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A Brief Introduction to Statistical Mechanics

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Commentary

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DESCRIPTION

Statistical mechanics is a mathematical framework in physics that applies statistical methods and probability theory to large groups of microscopic entities. It makes no assumptions or postulates any natural laws, but rather explains the macroscopic behavior of nature through the behavior of such ensembles. Statistical mechanics arose from the development of classical thermodynamics, a field that was successful in explaining macroscopic physical properties like temperature, pressure, and heat capacity in terms of microscopic parameters that fluctuate around average values and are characterized by probability distributions. This resulted in the fields of statistical thermodynamics and statistical physics being established.

The field of statistical mechanics is widely regarded as having been founded by three physicists: Ludwig Boltzmann is credited with developing the fundamental interpretation of entropy in terms of a collection of microstates; James Clerk Maxwell, who developed probability distribution models for such states; Josiah Willard Gibbs, who named the field in 1884. While classical thermodynamics is primarily concerned with thermodynamic equilibrium, non-equilibrium statistical mechanics has been applied to the issues of microscopically modeling the speed of irreversible processes driven by imbalances. Chemical reactions and particle and heat flows are examples of such processes. Classical mechanics and quantum mechanics are the two types of mechanics studied in physics. The standard mathematical approach for both types of mechanics is to consider two concepts: The complete state of the mechanical system at a given time, encoded mathematically as a phase point (classical mechanics) or a pure quantum state vector (quantum mechanics). An equation of motion that advances the state in time: The

Schrödinger equation or Hamilton's equations (classical mechanics) (quantum mechanics). Using these two concepts, the state at any other time, past or future, can be calculated in principle. However, there is disconnect between these laws and everyday life experiences because we do not consider it necessary (or even theoretically possible) to know the exact simultaneous positions and velocities of each molecule while carrying out processes at the human scale (for example, when performing a chemical reaction). Statistical mechanics bridges the gap between the laws of mechanics and the practical experience of incomplete knowledge by introducing uncertainty about the state of the system. Statistical mechanics introduces the statistical ensemble, which is a large collection of virtual, independent copies of the system in various states. Ordinary mechanics only considers the behavior of a single state. The statistical ensemble is a probability distribution that spans all possible system states. The ensemble in classical statistical mechanics is a probability distribution over phase points (as opposed to a single phase point in ordinary mechanics), which is typically represented as a distribution in a phase space with canonical coordinates. The ensemble in quantum statistical mechanics is a probability distribution over pure states that can be compactly summarized as a density matrix. The ensemble, as is customary for probabilities, can be interpreted in a variety of ways: An ensemble can be thought of as representing the various possible states that a single system could be in (epistemic probability, a type of knowledge), or as the states of the systems in experiments repeated on independent systems prepared in a similar but imperfectly controlled manner (empirical probability), in the limit of an infinite number of trials.