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

Chapter 7. How Much Energy You Have: Energy Budget, Range, Battery Monitor

Count what your loads take, know what your bank really gives, and find what drains it with everything off

How long your batteries carry the boat is arithmetic you can do yourself: what your loads take in a day, compared with what the bank really delivers and what charging puts back. This chapter gives you that count, the way to find out why a battery goes dead overnight, and the way to keep a battery monitor's count right.

AFTER THIS CHAPTER YOU CAN

- make a table of your loads over 24 hours and add it up in amp-hours, and in watt-hours where two voltages meet;
- work out how many amp-hours your bank really delivers, from its maker's depth of discharge, the rate, the temperature and its age;
- tell a battery that was discharged overnight from one that was never full, one that no longer holds its charge and a monitor that counted wrong;
- measure what your boat draws with everything off — on a battery monitor, or with a multimeter in series — and find the circuit that draws;
- work out how many days a battery carries the bilge pump and the alarms while you are away;
- compare a day's charging with a day's use at anchor and under way;

- check a battery monitor's settings and bring its count back to the truth;
- use less without buying anything.

Read first: → 1.7, → 3.2, → 3.6, → 6.1

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7.1. Daily use in amp-hours

How much energy does your boat use in a day? Count it the way a battery delivers it: in amp-hours. An amp-hour is current multiplied by time — one amp for one hour (→ 6.1). A load takes its current times the hours it runs, and every load added up over 24 hours is the day's use. That is the first half of the energy budget; the second half is what the bank really delivers (→ 7.2 · p. 6) and what charging puts back (→ 7.5 · p. 36).

Each load's current is on its label or in its manual, in amps or in watts; a figure in watts divided by the bank's voltage gives amps. The maker prints the current under a condition — a voltage, a mode, a temperature — and the condition goes with the number. → Table 7.1 · p. 3 shows what that looks like: each row is one maker's figure for one model, and the same job can differ tenfold from one model to the next. Your table is filled from your own labels.

Table 7.1. What some loads draw, as their makers print it, each for one model MFR

Load	The maker's figure	The condition that goes with it
Refrigerator, portable, with a compressor	0.98 Ah for each hour, on average	90 °F around it, 39 °F inside; the average includes the hours the compressor rests
Anchor light, LED	Less than 1 W	Watts: less than 0.083 A at 12 V
VHF radio, maker 1	350 mA standby; 600 mA receive; 2.0–6.0 A transmit	At 12.0 V, in the maker's own words; the transmit current only while the key is pressed, from 1 W to 25 W
VHF radio, maker 2	1 A receiving at full volume; 5 A transmitting at 25 W	At 13.8 V; no figure for listening printed
Chartplotter with a 10 or 12 in screen	2.3 A (10 in) or 2.5 A (12 in) typical; 5 A peak	At 12 V; the typical (RMS) figure is the one you count
Freshwater pump	5 A maximum	At 25 psi, while it runs
Bilge pump, 1500 GPH	4.8 A	At 12 V, while it runs; 7.0 A at 13.6 V (→ 12.4)
Electronic water sensor	0.006 A	While it waits for water (→ 12.5)
CO alarm	6 mA nominal	That maker's DC models
Stereo, switched off	Less than 200 mA	Through its yellow power wire, live at all times; its maker has that wire turned off at its breaker or switch when the boat is not in use
Battery monitor	Less than 1 mA (maker 1); 10 mA asleep, 20 mA with its display on (maker 2); 9 mA (maker 3)	Maker 3: with its backlight and its alarm relay off
Inverter, 800 VA, on with no load	6.5 W; 1 W in its ECO mode	The 12 V model; in ECO mode it checks for a load every 2.5 seconds by default
Inverter/charger, 2,000 W, on with no load	25 W; 7 W in its search mode	Typical, with 120 V at its output

Load	The maker's figure	The condition that goes with it
Charging relay (ACR)	175 mA with the banks joined; 15 mA open	That maker's relay, itself a load while it joins the banks (→ 8.3)

A load that switches itself on and off is counted by its average, not by the current it draws while it runs. The refrigerator's maker prints the average already, for one condition: a cooler cabin or a warmer setting inside lets the compressor rest longer, and that maker prints no second figure to say by how much. A bilge pump with a load-sensing automatic switch runs for about a second to test for water, before it moves any, as often as its maker sets: one maker's pumps test every two and a half minutes, and one of its models every 20 seconds (→ 12.3). Your pump's manual gives its own interval. MFR

Suppose a pump that tests every two and a half minutes draws 4 A for one second in every 150 seconds. Its average is 4 ÷ 150 = 0.027 A, and over a day 0.027 × 24 = 0.64 Ah. Suppose instead your anchor light has a bulb printed 12 V 10 W: 10 ÷ 12 = 0.83 A, at least ten times the LED of → Table 7.1 · p. 3, and 10 Ah over a 12-hour night.

Which loads run depends on where the boat is. At the dock a charger on shore power can carry the loads, but only on the banks it is wired to, and only while shore power stays on (→ 12.7). At anchor the anchor light burns from sunset to sunrise (→ 13.1), the refrigerator runs around the clock and the VHF radio listens. Under way the chartplotter and the radio run, the navigation lights at night, and the engine charges (→ 7.5 · p. 36). Make one table for each place where your boat spends its days.

> **WORKED EXAMPLE: A DAY AT ANCHOR, 12 V HOUSE BANK**
>
> Suppose a day at anchor with the loads of → Table 7.1 · p. 3. The bases: each current is that maker's figure for its model (in Sources), a figure in watts is divided by 12 V, and the hours are your estimate for this day.

Table 7.2. A day at anchor, worked example

Load	Current	Hours	Ah
Refrigerator (its average)	0.98 A	24	23.52
LED anchor light	under 0.083 A	12	under 1.00
VHF radio, standby	0.35 A	12	4.20
Chartplotter, 12 in	2.5 A	2	5.00
Cabin lights (your own figure)	1.0 A	4	4.00
Freshwater pump	5 A	1/3	1.67
CO alarm	0.006 A	24	0.14
Battery monitor (maker 1)	under 0.001 A	24	under 0.024
Stereo, power wire left on	under 0.2 A	24	under 4.80
Inverter on, no load (6.5 W)	0.54 A	24	13.00
Total			at most 57.35

What decides the answer is the hours, more than the currents: the refrigerator draws less than half of the chartplotter's current and takes more than four times its amp-hours, because it runs around the clock. The inverter left on with nothing plugged in takes 13.00 Ah, more than a fifth of the day (13.00 ÷ 57.35 = 23 %); in its ECO mode, 1 W, it would take 1 ÷ 12 × 24 = 2.00 Ah. Switched off when nothing needs it, it takes none. What the number means: this boat needs about 57 Ah from its house bank for each day at anchor, and → 7.2 · p. 6 says how big a bank delivers that.

NUMBERS · TWO VOLTAGES

Amp-hours add only at one voltage. Where a 24 V trolling-motor bank and a 12 V house bank meet in one budget, count watt-hours: volts times amp-hours. Suppose the trolling-motor bank gives 20 A for 3 hours, 60 Ah at 24 V: 60 × 24 = 1,440 Wh. Suppose the house bank gives 60 Ah at 12 V: 60 × 12 = 720 Wh. Together they gave 2,160 Wh. "120 Ah" is not an answer: the same amp-hour carries twice the energy at 24 V that it carries at 12 V (→ 6.4).

> **WHY IT WORKS**
>
> A battery does not care how a load uses its current, only how much flows and for how long. A compressor that draws several amps for a few minutes and then rests takes the same amp-hours as a smaller current that never stops, if the two averages are equal; that is why a load that cycles is counted by its average. The average holds only at the condition it was measured at: warm air around a refrigerator makes its compressor run longer, and rain makes a bilge pump run more. Energy is volts times current times time. At one voltage the volts are the same for every load, so counting amp-hours is enough; where two voltages meet, the volts no longer cancel, and only watt-hours add.

A load table kept from season to season, and worked across banks and voltages, is the subject of → module “Calculators”.

7.2. What the bank really delivers

How many of the amp-hours on your battery’s label can your boat really use? Fewer than the label says, for four reasons: the share of its capacity the battery’s maker lets you take, how fast you take it, the temperature, and the battery’s age. This section takes them in turn; together they turn the number on the label into the number you compare with the day’s use of → 7.1 · p. 2. It is about lead-acid batteries; a lithium battery has its own chapter (→ 11.1).

How deep: the maker’s depth of discharge

Depth of discharge is the share of a battery’s rated capacity taken out, in percent: 50 % means half the amp-hours of its 20-hour rating. Every deep discharge wears a lead-acid battery, and the deeper the discharge, the fewer of them it lasts. Makers draw their line in different places and in different senses. One maker of AGM batteries recommends an average depth of discharge no greater than 50 % of the 20-hour rating, and writes that the lower the average, the longer the battery lasts. A maker of flooded batteries writes not to discharge its batteries beyond 80 %: a maximum, kept as a margin against damage, not a target. MFR

Table 7.3. Cycles by depth of discharge, one maker's AGM and gel lines MFR

Depth of each discharge	AGM	Gel
80 %	400 cycles	500 cycles
50 %	600 cycles	750 cycles
30 %	1,500 cycles	1,800 cycles

One maker's AGM line gives 400 cycles at 80 % and 1,500 at 30 % (→ Table 7.3 · p. 7); those are its own batteries under its own test, not a figure for every AGM battery. A battery built for starting is not a house battery at all: one battery maker writes that starting batteries are not designed for regular discharges of more than 1 % to 3 % (→ 6.3).

PRACTICE

So the usable capacity of a battery, the figure a budget counts, is its 20-hour rating times the average depth of discharge its own maker recommends; a maximum, like the 80 % above, is not that figure. Two makers' numbers are not interchangeable, and a battery with no figure from its maker has none from this book either: its maker's manual or data sheet is where you look.

Suppose a 100 Ah battery whose maker recommends an average depth of 50 %: about 50 Ah to use on an average day. Suppose the bank of → Table 7.2 · p. 5, which uses at most 57.35 Ah a day, is built of such batteries: it needs at least 57.35 ÷ 0.50 = 114.7 Ah of 20-hour rating for one day between charges.

How fast: the rate

The amp-hours on a label belong to the rate printed beside them (→ 6.1). Taken faster, the same battery gives fewer. One maker's 12 V flooded battery is rated 95 Ah at the 5-hour rate, 106 Ah at 10 hours, 115 Ah at 20 hours and 128 Ah at 100 hours, and runs 200 minutes at 25 A and 51 minutes at 75 A. MFR

Suppose you work out what that battery gives at each current. At 25 A for 200 minutes it delivers 25 × 200 ÷ 60 = 83.3 Ah; at 75 A for 51 minutes, 75 × 51 ÷ 60 = 63.8 Ah. Its 20-hour current is 115 ÷ 20 = 5.75 A, at which it gives the 115 Ah on its label. The windlass, the bow thruster

and an inverter under load discharge the bank fast; the refrigerator, the lights and the radio discharge it slower than its 20-hour rate.

At the slow end the same table runs the other way: that maker's battery gives 128 Ah at the 100-hour rate against 115 Ah at the 20-hour rate. On that battery, a budget counted at the 20-hour rating gives small loads a little less than the battery delivers, and heavy loads more.

NUMBERS · THE PEUKERT EXPONENT

A battery monitor that has the setting models the rate with one number, the Peukert exponent. One monitor maker writes the relation as Cp = I to the power n, times t: the current raised to the exponent n, times the hours, stays the same from one rate to another, so the exponent comes from two of the battery maker's rated capacities. The higher the exponent, the faster the usable capacity shrinks as the current grows. That maker's default is 1.25, adjustable from 1.00 to 1.50; it recommends leaving the default unchanged except for lithium batteries, sets 1.01 for lithium where the exponent is unknown, and calls the exponent no more than a rough approximation of reality. A battery maker recommends 1.12 for its own AGM batteries. MFR

Suppose the monitor maker's own example: 75 Ah at the 5-hour rate, a current of 75 ÷ 5 = 15 A, and 100 Ah at the 20-hour rate, 100 ÷ 20 = 5 A. When the current to the power n, times the hours, is the same at both rates, n is the logarithm of the ratio of the hours divided by the logarithm of the ratio of the currents: n = log(20 ÷ 5) ÷ log(15 ÷ 5) = log 4 ÷ log 3 = 1.26. The flooded battery above gives 1.16 from its 5-hour and 20-hour ratings (19 A and 5.75 A), and 1.07 from its 20-hour and 100-hour ratings (5.75 A and 1.28 A): the exponent depends on which two rates you take, which is why it is an approximation, not a property of the battery.

How cold

A cold battery delivers less, and the makers say so with different numbers, each from its own reference temperature. One battery monitor maker gives a typical reduction, against the capacity at 68 °F, of 18 % at 32 °F and 40 % at −4 °F. A battery maker's user guide gives

100 % of the capacity at 80 °F and 50 % at 0 °F, and adds that above 80 °F a battery delivers more than its rating but its life is reduced.

PRACTICE

An AGM maker writes that its battery gives only about 60 % of its room-temperature capacity at 0 °F. Read your own battery maker's figure, at its reference temperature, for the temperature of your battery compartment in the season you budget for.

MFR

Suppose a 100 Ah battery in a compartment at 32 °F, by the monitor maker's figures: 18 % less leaves 82 Ah, and at −4 °F, 60 Ah. Suppose its maker's average depth of 50 %: on that cold morning 41 Ah are there to use, not 50.

How old

A battery loses capacity as it ages, and its label does not change. Makers count a battery as worn out at a share of its rating: two at 80 %, two others at 50 % (→ 6.6). What an old battery still holds is measured by a timed discharge, read against its maker's share (→ 6.6), never guessed from its years. Budget with the capacity it has now: a bank that has lost a fifth of its capacity runs out a fifth sooner, and a battery monitor that still counts the capacity on the label shows more charge than the bank holds (→ 7.6 · p. 39).

MFR

A battery also loses charge by itself, with nothing connected: one maker gives its flooded batteries 10 to 12 % a month at 77 °F and its AGM batteries 2 % (→ 6.6). Over one day that is small next to the loads; over a month at the dock it counts (→ 7.4 · p. 34).

> **WHY IT WORKS**
>
> In a budget the four reasons multiply; they do not add. A 100 Ah battery at 32 °F has about 82 Ah by one maker's figures; its maker's 50 % of that is about 41 Ah; and if it has aged to 80 % of its rating, about 33 Ah are left to use. A heavy load takes some of those away again. Where the rule stops working: the slow end of the rate works the other way, and on a battery like the one of that maker's rate table a small load gets a little more than the 20-hour figure. A lithium battery follows other numbers on every count — depth, rate and cold — and those are in → 11.1.

7.3. Battery dead overnight

 GASOLINE VAPOR  BILGE PUMP  CARBON MONOXIDE

Battery dead this morning? Before you charge it or switch anything back on, look at what the boat is doing now. A bank so flat that everything on it is dark has left what it feeds without power — the bilge pump's automatic switch, the high-water alarm and the CO alarm among them, where they are fed from that bank. A lithium bank with everything on it dark may have been disconnected by its battery management system (BMS), with the same loads dark: → 11.4 comes before any measurement here. On a boat with a battery monitor, read three numbers on it: the current flowing now, the amp-hours taken out since it was last full, and the state of charge — or "---", which means it has lost its count (→ 7.6 · p. 39). Then look around the boat for anything still on that should be off — a light, the inverter, the refrigerator, the stereo, a breaker on the panel — write down what you find, and switch it off. On a boat with no monitor, what you found on is your first answer; a DC clamp meter around the bank's negative cable, by the procedure "A DC current with a DC clamp meter" (→ 3.3), shows a load that still draws whole amps, and the procedures of this section find a smaller one. If the engine has to start now, its route is in → 9.5.

Then the question this section answers: why did the battery go flat, and what drains it when everything is off? A battery found flat in the morning has one of four stories behind it, and each has its own fix. This section tells them apart, measures the draw with everything off — on one bank and on two — and finds the circuit it is on.

Four causes, one flat battery

The battery was discharged in the night: something drew from it — a load left on, or a draw that runs while everything seems off. It was never full: the charge of the day before ended short, or never reached this bank, and a normal night took the rest. The monitor counted wrong: it said the battery was full, or had plenty, when it did not. Or the battery no longer holds its charge: it took a full charge and has less capacity to give than it had. All four end in the same flat battery in the

morning, which is why the observation alone names no cause (→ Table 7.4 · p. 11).

Table 7.4. What you see, what else gives the same sight, and what tells them apart

What you see	What else gives the same sight	What tells them apart
The battery is flat in the morning	A draw in the night; a charge that never filled it; a battery that has lost capacity; cold, which takes capacity away (→ 7.2 · p. 6)	The draw with everything off; whether the charge ended full; the battery's capacity test (→ 6.6)
The monitor showed full, and the battery died	A capacity set larger than the bank holds now; a count that was not set to full by a real full charge; a lead on the battery's negative terminal that bypasses the shunt; a monitor that was off for a while	The monitor's settings and its synchronization (→ 7.6 · p. 39); the cables on the battery's negative terminal, counted by eye (→ 3.6)
The monitor shows 0.00 A with everything off	No draw; a draw below the current the monitor counts as zero; a draw smaller than the monitor's own accuracy; a draw that bypasses its shunt; a second bank that feeds the draw	The monitor's current setting and its accuracy, in its manual (procedure "The draw on a battery monitor"); a multimeter in series
A multimeter in series reads 0 A	No draw; a second bank that feeds the draw (→ Fig. 7.2 · p. 19); a lead on the battery's negative terminal; a draw smaller than the range's last digit; the meter's fuse open; the red lead in a jack the dial does not read; a lithium bank disconnected by its BMS (→ 11.4)	The banks apart; the cables on the battery's negative terminal; the meter's range and its fuse, checked as its manual says (→ 3.2); the battery's voltage
The draw is gone after the battery switch goes OFF	A draw on a circuit after the switch	Breakers off one at a time
The draw stays with the battery switch OFF	A draw on a circuit wired around the switch; a load that is meant to stay on	The drop across each fuse; the always-on loads of → Table 7.1 · p. 3 added up

Route: the battery is dead in the morning

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → what the boat draws with everything off: step 1
- after charging → whether the charge reached this bank and ended full: step 2
- after rain or washing the boat → how often the bilge pump ran (→ 12.7); then step 1
- after the boat sat unused → the charge a battery loses by itself (→ 6.6), and what stayed connected: step 1
- after switching sources (shore power, generator, inverter) → whether the charger still reaches this bank (→ 1.7), and whether the inverter stayed on: step 2
- nothing you noticed → step 1

ROUTE: THE BATTERY IS DEAD IN THE MORNING

HOT BATTERY **BLOWN FUSE**

1 What the boat draws with everything off: the procedure “The draw on a battery monitor” in this section, or, with no monitor, “What the boat draws with everything off, with a multimeter in series”.

You will see: A draw larger than the loads that stay on by design account for — add the figures on their own labels, the way → Table 7.1 · p. 3 lists them: step 4. No more than they account for: step 2. A reading that differs from that sum by no more than the instrument’s own accuracy near zero — a monitor’s offset, or a meter range’s last digit and the counts its manual adds — tells you nothing: read the draw on the other instrument, or go on as with no reading. A reading below that sum, where a charging relay was kept apart only by its hold-open position, tells you nothing either: it can be a share of the draw (“Two banks”, in this section). No reading of the total — its procedure stopped, or the readings told you nothing: steps 2, 3 and 5 need none; a load that draws whole amps shows on a DC clamp meter (→ 3.3), and step 4 finds the circuit by the drop across each fuse; the total itself is then read by a pro (→ 7.8 · p. 45). Water that rises in the bilge: the card “Water in the boat — the pump can’t keep up or is silent” (→ emergency card) — in the middle of the procedure with a multimeter in series, right after its steps 13 and 14 and the first item of its restore; the rest

of that restore waits until the water is down. A bilge pump that starts again and again and keeps up with the water: → 12.1 — in the middle of that procedure, after its steps 13 and 14 and its whole restore.

2 **Was the bank full when the night began?**

You will see: A monitor whose settings you have checked and that set itself to full during the last charge (→ 7.6 · p. 39): it was full — step 3. A charger that showed its charge complete on this bank: it ended its charge, and whether that left the bank full depends on its setting for this battery type and on where it reads the voltage (→ 9.3) — step 3, with the charger kept on the list of what to follow. A charge that ended early — the engine run short, the panels in shade, the charger on another bank or its breaker off — or a monitor that shows "---": the charge did not fill it, and the charge is what to follow: the charger (→ 9.3), the engine (→ 9.1, → 9.2), the panels (→ 10.3), the sources together (→ 9.4). You cannot tell: step 3 meanwhile. A full charge by a charger, until it shows the charge complete, waits for shore power or a generator, and this route is taken again after the next night; at anchor or under way the engine and the panels put back what they can, and the count of → 7.5 · p. 36 shows whether they keep up.

3 **Did the night's use exceed what the bank delivers?**

You will see: The count for that night (→ 7.1 · p. 2) against the bank's usable capacity at that night's temperature (→ 7.2 · p. 6). More than the bank delivers: the budget is the fault — use less (→ 7.7 · p. 44) or charge more (→ 7.5 · p. 36). Less: step 5.

4 **Which circuit draws.**

You will see: The breakers, one at a time, in the procedure you took in step 1, where it reached that step; then the procedure "Which circuit draws: the drop across each fuse" in this section. Found: "When the draw is found", in this section. On no circuit you can read: the draw is on a circuit whose fuse you cannot reach, on one with no fuse at all, or too small for the millivolts across its fuse to show it — a pro, with your readings (→ 7.8 · p. 45); a positive wire with no fuse at the battery goes in field 1 of the Boat Passport.

5 **Does the bank still hold its capacity?**

You will see: The route "The battery seems weak, or goes flat" (→ 6.6), with its test for your battery's type. A monitor whose capacity setting is still the label's while the bank has lost capacity counts charge that is not there (→ 7.6 · p. 39). Below its maker's share: what its maker does then is in → 6.6.

PUT THE BOAT BACK IN SERVICE

- The procedures of steps 1 and 4 end with their own restore blocks; a charge you started in step 2 runs until its charger shows it complete, as the charger's manual says.

What draws with everything off

A parasitic draw is the current a battery delivers while everything on the boat is switched off. Part of it is there by design. A bilge pump's automatic switch, a high-water alarm and a CO alarm stay on by design, and draw little while they wait: in → Table 7.1 · p. 3, one maker's water sensor draws 0.006 A, one maker's CO alarm 6 mA and one maker's battery monitor less than 1 mA. Part of it is not needed and can be large: a stereo whose power wire is live at all times draws less than 200 mA switched off, by its maker's figure, and that maker has the wire turned off at its breaker or switch when the boat is not in use; an inverter left on with nothing plugged in, 6.5 W on one maker's model and 25 W on another's. MFR

One meter maker's guide names alarms, cameras and stereos added after the car was built as common causes of a drain in cars; on a boat, look first at what was added and where it takes its power. An PRACTICE engine's gauges and its own electronics are loads like any other: wired after the battery switch or around it, they show in the same readings (the gauges themselves → 13.4).

Is a draw too much? A meter maker's guide written for cars calls a draw under 50 mA normal and one over 100 mA suspect, once the car's electronics have gone to sleep. Those figures belong to cars. PRACTICE For your boat, two numbers answer the question: the sum of what the loads that must stay on draw, from their labels, and the days that the draw leaves your bank.

Suppose your boat's water sensor, CO alarm and battery monitor draw 0.006 + 0.006 + 0.001 = 0.013 A, and the meter reads 0.050 A with everything off: 0.037 A is drawn by something else. Over a day 0.050 × 24 = 1.2 Ah. Suppose a 100 Ah battery whose maker's average depth is

50 %: 50 ÷ 1.2 = 42 days before the draw alone reaches that depth. Suppose instead the meter reads 0.50 A: 0.50 × 24 = 12 Ah a day, and the same battery reaches its maker's depth in 50 ÷ 12 = 4.2 days.

Electronics take a while to settle into their smallest current after they are switched off, and a pump's automatic switch wakes by itself to test for water. A reading is taken once it has stopped falling, and after at least one test of a load-sensing pump — every two and a half minutes on one maker's pumps, every 20 seconds on one of its models (→ 7.1 · p. 2). A jump to amps for a second or a few seconds is such a test or a pump starting; one maker's water sensor also runs its pump for several seconds whenever its power comes back, to calibrate itself (→ 12.3).

Read the draw on the monitor first

A battery monitor is a meter already in series: its shunt sits in the bank's negative cable, and with every charging source off, the current it shows is what the bank delivers to its loads (→ 3.6). Read the draw there before you reach for a wrench. Four limits come with it. It sees only the current that passes its shunt, so a lead on the battery's negative terminal is not in its reading. It reads the bank whose return passes its shunt: with a second bank joined to it, it shows a share of the draw that you cannot predict — less, more or reversed (→ Fig. 7.2 · p. 19) — unless its shunt carries the return of every bank. It can count a small current as zero: one maker's monitor treats a current below its "current threshold" setting, 0.10 A by default, as zero, to keep small errors out of its count; set to 0.00 A, the function is off. And it has an accuracy of its own: the same maker gives its smart shunt a resolution of 0.01 A and an offset of less than 10 to 40 mA by model, so a reading of a few hundredths of an amp can be the monitor's own, and a real draw that small can read as none. What your monitor does with a small current, and how close to zero it reads, is in its manual. MFR

Suppose a draw of 90 mA on that monitor with its default left in place: it counts the draw as zero, and 0.09 × 24 = 2.16 Ah a day leave the bank without its state of charge going down by them.

Where a multimeter goes in series

A multimeter measures current only with that current flowing through it: the circuit is opened and the meter closes it again, in series. The draw is small, a few milliamps to a few hundred, too small for a general clamp meter to read (→ 3.3), and a multimeter on its current range reads it well: one meter's 6 A range shows 0.001 A as its last digit and is accurate to 1.0 % plus 3 digits. Three meter makers give the order for a current reading as power off, the circuit opened, the meter put in series, power on. Where circuits are wired around the battery switch, the boat cannot switch everything off: the procedure below turns the battery switch OFF before the circuit is opened and ON once the meter is in, but those circuits stay energized — their current is broken when the lug is lifted, they have no way back to the battery until the clips close the circuit through the meter, and the meter then carries their current. MFR

Suppose a draw of 0.050 A on that meter: 1.0 % of 0.050 A is 0.0005 A, and 3 digits are 0.003 A, so it reads within 0.0035 A of the truth — a display between about 0.047 and 0.053 A.

Where the circuit is opened decides what the meter sees. Every current a bank delivers comes back to its negative terminal. When that terminal carries one cable — the jumpers between the bank's own batteries aside — every return current runs through that cable, and a meter in it reads the whole draw of the bank; with a shunt, the same holds for the cable from the shunt's SYSTEM stud to the negative bus, where it is the only cable on that stud (→ Fig. 7.1 · p. 17). The meter goes in away from the battery: with a shunt, at the SYSTEM stud, with that cable lifted off it; with no shunt, at the far end of the battery's own cable, where it lands on the negative bus or, on a boat whose battery cable goes to the engine, on the engine block. A meter maker's guide written for cars lifts the cable at the battery post; on a boat the same return is opened away from the battery, and the meter there reads the same current.

A second cable on the battery's negative terminal — a charger's negative, a pump's, anything but the cable and the jumpers — is a second way back: its current never reaches the meter. Where the

device it serves also reaches the negative bus by another path — a second negative, a metal case, a cable shield — the meter in the main cable loses part of the other loads' current to it as well, because current divides between two paths. A second cable on the shunt's SYSTEM stud is the same for a meter at that stud: its current passes the shunt, and the monitor counts it, but not the meter. With a shunt, every load and charger returns through the shunt by its maker's design (→ 3.6), and with one cable on the SYSTEM stud the meter there reads what the monitor reads.

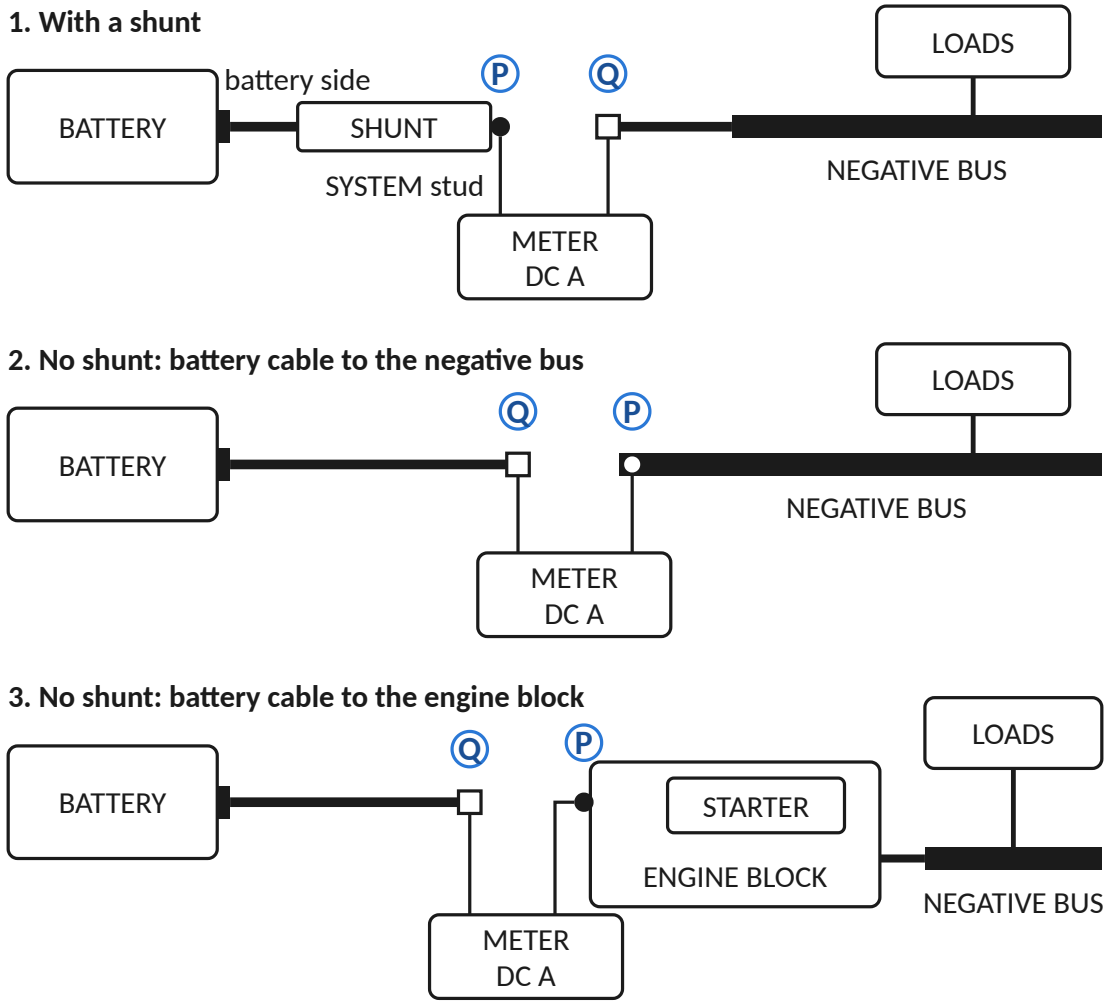


Fig. 7.1. Where the meter goes in series, between the stud P and the lifted lug Q: with a shunt, on its SYSTEM stud, in the cable to the negative bus; with no shunt, at the far end of the battery's one negative cable — on the negative bus, or on the engine block, where the starter's current returns through the same cable.

Two banks

On a boat with two banks, the meter in one bank's cable reads that bank's draw only while the banks are apart. When something joins their positives — a battery switch at BOTH, ALL, 1+2 or COMBINE, a parallel switch ON, a charging relay (ACR) that has closed — the loads draw from both banks at once, and their current returns to both negative terminals: part through the cable with the meter, part through the other bank's cable. The meter adds resistance to its own path, and how the return then divides depends on the two batteries' voltages and their own resistances: the meter can read less than the draw, nearly nothing, more than the draw, or a current the wrong way (→ Fig. 7.2 · p. 19).

A charging relay closes on a charging voltage and opens when the voltage falls to its maker's open setting and stays there for its delay: one maker's relay opens when the voltage falls to 12.75 V for 30 seconds, and that maker writes that the numbers vary from one relay to another (→ 8.3). Two full banks that rest above that setting can stay joined with nothing charging. A low voltage does not show the relay open either: the same maker's heavy-duty relay has a control that parallels the banks for an emergency start, and a relay held closed that way reads the same. That relay also has a LOCK OFF position, which holds it open.

MFR

A relay set to a position its maker gives for holding it open keeps the banks apart, unless its contacts have welded together: welded contacts can keep the banks joined in every position of the relay's control. The relay's own fuse out at one of the two banks separates them for certain, whatever its contacts do. Any other relay is taken as joined for this reading. Each bank is measured on its own, with the other apart from it.

PRACTICE

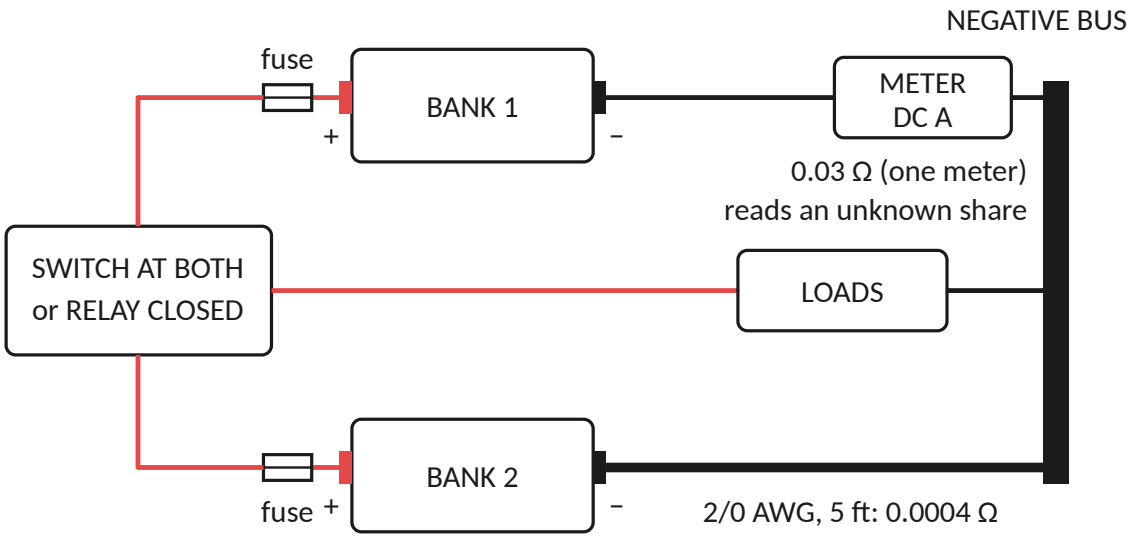


Fig. 7.2. Two banks joined on the positive side return the draw through both negative cables. The meter adds about 0.03 Ω to bank 1's cable, and how the return then divides depends on the two batteries' voltages and their own resistances: the meter reads a share of the draw that you cannot predict — less, more, or a current the wrong way.

WHY IT WORKS

A meter on its current range is not a perfect wire. One meter maker gives its current input a drop of 0.03 V for each amp, a resistance of 0.03 Ω. MFR A battery cable has far less.

Suppose bank 2's negative cable is 2/0 AWG and 5 ft long. By the ABYC formula R = 10.75 × L ÷ CM, with 133,100 CM for 2/0 AWG (→ 5.2), it has 10.75 × 5 ÷ 133,100 = 0.0004 Ω: the meter adds to bank 1's path far more resistance than either cable has.

With the banks joined, each bank's share of the draw is set by the whole of its own loop — the battery's voltage and its internal resistance, its fuse and the switch or relay, its cable, and in bank 1 the meter — and two batteries a little apart in voltage also pass a current from one to the other through both cables. So the meter in one bank's cable reads a share of the draw that you cannot predict: less, nearly none, more, or a current the wrong way, and nothing you can read at one cable tells you which. With the banks apart and one cable on the terminal, the meter's resistance changes nothing, because there is no other way back: everything the bank delivers passes it.

Procedure: The draw on a battery monitor

For a bank whose battery monitor shows current, with its shunt in the bank's negative cable (→ 3.6). It reads that bank, or every bank whose return passes the same shunt; a bank with a cable of its own is read on its own monitor or with a multimeter in series, by the next procedure. At anchor after dark, only with the anchor light on and its current, from its label, counted with the loads that stay on; a light that goes out with the battery switch makes this a procedure for daylight. You need the monitor's manual, for the setting that decides the smallest current it counts and for its accuracy near zero, and a pencil.



1. Count, by eye and without touching, the cables on the battery's negative terminal and on the shunt's battery side (→ 3.6). One cable from the battery to the shunt — the jumpers between the batteries of one bank aside, and the monitor's own lead where its maker puts it there: continue. Anything else: the monitor misses what that lead carries — write it into the Boat Passport (field 5); the total draw is then a pro's to read, and step 1 of the route says what you go on with.
2. Stop every source that can charge a bank: 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 — or, at the dock, take the readings after dark; a wind generator stopped as its manual says; a generator stopped, with its automatic start OFF; the engine stopped. Each source is stopped by its own act, and the monitor shows no charge going in.
3. On a boat with two banks or more whose returns do not all pass this shunt, with the engine stopped, set the battery switches so that this bank is apart from every other: a selector on this bank alone, never at BOTH, ALL, 1+2 or COMBINE; a parallel switch OFF; a charging relay (ACR) between the banks set to the position its maker gives for holding it open (→ 8.3), or its own fuse at one of the two banks taken out, where that fuse sits in a holder that opens

by hand, in the state the entry of the SHORT CIRCUIT sign gives for a fuse between two banks. A relay whose contacts have welded can keep the banks joined even at its hold-open position, so the fuse is the certain means ("Two banks", in this section). A relay with neither — no such position you can set, and no such fuse you can take out: the banks are taken as joined, and this monitor reads a share of the draw that you cannot predict — the total is a pro's to read, and step 1 of the route says what you go on with. This bank alone feeds its loads.

4. Switch every load off at its own switch, and the inverter at its own switch; at anchor after dark, every load but the anchor light. Leave the breakers on the DC panel as the boat is left; leave the bilge pump's switch, the high-water alarm and the CO alarm as you found them before step 3 — where it turned them off for a relay's fuse, back now that the fuse is out — the battery switch where step 3 set it or at its working position, and what is wired around it alone (→ 1.7). A load that has no switch but its breaker and starts by itself — a refrigerator, a freshwater pump, never a bilge pump or an alarm, whose breakers stay as you found them — goes OFF at its breaker only if it would run during the reading; write down which, because that circuit is then out of the reading and the search. Nothing you switched runs.
5. Set the monitor's smallest counted current to zero, as its manual says — on one maker's monitor, its current threshold to 0.00 A — and write down the value it had. A monitor with no such setting: its manual gives the smallest current it shows. Write down, from its manual, its accuracy near zero — on one maker's smart shunt, an offset of less than 10 to 40 mA by model. The setting reads zero, and the old value and the accuracy are written down.
6. Watch the current until it stops falling, and for at least two and a half minutes more. Write down the lowest steady reading. A jump to amps for a second or a few seconds is a pump testing for water or starting; a reading that keeps rising and falling is a load that step 4 missed — look again.

7. With the engine stopped, turn the battery switch to OFF — a selector that joins two banks, to OFF too — and read the current again. What still draws is wired around the battery switch: a memory wire or a solar charge controller and, where they are wired that way, the bilge pump's automatic switch, the high-water alarm and the CO alarm (→ 1.7; Boat Passport fields 10 and 11). Write it down. A monitor that goes dark with the switch OFF is fed after it, and gives no reading here.
8. With the engine stopped, turn the battery switch back to where it was in step 4. Then, of the breakers on the DC panel that are ON, turn one OFF at a time, watching the current, and back ON before the next; a breaker that was OFF before stays OFF. The breaker whose OFF takes the current down is a circuit that draws: write down which, and by how much. A draw that no breaker takes down, and that stayed in step 7, is wired around the battery switch: the procedure "Which circuit draws: the drop across each fuse" in this section.

PUT THE BOAT BACK IN SERVICE

- The monitor's smallest counted current back to the value you wrote down in step 5.
- With the engine stopped, every battery switch and parallel switch at its working position, a relay's control you set in step 3 back to automatic, and a relay's fuse you took out there back in its holder, by hand, in the state the entry of the SHORT CIRCUIT sign gives for a fuse between two banks; every breaker, every load and the inverter as you found them.
- 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.

- A CO alarm wired after the battery switch lost its power while the switch was OFF in step 7, and one on a breaker turned OFF in step 8 lost it 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).

Procedure: What the boat draws with everything off, with a multimeter in series

For a bank with no battery monitor, or to check one. It needs one cable that every return current of the bank passes (→ Fig. 7.1 · p. 17): with a shunt, the cable from the shunt's SYSTEM stud to the negative bus, where it is the only cable on that stud and the battery's negative terminal carries only the cable to the shunt; with no shunt, the battery's negative cable where it lands on the negative bus or on the engine block, where it is the only cable on the battery's negative terminal — in both cases, the jumpers between the bank's own batteries aside. Two cables or more on the SYSTEM stud: the monitor still reads the whole draw (the procedure "The draw on a battery monitor"). Two cables or more on the battery's negative terminal, where neither a meter in one of them nor the monitor reads the whole draw; a P reached only behind a panel with AC breakers on it; a P that is a bolt holding other lugs, the starter or another part: the total draw is a pro's to read, as it is wherever a step below stops, and step 1 of the route says what you go on with. At anchor after dark, only with the anchor light on and its current, from its label, counted with the loads that stay on; a light that goes out with the battery switch makes this a procedure for daylight. One bank at a time.

You need: a multimeter with a current function, and its manual, which names the fuse in its A jack and the largest current that jack carries with no limit of seconds — the meter's current rating in the steps below — and what its current range shows as its last digit, with the counts it adds near zero (→ 3.2): together smaller than the sum of the loads that stay on by design, or the reading cannot be compared with that sum; leads with insulated clips; the wrench for the nut on the stud — at the

engine block, a torque wrench and the torque the engine's manual gives for that bolt, and with no torque in the manual the engine block is not the place for this procedure (→ 3.8); insulating tape or a boot for the lug; the eye protection the entry of the SHORT CIRCUIT sign names; the current of each bilge pump on this bank, from its label or the Boat Passport (field 11); a pencil. Points P and Q are those of → Fig. 7.1 · p. 17.



1. Find P and Q on your boat: P, the stud where the cable lands — the shunt's SYSTEM stud, the cable's stud on the negative bus, or its lug bolt on the engine block; Q, that cable's lug. Count, by eye and without touching, the cables on the battery's negative terminal and, with a shunt, on its battery side and its SYSTEM stud, and the lugs on P; note every positive terminal within reach of a wrench at P. Compare the current of each bilge pump that returns through this negative with the current the meter's A jack carries. One cable as the paragraph above asks, Q alone on P, P reached without a hand in bilge water and not behind a panel with AC breakers on it, at the engine block a bolt that holds nothing else, and no pump above the meter's rating without a switch or breaker of its own: continue. Anything else, or a cable you cannot follow by eye: stop here — the paragraph above says what then.
2. Stop every source that can charge a bank: the charger and any inverter/charger at its own switch or at its breaker on the AC panel; an inverter or inverter/charger also OFF at the DC breaker or isolation switch that feeds it; 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 — or, at the dock, work after dark; a wind generator stopped as its manual says; a generator stopped, with its automatic start OFF. Each source is stopped by the act this step names for it.
3. On a boat with two banks or more, with the engine stopped, set the battery switches so that this bank is apart from every other: a selector on this bank alone, never at BOTH, ALL, 1+2 or COMBINE; a parallel switch OFF; a charging relay (ACR) between the banks set

to the position its maker gives for holding it open (→ 8.3), or its own fuse at one of the two banks taken out, where that fuse sits in a holder that opens by hand, in the state the entry of the SHORT CIRCUIT sign gives for a fuse between two banks. A relay whose contacts have welded can keep the banks joined even at its hold-open position, so the fuse is the certain means ("Two banks", in this section). A relay with neither — no such position you can set, and no such fuse you can take out: the banks are taken as joined, and the total is read on a monitor whose shunt carries the return of every bank, or by a pro — stop here, and the restore says what then. This bank alone feeds its loads.

4. Switch every load off at its own switch — at anchor after dark, every load but the anchor light — and wait until no bilge pump is running. Leave the breakers on the DC panel as the boat is left, and the bilge pump's switch, the high-water alarm and the CO alarm as you found them before step 3 — where it turned them off for a relay's fuse, back now that the fuse is out — except a pump whose current is above the meter's rating (step 1): OFF at its own switch or breaker until the restore. A load that has no switch but its breaker and starts by itself — a refrigerator, a freshwater pump, never a bilge pump or an alarm — goes OFF at its breaker only if it would run during the reading; write down which, because that circuit is then out of the reading and the search. The engine stays stopped from here to the end of the restore. Nothing you switched runs.
5. Get ready as the entry of the SHORT CIRCUIT sign says for a negative connection, and set the meter on DC volts with its leads as the entry of the METER LEADS sign says. Clip the black lead to P. With the battery switch of this bank at ON, put the red probe on a positive you can identify — the starter's battery stud at the engine block, the battery-side terminal of the battery switch of this bank where the probe reaches it without opening a panel, or the battery's own positive terminal — on that terminal alone. The meter reads battery voltage, about 12 V: the meter and its leads work. No voltage: the meter, or the battery itself — a lithium bank disconnected by its BMS reads none (→ 11.4), and a meter that fails is found by → 3.7; stop here, and the restore says what then.

6. With the engine stopped, turn the battery switch of this bank to OFF. Where a unit's positive terminal is within reach of the wrench at P — a charger's, an inverter's, a DC-DC charger's, or the fused lead some shunts carry to the battery's positive — switch off the DC breaker or isolation switch that feeds it, or take its own fuse at the battery out where it sits in a holder that opens by hand, in the state the entry of the SHORT CIRCUIT sign gives for that fuse; a monitor whose own fuse comes out stops counting while it is out (→ 7.6 · p. 39). Then read from P, the black lead still on it, every positive terminal within reach of the wrench, one at a time. Each reads 0 V: continue. Any voltage, or a terminal you cannot identify: stop here — the job is a pro's, and the restore says what then.
7. Prove the meter again before the wrench goes on: the red probe on the battery-side terminal of the battery switch of this bank, or on the battery's own positive terminal, against P. Battery voltage again: the zeros of step 6 were real. No voltage: the zeros proved nothing — find why the meter failed (→ 3.7) and take steps 5 to 7 again.
8. Take the black clip off P and the red probe away. With one wrench, undo the nut on P and lift the negative cable's lug Q off it; cover the lug at once with insulating tape or a boot, and lay it where it touches no metal. Q is off, covered and touching nothing. Until step 10, what is wired around the battery switch has lost its way back to the battery — where they are wired that way, the bilge pump's automatic switch, the high-water alarm and the CO alarm among them. With a shunt whose monitor showed a current with none flowing (→ 7.6 · p. 39): now that Q is off the SYSTEM stud and nothing else is on it, no current passes the shunt, and the monitor's zero current calibration, where it still has power, is done now, as its manual says.
9. Move the red lead from the V jack to the A jack, and turn the dial to DC amps; the black lead stays in COM. The display shows ⎓ and A.
10. Clip one lead to P and the other to bare metal of Q, the tape opened only where the clip bites. The meter now carries the current of everything wired around the battery switch: a small reading, a few milliamps or more. A minus sign before it: the leads

are the other way round from the current, and the number is the same — unless a source still charges, which also reads as a minus (step 2). A pump that runs for a few seconds now is a sensor calibrating itself as its power comes back (→ 12.3).

11. With the engine stopped, turn the battery switch of this bank to ON. Watch the reading until it stops falling, and for at least two and a half minutes more; write down the lowest steady reading. A jump to amps for a second or a few seconds is a pump testing for water or starting (→ 12.3). A reading that falls to zero after such a jump and stays there: the meter's fuse may have opened, and the bank's negative with it — go on with steps 13 and 14 now, and check the meter's fuse as its manual says (→ 3.2).
12. Of the breakers on the DC panel that are ON, turn one OFF at a time, watching the reading, and back ON before the next; a breaker that was OFF before stays OFF. The breaker whose OFF takes the reading down is a circuit that draws: write down which, and by how much. A reading that falls to zero and stays there after a breaker goes back ON: the branch of step 11 for the meter's fuse.
13. With the engine stopped, turn the battery switch of this bank to OFF and read again. What the meter reads now is wired around the battery switch (→ 1.7): write it down.
14. With the battery switch still OFF, take the clips off, put Q back on P with its washer and nut as they were, and tighten the nut — at the engine block to the torque in the engine's manual, with the torque wrench — until the lug does not turn when you push it by hand. Q sits on P, tight, with no tape between them.

PUT THE BOAT BACK IN SERVICE

- Water that rises in the bilge before this restore is done: once Q is back on P tight — by steps 13 and 14 if the meter is still in — only this comes next, with the engine stopped: the battery switches back to their working positions, a breaker that step 12 holds OFF at that moment back ON, and every pump you turned OFF in step 4 back at its own switch or breaker as you found it; then the card “Water in the boat — the pump can’t keep up or is silent” (→ emergency card). The rest of this restore waits until the water is down.
- If Q cannot go back on tight — a thread that will not hold, a nut that will not tighten — the battery switch of this bank stays OFF, every source you stopped stays stopped, and a pro puts the lug back: the bank’s negative is open, and everything it feeds, the bilge pump’s automatic switch, the high-water alarm and the CO alarm among them, has no power until then; the entries of the BILGE PUMP and CARBON MONOXIDE signs say what you do meanwhile. Water that rises meanwhile: the card “Water in the boat — the pump can’t keep up or is silent” (→ emergency card); while this negative is open, this bank’s own battery switch turned ON gives a pump fed from this bank no power.
- The red lead back to the V jack and the dial to OFF.
- With the engine stopped, every battery switch and parallel switch back to its working position, a relay’s control you set in step 3 back to automatic, and a relay’s fuse you took out there back in its holder, by hand, in the state the entry of the SHORT CIRCUIT sign gives for a fuse between two banks; a fuse you took out at the battery in step 6 back in its holder, by hand, in the state that entry gives for that fuse, and a breaker or isolation switch you turned off there back as you found it.
- Every charging source you stopped, back as you found it: the charger and any inverter/charger, the inverter’s DC breaker or isolation switch, 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.
- Every load you switched off back as you found it, and a pump you switched OFF in step 4 back at its own switch or breaker as you found it.

- A CO alarm on this bank lost its power while Q was off, while its breaker was OFF in step 12, and, wired after the battery switch, while the switch was OFF; the entry of the CARBON MONOXIDE sign says how you see that it is working again. Electronics that lost their clock or settings are set again by their manuals.
- Check that the bilge pump's automatic switch has power, by the procedure "The check that the automatic switch has power" (→ 12.2). A bilge pump that started again and again while the meter was in, and keeps up with the water: then → 12.1.

WHY IT WORKS

The steps put the meter in while nothing large can flow, and take it out the same way. With the battery switch OFF, the only current through the opened negative is that of the circuits wired around the switch — their standby currents, a few milliamps each for the loads of → Table 7.1 · p. 3, unless a pump runs; the switch goes ON only once the clips are on, and OFF again before they come off. The readings before the wrench are those of a negative connection anywhere: a known positive proves the meter, 0 V on every positive within reach says that a wrench slipping onto one of them closes no circuit, and the second proof says that the meter could have shown a voltage. In series the meter carries the current itself, and its own fuse is what limits it. One maker's meter reads up to 10 A, and above 10 A, up to 20 A, for 30 seconds followed by 10 minutes off; its A jack is fused at 11 A. A second maker's reads up to 10 A, a current above 6 A for 30 seconds with 10 minutes to recover, and its 10 A jack is fused at 10 A. A low-cost third has no fuse in its 10 A jack and limits every reading on it to 10 seconds, with 15 minutes between readings. MFR What the steps compare with a pump's current is the current a meter's A jack carries with no limit of seconds: up to 10 A on the first meter, up to 6 A on the second, and none on the third. The procedure stays on the A jack: the first meter's 6 A range shows a milliamp as its last digit, and a bilge pump that starts by itself would blow the much smaller fuse of a milliamp jack.

Which circuit draws

The breakers find the circuits after the battery switch, one at a time, with the monitor or the meter watching the draw. A circuit wired around the battery switch, or on a fuse panel with no breakers, is found without opening anything: a fuse carrying current has a small voltage across it, and a meter on its millivolt range reads it. One meter maker's guide gives this as the way to find the circuit without pulling a fuse.

PRACTICE

The voltage across a fuse is its current times its resistance. One maker of blade fuses publishes the typical cold resistance of each rating, and puts two test points on the top of its fuses for a probe (→ Table 7.5 · p. 30). The resistance is typical, not exact, so the result says which fuse carries current and roughly how much — never a pass or fail. A fuse maker that publishes no such table still lets you compare its fuses of one rating and one type: the larger the steady reading, the larger the current.

MFR

Table 7.5. Typical cold resistance of one maker's blade fuses, by rating MFR

Rating	Typical cold resistance
3 A	0.0311 Ω
5 A	0.01785 Ω
7.5 A	0.01091 Ω
10 A	0.00770 Ω
15 A	0.00480 Ω
20 A	0.00338 Ω
30 A	0.00197 Ω

The meter has a limit of its own at the bottom of its millivolt range. One maker's 600.0 mV range shows 0.1 mV as its last digit and is accurate to 0.5 % plus 2 digits: near zero, a reading can be up to 0.2 mV from the truth either way, so a fuse that carries nothing can read 0.1 or 0.2 mV. A reading within that band of zero tells you nothing, and two readings closer together than twice that band do not tell you which fuse carries more.

MFR

Suppose your meter reads 0.4 mV across a 10 A blade fuse of that maker. The current is 0.0004 ÷ 0.0077 = 0.052 A, about 52 mA; on the meter above, 0.4 mV can be anything from 0.2 to 0.6 mV, 26 to 78 mA — a current flows, roughly that much. Suppose a 15 A fuse of the same maker carries a draw of 20 mA: 0.020 × 0.0048 = 0.000096 V, about 0.1 mV, which that meter can show as anything from 0.0 to 0.3 mV, so the reading tells you nothing. On that meter a reading stands clear of the band — 0.3 mV or more — for certain only with about 0.5 mV across the fuse: 16 mA through a 3 A fuse, 65 mA through a 10 A fuse, 104 mA through a 15 A fuse, 148 mA through a 20 A fuse and 254 mA through a 30 A fuse.

Procedure: Which circuit draws: the drop across each fuse

For the fuses whose two ends you can reach with the probes without opening their holders: blade fuses by their test points or the metal at their two ends, on a fuse panel or a fuse block, one reached behind a panel with AC breakers on it included. A fuse held under a nut on a stud is not read in this procedure. You need a meter with a DC millivolt range whose last digit is 0.1 mV, and its manual for that range's accuracy (→ 3.2), the fuse maker's table of cold resistance if it publishes one, and a pencil.



1. Stop every source that can charge a bank: 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 — or, at the dock, work after dark; a wind generator stopped as its manual says; a generator stopped, with its automatic start OFF; the engine stopped. Switch every load off at its own switch — at anchor after dark, every load but the anchor light, whose fuse then reads its own current. Leave the breakers on the DC panel as the boat is left, the bilge pump's switch, the high-water alarm and the CO alarm as they are, and the battery switch at its working position. A load that has no switch but its breaker

and starts by itself — a refrigerator, a freshwater pump, never a bilge pump or an alarm, whose breakers stay as you found them — goes OFF at its breaker only if it would run during the reading; write down which, because that circuit is then out of the search. A fuse panel or fuse block reached behind a panel with AC breakers on it: before a hand or a probe goes behind that panel, take shore power, the inverter and the generator off the boat — shore power unplugged — as the entry of the AC — PRO sign says. Nothing charges and nothing you switched runs.

2. Set the meter on DC millivolts with its leads as the entry of the METER LEADS sign says, and check that the display shows ⎓.
3. Put the probes on the two ends of one fuse — its two test points, or the metal at its two ends — and read; then the next fuse, until you have read them all, and write down each fuse, its rating, its circuit and its reading. A reading no larger than the meter's accuracy near zero (on one maker's meter, 0.2 mV): no current you can tell. A steady reading above it: current flows through that fuse. OL, or a reading in volts: not a current — the fuse is open, with something still connected after it, and that circuit is dead now; on a circuit that feeds the bilge pump, the high-water alarm or the CO alarm, that is the first thing you act on, by the route "A branch breaker trips or a fuse blows" (→ 4.8).
4. For each fuse whose reading is above that band, divide the reading in volts by that fuse's cold resistance in ohms from its maker's table: the result is roughly its current in amps. The fuse with the largest current is the circuit to follow; with no table from its maker, in each group of fuses of one maker, one rating and one type, the fuse with the largest reading. Readings that differ by no more than twice the meter's accuracy near zero are not ranked: follow each of them.
5. Follow that circuit to what it feeds, by its label and your one-line diagram (→ 2.3), and write the circuit and its current into the Boat Passport (field 10).

PUT THE BOAT BACK IN SERVICE

- Every load and every breaker you switched off back as you found it; 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; the meter's dial to OFF.
- The AC sources, if you took them off in step 1: the inverter's DC breaker or isolation switch and its own switch as you found them, the generator's automatic start as you found it, and shore power back last, in the order of → 17.2.

WHY IT WORKS

A fuse is a short piece of metal chosen to melt at a current, and like any metal it has resistance: from about two to about thirty thousandths of an ohm in the ratings of → Table 7.5 · p. 30. Its resistance is what turns the current into a voltage you can read across it, the way a shunt does for a monitor. Where the rule stops working: the resistance rises as the fuse warms under its rated current, which is why the maker gives a cold figure; the small current of a draw leaves it cold. The clips or the contacts of a holder have their own resistance, so a reading taken across the holder instead of the fuse's own two ends adds theirs.

When the draw is found

 **BILGE PUMP**  **CARBON MONOXIDE**

A stereo whose power wire is live at all times draws what its manual says, and one maker has that wire turned off at its breaker or switch when the boat is not in use; where an electronics memory feed is taken from is the subject of → 13.3. An inverter left on draws what its idle figure says, in → Table 7.1 · p. 3: switched off at its own switch when nothing needs it, it draws none; in its maker's power-saving mode, less (→ 7.7 · p. 44). A current on a circuit where nothing should draw — a device that does not switch off, insulation that leaks to wet metal — is a fault, and a pro finds it with your readings (→ 7.8 · p. 45).

A draw on a circuit that feeds the bilge pump, the high-water alarm or the CO alarm: the circuit stays on, the bank that feeds it is kept charged — a charger on shore power, wired to that bank, while shore power stays on (→ 12.7); with no shore power, its days counted (→ 7.4 · p. 34) — and a pro finds the draw.

Turning the battery switch to OFF when you leave the boat stops only what is wired after it. A draw on a circuit wired around the switch goes on, and so do the bilge pump's automatic switch, the high-water alarm and the CO alarm where they are wired that way; where one of them is wired after the switch, it stops too (→ 1.7). Your Boat Passport says which (field 10, field 11); the entries of the BILGE PUMP and CARBON MONOXIDE signs say what you do when one of them is left without power. A lithium bank whose BMS disconnects it when it runs low takes everything on it dark at once, the bilge pump's automatic switch and both alarms included (→ 11.4).

7.4. The boat at the dock without you

How many days does the battery that feeds your bilge pump last while you are away? While you are away, that battery carries the automatic switch's standby current, the pump's runs, and everything else that stays connected to it: every circuit wired around the battery switch (→ 1.7) and, with a battery switch left ON, everything after it as well (→ 12.7). It also loses charge by itself (→ 6.6). A charger on shore power carries all of it — but only if the charger is wired to that battery and shore power stays on: which banks your charger reaches is on your energy map (→ 1.7).

The count is the one of → 7.1 · p. 2, with the loads that stay on and 24 hours a day; the battery's side is the usable capacity of → 7.2 · p. 6, in the season you leave the boat. The pump's real work is set by rain and seepage, which no label gives: your own monthly check tells you how often it runs (→ 12.7). Its tests for water are set by its maker's interval (→ 7.1 · p. 2).

WORKED EXAMPLE: HOW MANY DAYS THE PUMP'S BATTERY LASTS

Suppose one 12 V AGM battery rated 100 Ah at the 20-hour rate, whose maker's average depth of discharge is 50 %: 50 Ah to use. Suppose the battery switch is left OFF, and on this battery, wired around the switch, are a bilge pump with a load-sensing automatic switch, a high-water alarm with an electronic sensor, a CO alarm and a battery monitor. The bases: the pump's figures are those of → 12.7, for a pump that tests every two and a half minutes; the other currents are the makers' figures of → Table 7.1 · p. 3; the self-discharge is one AGM maker's 2 % a month (→ 6.6).

Table 7.6. What the pump's battery gives in a day, worked example

Load	How it is counted	Ah a day
Pump's automatic switch, testing for water	4 A for 1 second in every 150: 4 ÷ 150 × 24	0.64
Pump moving rain and seepage	4.8 A for 10 minutes: 4.8 × 10 ÷ 60	0.80
High-water alarm's sensor	0.006 A × 24	0.144
CO alarm	0.006 A × 24	0.144
Battery monitor	under 0.001 A × 24	under 0.024
Self-discharge	2 % of 100 Ah a month: 100 × 0.02 ÷ 30	0.067
Total		at most 1.819

50 ÷ 1.819 = 27.5 days before the battery reaches its maker's average depth. What decides the answer is not the alarms, which draw little, but the pump's work and anything else left on. Suppose a rainy spell makes the pump run 60 minutes a day: 4.8 Ah instead of 0.80, a total of 5.819 Ah, and 50 ÷ 5.819 = 8.6 days. Suppose instead a stereo on the same battery has its power wire left on, though its maker has that wire turned off when the boat is not in use: under 200 mA, up to 4.8 Ah a day more, a total of 6.619 Ah, and 7.6 days. Suppose instead a pump that tests every 20 seconds, as one maker's model does, with the same 4 A for each one-second test — a current assumed for the example, not that model's figure: its tests

> alone take 4 × 1 ÷ 20 × 24 = 4.8 Ah a day instead of 0.64, a total of 5.979 Ah, and 50 ÷ 5.979 = 8.4 days. Suppose a winter month with the compartment at 41 °F: by one monitor maker's figure of 1 % less capacity for each 1.8 °F below 68 °F, 15 % less, so 42.5 Ah to use, and 42.5 ÷ 1.819 = 23.4 days. The example counts the battery's 20-hour amp-hours, though these loads draw far less than its 20-hour current (→ 7.2 · p. 6).

What "lasts" means is not the same for every battery. Past its maker's depth, a lead-acid battery goes on running the pump, at the price of damage that a maker's margin exists to avoid (→ 7.2 · p. 6), and the pump moves less water as the voltage falls (→ 12.4). A lithium bank works to the end and then its BMS disconnects it, and everything on it goes dark at once — the pump's automatic switch, the high-water alarm and the CO alarm among them (→ 11.4).

 BILGE PUMP  CARBON MONOXIDE

So when you will be away longer than your count gives, decide how the pump and the alarms keep their power: a charger on shore power that is wired to their battery, with shore power that stays on; or a count of days with room to spare, and someone who looks at the boat before they run out — the bank's voltage, read where it reads with the battery switch as the boat is left: on the bank's monitor where it stays on, or at the battery's own terminals by the procedure "A battery's resting voltage" (→ 3.5) — and how often the pump runs, by the monthly check (→ 12.7). A battery switch you leave OFF takes with it whatever is wired after it: your Boat Passport says whether the pump and each alarm are wired around the switch or after it (field 10, field 11), and the entries of the BILGE PUMP and CARBON MONOXIDE signs say what you do while one of them has no power.

7.5. At anchor and under way

Does a day's charging put back what a day's use takes? Away from shore power, the engine and the panels have to return every amp-hour of → 7.1 · p. 2, and a little more. A bank that ends each day a little short is a

little emptier each morning, and the shortfall shows only after several days.

A little more, because a lead-acid battery takes back more amp-hours than it gave. One battery maker gives a typical 102 % to 110 % of the amp-hours taken out as what must be returned for a full recharge; one battery monitor maker sets its charge efficiency factor to 95 % by default, so that its count adds only 95 % of the amp-hours that go in. The two say the same thing in two ways. The battery maker adds that the amp-hours a full recharge takes depend on the depth of discharge, the rate of recharge and the temperature. MFR

What the engine puts back

Which battery an outboard's charging output charges, and how a house bank gets its share of it, is in → 9.1. An inboard with its own alternator and regulator is in → 9.2. Either way the figure on the brochure is not what reaches the bank. One outboard maker rates its 150 hp engine's alternator at 60 A and its 75 to 115 hp engines' at 35 A, and on the 150 hp engine raises the idle speed by itself to boost the alternator's output and recharge low batteries: at the ordinary idle speed it gives less. MFR

One maker of alternators for inboard engines prints its 165 A alternator's output by the alternator's own speed, cold and hot. Hot — at 194 °F — it gives 153 A at 6,000 alternator rpm, the top of its table, and 59 A at 1,500 alternator rpm, 36 % of its rating. The alternator's speed is the engine's speed times the ratio of their pulleys, so it is not the speed on your tachometer. A bank near full takes less current than it takes when it is low: the charge tapers as the battery fills (→ 9.4). The battery monitor shows what really goes in: its current while the engine runs, with the loads you have on. MFR

What the panels put back

A solar panel's day depends on where and when the boat is, how the panel faces the sun, and what shades it — rigging, a boom, a bimini. What a panel will really give on your boat, and how that feeds this

budget, is worked out in → 10.3. In the example below the solar figure is a supposition, to show the count.

> **WORKED EXAMPLE: A DAY AT ANCHOR, IN AND OUT**
>
> Suppose the day of → Table 7.2 · p. 5 with the inverter switched off: 57.35 − 13.00 = 44.35 Ah used. Suppose the monitor shows 30 A going into the house bank for the hour the engine runs: 30 Ah. Suppose the panels put 18 Ah into the bank that day. In: 30 + 18 = 48 Ah. By the battery maker's 102 % to 110 %, putting back 44.35 Ah takes 44.35 × 1.02 = 45.2 Ah to 44.35 × 1.10 = 48.8 Ah. The day ends between 2.8 Ah ahead and 0.8 Ah behind. What the number means: one day is even, and a week of the worst such days leaves the bank up to 7 × 0.8 = 5.6 Ah short — an hour less of the chartplotter, 2.5 Ah, covers each day's gap, and a monitor set to full by a real full charge shows whether it did (→ 7.6 · p. 39).

A trailer boat without shore power

A trailer boat with no shore power is charged by its outboard while it runs, and by a charger at home between trips. What stays connected on the trailer keeps drawing between trips: a stereo whose power wire is left on, a pump's automatic switch, a monitor.

Suppose an 80 Ah battery at the 20-hour rate, like one maker's deep-cycle battery in → 6.1, whose maker's average depth is 50 %: 40 Ah to use. Suppose the stereo's power wire is left on and the stereo draws 200 mA, the top of its maker's figure: 0.2 × 24 = 4.8 Ah a day, and 40 ÷ 4.8 = 8.3 days. Between trips two weeks apart, the battery reaches its maker's depth before the next trip from the stereo alone, and the outboard then has to recharge it under way. With that wire turned off at its breaker or switch, as the stereo's maker asks when the boat is not in use, the stereo takes none of it.

A charge at home between trips is the charger's job: by the procedure "A battery on a portable charger" (→ 6.6), with the battery taken out by the planned job on a battery (→ 6.5) or charged aboard where that procedure allows it. What a battery switch turned OFF stops, and what it does not, is in → 7.3 · p. 10.

The day's charge compared with the day's use, worked for your own panels, engine and loads, is the subject of → module "Calculators".

7.6. The battery monitor

What does your battery monitor really know, and how do you keep its count right? It measures one thing, the current through its shunt, and works out everything else from that: the amp-hours in and out, and from them a state of charge. The state of charge on the screen is a count, not a measurement (→ 3.6): it is as true as the moment it was last set to full, the capacity it counts against, and the current it was able to see.

What it counts

One maker's monitor measures the current in and out of the battery all the time and adds it up over time into the amp-hours added or taken; its state of charge is corrected for the Peukert exponent and for the charge efficiency. A second maker's monitor shows the amp-hours taken out since the last full charge. Both count against a capacity that you type in. A third maker's monitor learns the battery's capacity by itself, gives its state of charge as a share of the battery's actual full-charge capacity, not of its design capacity, and asks you not to lower the design capacity you enter to allow for a loss you believe the battery already has. So the first two count against the capacity you typed in until you change it, and the third adjusts its capacity over time by itself — each as its own maker's manual says. MFR

It counts only what passes its shunt. One maker asks that the negative of every load, inverter, battery charger, solar charger and other charging source be connected after the shunt, on its SYSTEM side, with nothing else on its battery side or on the battery's negative terminal (→ 3.6). Shunts differ by model: one maker's smart shunt takes its own power through a fused red cable from the battery's positive to a pin on the shunt, so a positive lands on the shunt's body (→ 7.3 · p. 10); a second maker's monitor puts its own negative lead on the battery side of the

shunt by design. Anything else on the battery's negative terminal is current the monitor never sees: it is never counted. MFR

How it is set to full

The count needs a fixed point, and a full battery is that point. One maker's monitor sets itself to 100 % when three conditions are met at once: the voltage is above the "charged voltage", the charging current has fallen below the "tail current", a share of the capacity, and both have held for the "charged detection time". Its defaults are 14.0 V for a 12 V battery, 4.00 % and 3 minutes. Until it has been set to full once, it shows "---"; between full charges its count drifts; it can also be set to full by hand. A second maker's monitor uses the charge voltage and the charging current that tapers to its set value; a third, a full-charge voltage and current, or a menu item that sets the state of charge to full by hand. MFR

A monitor set to full by hand on a battery that is not full counts from a false 100 %. And a charger that ends its charge while the current is still above the tail current never meets the condition: the monitor never sets itself to full, and its count goes on drifting. Its charged voltage and tail current are compared with what your charger does at the end of a charge (→ 9.3).

Table 7.7. The settings that decide the number, with one maker's defaults MFR

Setting	What it does	One maker's default
Battery capacity	The amp-hours it counts against; for a lead-acid battery that maker recommends the 20-hour rating, for the whole bank	200 Ah
Charged voltage	One of the three conditions for full	14.0 V for a 12 V battery
Tail current	The charging current, as a share of the capacity, below which the battery counts as full	4.00 %
Charged detection time	How long the two must hold	3 minutes

Setting	What it does	One maker’s default
Charge efficiency factor	The share of the amp-hours going in that the count adds	95 %
Peukert exponent	How fast the counted capacity shrinks as the current grows (→ 7.2 · p. 6)	1.25; 1.01 for lithium, where the exponent is unknown
Current threshold	The current below which the count takes the current as zero (→ 7.3 · p. 10)	0.10 A
Discharge floor	The state of charge treated as empty for the time remaining	50 %

WHY IT WORKS

A count keeps every small error it adds until a full charge sets it again. One maker’s shunt reads the current within 0.4 %, plus an offset of less than 10 to 40 mA by model, but the count also has to guess how much of the charge that went in the battery can give back, and how much of its capacity a fast discharge leaves, and those guesses are the charge efficiency and the Peukert exponent. One battery maker returns 102 % to 110 % of the amp-hours taken; a monitor set to 95 % counts one figure inside that range, not the battery’s own. The charge a battery loses by itself never passes the shunt at all, because it flows inside the battery: a monitor on a battery at the dock for a month cannot see it. And a capacity typed in from the label stays the same as the battery ages. Every one of these errors is cleared when the battery is really full and the monitor sets itself to 100 %, which is why one monitor maker writes that monitors of this kind need to reach 100 % each cycle, and that the inaccuracy multiplies with each cycle that does not reach a full charge.

What makes its number wrong

Table 7.8. What makes a monitor's number wrong, and the check

Cause	What you see	The check
A load's or a charger's negative on the battery's negative terminal or on the shunt's battery side	A load there: a state of charge higher than the truth; a charger there: lower	The cables on the battery's negative terminal and on the shunt's battery side, counted by eye (→ 3.6)
A capacity set larger than the bank holds — a wrong figure, or the label's on an aged bank	The battery dies with the monitor still showing charge	The setting against the label; a timed discharge for what it holds now (→ 6.6)
Not set to full since its count was lost	"---", or a count that drifts from the truth	A full charge that meets its three conditions
A monitor that was off for a while	A count that missed those hours (one maker's monitor cannot count while it is off)	A full charge, then the setting to full
Its cables at the shunt reversed	A charge shown as a discharge	The maker's manual: the negative cables on the shunt swapped (→ 7.8 · p. 45)
A current shown with no current flowing: the monitor's offset	A reading with everything off that a meter in series does not show	The meter first: a range whose last digit is too large, its fuse or the jack also give no reading (→ Table 7.4 · p. 11); then the maker's manual: the current threshold, or a zero calibration
Its current threshold	A small draw counted as zero	The threshold at zero for the reading (→ 7.3 · p. 10)

One maker's manual says what to do about two of these. Reversed charge and discharge currents mean that the negative cables on the monitor's shunt must be swapped. For a current shown with none flowing it gives two ways: the current threshold set above that current, a menu setting; or a zero current calibration, which it calls almost never needed, made with every cable on the shunt's SYSTEM side disconnected so that no current can flow — switching loads and

chargers off is not enough for it. A threshold set above the offset also hides a real draw below it, so the draw of → 7.3 · p. 10 is still read with the threshold at zero. On a shunt whose SYSTEM stud carries one cable, the calibration is a step of the procedure with a multimeter in series (→ 7.3 · p. 10). Swapping the shunt's cables puts a wrench on its battery-side stud as well and changes its wiring: a pro's job (→ 7.8 · p. 45). MFR

Procedure: Bringing the monitor back to the truth

For a monitor on a lead-acid bank that shows "---", a state of charge you no longer believe, or a battery that dies with charge still on the screen; a lithium bank's monitor settings and its check are in → 11.1. You need the monitor's manual and its menu, the battery's label, your charger's manual, and the Boat Passport.

 HOT BATTERY  GASOLINE VAPOR

1. Count the cables on the battery's negative terminal and on the shunt's battery side, by eye and without touching (→ 3.6). One cable from the battery to the shunt — the jumpers between the batteries of one bank aside, and the monitor's own lead where its maker puts it there: continue. Anything else: that lead bypasses the shunt, and the count will drift by what it carries; write it into the Boat Passport (field 5), and moving it is in → 7.8 · p. 45. Continue with step 2 either way.
2. Read each setting in the monitor's menu against → Table 7.7 · p. 40, the battery's label and its manual: the capacity of the whole bank at the 20-hour rate for a lead-acid bank, as one maker advises; the Peukert exponent and the charge efficiency at the monitor maker's defaults unless your battery's maker gives its own; the charged voltage and the tail current against what your charger does at the end of its charge (→ 9.3). Set what is wrong, as the monitor's manual says, and write every setting into the Boat Passport (field 12).
3. Charge the bank fully with its charger, until the charger shows the charge complete. The monitor sets itself to 100 %, and "---" is gone. If it does not, compare its charged voltage and tail current

again with the charger's last stage: a charger that stops while the current is above the tail current never lets the monitor set itself. Its manual's way to set it to full by hand is for a bank whose resting voltage, read as step 4 says, is on its maker's 100 % row.

4. Check the count against the battery itself: its resting voltage after its maker's rest, by the procedure "A battery's resting voltage" (→ 3.5), read in its maker's table. A monitor at 100 % on a battery below its maker's 100 % row: the count is wrong, the charge stopped short (→ 9.3), or the battery no longer takes a full charge (→ 6.6).
5. For a bank you suspect of having aged, its capacity now comes from a timed discharge (→ 6.6). A monitor that counts against a capacity you type in keeps the label's figure until you enter the one the test found; a monitor that learns its capacity is left as its maker asks.

PUT THE BOAT BACK IN SERVICE

- The charger back to the setting and the state you found it in; the procedure of step 4 ends with its own restore block.

7.7. Using less without buying anything

Where can a day's use come down without buying anything? Look first at the hours, then at the currents: in → Table 7.2 · p. 5 the loads that run around the clock take most of the day, whatever they draw, and one of them, the inverter on with nothing plugged in, takes more than a fifth of the day and does no work.

- The inverter. On with nothing plugged in, one maker's 800 VA inverter draws 6.5 W and another maker's inverter/charger 25 W, around the clock (→ Table 7.1 · p. 3). Switched off at its own switch or its remote panel when nothing needs AC, it draws none; in its maker's power-saving mode — ECO on the first, 1 W, in which it checks for a load every 2.5 seconds by default; search on the second, 7 W — it draws a fraction.

- The refrigerator. The one maker's figure in → Table 7.1 · p. 3 is for 90 °F around it: shade and free air around it, a warmer setting inside, and a lid opened less let its compressor rest longer. One maker's portable refrigerator has a battery protection setting, and that maker recommends its High or Medium level where the refrigerator runs from the start battery.
- The electronics. The 12 in chartplotter of → Table 7.1 · p. 3 takes 5.0 Ah in two hours at anchor; switched off when nobody looks at it, none. A VHF radio left switched on draws its standby current all day and night, 350 mA on one maker's model; at the dock or on a mooring with nobody aboard, nobody is listening.
- The lights. A light switched off draws nothing, and a cabin light left on draws its current for every hour of the night.
- The memory feeds. A stereo whose power wire is live at all times draws through it whether the stereo is on or off — up to 200 mA on one maker's model — and that maker has the wire turned off at its breaker or switch when the boat is not in use, which costs nothing. Where an electronics memory feed is taken from is in → 13.3; what a battery switch turned OFF stops, and what it does not, is in → 7.3 · p. 10.

The charge you put back counts as much as the charge you save. One battery maker's guide asks for its batteries to be fully charged after each use — a use being 30 minutes or more of running — and writes that lead-acid batteries have no memory effect and should not be fully discharged before a charge. A bank charged full whenever it can be also lets the monitor set itself to full (→ 7.6 · p. 39). PRACTICE

What to buy to use less — LED lights, a more efficient refrigerator, a monitor — is a purchase, and each purchase belongs to the chapter of its load (→ 13.1, → 13.2).

7.8. On board

How long your bank lasts is a count you can make from your labels, and why it went flat is a set of readings you can take. 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 changes far from help and on someone else's boat.

ON BOARD: GOLDEN RULE

Count before you trust a number: the day's use from your own labels, the bank's usable amp-hours by its maker's figures, and the draw with everything off measured, never guessed. A battery monitor is a count, true only after a real full charge has set it, against the capacity the bank has now, with nothing on the battery's negative terminal but its cable to the shunt.

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 7.9. What it means

What you notice	What is happening	First check	Yourself or a pro
The battery is flat in the morning	A draw in the night, a charge that never filled it, a monitor that counted wrong, or a battery that has lost capacity	The route "The battery is dead in the morning" (→ 7.3 · p. 10)	**Do it yourself, if… you can do its procedures, with their signs**
The monitor showed full, and the battery died early	A capacity set larger than the bank holds now, a count never set to full, or a lead that bypasses the shunt	The procedure "Bringing the monitor back to the truth" (→ 7.6 · p. 39)	**Do it yourself, if… you can do that procedure, with its signs; moving a lead: Hire a pro**
The monitor shows "---"	It has not been set to full since its count was lost	The procedure "Bringing the monitor back to the truth": a full charge that meets its three conditions (→ 7.6 · p. 39)	**Do it yourself, if… you can do that procedure, with its signs**

What you notice	What is happening	First check	Yourself or a pro
The monitor shows 0.00 A with everything off, and the battery still goes flat	A draw below its current threshold or within its own accuracy, a draw that bypasses its shunt, or a second bank feeding the draw	The procedure “The draw on a battery monitor” (→ 7.3 · p. 10)	**Do it yourself, if… you can do that procedure, with its signs**
The monitor shows a current with everything off that a meter in series does not	An offset in the monitor, or a meter that cannot show that current — a range whose last digit is too large, its fuse, the jack	The meter’s own checks (→ Table 7.4 · p. 11); then the current threshold or the zero calibration (→ 7.6 · p. 39)	**Do it yourself, if… you can do the procedure “What the boat draws with everything off, with a multimeter in series”, with its signs**
A meter in series in one bank’s cable reads almost nothing	Banks joined on the positive side, a second cable on the battery’s negative terminal, or the meter’s fuse	→ Fig. 7.2 · p. 19; the procedure “What the boat draws with everything off, with a multimeter in series” (→ 7.3 · p. 10)	**Do it yourself, if… you can do that procedure, with its signs**
The draw is still there with the battery switch OFF	A circuit wired around the switch, or a load meant to stay on	The procedure “Which circuit draws: the drop across each fuse” (→ 7.3 · p. 10)	**Do it yourself, if… you can do that procedure, with its signs**
The inverter is on, and nothing is plugged in	Its idle draw, around the clock	→ Table 7.1 · p. 3, → 7.7 · p. 44	**Do it yourself**
The bank ends each day at anchor with a little less charge	A day’s charge that does not put back a day’s use	The day’s count and the day’s charge (→ 7.1 · p. 2, → 7.5 · p. 36)	**Do it yourself**
The bank gives less in winter	Cold takes capacity away	Your battery maker’s figure for that temperature (→ 7.2 · p. 6)	**Do it yourself**

What you notice	What is happening	First check	Yourself or a pro
The battery is flat after the boat sat at the dock for weeks	The loads that stay on, the pump's work and self-discharge, more than the battery gives	The days of your battery (→ 7.4 · p. 34)	**Do it yourself**
A trailer boat's battery is flat at the start of every trip	A draw that stays on between trips, and no charge	→ 7.5 · p. 36; the draw with everything off (→ 7.3 · p. 10)	**Do it yourself, if… you can do its procedures, with their signs**

AWAY FROM HELP

1. **What fails most often:** the bank ends each day a little short, a charge that does not put back the day's use (→ 7.5 · p. 36); and a monitor whose count drifts because the bank is never charged full.
2. **What you lose:** first what the house bank feeds — the refrigerator, the lights, the electronics; with the banks joined, the start battery as well.
3. **How to get to shore without it:** the start battery kept apart from the house bank, the engine run long enough to charge, and the loads cut to the navigation lights, the radio and what steers the boat (→ 7.7 · p. 44).
4. **Spares to carry (with ratings):** the fuses your meter's manual names for its current jacks, by rating, voltage and speed (one meter: 11 A and 0.44 A, 1000 V, fast; → 3.2); and the fuse ratings your Boat Passport lists.
5. **What not to do at sea:** leave the banks joined for the night — a switch at BOTH, ALL, 1+2 or COMBINE, a parallel switch ON, or a charging relay's own combine control ON — which lets the house loads flatten the start battery along with the house bank (→ 8.5).

Do it yourself or hire a pro

DO IT YOURSELF OR HIRE A PRO · ENERGY AND THE DRAW

STOP · HOT BATTERY A battery that turns hot, swells, hisses or smells while it charges; a bilge pump that starts again and again while you measure, or water that rises in the bilge.

What to do this minute: The card "Battery smells, is swollen, or is hot" (→ emergency card). For water that rises in the bilge: the card "Water in the boat — the pump can't keep up or is silent" (→ emergency card) — in the middle of the procedure "What the boat draws with everything off, with a multimeter in series", right after its steps 13 and 14 and the first item of its restore (→ 7.3 · p. 10); the rest of that restore waits until the water is down. For a pump that starts again and again and keeps up with the water: → 12.1 — in the middle of that procedure, after its steps 13 and 14 and its whole restore.

HIRE A PRO · A lead on the battery's negative terminal or on the shunt's battery side moved to the shunt's SYSTEM side or the negative bus; the shunt's cables swapped as its maker's manual says; a draw on a circuit you cannot read, or a current where nothing should draw; the total draw on a bank where the procedure "What the boat draws with everything off, with a multimeter in series" stops (→ 7.3 · p. 10); a lug that would not go back on tight; and a timed discharge of a bank you suspect of having aged (→ 6.6). Order the work in the words of "What to tell the pro" below, and accept it by the checks there.

If no pro is available: The monitor's reading and the drop across each fuse stay yours meanwhile. A draw that has not been found: the bank that carries it is kept charged — a charger on shore power, wired to that bank, while shore power stays on — or you count its days (→ 7.4 · p. 34).

When a pro may do it differently: A pro may measure a draw with an instrument of their own, or on the monitor by its maker's method, and may move a lead to the negative bus instead of the shunt's SYSTEM stud where both carry the current past the shunt. You see it in the readings written in the pro's report and in the cables on the battery's negative terminal.

DO IT YOURSELF, IF…

The procedures of this chapter, each with the signs at its start: “The draw on a battery monitor”, “What the boat draws with everything off, with a multimeter in series” and “Which circuit draws: the drop across each fuse” (→ 7.3 · p. 10); “Bringing the monitor back to the truth” (→ 7.6 · p. 39).

DO IT YOURSELF · The day’s count and the days of your battery; reading the battery monitor and its settings; counting the cables on the battery’s negative terminal and on the shunt by eye; switching off what is left on.

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). There you read the battery monitor and the panel’s voltmeter, change none of the monitor’s settings, and tell the base or the owner what you read.

What to tell the pro

WHAT TO TELL THE PRO

For a draw you could not place, ask for this: “Find the draw on this bank: with everything off it reads this many amps with the battery switch ON and this many with it OFF, and these fuses showed these millivolts. Find the circuit and the device, and write down what it draws.” For a lead that bypasses the shunt: “Move every load and charger negative on the battery’s negative terminal or on the shunt’s battery side to the shunt’s SYSTEM side or the negative bus, so that the battery’s negative terminal carries one cable, to the shunt.” For a monitor that shows a charge as a discharge: “Swap the shunt’s cables as its maker’s manual says, and set the monitor up for this bank.” Accept the work by three checks. The battery’s negative terminal carries one cable, the jumpers of the bank aside. With every charging source and every load off, the monitor’s current, read with its threshold at zero, shows the draw the pro wrote down, within the monitor’s own accuracy, and a charge going in shows as a charge. The Boat Passport (fields 5, 10 and 12) is updated the same day.

REMEMBER

- A load takes its current times its hours; a load that cycles is counted by its average; amp-hours add only at one voltage, watt-hours across two.
- A bank's usable amp-hours are its 20-hour rating times the average depth of discharge its maker recommends, fewer at a fast rate, in the cold and as it ages.
- A battery flat in the morning has four possible causes: a draw, a charge that never filled it, a monitor that counted wrong, a battery that has lost capacity.
- The draw is read on the monitor first, with its current threshold at zero and its own accuracy in mind; a multimeter in series reads the whole draw only where every return current of the bank passes one cable, opened away from the battery, with the banks apart.
- Breakers switched off one at a time find a draw after the battery switch; the drop across each fuse finds it on the circuits wired around the switch, with no fuse pulled.
- A draw is judged in days of your own bank.
- A monitor is right after a real full charge has set it, against the capacity the bank has now, and with nothing on the battery's negative terminal but its cable to the shunt.

Self-check

1. **Before you measure.** Suppose your battery switch is at BOTH, and you put the meter in series in bank 1's negative cable (→ Fig. 7.2 · p. 19). The loads draw 0.20 A in all. Will the meter read 0.20 A, more, or less?

   Answer: you cannot tell in advance: with the banks joined, the return current divides between the two negative cables by the batteries' voltages and their own resistances, and the meter can read less, nearly zero, more, or a current the wrong way. With the switch on bank 1 alone, nothing else joining the banks

and one cable on bank 1's negative terminal, the meter reads bank 1's whole draw (→ 7.3 · p. 10).

2. **Two voltages.** Suppose your 24 V trolling-motor bank gave 50 Ah today and your 12 V house bank 40 Ah. What did they give together?
   Answer: 50 × 24 = 1,200 Wh and 40 × 12 = 480 Wh, together 1,680 Wh. "90 Ah" is not an answer (→ 7.1 · p. 2).
3. **Days.** Suppose your meter reads 0.15 A with everything off, on a 100 Ah battery whose maker's average depth of discharge is 50 %. How many days does the draw alone take to reach that depth?
   Answer: 0.15 × 24 = 3.6 Ah a day, and 50 ÷ 3.6 = 13.9 days (→ 7.3 · p. 10).
4. **A fuse.** Suppose your meter reads 1.0 mV across a 5 A blade fuse of the maker of → Table 7.5 · p. 30. About how much current flows through it?
   Answer: 0.001 ÷ 0.01785 = 0.056 A, about 56 mA: a circuit to follow. The resistance is typical, so the figure is approximate, and on a meter accurate to 2 digits near zero, 1.0 mV may be 0.8 to 1.2 mV: 45 to 67 mA (→ 7.3 · p. 10).
5. **On your boat.** Make the table of → 7.1 · p. 2 for one day at anchor or at the dock, from the labels and manuals of your own loads, and add it up.
   Answer: compare the total with your bank's usable amp-hours (→ 7.2 · p. 6): a day's use larger than the bank's usable amp-hours means a bank that cannot carry that day between charges.
6. **On your boat.** Count, by eye, the cables on your battery's negative terminal and, if you have a shunt, on its battery side. Then open your monitor's menu and write down its capacity, its charged voltage, its tail current and its current threshold.
   Answer: one cable to the shunt, the bank's jumpers aside, means the monitor sees every current; anything else is a lead it never counts (→ 7.6 · p. 39). The settings are compared with → Table 7.7 · p. 40, your battery's label and your charger's last stage.
7. **On your boat.** Write into the Boat Passport (field 10) what draws with every battery switch OFF, from your monitor or by a procedure of → 7.3 · p. 10, and which of those loads must stay on.
   Answer: the sum of the loads that must stay on, from their labels, against the

reading: a reading larger than that sum by more than the instrument's own accuracy is a draw to find (→ 7.3 · p. 10).

Terms

energy budget
The amp-hours (or watt-hours) your loads take in a day, compared with what the bank can give and what charging returns.

standby current
The current a device draws while it is switched on but idle, or switched off but still connected to the battery.

duty cycle
The share of time a load that switches itself on and off actually runs.

watt-hour (Wh)
Volts times amp-hours: the energy a battery gives, comparable across voltages.

depth of discharge
The share of a battery's rated capacity taken out, in percent; 50 % means half the 20-hour rating.

usable capacity
The part of a battery's rated amp-hours a budget counts: the 20-hour rating times the average depth of discharge its maker recommends.

Peukert exponent
A number a battery monitor uses to shrink the capacity it counts as the discharge current grows; worked out from two of the maker's rated capacities.

parasitic draw
The current a battery delivers while everything on the boat is switched off.

battery monitor
An instrument that counts the amp-hours into and out of a battery through a shunt and shows a state of charge calculated from that count.

shunt
A calibrated resistor in the main negative cable whose small voltage tells a battery monitor the current; rated in amps and millivolts.

synchronization (monitor)
The moment a battery monitor sets its count to 100 %, when the charging voltage, the tail current and the time its settings name are all met.

tail current
The charging current, as a percentage of the battery's capacity, below which a monitor counts the battery as full.

charge efficiency factor
A monitor's setting for the share of the charging amp-hours that the battery can give back.

current threshold (monitor)
A monitor's setting below which it counts the current as zero.

discharge floor
The state of charge a monitor treats as empty for its time-remaining figure.

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