Calculation of the Cross-Section for the 1S→2P Transition of an Electron Bubble in Helium II

Wei Guo and Humphrey J. Maris

Department of Physics, Brown University, Providence, Rhode Island 02912, USA

Abstract. In a recent paper, we have calculated the effect of thermal and zero-point fluctuations on the 1S to 1P optical transition of the electron bubble in superfluid helium. We obtained a line shape that was in good agreement with the experimental results of Grimes and Adams (*Phys. Rev.* **45**, 2305 (1992)). Here we extend these calculations to consider the line shape for the 1S to 2P transition and compare the results with the data of Zipfel and Sanders.

Keywords: electrons, bubbles, helium, photons.
PACS: 67.40, 78.20c

The optical properties of electron bubbles in superfluid helium have been studied in a number of experiments. The photon energy required to cause the electron to make a transition from the 1S to the 1P state has been measured by Grimes and Adams,[1, 2] and Parshin and Pereversev.[3] The 1S→2P transition has been studied by Zipfel and Sanders.[4] At zero pressure the 1S→1P transition requires a photon of energy 0.1 eV, and the 1S→2P transition energy is 0.5 eV.

The line shape of these transitions is determined by the fluctuations in the shape and size of the electron bubble. Both zero-point and thermal fluctuations contribute to the line shape. As a consequence, measurements of the line shape as a function of temperature and pressure provide an interesting test of calculations of the fluctuations of a helium surface. In a recent paper[5] we have calculated the amplitude of these fluctuations and have determined the line shape for the 1S→1P transition. The results were in excellent agreement with the measurements of Grimes and Adams.[2] In this note, we apply the same method to calculate the shape of the 1S→2P transition.

Here, we describe the essential physics of the method; the calculation follows along the same general lines as already presented for the 1S→1P transition in ref. 5. The total energy E_b of the electron bubble is taken as

$$E_b = E_{el} + \alpha A + PV , \qquad (1)$$

where E_{el} is the energy of the electron, α is the surface tension, P is the applied pressure, A is the surface area, and V is the volume of the bubble. For a mode of vibration in which the surface displacement varies as $Y_{lm}(\theta,\phi)$, the vibrational frequency ω_l is found. The statistical distribution of amplitudes for each mode l,m is then determined. For a set of mode amplitudes, we calculate the difference in energy between the 1S and 2P levels. Averaging over the statistical distribution of mode amplitudes then gives the line shape. Since the amplitude of the fluctuations of the bubble surface is small, it is sufficient to consider that the shift in the energy levels is proportional to the displacement. Within this approximation, the shift in the 1S level depends only on the normal mode with $l=0$, and the 2P level is shifted by the $l=0$ mode, and by the five degenerate modes with $l=2$.

In the previous calculation for the 1S→1P transition, the energy of the electron was sufficiently far below the potential barrier provided by the wall of the bubble that the penetration of the wave function into the helium could be neglected. However, for the 1S→2P transition it is necessary to allow for the finite height (~1 eV) of the barrier, and to do this we followed the method used by Grimes and Adams.[1] The results for the line shape at different pressures and temperatures are shown in Fig. 1. It can be seen that the line width increases with pressure and temperature,

CP850, *Low Temperature Physics: 24th International Conference on Low Temperature Physics;* edited by Y. Takano, S. P. Hershfield, S. O. Hill, P. J. Hirschfeld, and A. M. Goldman

and hence the peak value of the cross-section decreases with an increase in these parameters.

The only experimental study of the 1S→2P transition is the work of Zipfel at a temperature of approximately 1.3 K. She made measurements of the line shape over a range of pressure up to 15 bars. In Fig. 2 we compare her results for the full width at half maximum with the results of our calculations. It can be seen that, allowing for the scatter in the experimental results and the approximations that have been made in the theory, the agreement between experiment and theory is good.

This work was supported in part by the National Science Foundation through Grant No. DMR-0305115.

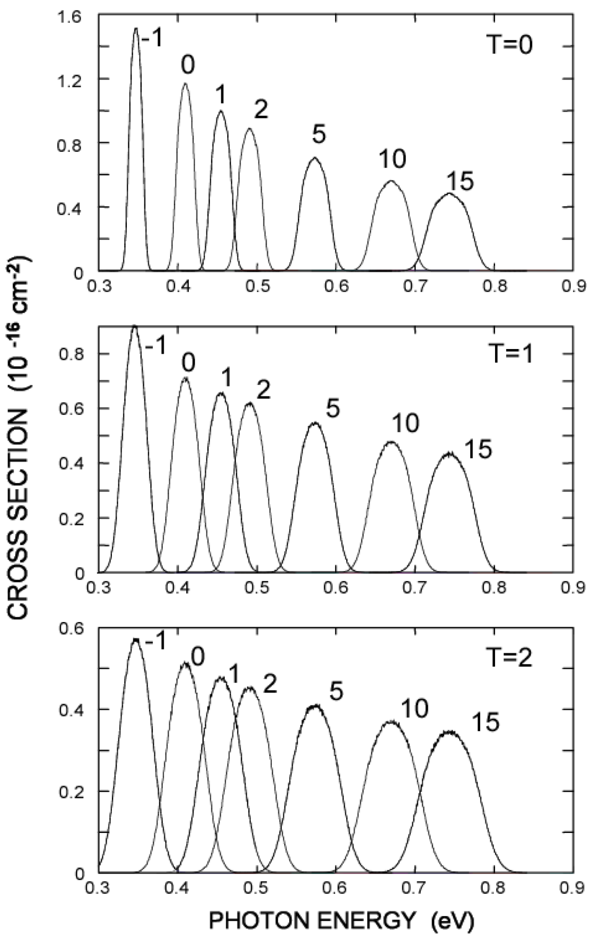

FIGURE 1. Calculated shape of the absorption cross-section for the 1S→2P optical transition as a function of pressure at temperatures of 0, 1 and 2 K. The different curves are labeled by the pressure in bars.

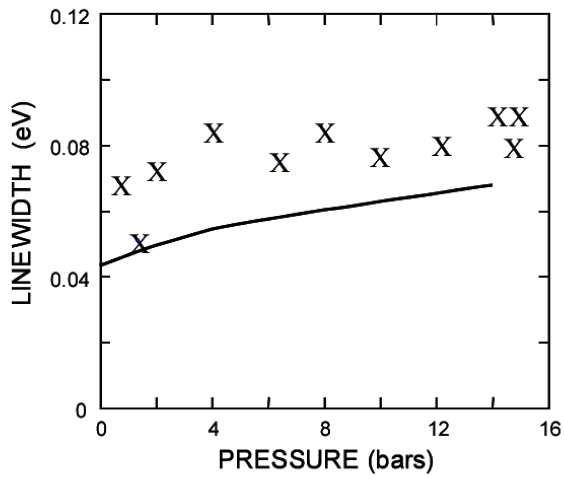

FIGURE 2. Full width at half height of the 1S→2P cross-section as a function of pressure at 1.3 K. The crosses are the measurements of Zipfel (ref. 4) and the solid curve is the calculated width.

REFERENCES

1. C.C. Grimes and G. Adams, *Phys. Rev. B* **41**, 6366 (1990).
2. C.C. Grimes and G. Adams, *Phys. Rev. B* **45**, 2305 (1992).
3. A. Ya. Parshin and S.V. Pereversev, Pis'ma Zh. ksp. *Teor. Fiz.* **52**, 905 (1990) [*JETP Lett.* **52**, 282 (1990)].
4. C.L. Zipfel, Ph.D. thesis, University of Michigan, 1969, unpublished; C.L. Zipfel and T.M. Sanders, in *Proceedings of the 11th International Conference on Low Temperature Physics*, edited by J.F. Allen, D.M. Finlayson, and D.M. McCall (St. Andrews University, St. Andrews, Scotland, 1969), p. 296.
5. W. Guo and H.J. Maris, *J.Low Temp. Phys* **137**, 491 (2004).