%, or shows charge when the bank dies	A tail current set below the current at which the charger stops, a capacity set wrong, or current that bypasses the shunt — a Bluetooth module inside the battery, or a load wired to the battery's own negative terminal	"The monitor on a lithium bank" (→ 11.1 · p. 2); field 5 of the Boat Passport (→ 2.3)	**Do it yourself**

What you notice	What is happening	First check	Yourself or a pro
No charge from solar or the charger on a cold morning	The battery or its BMS stopping a cold charge; a heated battery that resumes only above its own restart temperature	→ 11.5 · p. 38; the route of → 10.2, step 1	**Do it yourself**
The charger shows charging, and the monitor shows nothing going in	The BMS refusing the charge or disconnected, or a charger that does not see a battery in protection mode	The route in → 9.3; → 11.4 · p. 25	**Do it yourself, if… you can do those routes, with their signs**
The alternator or its regulator failed after the lithium bank went dark with the engine running	A load dump: the alternator lost its battery	What charges the bank and what protects the alternator (→ Table 11.3 · p. 20)	**Hire a pro**
The main protection is an ANL, an MRBF or a fuse you cannot read, on a lithium bank	Its interrupting rating can be below the bank's short-circuit current at the bank's voltage	The procedure "Reading the main protection of a lithium bank" (→ 11.2 · p. 7)	**Reading: do it yourself; choosing: Hire a pro**
Blade fuses or a fuse block right at the lithium bank	Each meets nearly the bank's short-circuit current in a short at its output	"The other fuses at a lithium bank" (→ 11.2 · p. 7)	**Reading: do it yourself; working out the current and replacing: Hire a pro**
A battery switch with BOTH, or a charging relay, between the lithium bank and a lead-acid bank	The two banks joined, by a means the lithium battery's maker allows or forbids in its manual	"Lithium joined to lead-acid" (→ 11.3 · p. 15); "What to fix first" (→ 11.6 · p. 41)	**Keeping the banks apart until then: do it yourself, if… "What to fix first" lets you; changing the means: Hire a pro**

What you notice	What is happening	First check	Yourself or a pro
The bilge pump or the CO alarm is fed from the lithium bank	It goes dark whenever the BMS takes the bank away	"What goes dark with it" (→ 11.4 · p. 25); steps 9 and 10 of the audit (→ 11.6 · p. 41)	**Feeding it from another source: Hire a pro**
A lithium battery that is hot, swollen, hisses or smells, or a cable at its terminal that is hot	A battery or a connection in trouble	The card "Battery smells, is swollen, or is hot" (→ emergency card)	**STOP**

AWAY FROM HELP

1. **What fails most often:** what makes the BMS open — a cell drawn low after a night of loads, a cold morning on charge, a source above its maker's voltage — and a lug that loosens and heats. PRACTICE
2. **What you lose:** everything on the bank at once: the lights, the electronics, and the bilge pump's automatic switch and the alarms where they are fed from it; an alternator that charges only that bank loses its battery.
3. **How to get to shore without it:** the start battery and its engine, where they are kept apart from the lithium bank (→ Fig. 11.3 · p. 22); a handheld VHF and a phone; the bilge pump run from another bank, or a manual pump or a bucket while someone watches the water (→ 12.8).
4. **Spares to carry (with ratings):** a main protection of the type, rating and interrupting rating the battery maker names, for a pro to install; a fuse of the rating, type and interrupting rating of each fuse holder at the bank; the battery's manual on paper and its app on a charged phone; where its manual names a charger for waking it, that charger.
5. **What not to do at sea:** HOT BATTERY a lead-acid bank does not stand in for a dark lithium bank: joined to it, the lithium bank pushes its current into it, or its BMS cuts off everything on it (→ 11.3 · p. 15). And a charge setting raised above the battery maker's numbers does not finish a charge sooner: the BMS stops the charge at its cell limits, and an alternator charging only that bank loses its battery when it does (→ 11.3 · p. 15).

Do it yourself or hire a pro

DO IT YOURSELF OR HIRE A PRO · A LITHIUM BANK

STOP · **HOT BATTERY** A lithium battery that hisses, vents, swells, smells or is hot; a cable at its terminal that is hot; smoke at the bank.
What to do this minute: The card "Battery smells, is swollen, or is hot" (→ emergency card); at smoke, the card "Smoke, a burning smell, or an overheated wire" (→ emergency card).

HIRE A PRO · The main protection installed, replaced or chosen — and every case of → "The main protection of a lithium bank" · p. 11 that leaves it to a pro; a fuse at the bank whose interrupting rating is below the bank's short-circuit current or cannot be read; a positive with no fuse at its start; any work at the terminals of a battery with an external BMS, of a system its maker reserves to qualified personnel, or of a bank in series; a way of waking a battery that takes its cables off or puts another battery on its terminals; a bank its BMS disconnects again after the one wake the entry of the BLOWN FUSE sign allows; new wiring at the bank — a DC-DC charger, a BMS signal lead, a pump or an alarm moved to another source, the join between a lithium and a lead-acid bank replaced; a regulator program or a link you cannot set from its manual. Order the work in the words of "What to tell the pro" in this section, and accept it by the checks there.
If no pro is available: Until the pro comes, the bank is used as → "The main protection of a lithium bank" · p. 11 says for its main protection; a source with no setting the battery maker allows stays off it (→ 11.3 · p. 15), and the alternator and a join to a lead-acid bank are dealt with as → "What to fix first" · p. 44 says; a bilge pump or an alarm the BMS can take with it is watched as → "What goes dark with it" · p. 30 says.

When a pro may do it differently: A pro may choose a main protection of another type than Class T, where the battery's maker allows it and its interrupting rating at the bank's voltage meets the bank's short-circuit current; or add a fuse on each battery of a parallel bank, where its maker asks for one. You see it in the marking of the part, in its maker's data, and in the arithmetic the pro writes into the Boat Passport.

DO IT YOURSELF, IF…

- The procedures and the route of this chapter, each with the signs at its start: "Reading the main protection of a lithium bank" (→ 11.2 · p. 7), "The lithium bank went dark, or stopped taking a charge" (→ 11.4 · p. 25), "The one-evening audit of a lithium system" (→ 11.6 · p. 41).
- **HOT BATTERY** A charge setting of a charger, a regulator or a charge controller that its manual lets you change, to the battery maker's numbers — then you change it as that manual says and write it into field 12.
- **SHORT CIRCUIT** **GASOLINE VAPOR** **METER LEADS** **BATTERY ACID** **HOT BATTERY** **BILGE PUMP** **CARBON MONOXIDE** The planned job on a drop-in lithium battery whose maker's manual speaks to the owner, on its own or in a bank joined in parallel that its manual allows, whose bank is tied to no bank in series, one that takes a lead-acid battery's place included: taking it out and putting it or a new one back in, both in one session, or cleaning or tightening its terminals — by the procedure "A planned job on a drop-in battery" (→ 11.6 · p. 41).
- **BLOWN FUSE** A bank its BMS disconnected on a short, where the entry of the BLOWN FUSE sign lets you wake it — then you do it as that entry says, by the method its maker's manual gives.

DO IT YOURSELF · Reading the battery's label, manual and app, the battery monitor and every source's display; setting the monitor for the bank; tracing by eye what feeds the pump and the alarms; asking the battery maker and your insurer in writing; writing the Boat Passport.

GASOLINE VAPOR **BILGE PUMP** **CARBON MONOXIDE**

On someone else's boat there are three levels, not four: switches and buttons — yes; tools — no; the gray zone — only with the permission of the charter base or the owner, by phone (→ 2.6). A lithium battery's own button or app is a switch, turned as → 11.4 · p. 25 says; its terminals, its fuses and its cables are tools.

What to tell the pro

WHAT TO TELL THE PRO

For the main protection, ask for this: “The bank is this many batteries of this model in parallel, at this voltage; its maker gives this short-circuit current for one battery — or none — and names this type. On the bank now is this type, this rating, and this interrupting rating at this voltage — or one I cannot read. Install the main protection the battery’s maker names, rated to interrupt the bank’s short-circuit current at the bank’s voltage, and give me in writing the figure you used and the part’s interrupting rating at that voltage.” For the fuses beside it: “Work out the current at each fuse at this bank, and replace each fuse whose interrupting rating is below it.” For the alternator: “Keep the alternator on a battery, or stopped, whenever the BMS opens — at the end of a charge and at a disconnect on the discharge side alike — by a DC-DC charger, a regulator linked to the BMS, or the means the battery’s and the regulator’s makers name, and show me how each case is covered.” For the pump and the alarms: “Feed the bilge pump’s automatic switch, the high-water alarm and the CO alarm from a source this BMS does not control, each with its own fuse at its battery, and show me each one working with the lithium battery switched off by its own button or app — or, on a battery without one, by the means you use to take the bank away.” For a join to a lead-acid bank: “Replace this join with the means the lithium battery’s maker names.” Accept the work by these checks. The new main protection carries its type and rating on its body, and its interrupting rating at the bank’s voltage stands in its maker’s data; the figure it was chosen against is written down. Every lead from the bank has its own fuse at its start, except the starter cable traced to the starter (→ 4.2). What the pro said would stay powered stays powered with the bank switched off. The work, the readings and the settings are written into fields 7, 9, 12 and 16 of the Boat Passport the same day.

REMEMBER

- A LiFePO4 battery’s voltage stays nearly flat through most of its discharge: its state of charge is counted, not read (→ 11.1 · p. 2).
- Compare banks by the amp-hours their makers let you take, not by their labels.

- A bank's short-circuit current is its maker's figure for one battery times the batteries in parallel, and a fuse's interrupting rating is read at the bank's voltage (→ 11.2 · p. 7).
- The BMS protects the cells; the cable from the bank is protected by the fuse at its start.
- Every source charges a lithium bank by its battery maker's numbers, and the alternator needs a battery, or a stop, for the moment the BMS opens (→ 11.3 · p. 15).
- There are four kinds of BMS; a reading at the terminals tells you little, and a disconnect takes the pump and the alarms with it where they are fed from that bank (→ 11.4 · p. 25).
- In the cold, what counts is the battery's own temperature against its maker's charging range and current (→ 11.5 · p. 38).
- One evening with the engine stopped reads most of a lithium system; the findings go into the Boat Passport in the order of what harms most (→ 11.6 · p. 41).

Self-check

1. **Before you measure.** Suppose a bank of two lithium batteries in parallel whose maker gives 5,818 A as one battery's short-circuit current, and a terminal fuse that interrupts 10,000 A at 14 V. What current can the bank push into a short at its terminals, before the jumpers and the cable, and how does it compare with the fuse?
   Answer: 2 × 5,818 = 11,636 A, more than the 10,000 A of the fuse. The jumpers and the cable lower that current by an amount a pro works out from their resistance (→ 11.2 · p. 7).
2. **The cold.** Suppose a 100 Ah lithium battery whose maker allows 0.1C from 14 °F to 32 °F and 0.05C from −4 °F to 14 °F. What is the largest charging current that maker prints for it at 20 °F, and at 10 °F?
   Answer: 0.1 × 100 = 10 A at 20 °F; 0.05 × 100 = 5 A at 10 °F (→ 11.5 · p. 38).
3. **The terminals.** Suppose the BMS of a drop-in battery has disconnected it, and your meter, proven on another battery, reads 0.3 V at its terminals. What does the reading tell you?

Answer: that its BMS switch is open at this moment. It says nothing about the next minute: one maker's BMS resets by itself after five seconds in most fault conditions, and the cells behind the switch stay charged (→ 11.4 · p. 25).

4. **On your boat.** Read your lithium bank's main protection by the procedure in → 11.2 · p. 7, and write its type, rating and interrupting rating with its voltage, and the bank's short-circuit current, into field 7 of the Boat Passport.
   Answer: the four entries as read, with "unknown" where you could not read one. No figure from the battery maker, another type than one it names, an unknown interrupting rating, or one below the bank's short-circuit current goes on the first line as well (→ 11.2 · p. 7).
5. **On your boat.** Trace by eye what feeds the bilge pump's automatic switch, the high-water alarm and the CO alarm, and write into field 15 which of them the lithium bank's BMS would take with it.
   Answer: each one with its source — the lithium bank, at the battery, wired around the switch or after it; another bank; its own battery — and "not traced" where you could not follow a wire, counted as on the lithium bank. Each on the lithium bank goes dark with its BMS (→ 11.4 · p. 25).
6.  HOT BATTERY **On your boat.** Read each charging source's setting against your battery maker's numbers (→ Table 11.2 · p. 16), and what stops each source in the cold, and write them into field 12.
   Answer: for each source, its setting and its maker's number side by side, and its stop in the cold — the BMS, a signal, its own cut-off, or none found. A setting that differs is changed as its manual says; a source with none allowed by the battery maker is in → "What to fix first" · p. 44.

Terms

LiFePO4
Lithium iron phosphate: the lithium chemistry of the batteries in this chapter, printed as LiFePO4 on the label.

BMS (battery management system)
The circuit that watches a lithium battery's cells and protects them, by switching them off from the terminals or by signals that switch loads and chargers off.

external BMS
A BMS in a separate unit, which the battery must be connected to; it switches loads and chargers off by signals, or by a contactor in the DC system.

drop-in battery
A lithium battery made to take a lead-acid battery's place, with its BMS inside its case.

low-voltage disconnect
A BMS's state after it has stopped a lithium battery's discharge because a cell fell below its maker's threshold.

short-circuit current (of a battery, of a bank)
The current a battery pushes into a short across its terminals, as its maker gives it; the bank's short-circuit current is that of its batteries in parallel added together.

interrupting rating (AIC)
The largest current a fuse or breaker can interrupt at its rated voltage and stay intact.

Class T fuse
A compact bolt-down fuse with a very high interrupting rating on DC.

load dump
The voltage spike when a running alternator suddenly loses the battery it was charging.

DC-DC charger
An electronic charger that takes power from one bank and delivers a controlled charge to another.

C-rate (0.1C)
A current given as a share of a battery's capacity in amp-hours: 0.1C on a 100 Ah battery is 10 A.

pre-alarm (BMS)
A warning a BMS gives before it switches the loads off.

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