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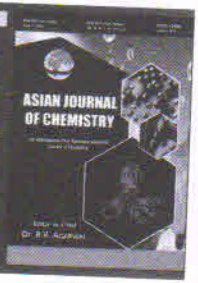

REVIEW

From Equilibrium to Emergence: The Physical Foundations of Chemical Order – A Conceptual Framework Linking Thermodynamics, Quantum Mechanics and Systems Chemistry

HARASIT KUMAR MANDAL[1,*], SUPARNA RUDRA HARI[2], SUSHANTA SAHA[1] and TULIKA GHOSH[1]

[1]Department of Chemistry, Sree Chaitanya College, Habra-743268, India
[2]Department of Chemistry, Brainware University, Barasat, Kolkata-700125, India

*Corresponding author: E-mail: harasitju@gmail.com

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Chemistry has evolved from empirical pattern recognition to a unified, physics-informed science governed by universal principles. This perspective traces the conceptual progression of chemical thought from Mendeleev's periodic classification to thermodynamics, quantum mechanics and the emerging systems view of self-organisation and complexity. By dividing this trajectory into four historical phases *viz.* (i) thermodynamic and kinetic universality, (ii) nonideal solution theory and ionic interactions, (iii) quantum-mechanical interpretation of matter and bonding, and (iv) self-organisation in far-from-equilibrium systems. Each phase contributed to a deeper understanding of matter-energy relationships and strengthened the theoretical foundations of chemistry. Emphasis is placed on the interplay between the macroscopic laws and microscopic models, with recurring themes of order, symmetry and energy flow serving as unifying principles across both equilibrium and non-equilibrium phenomena. This conceptual synthesis illustrates the natural convergence of thermodynamics, statistical mechanics, and quantum theory, giving rise to systems chemistry and the modern study of emergent behaviour. Beyond its historical narrative, the work asserts that an analysis of chemistry through its evolving paradigms reveals a coherent scientific continuum integrating atomic theory, information and complexity, thereby positioning chemistry as a central discipline for elucidating organisational principles in natural systems.

Keywords: History of chemistry, Quantum mechanics. Chemical bonding and Oscillations, Patterns, Origin of life.