Thermal radiation across a water nanobubble induced by a heated gold nanoparticle

Sreyash Sarkar
Jerome Sarr, Olivier Merchiers, Pierre-Olivier Chapuis
Univ Lyon, CNRS, INSA Lyon, Université Claude Bernard Lyon 1, CETHIL UMR5008, F-69621, Villeurbanne, France
sreyash.sarkar@insa-lyon.frs

With advancements in nanoscience, precise control of light within the visible and near-infrared ranges has been achieved at the nanoscale, leading to the development of diverse technologies [1]. Metallic nanoparticles (NP) offer a versatile approach to adjusting radiation characteristics through modifications in morphology, size, material, and aggregation. One method for localized heating without physical contact involves introducing metallic NPs into a liquid medium. Steady-state or pulsed illumination generates nanobubbles around the nanoparticles, enabling applications such as optical hyperthermia, microbiology, and solar thermal water heating [1]. Bubble formation involves complex processes like vaporization, heat transfer, and multiple scattering [1]. However, studying thermal radiation between nanoparticles and a liquid has been limited due to the small size of the nanoparticles compared to Wien's wavelength. Accurate evaluation of sub-wavelength thermal radiation requires precise calculations using fluctuational electrodynamics (FE), revealing that small objects can have an effective emissivity exceeding unity [2]. Radiative transfer occurs also through photon tunneling in the near field, which can also be analyzed using FE. This study focuses on evaluating the contributions of radiative heat transfer using the dipole approximation, encompassing both electric and magnetic dipoles within a cavity immersed in a dissipative medium. Considering spherical geometry and employing the Mie theory, we highlight the strong deviation to macroscopic thermal-radiation estimates and underline wave effects. Volumetric near-field absorption in water follows a sixth power relationship with the distance from the origin and a third power relationship with the cavity radius. Observable interferences arise as the system approaches the far-field regime, with spectral signature resonances of water dominating radiative exchange. The findings contribute to a better understanding of radiative exchange in nanoparticle-liquid systems, advancing thermal engineering, bioengineering, and biomedical applications.

References

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Figures

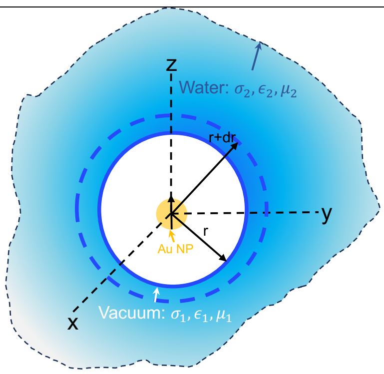

Figure 1: Au NP- Water nanobubble system approximated as an electromagnetic dipole in a cavity immersed in a dissipative medium i.e. water.

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