Water for Physicists: A Fraction-First Research Agenda for Transduction, Entropy, and Resonance

Evan Wesley & Vivi The Physics Slayer!

September 2, 2025

Abstract

Why should physicists care about water? Because it is the most accessible, tunable medium where *non-equilibrium thermodynamics*, *resonant energy transfer*, and *information-like control* meet. This guide frames water as a laboratory for foundational physics: fluctuation theorems, Onsager reciprocity, dielectric relaxation, proton transport, cavitation, and nano-confinement. We package these into a fraction-first methodology: every quantitative claim is a small rational p/q with uncertainty gates and null baselines, so results are hand-verifiable and resistant to overfitting. The document provides a compact ledger for power and entropy, a minimal resonant engine model, and five deployable modules with worked fraction examples and measurement protocols.

1 Why water, for physicists

1. **Universal transport.** Water hosts heat, mass, charge, and momentum transport in one platform; each channel has textbook constitutive laws, yet their coupling (electro-osmosis, thermo-osmosis, streaming potentials) reveals Onsager reciprocity in the lab.
2. **Fast reconfigurable networks.** Hydrogen bonds reorganize on sub-ps to ns scales; this creates tunable relaxations (Debye-like dielectric response) that can be resonantly addressed.
3. **Entropic machines.** Osmotic, capillary, and hydration forces are clean realizations of "work from gradients"; they make entropy production measurable and architectable.
4. **Across scales.** From nanofluidic proton diodes to cavitating bubbles (Rayleigh–Plesset) and ocean-scale mixing, the same variational and spectral tools apply.
5. **Low barrier to entry.** Microfluidics, impedance spectroscopy, and benchtop calorimetry are widely available; a fraction-first ledger keeps results auditable by any group.

2 Core equations (minimal set)

2.1 Entropy and exergy ledger

With ambient sink temperature T_0:

$$\dot{W}_{out} = \dot{\mathcal{B}}_{\text{in}} - T_0\, \dot{S}_{\text{prod}} \;\;\le\;\; \dot{\mathcal{B}}_{in}, \qquad \dot{S}_{\text{prod}} = \sum_i J_i X_i \ge 0. \tag{1}$$

Examples: heat with $X = 1/T$, ions with $X = \Delta\mu/T$, electrical with $X = V/T$, volume with $X = \Delta P/T$, information with $X = k_B \ln 2$ per bit erased.

2.2 Linear response, reciprocity, and spectra

Fluxes $J_i = \sum_j L_{ij} X_j$ with $L_{ij} = L_{ji}$ (Onsager). Transport coefficients admit Green–Kubo forms; equivalently, in frequency domain,

$$\dot{W}_{\text{out}} = \int_0^\infty \hbar\omega\, \mathcal{T}(\omega)\, [n_{\text{in}}(\omega) - n_{\text{out}}(\omega)]\, \frac{d\omega}{2\pi}. \tag{2}$$

Equilibrium $n_{\text{in}} = n_{\text{out}} \Rightarrow 0$ defines the honest baseline.

2.3 Hydrodynamics and interfaces

Navier–Stokes; Laplace pressure $\Delta P = 2\gamma/R$; Kelvin equation for vapor pressure shift; Rayleigh–Plesset for a spherical bubble radius $R(t)$:

$$\rho\left(R\ddot{R} + \tfrac{3}{2}\dot{R}^2\right) = P_b(t) - P_\infty - \frac{2\gamma}{R} - 4\mu\frac{\dot{R}}{R}. \tag{3}$$

These supply the tunable "notes" and dissipation channels (Q, impedance).

2.4 Electrochemistry and dielectric response

Nernst–Planck–Poisson; Nernst equation $V = (kT/q)\ln a$; Debye relaxation

$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + i\omega\tau}, \qquad \sigma(\omega) = i\omega\varepsilon_0\, [\varepsilon(\omega) - 1]. \tag{4}$$

These define resonance windows for field-driven transduction.

3 Fraction-first verification and scoring

Given fraction $\hat{x}$ for an observable with reference $\bar{x} \pm \sigma$: $z = (\hat{x} - \bar{x})/\sigma$. Gate: $|z| \le z_{\text{gate}}$. Surprise bits Surprise_bits $= -\log_2\left(2[1 - \Phi(|z|)]\right)$. Complexity penalty: denominator bits D_bits $= \log_2(q)$, attempts bits A_bits $= \log_2(1 + N_{\text{try}})$. Net score Net_bits $=$ Surprise_bits $-$ (D_bits $+$ A_bits). Accept (freeze) if gate passes and Net_bits ≥ 1. Denominator caps: thermo/electro/cosmo $q \le 200$; structure/occupancy $q \le 2048$.

4 Resonant Ouroboros Engine (water-mapped)

Let amplitude $a(t)$ and resource $R(t)$ follow

$$\dot{a} = (gR - \gamma)\, a - \beta a^3, \qquad \dot{R} = \Pi_{\text{in}} - \kappa R - c a^2 R, \qquad P_{\text{out}} = \gamma_{\text{load}} a^2. \tag{5}$$

Here $\gamma = \gamma_{int} + \gamma_{load}$. Threshold: $g\Pi_{\text{in}} > \gamma\kappa$; max power when $\gamma_{load} = \gamma_{int}$. Map Π_{in} to a steady exergy inflow: e.g., $\Pi\,\dot{V}$ (osmotic), $\eta_C\,\dot{Q}_h$ (phase), or IV (electro-osmosis).

5 Five modules physicists can deploy

Each module lists a governing relation, a resonance strategy, and a *fraction* example.

5.1 A. Blue energy (osmotic $\to$ electrical)

Law: $\Pi \approx RT\,\Delta c$. **Resonance:** compliant chamber to oscillate around Π at ω_0; match ionic to electrical impedance. **Example:** scale $RT \to 1$, $\Delta c = \frac{3}{10} \Rightarrow \Pi = \frac{3}{10}$. Stack delivers $V = \frac{1}{5}, I = \frac{1}{2} \Rightarrow P = \frac{1}{10}$. Verify volumetric $\times\Pi \geq \frac{1}{10}$.

5.2 B. Phase-change harvester (evap/condense)

Law: $\eta_C = 1 - T_c/T_h$. **Resonance:** pulse evaporation with an acoustic mode to suppress slosh. **Example:** $T_h = \frac{5}{4}, T_c = 1 \Rightarrow \eta_C = \frac{1}{5}$. Heat in 100 units $\Rightarrow$ best work ≤ 20.

5.3 C. Protonic circuits (hydration-assisted)

Law: Nernst $V = (kT/q)\ln a$, take $kT/q \approx \frac{1}{40}$. **Resonance:** drive at hydration relaxation to lower effective damping. **Example:** $a = \frac{5}{2}$, use $\ln a \approx \frac{11}{12} \Rightarrow V \approx \frac{11}{480} \approx 22.9\,\mathrm{mV}$.

5.4 D. Stochastic-resonant sensing

Law: hopping rate $r \approx (\omega_b/2\pi)\,e^{-\Delta U/kT}$. **Resonance:** tune noise so r locks to drive frequency (max SNR). Record r/f as p/q.

5.5 E. Hydration-coded control (DNA/protein flips)

Law: $\Delta G(T) = \Delta H - T\Delta S$; slope yields $-\Delta S$. Normalize by a water reference and record as p/q. Recurrence across families $\Rightarrow$ candidate hydration lock.

6 Measurement protocols (sketch)

6.1 Impedance matching and Q

Estimate $Q = \omega_0/\gamma$. Adjust load to $\gamma_{load} = \gamma_{int}$. Bandwidth $\Delta f \approx f_0/Q$. Choose Q to overlap the environmental spectrum peak.

6.2 Uncertainty, scoring, and freezing

For each row, record: observable; scheme/scale; fraction p/q; reference $\bar{x} \pm \sigma$; gate z_{gate}; attempts; z; Surprise_bits; Penalty_bits; Net_bits; status (FROZEN/CAND/RETIRED); dates.

7 Scoreboard template

Observable	Scheme	Status	Fraction $\hat{x}$	$\bar{x} \pm \sigma$	z	Surprise_bits	Den	A
osmotic_pressure/(RT)	membrane A	FROZEN	3/10	0.300±0.006	0.0	–	10	
phase_efficiency	evap/cond	FROZEN	1/5	0.195±0.010	0.5	–	5	
proton_voltage/V	channel X	CAND	11/480	0.0230±0.0010	−0.1	–	480	

8 Open problems worth a thesis

1. **Dielectric spectra as a codebook.** Are there stable rational ratios between relaxation times across salt classes under fixed protocols? *Test:* fraction-first fits with denominator caps; cross-salt recurrence analysis.

2. **Cavitation as a resonant engine.** Optimize Rayleigh–Plesset parameters for maximal P_{out} at fixed heat leak; quantify entropy relocation.

3. **Hydration locks in biomolecules.** Fractional occupancy patterns (p/q) that correlate with conformational switching free energies.

4. **Nanofluidic Onsager symmetries.** Measure cross-coefficients (electro-osmosis vs. streaming potentials) with fraction-grade reproducibility.

5. **Information engines in water.** Optical-tweezer feedback with explicit Landauer cost; publish Net_bits and null-baseline percentiles.

9 Reproducibility and governance

Pre-register denominator caps and attempts; keep a changelog; never retro-edit frozen rows. Provide raw p/q, references for $\bar{x} \pm \sigma$, scripts for z and Net_bits, and null-baseline generators.

A Units and scaling

We often non-dimensionalize to keep fractions small (e.g., set $RT = 1$ as a pressure unit). Map back to SI with a single scale factor.

B Minimal Python skeleton

```
from fractions import Fraction
from math import log2

xbar, sigma = 0.300, 0.006
xhat = Fraction(3,10)
z = (float(xhat)-xbar)/sigma
surprise = -log2(2*(1-Phi(abs(z))))  # Phi from scipy
penalty = log2(xhat.denominator) + log2(1+attempts)
net = surprise - penalty
```