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THE QUANTUM OF ENERGY TRANSPORTED DURING EVAPORATION: INVESTIGATION OF A FUNDAMENTAL CONSTANT

Abstract

The Earth has the largest evaporating interface in the solar system. Evaporation affects us personally (it cools the body perspiration), impacts everyone globally by driving the hydrological cycle and controlling Earth's climate, and provides insight into the origins of the universe and of life (for instance, drying droplets are often used create molecular self-assemblies). Efficient management of the energy consumed during evaporation is of tremendous importance to the global multi-billion dollar energy industry, and thus to our economic welfare. Furthermore, understanding how energy is transported to the water-vapour interface is critical to the development life support systems for spacesuits and spacecraft, and to the efficient management of limited energy resources on space missions.

It is therefore surprising that, despite its ubiquitous presence and importance, the evaporation process is still not understood. For the past 130 years, evaporation models have used the classical kinetic theory (CKT) approach, which has neglected important physical phenomena, such as interfacial temperature discontinuities, resulting in poor agreement with experiments, inconsistent predictions of liquid properties, and an incomplete picture of how the energy is transported.

Here, the statistical rate theory (SRT) approach (based on the quantum-mechanical concept of state-transition probabilities) is used to model evaporation. The quantum of *molecular* transport is generally accepted to be one molecule since no less than a single molecule can evaporate in an instant. However, specifying the quantum of *energy* transport is more difficult. The frequencies of water O-H bonds that straddle the interface have been reported to shift with the hydrogen bonding of surface molecules with the bulk liquid phase [1]. Using SRT, an expression for the heat flux conducted to the interface during evaporation is derived. We examine the SRT heat flux expression using steady evaporation experiments of water, and we show that the quantum of energy transported in an instant corresponds to the frequency shifts of the water O-H bonds. Our derivation introduces a ratio of the entropy change from molecular transport to that from energy transport; we find that it is both constant and independent of the evaporation system. This **evaporation constant** leads to predictions of the heat flux that agree with the experiments. Thus, SRT captures atomic-level details of the evaporation process and eliminates the necessity of measuring temperature gradients at the interface, thereby reducing the cost and complexity of both ground-based and space experiments.

[1] Stiopkin et al. Nature, 2011, 474, 192-195.