Evanescent waves cannot exist in the near-field!

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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 thermal 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 perpendicular 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 thermally excited evanescent waves. EM stands for electromagnetic. See QM argument in comments to http://news.mit.edu/2015/nanoscale-heat-transfer-1125

Background

In near-field heat transfer, the theory [2] of evanescent waves assumes the long wavelength form of the Planck law which only depends only on the temperature of the surface atom. EM confinement of the atom is not considered. The Planck law at 300 K is shown in Fig. 1.

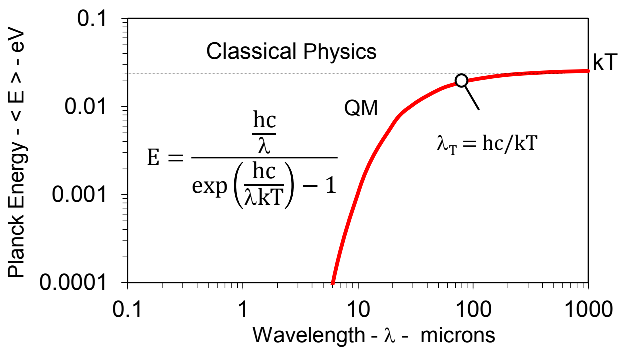

Figure 1 Planck energy of the atom at 300 K

However, the heat capacity of the atom at 300 K given by its Planck energy <E> does indeed depend on the wavelength λ of its EM confinement. Planck energy <E> is used here as the measure of heat capacity of the atom as it is more fundamental than specific heat given by its derivative with respect to temperature. If the atom is in the free surface of a body or in the surfaces of macroscopic gaps, the EM confinement is in the long wavelength λ > 100 microns region corresponds to classical physics where the atom by the Planck law does have heat capacity as shown in Fig. 1. But for wavelengths $\lambda < 100$ microns, QM differs from classical physics in that the heat capacity of the atom given by the Planck law depends on EM confinement. For an evacuated gap of dimension g at 300 K, the EM confinement corresponds to a standing half-wave, i.e., $\lambda/2 = g \approx 50$ microns. Hence, near-field heat transfer by evanescent waves is unequivocally valid by QM for EM confinement at $\lambda > 100$ microns or gaps $g > 50$ microns.

However, for EM confinement < 100 microns (or gaps $g < 50$ microns), Fig. 1 shows the heat capacity of the atom decreases by 2 orders of magnitude for wavelengths $\lambda < 6$ microns (or gaps $g < 3$ microns). Therefore, 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 standing for fluctuation dissipation theorem. Similarly, Maxwell's solutions in the near-field heat transfer of nanoscale gaps that rely on the FDT are also questionable.

What this means is thermally excited evanescent waves cannot exist in near-field heat transfer and the MIT claim based on the existence of evanescent waves in the enhancement of near-field heat transfer beyond the blackbody limit is not consistent with QM. Instead, a QM mechanism other than evanescent waves tunnels EM energy across nanoscale gaps in the near–field.

Proposal

Heat transfer at the nanoscale in general, and the near-field in particular is proposed to be a natural consequence of QM in combination with QED induced EM radiation. QED stands for quantum electrodynamics. However, QED as the complex theory of light interaction with matter advanced by Feynman [3] is reduced to a far more simpler form. By QM, heat absorbed in a nanostructure cannot be conserved by an increase in temperature, and therefore conservation proceeds by QED inducing the creation of non-thermal standing EM radiation inside the nanostructure. Following Planck's derivation of black-body radiation over a century ago, the notion of standing EM waves in a macroscopic cavity is extended to nanostructures using a QM box having sides separated by distance d with conservation of heat proceeding by QED inducing the creation of standing EM radiation having half-wavelength $\lambda/2 = d$ instead of an increase in temperature. The frequency υ of the EM radiation is , $\upsilon = (c/n)/\lambda$, where the velocity of light c is corrected for reduced speed by the refractive index n of the nanostructure.

However, for QED to induce conversion of heat to standing EM radiation, the sides of the QM box are required to provide high EM confinement wavelengths $\lambda < 100$ microns as otherwise absorbed heat is conserved by an increase in temperature. Unlike the macroscale, high EM confinement occurs naturally because of the high surface-to-volume ratio of nanostructures. In the near-field, the EM confinement of the QM box at nanoscale wavelengths < 100 nm naturally occurs at gaps $g < \lambda/2 = 50$ nm as almost all of the heat is inherently absorbed in surfaces because of the high surface-to-volume ratios inherent in nanoscale gaps. Even in discrete nanostructures having refractive index n with surfaces separated by characteristic dimension d, the high surface-to-volume ratios provide a QM box having high EM confinement of absorbed heat allowing the creation of standing EM radiation with half-wavelength $\lambda/2 = nd$.

Since the source of the QED induced EM radiation is also the heat absorbed in the surfaces of the QM box that momentarily formed the EM confinement , the standing EM radiation if not absorbed within the QM box is free to escape to the surroundings, e.g., a nanoparticle upon absorbing heat emits EM radiation at wavelength $\lambda = 2nd$ depending on its characteristic dimension d and refractive index n. See diverse QED applications at http://www.nanoqed.org , 2010 -2016.

Application

Near-field radiative heat transfer across nanoscale gaps [4, 5] cannot be conserved by changes in surface temperature because the surface atoms under EM confinement given by the Planck law lack the heat capacity to change in temperature. Instead, the heat at IR wavelengths tunnels across the nanoscale gap by standing wave QED induced EM radiation at nanoscale wavelengths $\lambda < 100$ nm. Here, $\lambda = 2$ ng ≈ 2 g, where n ≈ 1 as the gap is evacuated. Evanescent wave tunneling does not occur. 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

QED tunneling [4,5] 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 Fig. 1. 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 where temperature changes do not occur surround nanoscale gaps, the size of the dead space depending on the temperature of the body. At 300 K, Fig. 1 shows a dead-space g $\approx$ 50 microns at $\lambda \approx 100$ 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 $\approx$ 50 microns; whereas, for separations d < g $\approx$ 50 microns, the radiative heat is given by the blackbody limit evaluated at d = g $\approx$ 50 microns.

Conclusion

Near-field heat transfer does not exceed the blackbody limit as thermally excited evanescent waves cannot exist because of QM. Enhancements of 100 to 1000 times above the black-body limit are therefore not likely to be found in practice.

References

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