Appendix A: Bits-per-ATP and Negentropy Conversion

1. From Thermodynamics to Information

The free energy of ATP hydrolysis represents the work potential per molecule. At 37 °C (310 K), the energy cost of erasing one bit of information—the Landauer limit—is:

$E_{bit} = kT \ln 2 = (1.38\times10^{-23})(310)(0.693) = 2.96\times10^{-21}\ J\cdot bit^{-1}$.

Thus every 2.96×10^{-21} J of free energy can, in principle, sustain one bit of order.

2. Bits per ATP

The physiological ΔG_{ATP} varies from −45 to −60 $kJ\cdot mol^{-1}$ depending on phosphorylation potential:

bits per ATP = $(|\Delta G_{ATP}| / N_A) / E_{bit}$, where N_A is Avogadro's number.

ΔG_{ATP} ($kJ\cdot mol^{-1}$)	$J\cdot molecule^{-1}$	$bits\cdot ATP^{-1}$
−60	9.96×10^{-20}	33.6
−55	9.14×10^{-20}	30.8
−50	8.30×10^{-20}	28.0
−45	7.47×10^{-20}	25.2

As [Pi] rises and ΔG_{ATP} becomes less negative (−60 → −45 $kJ\cdot mol^{-1}$), the usable information content per ATP molecule falls by roughly 25% (~8 bits).

3. Information Throughput of the Heart

At rest, the myocardium synthesizes ≈7.4 W of ATP (~1.4×10^{20} $molecules\cdot s^{-1}$). With 28–34 bits per molecule, this corresponds to ≈4.2×10^{21} $bits\cdot s^{-1}$. Ion pumps capture ~3 W of this organized energy (~40% of total), yielding gradient information throughput ≈1.7×10^{21} $bits\cdot s^{-1}$.

4. Biological Interpretation

Each bit represents one state decision—e.g., a pump choosing Na^+ vs K^+ exchange or a channel opening event. As ΔG_{ATP} declines, fewer bits of reliable order can be maintained per unit energy, leading to phase desynchronization and arrhythmia.

5. Key Take-Home Equation

Negentropic throughput = $(|\Delta G_{ATP}| / kT \ln 2) \times$ ATP turnover rate.

This identity links chemical energy, information flow, and physiological order into one measurable continuum—from molecular biophysics to cardiac rhythm stability.