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# This Week's Citation Classic®

**Pippard A B.** Ultrasonic attenuation in metals. *Phil. Mag.* **46**:1104-14, 1955.
[Royal Society Mond Laboratory, Cambridge, England]

The main part of the text develops the theory of sound-wave absorption by conduction electrons of arbitrary mean free path and gives explicit formulas for longitudinal and transverse waves. The electrons, assumed free, are treated classically. [The *SCI*® indicates that this paper has been cited in over 325 publications since 1955.]

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In October 1954, Bömmel[1] reported that ultrasonic waves in lead were strongly attenuated at very low temperatures, and within two months Mason[2] and Bob Morse[3] had independently submitted short notes explaining why the conduction electrons would absorb sound efficiently when the time between collisions with the ionic lattice was long. Bob was on leave in Cambridge and we discussed the first draft of his note. He later remarked that this solution was incomplete because it assumed unnecessarily that the free path of the electrons between collisions was smaller than the sound wavelength. Since I had, some years before, worked on the anomalous skin effect, to which the problem of long free paths is central, I found his remark stimulating.

I then joined my parents for an Easter break at Lyme Regis, and in the intervals of long cliff walks I worked out Bob's idea. Only one novelty was needed—when the electrons were scattered by the lattice, it was necessary to remember that the lattice was being shaken by the passage of the wave. Otherwise the calculation was straightforward, and I returned to Cambridge a week later with the general formula for attenuation of sound, whatever the electronic free path might be. I suggested to the head of my research group that it might make a good seminar, but he thought the topic was not of sufficient general interest. Since I rather agreed with him, I did not press the matter, but published the calculation and forgot about it.

When, however, Bömmel[4] went on to show that a magnetic field caused the attenuation to oscillate with field strength, and when simultaneously the general problem of how electrons behave in real metals (rather than the simplified free-electron model that I had adopted) suddenly became a major research field,[5] ultrasonic measurements were in fashion, and the theory was extended by many physicists, myself included. The immediately useful extensions were not hard, but the more general theory proved quite difficult, especially attempts to get the same result by using quantum mechanics, which does not take kindly to electrons that suffer scattering. As late as 1974 rederivations of my formulas were appearing,[6] and formidable indeed they are in comparison with the classical approach.

It seems, nevertheless, that the classical formulas are pretty sound and can be applied even in situations where one might think quantum corrections would matter. As a result they have frequently been applied to phonons, the very high-frequency sound waves excited thermally, which play a major role in the thermal capacity and thermal conductivity of a solid. The formula has also been used to account for some curiosities of thermal capacity in disordered solids. It is undoubtedly a basic result, but the physical ideas were almost all Bob's; my good fortune was to have had the experience that made the working out so easy.

1. **Bömmel H E.** Ultrasonic attenuation in superconducting lead. *Phys. Rev.* **96**:220-1, 1954. (Cited 100 times since 1955.)
2. **Mason W P.** Ultrasonic attenuation due to lattice-electron interaction in normal conducting metals. *Phys. Rev.* **97**:557-8, 1955. (Cited 60 times.)
3. **Morse R W.** Ultrasonic attenuation in metals by electron relaxation. *Phys. Rev.* 97:1716-17, 1955.
4. **Bömmel H E.** Ultrasonic attenuation in superconducting and normal-conducting tin at low temperatures. *Phys. Rev.* **100**:758-9, 1955. (Cited 65 times.)
5. **Pippard A B.** *The dynamics of conduction electrons.* New York: Gordon and Breach, 1965. 150 p.
6. **Grünewald G & Scharnberg K.** Lifetimes of long wavelength longitudinal phonons in impure metals. *Z. Phys.* **268**:197-205, 1974.

 