# Internal Friction in Solids

## III. Experimental Demonstration of Thermoelastic Internal Friction

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(Received July 13, 1937)

In order to demonstrate the presence of thermoelastic internal friction, the authors measured the internal friction of a copper reed over a wide frequency range (50 to 4000 cycles/sec.). They obtained a maximum precisely at the predicted frequency. The observed variation of internal friction with frequency proves that, over a wide frequency range, the internal friction due to the flow of heat back and forth across a reed is of a larger order of magnitude than that due to all other causes. Independent experiments of Bennewitz and Rötger on wires of silver, aluminum, brass, steel, and glass are shown to furnish an equally striking demonstration of thermoelastic internal friction.

IN a previous paper[1] one of the authors predicted that the internal friction of a reed vibrating transversely has a high maximum at the frequency

$$\nu_0=(\pi/2)Dd^{-2}, \qquad (1)$$

where $D$ is the thermal diffusion constant of the material, and $d$ is the width of the reed in the plane of vibration. Although the literature on the internal friction of reeds is very extensive, a thorough search failed to find measurements made over a sufficiently wide range to test this prediction. In fact, all experiments with metal reeds had been made at frequencies of the order of one cycle per second. We therefore designed an experiment to measure the internal friction of a reed over a wide frequency band. This band was so chosen as to include the frequency $\nu_0$ at which a maximum was expected.

The method adopted for the measurement of internal friction was that developed by Wegel and Walther,[2] namely the measurement of the width, $\Delta\nu$, at half-maximum of a resonance curve (plot of square of amplitude against frequency). A measure of internal friction at each resonance frequency is then given by

$$Q^{-1}=\Delta\nu/\nu.$$

Our measurements were made on copper reeds 3 mm wide cut from a cold rolled sheet 0.45 mm thick. Preliminary measurements showed that the lower the frequency, the greater was the care necessary to avoid energy loss through supports. Hence at lower frequencies the reed (30.0 cm long) was suspended at its center by a silk thread, only those types of vibration being investigated which had nodes at the center. At higher frequencies we used a shorter reed (13.0 cm long) soldered onto a massive block of brass.

Our measured values of $Q^{-1}$ are given in Fig. 1, the crossed circles representing observations on the long reed, the full circles observations on the short reed. The full line curve gives the theoretical dependence upon frequency of that part of the internal friction which arises from the thermoelastic effect.[1] The theoretical and experimental maxima occur at precisely the same frequency.

While this experiment was in progress Benne-

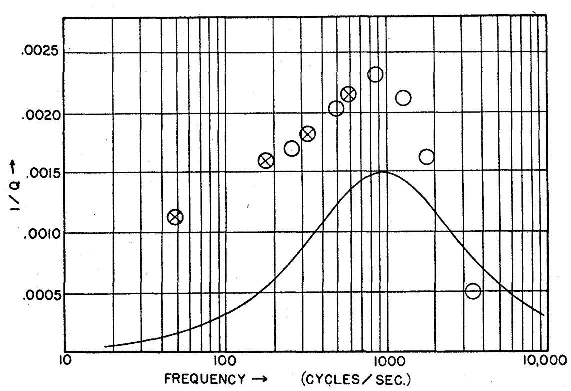


FIG. 1. Internal friction of vibrating reeds. Solid curve, calculated values. Open circles, reed 13 cm long, one end clamped. Circles with crosses, reed 30.5 cm long, both ends free.

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[1] C. Zener, Phys. Rev. 52, 230 (1937).
[2] R. L. Wegel and H. Walther, Physics 6, 141 (1935).

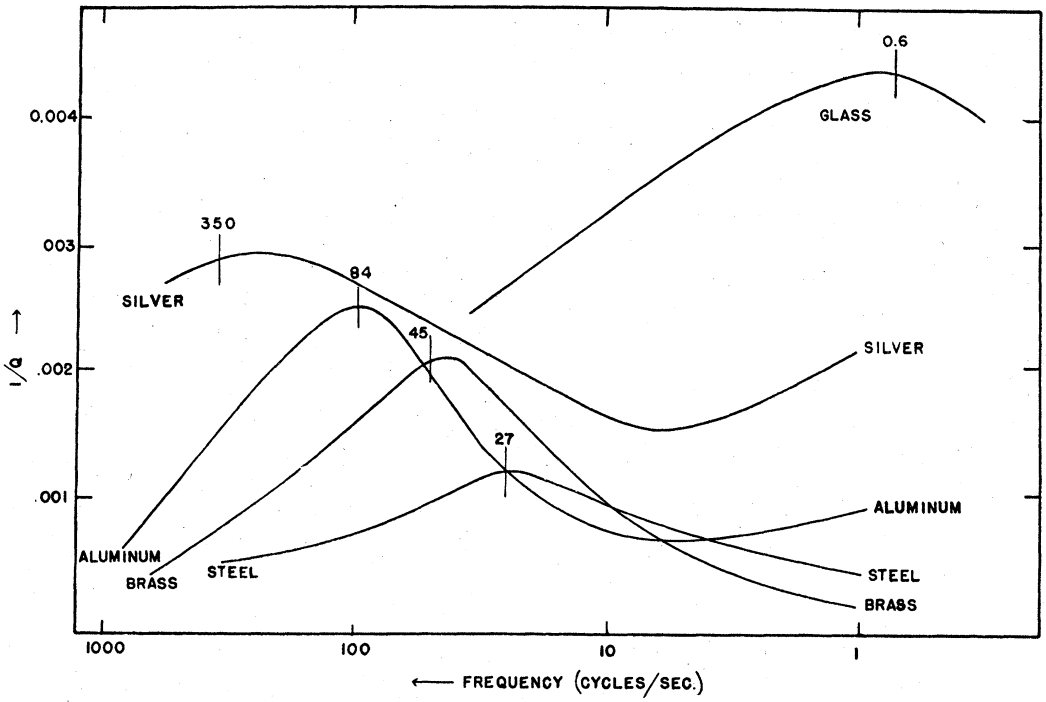


FIG. 2. Internal friction measured by Bennewitz and Rötger. The calculated values of the maxima are marked by vertical lines.

witz and Rötger[3] published the results of their experiments on the internal friction of wires vibrating transversely. Fig. 2 gives the curves which they fitted to their observations. While Bennewitz and Rötger correctly interpreted the maximum in each curve as due to a relaxation phenomenon, they did not realize the nature of this relaxation phenomenon.

We naturally suspected the maxima in these curves to be due to the thermoelastic effect. We thereupon calculated the position of each maximum by the theoretical formula

$$\nu_0 = 0.539D/a^2$$

of the preceding paper, where $a$ is the radius of the wire. The calculated value of $\nu_0$ for each wire is shown as a vertical line in Fig. 2. In each case the calculated $\nu_0$ practically coincides with the position of the observed maximum. The slight displacement to lower frequencies of the observed $\nu_0$'s for the metal wires with respect to the calculated $\nu$'s may be explained by an abnormal low thermal conductivity of the drawn metal wires.

A detailed comparison of these experiments with theory is given in Table I. As in the authors' experiment with a reed, the observed heights of the maxima are larger than the theoretical value $\frac{1}{2}(E_S - E_T)/E_S$. This discrepancy may also be due to the cold working of the samples. The curves for the soft wires of silver and aluminum show an unexpected rise in the low frequency range. Such a rise is also indicated by the curve for our copper reed. Since that part of internal friction which is due to plastic flow is larger the lower the frequency, this unexpected rise at low frequencies is probably due to plastic flow.

TABLE I. *Comparison of observed and calculated frequencies for maximum internal friction.*

| Type of wire<br>$2a$, in mm | glass<br>1.25 | steel<br>1.0 | brass<br>1.25 | Al<br>1.5 | Ag<br>1.01 |
|---|---|---|---|---|---|
| $\nu_0$, observed<br>$0.539 \times Da^{-2}$ | 0.66<br>0.5–0.6 | 25<br>27 | 40<br>45 | 83<br>84 | 240<br>350 |
| †Obs. max. $\times 2 \times 10^3$<br>$10^3(E_S - E_T)/E_T$ | 8.7 | 2.6<br>2.4 | 4.4<br>3.2 | 5.2<br>4.6 | 6.0<br>3.4 |

† The observed maximum has been obtained by multiplying the $\lambda_{max}$ of B. and R. by $2(\log_e 10)/\pi = 1.46$.

[3] K. Bennewitz and H. Rötger, Physik. Zeits. **37**, 578 (1936). These authors describe the internal friction by a logarithmic decrement $\lambda$, which is related to the $Q^{-1}$ here used by the relation $Q^{-1} = (\log_e 10)\pi^{-1}\lambda$.