We would like to express our thanks to Mr. W. H. Dingle, Transducer Group Leader, for his generous advice and continued interest throughout the work.

* This work arose as part of an investigation under Defence Research Board Project No. D12-55-25-02 and is published with permission of the Board.

[1] H. G. Baerwald and D. A. Berlincourt, J. Acoust. Soc. Am. 25, 703–710 (1953).

[2] Hueter, Neuhaus, and Kolb, J. Acoust. Soc. Am. 26, 696–703 (1954).

[3] D. A. Berlincourt, "Aging in barium titanate ceramics," Brush Laboratory Company Technical Report No. 4.

[4] United Kingdom Provisional Patent Specification No. 11365, filed April 24, 1953.

[5] The samples were prepared by Mr. Ian F. Wright, Industrial Minerals Division, Department of Mines and Technical Surveys.

[6] Full details of the methods of preparation and measurement of the constants of the samples will be published in a future paper.

[7] C. B. Sawyer and C. H. Tower, Phys. Rev. 35, 269–273 (1930).

Comments on "Mechanical Mechanism of Destructive Effects of Sound on Tissue"

FLOYD DUNN
Bioacoustics Laboratory, University of Illinois, Urbana, Illinois
(Received September 25, 1956)

A recently proposed theory to explain some of the nonthermal, noncavitation effects of intense high-frequency sound on living tissue is discussed in the light of more recent experiments. It is concluded that the assumption of the theory that the observed effects are caused by unidirectional forces (proportional to the square of the particle velocity amplitude) of the acoustic field which create sufficiently great displacements in structural members of the tissue to produce elastic failure, is not supported by experimental results.

IN a recent paper by Welkowitz[1] a specific mechanical mechanism is proposed to explain some of the nonthermal, noncavitation effects of intense high-frequency sound on living tissue. The proposed theory assumes that the observed effects are produced by unidirectional forces proportional to the square of the particle velocity amplitude of the acoustic wave. It is hypothesized that these forces cause elastic failure in the system when a structural component of the tissue is displaced from an equilibrium position to a second position from which recovery cannot occur. The quantitative formulation of these assumptions leads to the following relation for the irradiation time, t_B, required for failure to occur,

$$t_B = -\left(\frac{R}{K}\right)\ln\left[1-\left(\frac{u_0}{u}\right)^2\right], \tag{1}$$

where R is a viscous force coefficient, K is an elastic constant, u_0 is the threshold value of the particle velocity amplitude below which failure never occurs, and u is the particle velocity amplitude at which failure occurs in time t_B. Welkowitz cites two examples of experimental data, one by Fry *et al.*[2] and another by Welkowitz and Fry[3] in order to support his theory. The results presented by Fry *et al.* give the minimum irradiation time as a function of the transducer driving voltage required to produce paralysis of the hind legs of frogs irradiated in the lumbar enlargement of the spinal cord. The work of Welkowitz and Fry gives the minimum irradiation time required for a 10% permanent reduction of the action potential of excised frog muscle tissue as a function of the sound pressure amplitude. For both sets of data, the writer plots the minimum irradiation time as a function of $-\ln[1-(u_0/u)^2]$ and obtains a reasonably linear relation from which the constant (R/K) of Eq. (1) can be evaluated.

One of the major projects currently being conducted at this laboratory is a comprehensive investigation involving the determination of ultrasonic dosage relations for a given functional endpoint in a young mammal.[4,5] The purpose of this study is to obtain experimental results which will be fruitful in the elucidation of the physical mechanism involved in producing the observed functional change. Although this study is still in an early stage, some interesting results have already been obtained. The relation between the reciprocal of the time duration of exposure for paralysis of the hind legs of young mice and the square root of the acoustic intensity has been determined with a high degree of accuracy for a frequency of 982 kcps, a base temperature of 10°C

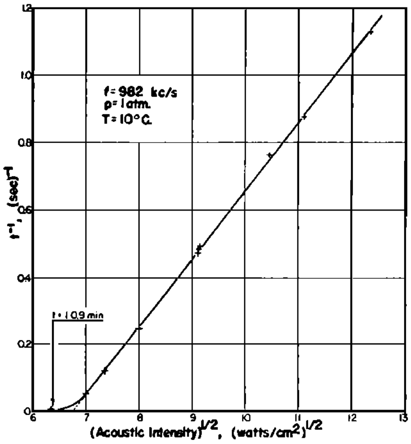

FIG. 1. The experimentally determined paralysis relation. This curve displays the relationship between the reciprocal of the exposure time and the square root of the acoustic intensity for the production of paralysis of the hind legs of the irradiated young mice.

and a hydrostatic pressure of one atmosphere.[4,5] A statistical analysis of the data is made in order to determine the relationship between the time duration of irradiation and the chosen acoustic field variable.

A linear relationship obtains for the paralysis relation (the reciprocal of the time duration of exposure for the end point to occur as a function of the square root of the acoustic intensity) from approximately 48 w/cm² (30 sec time duration of exposure) to 160 w/cm² (0.8 sec time duration). The paralysis relation is shown in Fig. 1. A statistical analysis of the nine experimentally determined points in the linear portion yields a value for the standard deviation of the points from the straight line of best fit of $\pm 1.3\%$. An analysis performed to determine the degree of nonlinearity of the "linear portion" of the threshold region yields a quadratic coefficient of such magnitude that the deviation from the statistically determined linear curve is considerably less than the standard deviation. The paralysis relation, therefore, possesses an extensive region, which is, to a high degree of accuracy, a linear relationship between the reciprocal of the exposure time and the square root of the acoustic intensity, i.e.,

$$t_{50}^{-1} = m(u-u_0), \tag{2}$$

where t_{50}^{-1} is the reciprocal of the time duration of exposure corresponding to the particle velocity amplitude u required to produce paralysis of the hind legs of 50% of the animals and m is the slope of the linear curve.

From Fig. 1 it is clear that the value of u_0, the particle velocity amplitude below which failure never occurs, cannot correspond to a value of $I^{\frac{1}{2}}$ greater than 7.0, i.e., the lowest experimental point

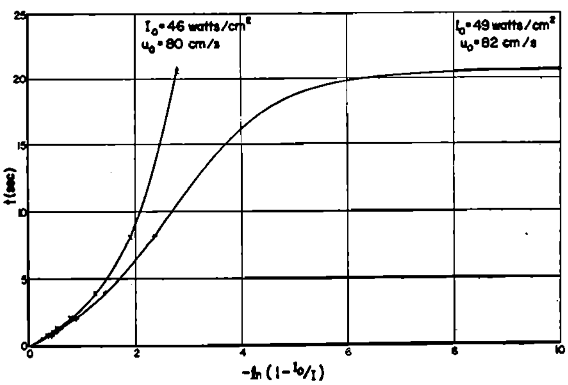

FIG. 2. The experimental paralysis relation plotted in accordance with the equation $t_B = -(R/K)\ln(1-I_0/I)$.

on the linear portion of the paralysis curve. The maximum value of u_0 which need be considered, therefore, corresponds to an intensity of 49 w/cm².

Figure 2 shows the experimentally determined paralysis data plotted in accordance with Eq. (1) for two values of u_0. The cases considered correspond to values of u_0 of 49 w/cm² (plane traveling wave case), the value indicated above, and 46 w/cm². The two curves are shown plotted to include the full range of values covered by the experimental measurements for which the linear paralysis relation was obtained. It is clear from the curves of Fig. 2, that a linear relationship between the exposure time (to produce paralysis of the hind legs of the animals irradiated) and the function $-\ln(1-I_0/I)$ is not obtained, for the factor (R/K) constant, as postulated by Welkowitz. The curve which corresponds to the 46 w/cm² value illustrates the greater deviation from the linear form required by the theory of Welkowitz when values of u_0 less than that corresponding to an intensity value of 49 w/cm² are chosen for the threshold value.

Concerning the experimental verification of the theory proposed by Welkowitz, the following considerations should be noted. First, the two sets of experiments used by the author to support his proposed theory[2,3] were not carried out with precision and accuracy comparable to that of the more recent work.[4,5] Second, the range of the parameters studied by Welkowitz and Fry[3] was considerably restricted by comparison with the work on the mouse spinal cord.

It is, therefore, concluded that the theory proposed by Welkowitz, which assumes that the observed effects are produced by unidirectional forces proportional to the square of the particle velocity amplitude of the sound wave and that these forces cause elastic failure in the system when a structural component is displaced from an equilibrium position to a second position from which recovery cannot occur, is not supported by more recent and more accurate experimental results.

[1] W. Welkowitz, J. Acoust. Soc. Am. 27, 1142 (1955).
[2] Fry, Tucker, Fry, and Wulff, J. Acoust. Soc. Am. 23, 364 (1951).
[3] W. Welkowitz and W. J. Fry, J. Cellular Comp. Physiol. 48, (1956).
[4] W. J. Fry and F. Dunn, J. Acoust. Soc. Am. 28, 129 (1956).
[5] F. Dunn and W. J. Fry, Paper HD-6, 2nd I.C.A. Congress, Cambridge, Massachusetts, (June 21, 1956).

Erratum: Equivalent Circuit for Spherical Radiation in a Solid

[J. Acoust. Soc. Am. 28, 724 (1956)]

V. Salmon
Stanford Research Institute, Menlo Park, California

In the illustration, the denominator of the expression for the compliance C is in error. For $2(1-\sigma)$ read $2(1-2\sigma)$.

THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA VOLUME 29, NUMBER 3 MARCH, 1957

Acoustical Society News

Special Summer Program on Noise Reduction at the Massachusetts Institute of Technology, August, 1957

A Special Summer Program on Noise Reduction, under the direction of Professor Leo L. Beranek with assistance from the instructing staff of M.I.T. and distinguished industrial engineers, is being offered at M.I.T. in August, 1957. The program comprises two one-week units. From Monday, August 12 through Friday, August 16, the fundamentals of noise reduction will be taught, and from Monday, August 19 through Friday, August 23, new advances in the science of noise control will be taught

The program is directed toward the man with a noise problem, rather than toward noise experts. In the first week, the behavior of sound waves, instrumentation for noise measurement, fundamentals of hearing, sound in enclosures, acoustical materials, and principles of vibration isolation will be discussed. In the second week, criteria for noise control, ventilation system quieting, quieting of office buildings and homes, design of mufflers, instrumentation for vibration measurement, machine and shop quieting, train and automobile quieting, noise from air jets and jet engines, quieting in the aviation industry, instrumentation for measurement of high intensity noise fields, and case histories will be presented.

Students may attend either or both of the weeks.

Exhibits, a field trip, and entertainment features are provided for, in addition to the formal material. Low-cost dormitory facilities for individuals or couples and cafeterias are available. For information, write to the Director of the Summer Session, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

Director of the Summer Session
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Congress of Linguists

The Eighth International Congress of Linguists will take place in Oslo, Norway, from August 5th to 9th, 1957. In its plenary sessions the following four topics will be treated:

(1) What can typological studies contribute to historical comparative linguistics?
(2) The importance of distribution *versus* other criteria in linguistic analysis.
(3) To what extent can meaning be said to be structured?
(4) What can the new techniques of acoustical phonetics contribute to linguistics?

There will be in addition meetings at which special problems will be treated in detail. Of interest to readers of the Journal are the sections entitled "Mathematical linguistics" and "New electro-acoustical equipment of value to linguists. Practical applications: machine translation, phonetic typewriters, synthetic speech."

Attendance at the Congress is restricted to those invited by the organizing committee. Persons who are interested in attending the Congress but who have not received invitations are requested to apply for invitations and further information to the Secretary of the Congress:

Miss Eva Sivertsen
Kirkeveien 98 A III
Oslo NV
Norway

International Symposium on the Phonatory Function of the Larynx

Dr. R. B. Vallancien, Head of the Laboratory of Oto-Rhino-Laryngology of the Faculty of Medicine of Paris, summarizes, as follows, the recent International Symposium on the Phonatory Function of the Larynx, held in Paris, October 20–21, 1956.

The Symposium was organized by Professor Aubin of the Chair of Oto-Laryngology of the Faculty of Medicine of Paris.

After two anatomic communications by Dr. Truffert and Professor Rethi about the new researches relating to vocal muscles and their innervation, Dr. van den Berg gave a critique of the neurochronaxic theory. Despite the author's arguments, and on the basis of his own electromyographic experimentation, he calls into question their experimental conclusions.