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On the applicability of Kirchhoff's law to a subwavelength particle in thermodynamic equilibrium with the environment

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A new method for calculating the absorption coefficients of subwavelength particles (SP) is proposed. In this technique, the radiation flux is represented by a set of spatial spectral modes that are absorbed by the SP in accordance with the product $\varepsilon_i \cdot f(D, \lambda)$. Moreover, at $\lambda \leq \lambda_{cutoff}$ $f(D, \lambda) = 1$, and at $\lambda > \lambda_{cutoff}$ $f(D, \lambda) = (2D/\lambda)^2$, where: D – is the diameter of the SP, λ – is the wavelength, λ_{cutoff} – is the cutoff wavelength, ε_i – is the integral absorption coefficient of a "large" body made of a material similar to the material of the SP. Calculations of the emission and absorption coefficients of a medium in thermodynamic equilibrium with the environment have been carried out. For comparison, along with the proposed methodology, a method for calculating the absorption coefficient of the SP was used, based on consideration of the depth of penetration of radiation into the SP material. It is shown that the feasibility of Kirchhoff's law for SP depends on the particle diameter and on the ambient temperature. With "large" D, the emission and absorption coefficients are equal (Kirchhoff's law holds), however, with a decrease in D, the absorption coefficient becomes greater than the emission coefficient (Kirchhoff's law does not hold).

Keywords: blackbody, Planck's law, Stefan-Boltzmann's law, Wien's displacement law, Kirchhoff's law, diffraction, radiation flux density, radiation coefficient, absorption coefficient, spatial spectral mode, mode energy, Larmour formula.

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REFERENCES

1. Greffet J.-J., Bouchon P., Brucoli G., Sakat E. and Marquier F., arXiv:1601.00312v1 [physics.optics].2016. P. 1–6.
2. Bouchon P., Brucoli G. and Marquier F., Physical Review X. **8**, 021008 (2018).
3. Miller D. A. B., Linxiao Zhu and Shanhui Fan, Proceedings of the National Academy of Sciences (PNAS). **114** (17), 4336–4341 (2017).
4. Linxiao Zhu and Shanhui Fan, Physical Review B. **90**, 220301 (2014).
5. Snyder W. C., Zhengming Wan and Xiaowen Li, Applied Optics **37** (16), 3464–3470 (1998).
6. Pendry J. B., Journal of Physics: Condensed Matter. **11**, 6621–6633 (1999).
7. Schuller J. A., Taubner T. and Brongersma M. L., Nature Photonics **3**, 658–661 (2009).
8. Boriskina S. V., Green M. A., Catchpole K. et al., Journal of Optics **18** (7), 073004 (2016).
9. Robitaille P.-M. and Robitaille J. L., IEEE Transactions on Plasma Science **31** (6), 1263–1267 (2004).
10. Park Y., Asadchy V. S., Bo Zhao, Cheng Guo, Jiahui Wang and Shanhui Fan, American Chemical Society Photonics **8** (8), 2417–2424 (2021).
11. Ghanekar A., Jiahui Wang, Shanhui Fan and Povinelli M. L., American Chemical Society Photonics **9** (4), 1157–1164 (2022).
12. Pajovic S., Tsurimaki Y., Xin Qian and Gang Chen, Physical Review B. **102**, 165417 (2020).
13. Jun Wu, Zhongmin Wang, Han Zhai, Zhangxing Shi, Xiaohu Wu and Feng Wu, arXiv:2109.13502 [cond-mat.mes-hall]. https://doi.org/10.48550/arXiv.2109.13502
14. Jason Y. H., Soric C. and Alu A., Proceedings of the National Academy of Sciences (PNAS) **113** (13), 3471–3475 (2016).
15. Mie G., Annalen der Physik. **25**, 377 (1908).
16. Bohren C. F. and Huffmann D. R., Absorbtion and Scattering of Light by Small Particles, New York- Chichester-Brisbane-Toronto-Singapore, John Wiley & Sons, 1983.
17. Landau L. D. and Lifshitz E. M. Course of theoretical physics. Vol. 8. Electrodynamics of continuous media Pergamon Press, 1960.
18. Bourn M. and Wolf E., Principles of optics, Oxford-London-Edinburgh-New York-Paris-Frankfurt, Pergamon Press, 1964.
19. Martynenko Yu. V. and Ognev L. I., ZHurnal tekhnicheskoj fiziki **75** (11), 130–132 (2005) [in Russian].
20. Dombrovsky L. A., Thermophysics of high temperatures **37** (2), 284–293 (1999).
21. Joulain K., Ezzahri Y. and Carminati R., arXiv:1509,05927v2 [physics. class-ph].
22. Joulain K., HAL Id: hal-01860367. https: hal.archives-ouvertes.fr/hal-01860367.
23. Tribel`skij M. I. and Miroshnichenko A. E., Uspexi fizicheskix nauk **192** (1), 45–68 (2022) [in Russian]; arXiv:2009.08538v1 [physics.optics] [in Englich]
24. Elzoukal M., Yang Ch., Albert A., Lubner S. and Prasher R., Cell Reports Physical Science **1** (12), 100259 (2020).
25. Sviridov A. N. and Saginov L. D., Applied Physics, № 1, 57–62 (2021) [in Russian].
26. Sviridov A. N. and Saginov L. D., Applied Physics, № 2, 12–21 (2021) [in Russian].
27. 27 Sviridov A. N. and Saginov L. D., Applied Physics, № 3, 17–25 (2021) [in Russian].
28. Sviridov A. N. and Saginov L. D., Applied Physics, № 1, 42–50 (2022) [in Russian].
29. Fridrixov S. A. and Movnin S. M., Fizicheskie osnovy` e`lektrotexniki, Moscow, Vy`sshaya shkola, 1982 [in Russian].
30. Gagliardi R. M. and Karp Sh., Optical Communications, New York-London-Sydney-Toronto, John Wiley &Sons, 1976, Moscow, Svyaz`, 1978.
31. Goussorgues G., La Thermography Infrarouge. Principes – Technique – Applications, Deuxieme.edition, Paris, Tachnique et Documentation Lavoister, 1984, Moscow, MIR, 1988.
32. Kumar N., Spontaneous Emission Rate Enhancement Using Optical Antennas. Electrical Engineering and Computer Sciences.University of California at Berkeley. Technical Report № UCB/EECS-2013-107. http://www.eecs.berkeley.edu/Pubs/TechRpts/2013/EECS-2013-107.html
33. Tsakmakidis K. L., Boyd R. W., Yablonovitch E. and Xiang Zhang, Optics Express **24** (16), 17916–17927 (2016).
34. Knyazev B. A. and Kuz`min A. V., Vestnik Novosibirskogo Gosudarstvennogo Universiteta. Seriya: Fizika, **2** (1), 108–122 (2007) [in Russian].
35. Landau L. D. and Lifshhicz E. M., Statisticheskaya fizika **5**, Moscow, Nauka, 1976 [in Russian].
36. Dmitriev A. S., Vvedenie v nanoteplofiziku, Moscow, BINOM, 2015 [in Russian].