

Lawrence Berkeley National Laboratory

LBL Publications

Title

Bremsstrahlung in A Dense Plasma

Permalink

<https://escholarship.org/uc/item/5h0308fd>

Authors

Stack, John D

Sessler, Andrew M

Publication Date

1963

University of California
Ernest O. Lawrence
Radiation Laboratory

BREMSSTRAHLUNG IN A DENSE PLASMA

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545*

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California
Contract No. W-7405-eng-48

BREMSSTRAHLUNG IN A DENSE PLASMA

John D. Stack and Andrew M. Sessler

January 15, 1963

BREMSSTRAHLUNG IN A DENSE PLASMA*

John D. Stack and Andrew M. Sessler

Lawrence Radiation Laboratory
University of California
Berkeley, California

January 15, 1963

The bremsstrahlung emitted by an electron scattered in a Coulomb field was first calculated by Bethe and Heitler.¹ The total cross section for production of photons with wave number between k and $k + dk$ by a nonrelativistic electron of kinetic energy ϵ is

$$\frac{d\sigma}{dk} dk = \frac{16}{3} Z^2 r_0^2 \left(\frac{e^2}{\hbar c} \right) \left(\frac{mc^2}{\epsilon} \right) \log \left(\sqrt{\frac{\epsilon}{\hbar ck} + 1} + \sqrt{\frac{\epsilon}{\hbar ck} - 1} \right) \frac{dk}{k}, \quad (1)$$

where Ze is the charge of the (heavy) ion, and r_0 is the classical electron radius.

Bremsstrahlung in a plasma has been computed by a number of authors in the approximation of replacing the Coulomb field by a cut-off Coulomb or static Debye potential.² It is the purpose of this communication to call attention to another important effect of the medium upon the rate of emission of bremsstrahlung. This may be described as a modification of the relation of the photon's energy to its wave number, due to the index of refraction of the medium. Equivalently, we note that one must include in the calculation of bremsstrahlung in a medium the photon-medium interactions which result in the "clothing" of a "bare" photon. The replacement of a particle by a quasi-particle has long been known to be important in the description of strongly interacting systems of massive particles such as liquid helium;³ the effect can be particularly dramatic for a photon because the medium gives a nonzero

effective mass to the quasi-photon.⁴

The interaction between the electromagnetic field and the plasma leads to the "dressing" of photons as well as their emission and absorption. When the quasi-photon lifetime is finite, no general theory exists for systematically treating both of these effects. However, one can take the first step toward such a theory by using the results of the simple pair or random-phase approximation in which the lifetime is still infinite. In this approximation, the index of refraction (in the long wavelength limit) is given by $n = 1 - \omega_p^2/\omega^2$, which implies the dispersion relation

$$k\omega = \left[(\kappa\omega_p)^2 + (\kappa ck)^2 \right]^{1/2}, \quad (2)$$

where ω_p is the plasma (angular) frequency. Thus, in first approximation, a quasi-photon has an effective mass $m^* = \kappa\omega_p/c^2$. The radiation of quasi-photons by electrons in collision with ions is readily calculated by using perturbation theory in the manner of Bethe and Heitler, due account being taken of the change in normalization of the electric field and of the change in the density of final states.⁵ If one approximates the screened potential by its static approximation then the total cross section for production of photons with wave number between k and $k + dk$ by an electron of kinetic energy ϵ is

$$\frac{d\sigma}{dk} dk = \frac{4}{3} Z^2 r_0^2 \left(\frac{e^2}{\kappa c} \right) \frac{mc^2}{\epsilon} \left\{ \frac{(|\tilde{p}_1| + |\tilde{p}_2|)^2}{(|\tilde{p}_1| + |\tilde{p}_2|)^2 + (\kappa k_D)^2} - \frac{(|\tilde{p}_1| - |\tilde{p}_2|)^2}{(|\tilde{p}_1| - |\tilde{p}_2|)^2 + (\kappa k_D)^2} \right. \\ \left. + \ln \left[\frac{(|\tilde{p}_1| + |\tilde{p}_2|)^2 + (\kappa k_D)^2}{(|\tilde{p}_1| - |\tilde{p}_2|)^2 + (\kappa k_D)^2} \right] \right\} \frac{c^3 k^2 dk}{\omega^3}, \quad (3)$$

where \underline{p}_1 and \underline{p}_2 are the initial and final momenta of the electron, k_D is the Debye wave number, and the energy loss of the electron is

$$h\omega = \frac{|\underline{p}_1|^2 - |\underline{p}_2|^2}{2m} = \left[(\hbar\omega_p)^2 + (\hbar ck)^2 \right]^{1/2}. \quad (4)$$

Screening may be neglected by setting k_D to zero, in which case Eq. (3) differs from Eq. (1) by the replacement of dk/k by $c^3 k^2 dk / \omega^3$. This modification removes the infrared divergence of Eq. (1), because ω approaches ω_p as k approaches zero. Physically, the nonzero mass of the quasi-photon means that an electron of given energy can radiate at most a finite number of quasi-photons. The resulting difference in the energy loss of an electron is significant only for a very slow electron or in a very dense plasma. A second qualitative difference between Eq. (3) and Eq. (1) is the absence of any radiation for ω less than ω_p . In particular, if the correct frequency-dependent shielded potential is employed in the derivation, the classical limit taken, and the result then averaged over a thermal distribution, one easily obtains Dawson and Oberman's⁶ result for the plasma emission coefficient.

The authors wish to thank Drs. H. DeWitt, J. Garrison, A. Kaufman, and K. Watson for enlightening conversations.

Footnotes and References

- * Supported by the U. S. Atomic Energy Commission.
1. H. Bethe and W. Heitler, Proc. Roy. Soc. A, 146, 83 (1934).
 2. L. Oster, Revs. Modern Phys. 33, 525 (1954); P. A. G. Scheuer, Monthly Notices of the Roy. Astron. Soc. 120, 231 (1956).
 3. L. D. Landau, J. Phys. (U.S.S.R.) 5, 71 (1941); L. D. Landau, Sov. Phys. — JETP 3, 920 (1956).
 4. An interesting consequence of the nonzero mass of the quasi-photon is the possibility of its decay into a neutrino pair: J. D. Adams, M. A. Ruderman, and C. H. Woo, Phys. Rev. (to be published).
 5. J. M. Jauch and K. M. Watson, Phys. Rev. 74, 950, 1485 (1948).
 6. J. Dawson and C. Oberman, Phys. of Fluids 5, 517 (1962).

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

