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Phosphorylation Hypothesis: A Fourth Sink of ATP for Cellular Information Processing?

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Adenosine triphosphate (ATP) molecule is used in living cells as a universal "energy currency." The Gibbs free energy liberated from hydrolysis reaction of ATP to ADP + Pi is used for (a) biosynthesis, (b) ionic and neutral molecular pumping, and (c) mechanical movement. They are known collectively as the three major energy sinks at the cellular level. Using biochemical activities of various enzymes, a cell carries out information processing, known as signal transduction. Essentially all signal transduction reactions also require ATP (or GTP) hydrolysis. In the past, such energy dissipative reactions are considered as "futile." However, it is clear that the free energy derived from a futile cycle is used to correct errors in biomolecular recognition, improve robustness in cell development, overcome Boltzmann's equilibrium law of probability, and drive Maxwell's demons (one notes that Gibbs' chemical potential is a thermodynamic force without mechanical interpretation). The free energy involved in processing information will be explained in terms of stochastic entropy production — the central concept in irreversible and nonequilibrium steady-state (NESS) thermodynamics.