Putting the quantum to work: Otto Sackur's pioneering exploits in the quantum theory of gases

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Abstract:

In the wake of the First Solvay Conference (1911), many leading physicists had begun embracing the quantum hypothesis as a key to solving outstanding problems in the theory of matter. The quantum approach proved successful in tackling the solid state, resulting in the nearly definitive theories of Debye (1912) and of Born & von Karman (1912-13). However, the application of the old quantum theory to gases was hindered by serious difficulties, which were due to a lack of a straightforward way of reconciling the frequency-dependent quantum hypothesis with the aperiodic behavior of gas molecules.

A breakthrough came from unlikely quarters. Otto Sackur (1880-1914) had been trained as a physical chemist and had almost no experience in the research fields traditionally associated with quantum theory (heat radiation, statistical mechanics, thermodynamics). However, in 1911, he discovered an expression for the absolute entropy of a monoatomic gas. A Dutch high-school student, Hugo Martin Tetrode, reached the same result at about the same time independently. The Sackur-Tetrode equation rendered entropy as an extensive variable (in contrast to the classical expression, cf. the Gibbs paradox) and expressed the thermodynamically undetermined constant in terms of molecular parameters and Boltzmann's and Planck's constants. This result was of great heuristic value because it suggested the possibility of deriving the thermodynamic variables of a gas quantum mechanically. At the same time, the Sackur-Tetrode equation offered a conventient means to evaluate the parameters of molecular gases, thus promising a grand unification of quantum theory, thermodynamics, and physical chemistry.

The key steps toward the Sackur-Tetrode equation were the partitioning of the phase space into elementary cells and the use of Planck's constant in fixing the cell's volume. Following upon this feat, Sackur attempted to develop a general quantum theory of the ideal gas, however only with partial success -- and with a dose of naivete, especially when compared with the approach of Nernst, Keesom, Sommerfeld & Lenz, Stern and Tetrode. However, Sackur's bold attempt to deploy the quantum hypothesis across classical statistical mechanics eventually proved instrumental in preparing Planck's path to the theory of a quantum gas. In this paper, we tell the story of this enthusiastic practictioner of the old quantum theory.