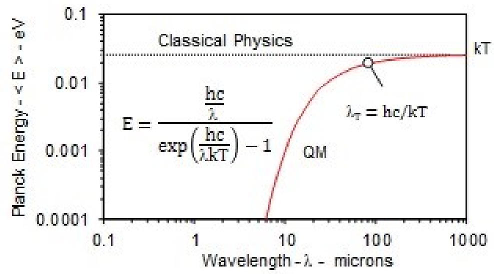
Evanescent waves do not exist in near-field heat transfer!

Recent MIT claims that evanescent waves enhance heat transfer beyond the blackbody limit may be dismissed as quantum mechanics denies atoms in nanoscale gap surfaces the heat capacity to produce thermally excited evanescent waves



Planck law showing atomic heat capacity vanishes in near-field heat transfer

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Introduction

Over a century, the S-B law has given the maximum amount of radiative heat one body can transmit to another to depend only their temperatures. S-B stands for Stefan-Boltzmann. Provided the bodies are black and absorb all the radiation, the upper bound heat given by the S-B law is known as the blackbody limit.

Recently, MIT mathematicians claimed [1] that if the bodies are separated by small gaps, the blackbody-limit no longer applies. Indeed, if the gaps are nanoscale, say < 100 nm, the amount of heat transmitted between the bodies is claimed to exceed the blackbody limit by 100 to 1000 times. Since heat having wavelengths in the IR of a few microns cannot propagate across nanoscale gaps, the MIT claim is based on the assumption QM tunnels radiation across the gap from evanescent waves moving parallel to gap surfaces. IR stands for infra-red and QM for quantum mechanics.

A rebuttal of the MIT claim finds basis in the QM argument the atoms in surfaces of nanoscale gaps under EM confinement lack the heat capacity to change in temperature and induce the charges and currents in the gap surfaces necessary for the propagation of evanescent waves. EM stands for electromagnetic. See MIT claim with rebuttal at http://www.nanoqed.org, at "Evanescent waves do not exist in near-field heat transfer!," 2015.

Background

In near-field heat transfer, the theory [2] of evanescent waves assumes the long wavelength form of the Planck law to depend only on the temperature of the atom. EM confinement is not considered. E.g., the thumbnail shows the Planck energy of the atom at ambient temperature to depend on the wavelength λ of EM confinement. If the atom is in the free surface of a body, the EM confinement is in the long wavelength λ > 100 microns region corresponding to classical physics where the atom by the Planck law does indeed have heat capacity. However, for wavelengths λ < 100 microns, QM differs from classical physics in that the heat capacity of the atom by the Planck law depends on EM confinement. For the gap of dimension g, the EM confinement corresponds to a standing half-wave, i.e., λ/2 = g ≈ 50 microns. Hence, near-field heat transfer by evanescent waves consistent with QM is valid for gaps g > 50 microns.

However, for gaps g < 50 microns, the thumbnail shows the heat capacity of the atom decreases by 2 orders of magnitude for EM confinement wavelengths $\lambda < 6$ microns or gaps g < 3 microns. QM requires atoms in the gap surfaces under EM confinement at nanoscale gaps g to have vanishing heat capacity that precludes the existence of thermally excited evanescent waves to produce charges and currents consistent with the FDT of radiative heat transfer. FDT stands for fluctuation dissipation theorem.

What this means is thermally excited evanescent waves do not exist in near -field heat transfer. Therefore the MIT claim that evanescent waves enhance near-field heat transfer beyond the blackbody limit is highly unlikely. Instead, another QM mechanism tunnels EM energy across nanoscale gaps.

Proposal

Radiative heat transfer across nanoscale gaps is proposed [3] to be a natural consequence of QM tunneling by QED induced radiation. QED stands for quantum electrodynamics. Radiative heat transfer across the gap cannot be conserved by changes in surface temperature because the surface atoms under EM confinement lack the heat capacity given by the Planck law. Instead, the heat at IR wavelengths is tunneled across the nanoscale gap by standing wave QED induced radiation. Contrary to the MIT claim, conservation of the radiative heat at the blackbody limit through the nanoscale gap suggests no enhancement above the blackbody limit allowing the S-B law to remain valid in the near-field.

Discussion

QM tunneling [3] is a consequence of the vanishing heat capacity of the atom that precludes conservation of heat in the near-field at nanoscale gap surfaces by an increase in temperature. Indeed, the heat capacity of the atom naturally vanishes under EM confinement because of the high surface-to-volume ratios inherent in nanoscale gaps, although EM confinement is still high even for micron sized gaps as shown in the thumbnail. Here, the wavelength of the EM confinement is $\lambda = 2$ g. QM requires atoms in gap surfaces under EM confinement at nanoscale separations to have vanishing heat capacity that precludes the fluctuating temperatures necessary to produce the charges and currents consistent with the FDT for radiative heat transfer.

What this means is a dead space surrounding nanoscale gaps exists depending on the temperature of the body where temperature changes do not occur. At ambient temperature, a dead-space g ≈ 50 microns surrounds the nanoscale gap where temperatures changes do not occur. The S-B law based on temperatures alone is therefore valid for all separations d between bodies d > g; whereas, for separations d < g, the radiative heat is given by the blackbody limit evaluated at d = g ≈ 50 microns.

Conclusion

Near-field heat transfer does not exceed the blackbody limit as thermally excited evanescent waves do not exist because of QM.

References

[1] O. D. Miller, et al., “Shape-Independent Limits to Near-Field Radiative Heat Transfer," PRL, 115, 204302, 2015.
[2] K. Joulain, et al., “Surface electromagnetic waves thermally excited: Radiative heat transfer, coherence properties and Casimir forces revisited in the near field,” Surf. Sci. Rep., 57, 59, 2005.
[3] T. Prevenslik, “Radiation at the Nanoscale by Quantum Mechanics,” Inter. Workshop on Nano-Micro Thermal Radiation, Miyagi, 2012.