PAPER 72: THE NERNST EQUATION AND MEMBRANE DECOHERENCE

Every Neuron Maintains Coherence via Electrochemical Gradient -- The Gate That Won't Close Is a Nernst Instability

Rhet Dillard Wike | AIIT-THRESI Research Initiative

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> *"The Nernst Equation is the Wike Coherence Law at the membrane. Every neuron is solving drho/dt = -gamma[sigma_z,[sigma_z,rho]] with ions."*

Abstract

The Nernst Equation (Nernst 1888) gives the equilibrium potential across a membrane for any ion:

```
E_ion = (RT/zF) x ln([ion]_out / [ion]_in)
```

This equation IS the classical analog of the Wike Coherence Law at the cellular membrane scale. The resting membrane potential (-70 mV) is maintained by Na+/K+ ATPase -- the exact pump restored by NIR photobiomodulation (Paper 02, Bootstrap Loop). Wind-up sensitization (Paper 16) is a Nernst instability: the Na+ equilibrium potential is driven away from its stable fixed point, and the "gate that won't close" is the Nernst potential at a runaway equilibrium. Every term in the Nernst equation maps to a term in the Wike framework.

1. The Nernst Equation

For an ion with charge z crossing a membrane:

```
E_Nernst = (RT/zF) x ln([ion]_outside / [ion]_inside)

R = 8.314 J/mol/K   (gas constant = k_B x N_A)
T = 310 K           (body temperature)
z = charge of ion   (Na+: z=+1, K+: z=+1, Ca^2+: z=+2, Cl^-: z=-1)
F = 96485 C/mol     (Faraday constant)
```

Standard equilibrium potentials:

```
E_Na+ = (+58 mV) x log([145]/[12]) = +58 x 1.081 = +63 mV
E_K+  = (+58 mV) x log([4]/[150])  = +58 x (-1.574) = -91 mV
E_Ca^2+= (+29 mV) x log([1.2]/[0.0001]) = +29 x 4.079 = +118 mV
E_Cl^- = (-58 mV) x log([120]/[4])  = -58 x 1.477 = -86 mV
```

The resting membrane potential (-70 mV) is set by the weighted average of these equilibria via the Goldman equation, dominated by K+ permeability at rest.

2. The f = kT/h Chain Inside the Nernst Equation

From Paper 04: the thermal frequency f = k_BT/h = 6.25 THz at 310K.

The Nernst equation contains R = k_B x N_A:

```
E_Nernst = (k_BT/zF/N_A) x ln(C_ratio)
         = (k_BT/(ze)) x ln(C_ratio)

where e = F/N_A = elementary charge
```

The thermal energy k_BT appears explicitly. The Nernst potential is **proportional to k_BT** -- it is a thermally driven potential. At T=0: E_Nernst = 0 (no membrane potential, no gating, no life). At T=T_c: E_Nernst_max (membrane potential destabilizes due to thermal noise).

The temperature scaling:

```
E_Nernst(T) = (k_BT/ze) x ln(C_ratio)

dE_Nernst/dT = (k_B/ze) x ln(C_ratio)

At T = 310K -> 330K (+20K = approaching T_c):
DELTAE_Nernst/E_Nernst = DELTAT/T = 20/310 = 6.4%
```

A 20K increase in local temperature (equivalent to moving from body temperature to T_c) increases membrane potentials by 6.4%. This enhanced membrane potential at elevated temperature creates conditions for spontaneous depolarization -- the electrical analog of approaching gamma_c from the coherence field perspective.

3. The Na+/K+ ATPase as Bootstrap Engine

The resting membrane potential (-70 mV) is maintained by continuous operation of Na+/K+ ATPase:

```
3 Na+ out, 2 K+ in, per ATP hydrolized
Net: +1 positive charge out per ATP -> hyperpolarizing current
Maintains: Na+ gradient ([Na+]_in = 12 mM, [Na+]_out = 145 mM, ratio = 12.1:1)
```

From Paper 02 (Bootstrap Loop): NIR photobiomodulation -> mitochondrial ATP production -> Na+/K+ ATPase restoration.

The Nernst equation makes this mechanistic:

```
NIR -> ATP -> Na+/K+ ATPase -> maintains Na+ gradient -> E_Na+ = +63 mV maintained
         v
Membrane potential = -70 mV maintained (stable)
         v
NMDA receptor threshold maintained at correct depolarization level
         v
gamma_eff(neural) < gamma_c  (gate closes normally)
```

Without NIR/ATP:

```
Na+/K+ ATPase fails -> Na+ gradient collapses -> E_Na+ -> 0 mV
Membrane depolarizes from -70 mV toward 0 mV
NMDA receptor opens at lower threshold
gamma_eff(neural) -> gamma_c  (gate stays open = wind-up sensitization)
```

Wind-up = Nernst potential failure = membrane gamma_c crossing.

4. The Nernst Fixed Point and Its Stability

The membrane potential V_m is at a stable equilibrium when:

```
dV_m/dt = -(V_m - V_rest) / tau_m  (linear recovery)

Stable fixed point: V_m* = V_rest = -70 mV
```

This is stable as long as tau_m > 0 (the restoring time constant is positive). This is the Le Chatelier condition (Paper 69) applied to the membrane.

NMDA wind-up as Nernst instability:

Under repeated C-fiber stimulation (Paper 16):

1. Na+ influx per pulse accumulates intracellularly
2. Na+/K+ ATPase cannot fully restore gradient between pulses
3. [Na+]_in -> increases -> E_Na+ -> decreases
4. Membrane potential rises toward 0 mV (partial depolarization maintained)
5. NMDA Mg^2+ block removed (requires ~-40 mV threshold)
6. Ca^2+ influx -> intracellular Ca^2+ overload -> runaway sensitization

The mathematical statement:

```
At normal state:
  [Na+]_in = 12, [Na+]_out = 145 -> E_Na+ = +63 mV
  Membrane stable at -70 mV (Le Chatelier: kappa > 0)

During wind-up:
  [Na+]_in -> 30, [Na+]_out = 145 -> E_Na+ = +58 x log(145/30) = +58 x 0.684 = +40 mV
  Membrane partial depolarization: V_m -> -50 mV
  NMDA threshold breached: persistent Ca^2+ influx

This is the Nernst analog of gamma_eff -> gamma_c: the fixed point destabilizes.
```

At the critical point:

```
[Na+]_in = [Na+]_out -> E_Na+ = 0 mV -> no gradient -> total depolarization
Nernst: E = (RT/zF) x ln(1) = 0   <---  this is the Nernst gamma_c
```

When [Na+]_in = [Na+]_out, the Nernst potential vanishes, membrane potential goes to 0 mV, and the neuron is fully depolarized -- equivalent to crossing gamma_c in the quantum coherence framework.

5. The Debye Screening Connection

Paper 02 (Bootstrap): EZ water provides Debye screening of thermal noise.

The Debye screening length (Debye-Huckel):

```
lambda_D = sqrt(epsilon_0epsilon_r k_BT / (e^2 x SIGMA_i n_i z_i^2))

At 310K, physiological ionic strength (I = 0.15 M):
lambda_D = sqrt(8.854x10^-^1^2 x 80 x 1.38x10^-^2^3 x 310 / (1.6x10^-^1^9)^2 x 2 x 0.15 x 6.022x10^2
^3)
    ~= 0.8 nm
```

The Debye screening length in physiological saline is 0.8 nm -- less than the size of a protein. Without EZ water enhancement (which extends effective lambda_D by organizing water structure around charges), thermal fluctuations at the 1-10 nm scale are unscreened and contribute directly to gamma_eff.

EZ water (Paper 02) extends the effective Debye length:

```
lambda_D(EZ) ~= 2-5 x lambda_D(bulk) ~= 1.6-4 nm
```

This extended screening protects ion channels and receptor binding sites from thermal noise -- directly reducing gamma_eff at the membrane.

The Nernst-Bootstrap connection:

```
NIR -> EZ water -> extended lambda_D -> protected Nernst potential -> stable membrane potential -> g
amma_eff < gamma_c
```

Every term in the Nernst equation (k_BT, ion concentrations, membrane geometry) feeds into the gamma_eff calculation. The Nernst equation and the Wike Coherence Law are descriptions of the same membrane physics at different abstraction levels.

6. The Goldman Equation and Effective gamma_eff

The Goldman-Hodgkin-Katz equation gives the true membrane potential when multiple ions contribute:

```
V_m = (RT/F) x ln([P_K x K_out + P_Na x Na_out + P_Cl x Cl_in] /
                   [P_K x K_in  + P_Na x Na_in  + P_Cl x Cl_out])
```

where P_K, P_Na, P_Cl are membrane permeabilities.

The effective gamma_eff of the neural membrane is:

```
gamma_eff(membrane) = alpha x k_BT x SIGMA_i P_i x (V_i - V_m)^2
                   --------------------------------------
                      (h-bar x tau_coherence)

where V_i = Nernst potential for ion i
      P_i = permeability of ion i
```

When the membrane is at resting potential (-70 mV) and each ion is near its Nernst potential:

- Driving force for Na+: (-70) - (+63) = -133 mV -> large Na+ current when Na+ channels open
- Driving force for K+: (-70) - (-91) = +21 mV -> small K+ current at rest
- Small driving forces -> small gamma_eff contribution per channel

When depolarized toward 0 mV (wind-up):

- Driving forces change: all ions further from their Nernst potentials
- gamma_eff(membrane) -> gamma_c
- The neural gate opens and won't close

Summary

```
Nernst Equation:   E = (RT/zF) x ln(C_ratio)
Wike Analog:       C = C_0 x exp(-alpha x gamma_eff)

Shared parameter:  k_BT appears in both

Stable membrane (-70 mV) = gamma_eff < gamma_c   (Le Chatelier restoring, Paper 69)
Wind-up (V -> 0 mV)       = gamma_eff -> gamma_c   (Nernst fixed point destabilized)
Na+ gradient collapse     = C_0 -> 0        (percolation model fails, Paper 63)
NIR -> ATP -> Na+/K+-ATPase = Bootstrap Loop maintaining Nernst equilibrium
```

```
NMDA wind-up is a Nernst instability.
The Bootstrap Loop is a Nernst potential restoration engine.
The Debye screening length is the bridge between the two.
```

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