

Battery Thermodynamics Cheat Sheet

Gibbs energy, the Nernst equation, heat and specific energy

ENGINEERING
CHEAT SHEET

Key equations

Quantity	Equation	Notes
Battery energy	$\text{Energy (Wh)} = V \times Ah$	$\div 1,000$ for kWh, $\times 3,600$ for joules. Use nominal voltage for estimates
Electrical work	$W = Q V$	Q in coulombs, V in volts, W in joules
Gibbs energy and voltage	$\Delta G = -n F E$	n = electrons, F = 96,485 C/mol. Negative ΔG = positive voltage
Gibbs, enthalpy, entropy	$\Delta G = \Delta H - T \Delta S$	ΔG sets max electrical work, ΔS sets reversible heat
Nernst equation	$E = E^0 - (R T / n F) \ln Q$	At 25 °C: $E = E^0 - (0.0592 / n) \log_{10} Q$
Entropic coefficient	$dE / dT = \Delta S / n F$	Usually a fraction of a mV/K in Li-ion cells
Heat generation (Bernardi)	$q = I (E_{oc} - V) - I T (dE_{oc} / dT)$	First term: irreversible. Second term: reversible (entropy)
Specific energy	$Wh/kg = (Ah/kg) \times V$	Also total energy (Wh) $\div$ mass (kg)
Theoretical specific capacity	$Q / M = n F / (3,600 \cdot M_{molar})$	Molar mass in kg/mol of active materials; result in Ah/kg

Key takeaways

- Voltage comes from the Gibbs free energy of the cell reaction. A charged battery is **metastable**: it holds free energy that is released through a controlled reaction.
- Open-circuit voltage changes with state of charge, so it works as a rough SoC indicator.
- Worked example, Li-MnO₂: 285.6 Ah/kg $\times$ 3.0 V $\approx$ **857 Wh/kg** theoretical. Real cells deliver a fraction because of inactive materials, voltage sag and pack overhead.
- Extensive properties (mass, capacity, ΔG) scale with size. Intensive properties (OCV, temperature, specific energy) do not.
- Higher specific energy comes from high-capacity electrodes, higher cell voltage and lightweight components. LFP trades energy for safety and life.
- Example: 4 Ah at 3.85 V = 15.4 Wh. A 400 V, 200 Ah pack = 80 kWh.

Nominal voltage and typical practical specific energy

Chemistry	Nominal V	Wh/kg
Lead-acid	2.0 V	30-50
NiMH	1.2 V	60-120
LFP	3.2 V	90-160
Li-ion (NMC / LCO)	3.6-3.7 V	150-250