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# INVESTIGATIONS OF THE BARRIER PERCEPTION MECHANISMS OF THE BLIND

CZESŁAW PUZYNA

Department of Acoustics, Central Institute of Occupational Safety,
00-349 Warszawa, Tamka 1

Researches carried out in different countries have shown that the capability of recognizing and interpreting the information carried by audible sound waves plays a decisive role in the space orientation of the blind.

This article presents the results of: acoustical measurements of test acoustical signals used by the blind such as steps, the tapping of a walking stick and clapping; model investigations analyzing acoustical phenomena occurring in the environment of a conventional barrier such as a screen; open space experiments with a group of blind people in order to define a perception distance for the above barrier under different acoustical conditions; investigations carried out under laboratory conditions defining a relationship between the threshold distance of barrier perception and the area of the barrier surface when using a sonic aid (the so-called *sound torch*) and without such a device.

The results have shown that the threshold distance is proportional to the logarithm of the area of the barrier. Thus for the group of psycho-physical phenomena discussed we may use the Weber-Fechner law where the reaction is measured by the the distance of perception and is stimulated by sound waves reflected from the screen surface. The efficiency of perception is influenced by the difference between the acoustical absorption coefficients of the screen and the environment, and also depends on the individual capabilities of the subjects.

## 1. Introduction

The *space orientation* can be defined as the capability of moving and orientation in a physical environment whether inborn or acquired (for example through learning). It means the capability of localization, i.e. of limiting or confining an object such as a source of an acoustical signal, a barrier etc. to a particular place by means of stimuli acting on the senses through factors carrying particular information. When those factors are represented by acoustical waves, which indirectly cause auditory sensations, the range of such sensations for a given man in given circumstances is called his *auditory horizon*.

The capability of localization is very important in all those circumstances where it is difficult or impossible to use sight. Such circumstances occur mostly at night under conditions of poor lighting, for example during railway works, in and outside industrial halls and in mines when the lights go out. They may also occur during a foggy day, a fire which causes heavy smoke and a battlefield at night. The extreme case, very important from the cognitive point of view, is the case of the blind. An explanation of the perception of barriers and acoustical signal sources by means of hearing should facilitate the learning of space orientation by the blind. It will also permit definition of the basic criteria for designing efficient rehabilitation equipment, as well as criteria for building architectural interiors destined for use by the blind.

Until recently, a number of theories have been developed in order to try and explain the mechanisms of the perception of barriers by the blind. We can mention TRUSCHEL's acoustic theory, KUNZ's compression theory, the thermic theory of CROGIUS, VILLEY's auditory theory, the pressure theory of LAMARQUE as well as HELLER's theory of the complex reception of impressions. All these theories describe the phenomena of perception, interpreting the mechanisms of their creation from specific points of view.

Most of the research, however, has tended to presume that a decisive role is played by hearing (W. DOLAŃSKI [4] and W. S. SWIERŁOW [11]) or (e.g. M. GRZEGORZEWSKA [5]) by the "sense of barriers" which acts first of all by means of hearing and touching. Generally speaking, those mechanisms are based on the capability of reception and interpretation of the informational content of acoustical waves. They allow the receiver to assess the directivity of the acoustical field in a given area and, consequently, to obtain a more or less exact orientation depending on the images received and the capability of association.

The latest investigations, by M. KOTZIN, J. KOHLER, and others have shown that auditory impressions are necessary and sufficient for the perception of barriers. As an example, measurement results of the perception distance of a single barrier by a blind person are presented in Fig. 1. A cardboard disk of area $S_e = 1962\ \mathrm{cm}^2$ served as a barrier in this test. That disk was moved noiselessly in the direction of the subject from various sides. The dashed line shows the results of the experiment when using a "sound torch", and the continuous line — the results without such an aid. In subsequent and other current researches [2, 7, 8] we can observe a tendency to standardize the methods of measuring the threshold distance and the limits of perception of a barrier by children, people who were born blind, those who have recently become blind, and also blindfolded people. The experiments were performed in silence, under natural conditions and with a "sound torch" having specific acoustic characteristics.

## 2. Characteristics of natural acoustical signals

The sound of steps, the tapping of a stick and clapping are all sound signale which help the blind in space orientation (Fig. 2). They were registered in three rooms of different acoustic characteristics, namely: in a reverberation chamber,

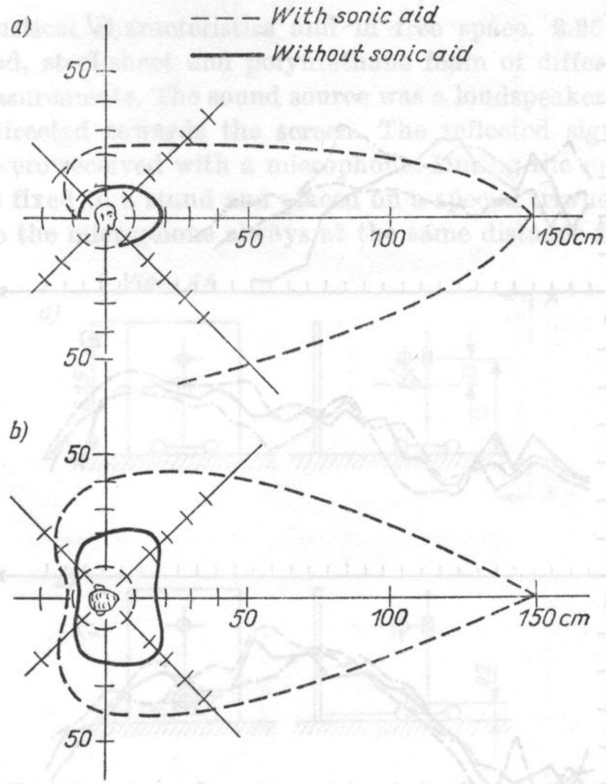


Fig. 1. Directivity characteristics of barrier perception according to J. Kohler [7]

in an average room and in an anechoic chamber. As is shown in the figure, the highest values of the particular groups of spectra occur in different frequency ranges and, therefore, each of the described signals will be optimally heard on a background noise of different acoustical characteristics.

On the basis of the described investigations and other studies it can be stated that at low frequencies the stick tapping spectra include information connected with the nature of the vibrations of stick-hand system, as well as with the construction, material and primarily the length of the stick, whereas at medium and high frequencies the information is rather more connected with the vibration of the ground caused by the tapping, i.e. with the elastic characteristics of the ground. It can be assumed, therefore, that the employment of a stick should be more useful when moving around an unknown territory, with unpredictable obstacles and irregularities in the ground due to changing structure and surface quality. In the case discussed the propagation of structure borne waves through the stick, received by hand as vibrations, can be treated as a parallel, additional and complementary information channel, especially when the informational content of aerial sound waves is masked by acoustic disturbances of the environment, as for example in a noisy street.

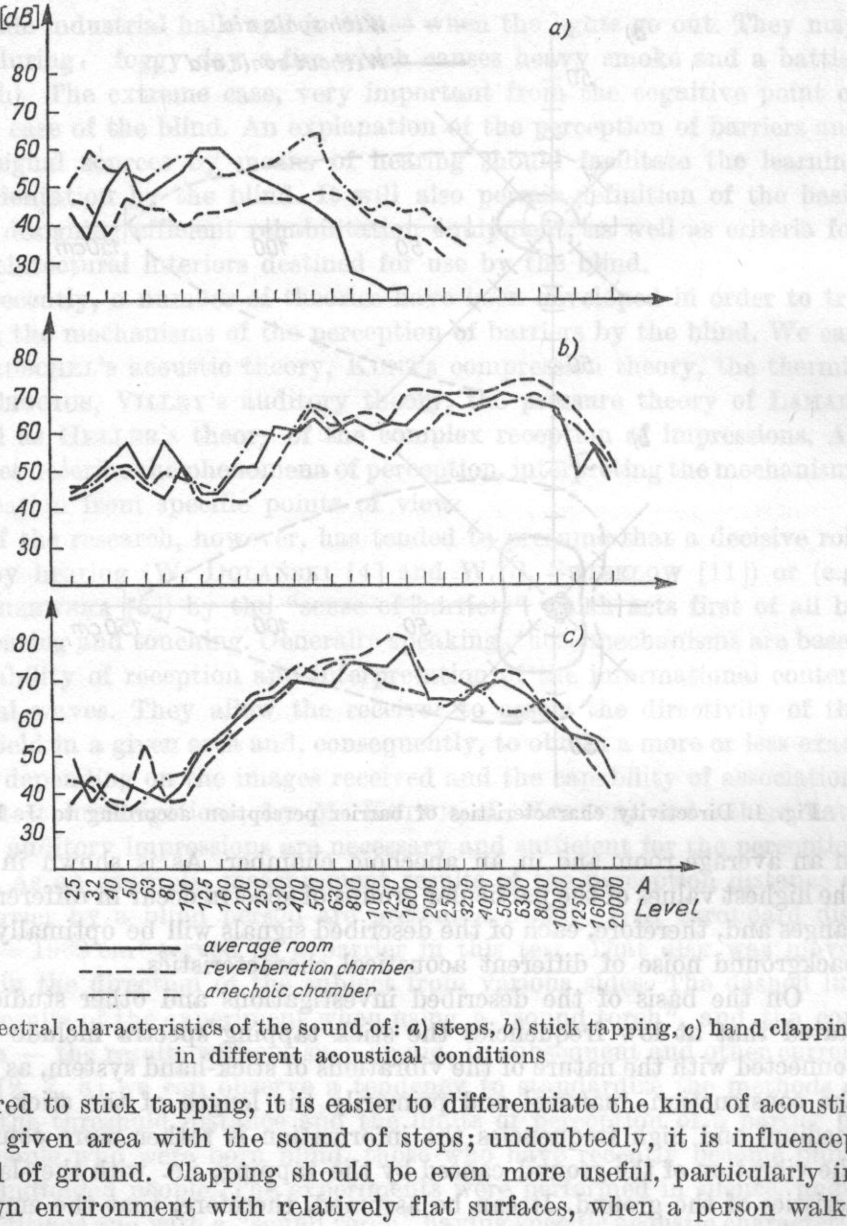


Fig. 2. The spectral characteristics of the sound of: *a*) steps, *b*) stick tapping, *c*) hand clapping in different acoustical conditions

Compared to stick tapping, it is easier to differentiate the kind of acoustic field in the given area with the sound of steps; undoubtedly, it is influencep by the kind of ground. Clapping should be even more useful, particularly in a well known environment with relatively flat surfaces, when a person walks quickly and when information about fragments of the route with special acoustical characteristics is valuable.

### 3. Results of model experiments

In order to test the theoretical hypotheses discussed in practice, a series of experimental model investigations were performed. They were carried out under different acoustical conditions, i.e. in a reverberation chamber, in a room of average acoustical characteristics and in free space. 2.25 m high screens made of plywood, steel-sheet and polyurethane foam of different widths were used for the measurements. The sound source was a loudspeaker which produced sound signals directed towards the screen. The reflected signals (or masked by the screen) were received with a microphone. During the measurements the microphone was fixed to a stand and placed on a special triwheeled car (Fig. 3) in order to have the microphone always at the same distance from the ground.

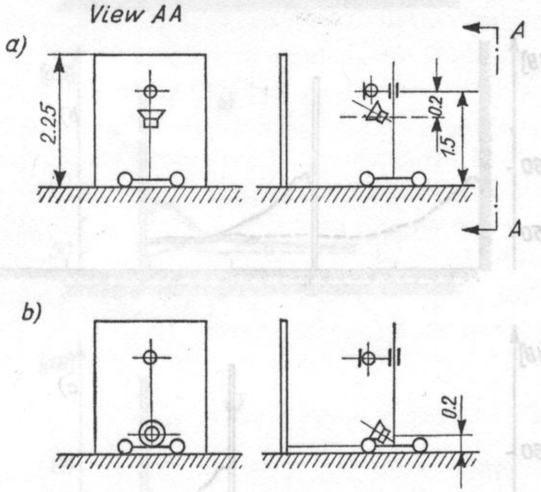


Fig. 3. Schematic diagrams of sound source position (a loudspeaker) in relation to the ears (a microphone) during man-barier model investigation referring to *a*) clapping (talking), *b*) sound of steps (stick tapping)

The distance was 1.5 m corresponding to the standard distance of the ear from the earth. Four basic positions of the loudspeaker, corresponding to every-day situations, were employed: firstly the loudspeaker was placed on the stand, a little below the microphone and during the measurements it was moved together with the microphone (Fig. 3a) — this corresponded to the situation of the person approaching the barrier clapping or speaking for example. In the second situation the loudspeaker and the microphone were placed on the same stand just above the earth (Fig. 3b), corresponding to the situation in which the source of information is represented by the steps of the person approaching the barrier or by stick tapping. Measurements were made to define the value of the acoustical pressure level as a function of the distance along an axis perpendicular to the given barrier. The curves in Fig. 4 show the changes of the level: in the reverberation chamber (Fig. 4a), in an interior with average acoustical characteristics (Fig. 4b), and in free space (Fig. 4c); in two situations — with the screen (continuous line) and after removing it (dashed line).

It can be observed that in an acoustical field that is almost perfectly diffused (anechoic chamber — Fig. 4a) the curves were flattest and the level

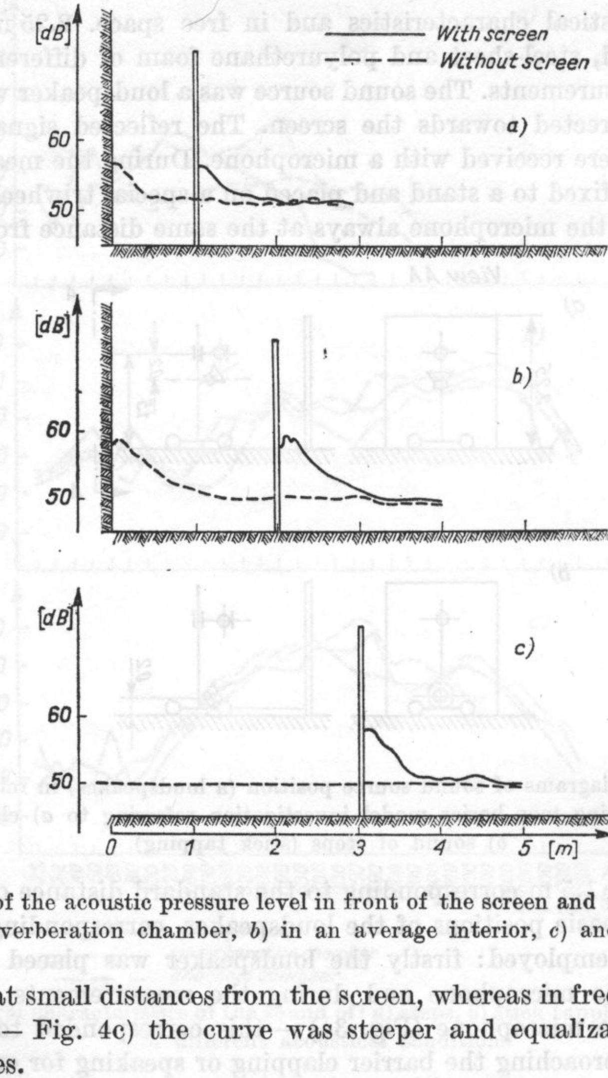


Fig. 4. Increase of the acoustic pressure level in front of the screen and in front of the wall, *a*) in the reverberation chamber, *b*) in an average interior, *c*) and in free space

was equalized at small distances from the screen, whereas in free field conditions (in free space – Fig. 4c) the curve was steeper and equalization occurred at longer distances.

In all cases, removal of the screen caused equalization of the acoustic pressure level in the previous location of the screen.

On the basis of the investigations described above and other tests we can differentiate two areas of increased acoustic pressure level in front of the barrier (shown in Fig. 4c). We can distinguish a narrower area whose width is close to a quarter of the wavelength of incident wave and a wider one embracing the region between the barrier and the place where equalization of the pressure of the waves occurs.

To illustrate the influence of the absorbing properties of the screen on the widths of the described areas, Fig. 5 shows the results of measurements made in a similar way to those described above when using three screens – one made

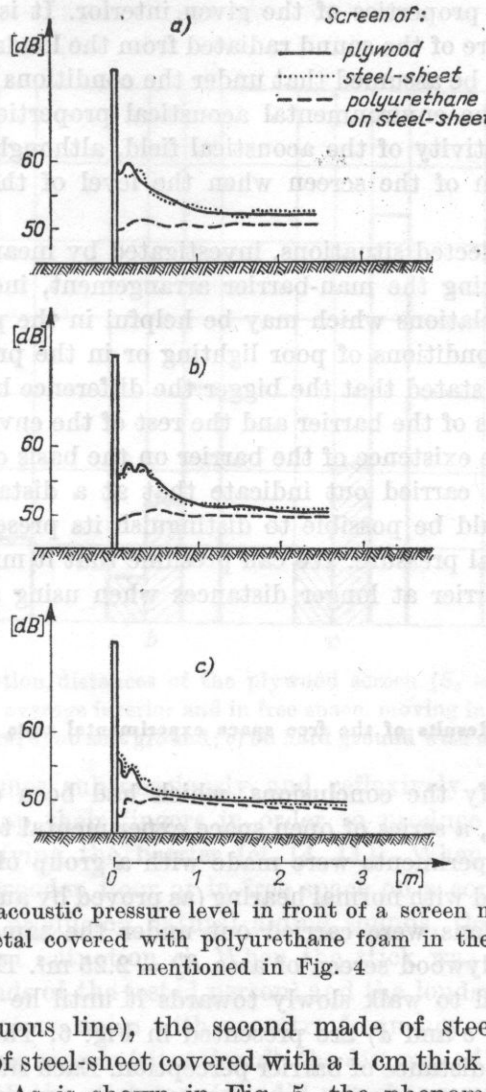


Fig. 5. Increase of the acoustic pressure level in front of a screen made of plywood of sheet metal and of sheet metal covered with polyurethane foam in the three situations *a*, *b*, *c* mentioned in Fig. 4

of plywood (continuous line), the second made of steel-sheet (dotted line) and the third made of steel-sheet covered with a 1 cm thick layer of polyurethane mats (dashed line). As is shown in Fig. 5, the phenomenon of the acoustic pressure increasing very close to the barrier is true only for the plywood and steel-sheet screens since it is barely noticeable when the screen is made of steel-sheet covered with polyurethane foam. It seems that the perception of a screen by means of the auditory organ should be influenced by the absorbing properties of the surface layer. For example, the presence of a wall "masked" by a curtain hanging on it, or a brick enclosure "masked" by grape leaves, might be more difficult to perceive.

It is worth-while to mention that, especially in a reverberant chamber but also in an average interior, the introduction of the screen covered with polyurethane mats (in comparison to the plywood and steel-sheet screens) changes the acoustic properties of the given interior. It is shown by decrease in the acoustic pressure of the sound radiated from the loudspeaker in the tested area. It can therefore be assumed that under the conditions discussed we should notice a change in the environmental acoustical properties and, particularly, a change in the directivity of the acoustical field, although it is more difficult to define the position of the screen when the level of the source of acoustic signals is the same.

The described selected situations, investigated by means of electroacoustic apparatus and imitating the man-barrier arrangement, indicate the existence of specific physical relations which may be helpful in the proper design of the environment under conditions of poor lighting or in the presence of the blind.

Hence, it can be stated that the bigger the difference between the acoustic absorption coefficients of the barrier and the rest of the environment, the easier it is to distinguish the existence of the barrier on the basis of acoustical stimuli.

The experiments carried out indicate that at a distance relatively close to the barrier it should be possible to distinguish its presence on the basis of an increased acoustical pressure. We can presume that it might also be possible to distinguish the barrier at longer distances when using aiding, intermittent sounds.

#### 4. Results of the free space experimental tests

In order to verify the conclusions, which had been drawn on the basis of the model research, a series of open space experimental tests were performed in free space. The experiments were made with a group of people born blind, 20-30 years of age, and with normal hearing (as proved by audiometer tests).

These investigations were carried out under the same conditions as the model tests, with a plywood screen of area $S_e = 2.25\ \mathrm{m}^2$. Each of the subjects, facing the screen, had to walk slowly towards it until he or she perceived it. Four situations (*a*, *b*, *c* and *d*) are presented in Fig. 6. The columns in Fig. 6 represent the average distance of barrier perception. Each situation was repeated in a reverberation chamber (columns dashed diagonally left), in an average interior (columns dashed diagonally right) and in free space (columns not dashed). In the situation *a*, when the subject was wearing ear-protectors, the protectors considerably limited the inflow of sound information of the presence of the screen. The distance of perception was relatively small and was identical with the region of increased acoustic pressure around the barrier. Generally, most of the tested subjects put the ear-protectors on unwillingly, complaining that they did not feel well wearing them.

The distance of perception increased when the subjects were not wearing ear-protectors and when they were walking on a soft carpet or in free space along a grassy path (situation *b*). The individuals tested (not obeying the instruc-

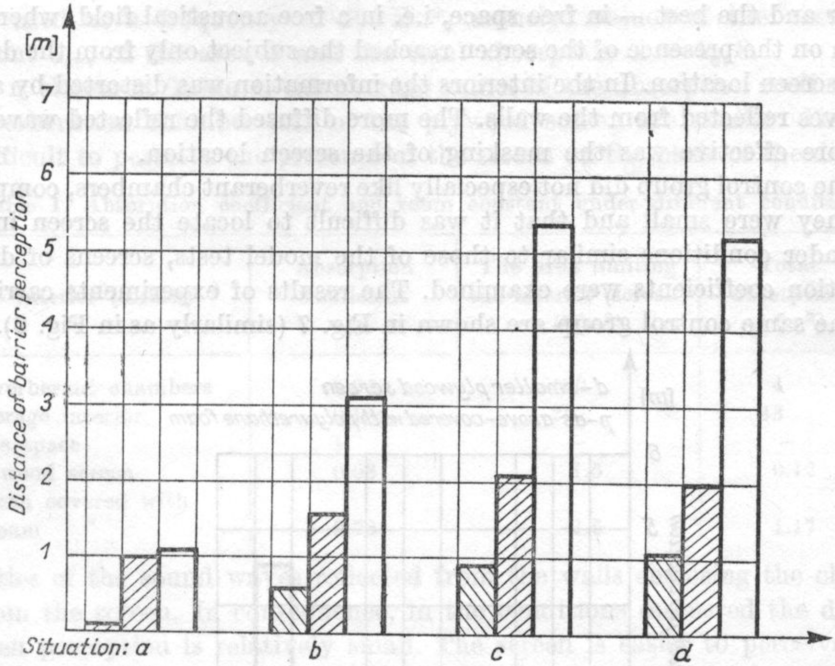


Fig. 6. Average perception distances of the plywood screen ($S_e$ = 2.25/cm²) in the reverberation chamber in an average interior and in free space, moving in the following situations: *a*) wearing ear-protectors; *b*) on soft ground; *c*) on hard ground with a stick; *d*) with a sonic aid

tions given) sometimes subconsciously and reflexively tried to shuffle their feet, murmur or snap their fingers in order to produce sounds which would help them in perceiving the barrier (cf. [4, 11]). When the subjects moved on the concrete or wooden floor or in free space on a concrete path with help of a walking stick, producing natural aiding sounds, the perception distance was *further increased* (*situation c*). *When the stick was replaced by a loudspeaker* (held in hands of the tested person) and the loudspeaker intermittently emitted one-third octave noise with a centre frequency of 4000 Hz, thus producing artificial aiding sounds (situation *d*), the distance of perception, compared to that obtained with the stick tapping, did not change significantly. This was perhaps due to the fact that the subjects were not used to carry a cumbersome, heavy loudspeaker, although some of them said they did not mind it nor found it helpful whereas others were satisfied with being able to direct the beam of sound waves aside. Most of the persons, however, complained that the signal of a frequency of 4000 Hz was unpleasant. Signals were said to be pleasant when limited to 400-2500 Hz.

In the two last situations (*c* and *d*), when the distance of barrier perception significantly increased, the effect was achieved by means of the sonic aid.

In each of the described situations the worst screen perception was observed in the reverberation chamber, better results were obtained in the average interior and the best — in free space, i.e. in a free acoustical field, where information on the presence of the screen reached the subject only from the direction of the screen location. In the interiors the information was distorted by acoustical waves reflected from the walls. The more diffused the reflected waves were, the more effective was the masking of the screen location.

The control group did not especially like reverberant chambers, complaining that they were small and that it was difficult to locate the screen in them.

Under conditions similar to those of the model tests, screens of different absorption coefficients were examined. The results of experiments carried out with the same control group are shown in Fig. 7 (similarly as in Fig. 6). Every

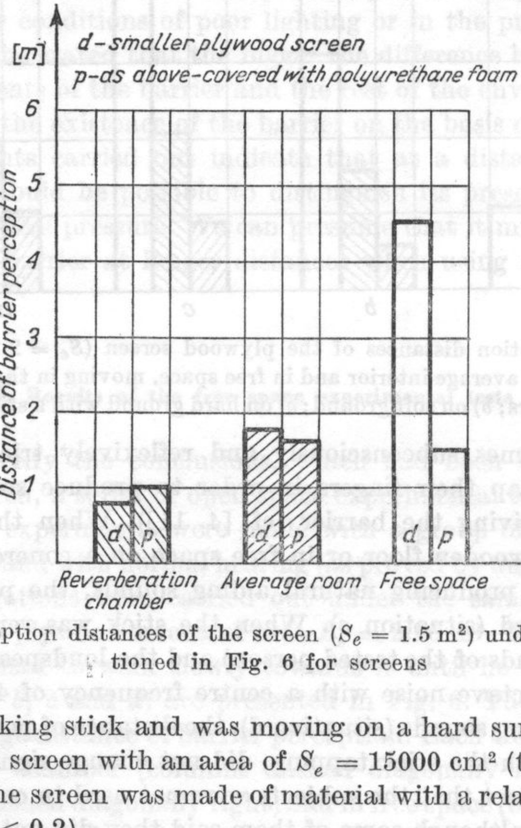


Fig. 7. Average perception distances of the screen ($S_e = 1.5$ m$^2$) under the conditions mentioned in Fig. 6 for screens

subject used a walking stick and was moving on a hard surface towards:

(a) A plywood screen with an area of $S_e = 15000$ cm$^2$ (the columns denoted by the letter *d*). The screen was made of material with a relatively small absorption coefficient ($\alpha < 0.2$).

(b) The same plywood screen covered with two layers of polyurethane foam (columns denoted by the letter *p*). Thus the screen had relatively big absorption ($\alpha > 0.4$). As is shown in Fig. 7, the distance of perception of the screen covered with foam is a little larger in the reverberation chamber, a little smaller in the average interior and significantly smaller in free space, compared to the distances for the uncovered screen.

To explain the described results we can compare the average values for the three characteristic interiors where the measurements were made and for the screens used at a frequency of 500 Hz*, namely: values of the absorption coefficient $a_{av}$, of the area $S$ and the total absorption $A = a_{av}S$.

As is shown in Table 1, the average values of the absorption coefficient of the reverberation chamber and of the plywood screen are similar. Therefore it is difficult to perceive the presence of the screen on the basis of the different

**Table 1.** Absorption coefficient and room constant under different conditions

| Interior (screen) | Absorption coefficient $a_{av}$ | The area limiting the interior (screen) $S$ [m²] | Total absorption $A$ [m²] |
|---|---|---|---|
| Reverberant chambers | 0.05 | 80 | 4 |
| Average interior | 0.18 | 267 | 48 |
| Free space | 1 | — | — |
| Plywood screen | 0.08 | 1.5 | 0.12 |
| Screen covered with foam | 0.78 | 1.5 | 1.17 |

intensities of the sound waves reflected from the walls enclosing the chamber and from the screen. In consequence, in the conditions discussed the distance of screen perception is relatively small. The screen is easier to perceive when it is covered with foam, a material with high absorption coefficient which lowers the intensity of the reflections from the screen surface, so that the acoustic field becomes inhomogeneous and shows clear directional characteristics.

The information that the screen is in front of the subject might additionally facilitate the definition of the distance of the screen.

The absorption coefficient of the average room differs from the absorption coefficient of both the plywood and the polyurethane foam. Hence the distances of perception of the screens covered with foam and without foam are relatively small.

In free space, however, the values of the absorption coefficient of the space and the absorption coefficient of the plywood screen are considerably different, and this facilitates good perception of the screen up to 4.5 m in front of it. When the screen is covered with foam (a material with a high absorption coefficient), the absorption coefficient of the screen becomes similar to that of the free space which, as is shown in Fig. 7, considerably decreases the distance of screen perception (to 1.5 m).

In summary, the efficiency of perception of a given barrier depended not only on the intensity of the reflected waves, i.e. on the increased acoustic pressure around the barrier, but also on the difference of the intensity of reflections from the barrier from that of its environment. Thus it was based on an auditory evaluation of the acoustical energy distribution of the waves reaching the subject from the point where he or she was standing.

* The spectrum of stick tapping (Fig. 2) had the highest values at about this frequency.

### 5. Results of experimental laboratory tests

The results previously discussed show good agreement between the model and free space investigations. However the relatively small number of persons tested and the relatively large differences of the results – especially in the experiments carried out in free space (the influence of changing weather conditions) – made it difficult for the given acoustical conditions to define precisely the dependence of the threshold distance of barrier perception and the size of the barrier.

To achieve the assumed objective a series of experimental tests with a group of 19 blind people were performed. A subject was seated in an interior well attenuated with curtains (at a frequency 500 Hz of $\alpha_{av} = 0.58$), and the screen, as in J. Kohler's tests, was moved noiselessly towards the subject's face, until the moment the person perceived it. During the tests square plywood screens of four different dimensions were used: $S_{e1} = 10000$ cm², $S_{e2} = 2500$ cm², $S_{e3} = 625$ cm² and $S_{e4} = 156.25$ cm². The direct results of the tests were converted to functional and statistical relations using a Hewlett-Packard computer, type HP 9810A.

On the basis of the tests performed, Fig. 8 presents the results of the dependence between the threshold distance of perception $R$ and the area of the

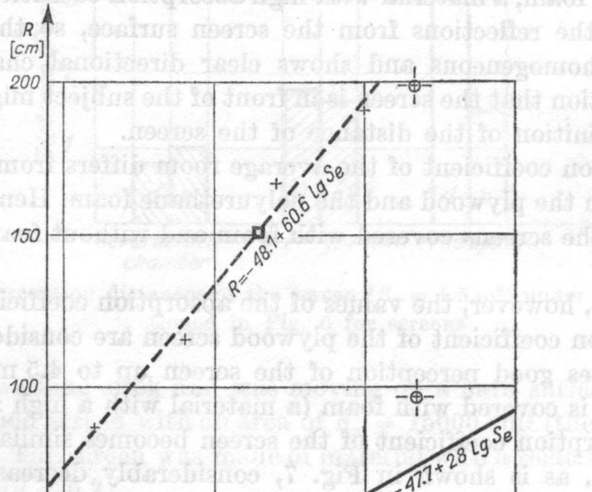


Fig. 8. Relationship between the threshold perception distance $R$ and the area $S_e$ of screens made od plywood with the sonic aid device (dashed line) and without it (continuous line)

screen $S_e$ for the situation without sonic aid (continuous line) and with intermittent sonic aid (dashed line) using a purpose-built "sound torch".

For the preliminary verification of the results presented in Fig. 8, the results of the investigations made by Kohler (cf. Fig. 1) who used a standard round screen of area $S_e = 1962\ \mathrm{cm}^2$ are marked with little squares, whereas our own results from the experimental free space investigations with a screen of area $S_e = 22500\ \mathrm{cm}^2$ (cf. Fig. 6) are marked with circles.

As is indicated in Fig. 8, the relations determined are linear. The linear correlation coefficients – without sonic aid $r_b = 0.975$ and with it $r_w = 0.991$ – were significant at the level $\alpha = 0.05$, and the regression equation for both the quoted relations is

$$R = R_0 + k \lg \frac{S_e}{S_0},$$

where $R$ is the distance of perception measured in cm, $R_0$ – the reference distance in cm, $k$ – the coefficient of the capability of perception, $S_e$ – the area of the screen in cm², and $S_0$ – the reference area equal to 1 cm².

The given equation indicates that the perception distance is proportional to the logarithm of the barrier area so that the Weber-Fechner law can be applied in this case, where the size of reaction is measured by the perception distance and the stimulus is represented by the sound waves reflected from the screen.

Investigations carried out in a similar way showed that a linear correlation coefficient for the discussed relationship was important at the level $\alpha = 0.05$ in other situations also, with only the distance $R_0$ and the coefficient $k$ changing.

Figure 9 presents the results of such investigations in the interiors attenuated with curtains (continuous lines – conditions $a$), after drawing the curtains together (dashed lines – conditions $b$) and after shielding the drawn curtains by metal sheets (dotted lines – conditions $c$), with sonic aid (a group of lines at the bottom of Fig. 9). The results indicate that when the dispersion of the acoustic field increased, the threshold perception distances of the screen localized with the help of the "sound torch" were smaller, implying that the perception was more difficult. The results are in agreement with the results of the field investigations, during which the longest perception distances (up to 5 m) were achieved in free space, i.e. in an unbounded acoustic field.

It is easy to notice, when comparing the free space and laboratory investigations, that the distances for the screens of corresponding areas were similar, irrespective of whether the screen was fixed and the person moved towards it or whether it was moved towards the sitting person. It may thus be concluded that the perception distance was determined by the similarity of the acoustical conditions – for screens of width 1 m the distance amounted to about 2 m.

A somewhat different course of events, presented in Fig. 9, occurred without a "sound torch", in conditions of relative quiet (a group of lines at the bottom

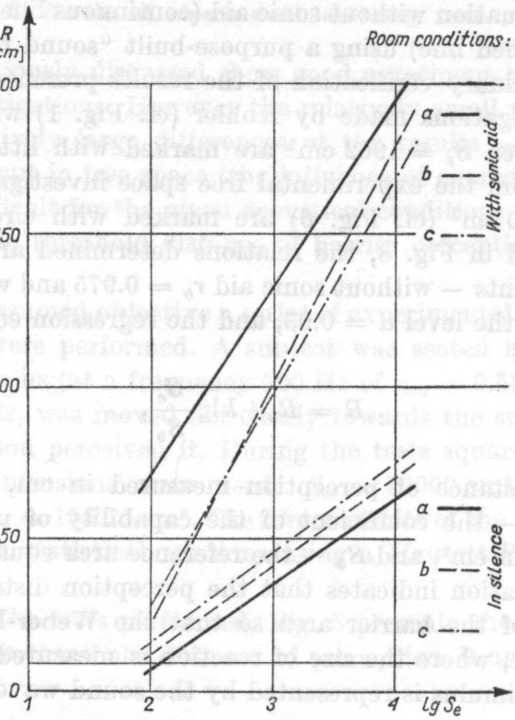


Fig. 9. Results of investigations as in Fig. 8: in silence and with sonic aid; *a* – in the interior with curtains, *b* – after drawing the curtains apart, and *c* – after shielding the curtains with sheet-metal

of Fig. 9). Under these conditions the threshold distances increased when the dispersion of the acoustic field increased. Hence dispersion of the field facilitated the perception of the screen.

Figure 10 shows the investigation results of the relation between threshold perception distance and the plywood screen area (the upper boundary of the area tatched in a given direction) and the plywood screen covered with polyurethane foam (the lower boundary of each area) in an interior with curtains (continuous line), after drawing the curtains together (dashed line) and after shielding the drawn curtains with metal sheets (dotted line). As is indicated in Fig. 10, the threshold distance of perception of a screen covered with polyurethane foam is always smaller than the threshold distance of perception of a screen of identical area but without the foam.

The biggest differences (giving the greatest decrease of perception distance) occur in the interior with curtains (*a*), because the absorption coefficient of the applied foam is similar to the absorption coefficient of the interior (curtains). Thus the screen with foam is more difficult to perceive on the background of curtains. When the curtains were drawn apart (*b*) and shielded with sheet (*c*), the differences were smaller. The difference of perception distances of the screens with and without the foam also decreased when the area of the screens decreased, i.e. when the acoustic absorptivity of their area decreased, which implies indirectly that the value of the stimulus needed for barrier perception also decreased.

Figure 11 presents the results of an investigation of the relation between the threshold distance of perception and the area of the plywood screen when

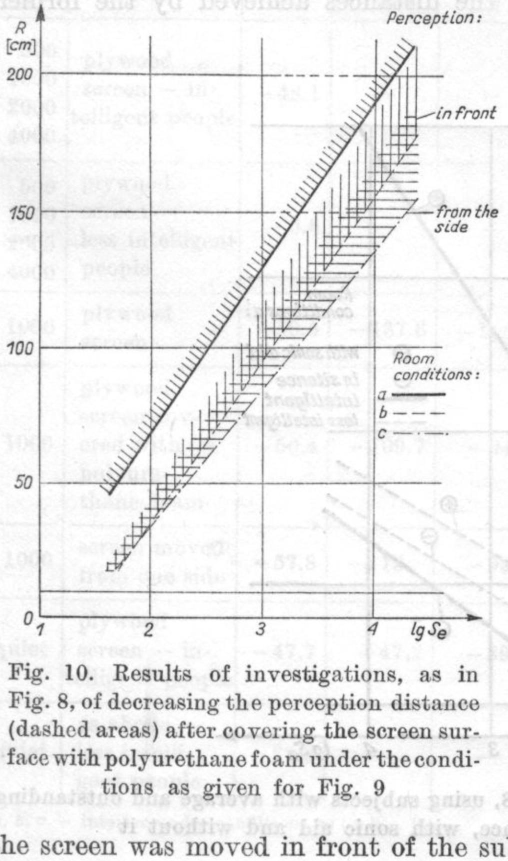


Fig. 10. Results of investigations, as in Fig. 8, of decreasing the perception distance (dashed areas) after covering the screen surface with polyurethane foam under the conditions as given for Fig. 9

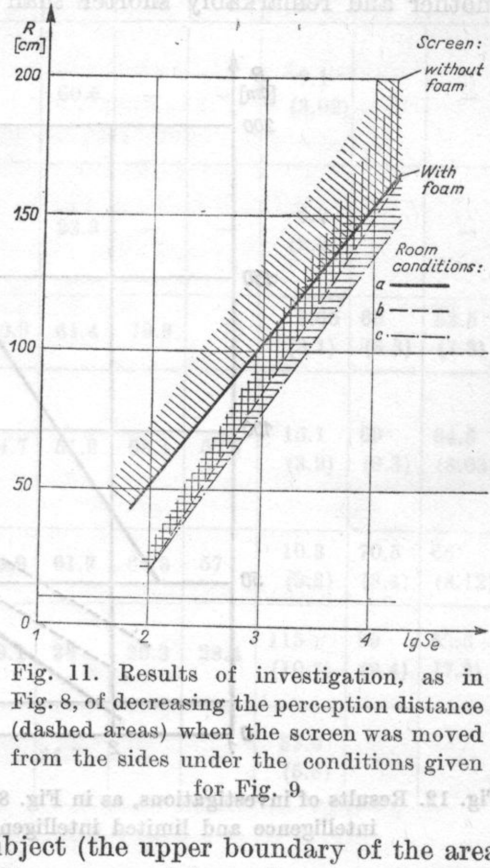


Fig. 11. Results of investigation, as in Fig. 8, of decreasing the perception distance (dashed areas) when the screen was moved from the sides under the conditions given for Fig. 9

the screen was moved in front of the subject (the upper boundary of the area hatched in a given direction) and when it was moved from the side of his left ear (the lower boundary of each area) under acoustic conditions *a*, *b* and *c* for the interior. It is easy to see that the differences in receiving information with a pair of ears and with only one ear become smaller when the absorption coefficient corresponding to the given conditions of the test is bigger, i.e. when less disturbing sounds reach the right ear facing the interior wall. It should be concluded therefore that in the free space, i.e. in a free acoustic field, there should not be any difference in the threshold distance of perceiving the screen with a pair of ears or with only one ear. Hence, it should be enough to receive the impression of the existence of the screen with only one ear. This may be significant for blind people with a unilateral deficiency of the auditory organ.

The results of measurements, which were made under acoustic conditions *a* with two groups of people — individuals of outstanding skills and intelligence (continuous line) and people with lower, limited intelligence (dashed line) — are shown in Fig. 12. As can be seen from Fig. 12, the perception distances of the screen with and without sonic aid for the latter group were similar to one another and remarkably shorter than the distances achieved by the former

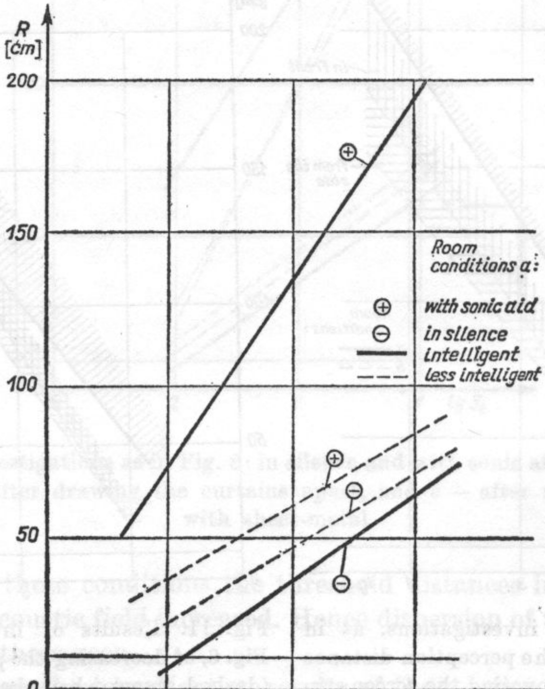


**Fig. 12. Results of investigations, as in Fig. 8, using subjects with average and outstanding intelligence and limited intelligence, with sonic aid and without it**

group with the help of a sonic aid. The results indicate that skills and intelligence might play a very important role in interpretation and association of acoustic information received through the senses in certain circumstances in free space.

As all relations presented in Figs. 8 to 12 may be described by the given regression equation, they can be compared with one another by comparing values of their components which correspond to the particular situations tested.

Table 2 presents (under measuring conditions *a*, *b* and *c*) values of the reference distance $R_0$, the perception coefficient $k$ and real threshold area of perception $S_{pr}$, i.e. the contact area of the screen and head, when $R = 10$ cm (the lengths of the sides of squares with such areas are given in brackets).

**Table 2.** Values of equation factors $R = R_0 + k\lg(S_e/S_0)$ corresponding to conditions of particular experiments

| Reinforcement frequency | Experiment conditions | $R_0$ [cm] | | | $k$ | | | $S_{pr}$ [cm$^2$] ($\sqrt{S_{pr}}$ [cm]) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *a* | *b* | *c* | *a* | *b* | *c* | *a* | *b* | *c* |
| 500<br>1000<br>2000<br>4000 | plywood screen – intelligent people | −48.1 | — | — | 60.6 | — | — | 9.1<br>(3.02) | — | — |
| 500<br>1000<br>2000<br>4000 | plywood screen – less intelligent people | −9.6 | — | — | 23.3 | — | — | 6.9<br>(2.6) | — | — |
| 1000 | plywood screen | −50.5 | −137.6 | −110.9 | 61.4 | 79.8 | 70 | 9.65<br>(3.1) | 69<br>(8.3) | 52.5<br>(7.3) |
| 1000 | plywood screen covered with polyurethane foam | −50.4 | −109.7 | −94.7 | 51.2 | 65.1 | 57.7 | 15.1<br>(3.9) | 69<br>(8.3) | 64.5<br>(8.03) |
| 1000 | screen moved from one side | −57.8 | −113 | −93.9 | 61.9 | 66.3 | 57 | 10.3<br>(3.2) | 70.5<br>(8.4) | 66<br>(8.12) |
| quiet | plywood screen – intelligent people | −47.7 | −47.2 | −39.1 | 28 | 29.3 | 28.4 | 115<br>(10.7) | 89<br>(9.4) | 53.5<br>(7.3) |
| quiet | as above – less intelligent people | −27.9 | — | — | 24.7 | — | — | 33.9<br>(5.8) | — | — |

*a, b, c* – interior under conditions as in Fig. 9.

As is indicated in Table 2, when using:

(a) plywood screens and a one-third octave aiding signal with a centre frequency of 1000 Hz,

(b) plywood screens and one-third octave aiding signal at centre frequencies of 500, 1000, 2000 and 4000 Hz,

(c) plywood screens covered with polyurethane foam and a 1000 Hz signal,

(d) a 1000 Hz signal and plywood screens moved towards the tested person from his or her sides,

(e) plywood screens moved from the front towards the tested person without any aiding signals, the values of the reference distance $R_0$ ranged between $-47.7$ and $-52.8$ cm, so the straight line in Fig. 8 was displaced $\pm 2.55$ cm in a parallel manner. We can presume therefore that this distance characterizes the conditions of the interior, and hence the characteristics of the acoustic field which occurs there.

However, the skill of perception, represented by the coefficient $k$, underwent significant changes. The best perception of the changes of the screen which was moved from the sides ($k = 61.9$) and front ($k = 60.6$) of the tested subject. The perception became worse after covering the plywood with polyurethane foam ($k = 51.2$) and the worst when perceiving the plywood screen without aiding sound, i.e. under the condition of silence ($k = 28$).

For the group of people with a relatively low level of intelligence (as assessed by tests) no essential differences in the perception of the screen with and without sonic aid were noticed. For this group, the value of the discussed coefficient was very low ($k_{av} = 24$). The results indicated that it was difficult for those people to interpret and associate the received sound information of the presence of the screen and the factual situation. Hence such tests may also indicate intelligence level of such people.

## 6. Conclusions

The discussed investigations show good agreement between the model, free space and laboratory tests, justifying the assertion that for blind people as well as for people with normal sight under conditions of poor lighting the basic source of information about barriers existing in their environment is audible acoustic vibration.

Impediment in the reception of these vibrations (e.g. by the use of ear-protectors, by attenuation of the steps of the subjects or by masking the area of the tests with disturbing sounds) substantially limited the efficiency of barrier perception.

In normal conditions the efficiency depended on the characteristics of the acoustical field. Particularly, with natural or artificial sonic aid, perception distances were the longer, the larger the area of acoustic field of the waves reflected from the barrier became. As the size of the area is defined by the difference between the measured acoustic pressure level and level which would occur in this place if there was only an acoustic field of freely propagating waves reflected from the screen, the perception of the screen was hindered by diffuse sound waves reaching the place from different sides. However, the perception was easier when the difference between the acoustic absorptivity of the barrier and of the environment was increased.

For the relationship between the perception distance and the area of the barrier the Weber-Fechner law can be applied.

**References**

[1] D. E. Aylor, *Perception of noise transmitted through barriers*, JASA, **59**, 2, 397-400 (1976).

[2] N. V. Clarke, *Obstacle detection with and without the aid of a directional noise generator*, Research Bull., **29**, 67-84 (1975).

[3] M. Cotzin, C. Ammous, K. Dallenbach, M. Supa, P. Worchel, *Facial vision*, Research Bull., **13**, 1-192 (1966).

[4] W. Dolański, *The sense of barrier – do the blind have it* (in Polish), PWN, Warszawa 1954, 246.

[5] M. Grzegorzewska, *Orientation of the blind in the free space*, in *Selected Papers* (in Polish), PWN, Warszawa 1964, 101-107.

[6] K. Klimasiński, *The role of imagination in the progress of thinking of blind children* (in Polish), Z. N. im. Ossolińskich PAN, Wrocław 1977, 103.

[7] J. Kohler, *Orientation by aural clues*, Research Bull., **4**, 14-50 (1964).

[8] P. Laws, *Entfernungshören und das Problem der Im-Kopf-Lokalisiertheit von Hörereignissen*, Acoustica, **29**, 5, 243-259 (1973).

[9] S. Miszczak, *Reflection disturbances in limited space* (in Polish), Zesz. Nauk. COBR Radia i Telewizji, Warszawa 1977, 294.

[10] W. Straszewicz, *Geometrical analysis of acoustic field characteristics in limited space*, Prace Nauk. Pol. Warsz., Elekt., **11**, 127 (1974).

[11] W. S. Swierłow, *Orientation of the blind in space* (in Polish), PZWS, Warszawa 1957, 210.

[12] J. S. Welch, *A psychoacoustic study of factors affecting human echolocation*, Research Bull., **4** (1964).

[13] *The selected problems from space orientation of the blind*, Zw. CRS, Warszawa 1974, t. I, 163, t. II, 222.

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# ACOUSTICAL INVESTIGATIONS OF THE EFFECT OF ADDITIVES ON THE ELASTIC PROPERTIES OF RAW KAOLIN*

EWA RYLL-NARDZEWSKA, JAN RYLL-NARDZEWSKI, ANDRZEJ KULIK

Department of Physical Acoustics, Institute of Fundamental Technological Research
00-049 Warszawa, ul. Świętokrzyska 21

and HENRYK PIECZAROWSKI

Institute of Glass and Ceramics, Pruszków Branch
05-800 Pruszków, ul. 17 Stycznia 77

To improve the mechanical strength of ceramic bodies various modifying agents are added in the raw state. The effect of the modifiers on the elastic properties of kaolin samples in the raw state and after firing was studied by acoustical methods: a resonance one and a pulse one. The results of the Young's modulus measurements obtained by the acoustical methods agree with the results obtained by other methods. The resonance methods have been found to be applicable for the examination of raw ceramic materials.

## 1. Introduction

The mechanical strength and plasticity of raw kaolin materials are often insufficient to form a sample into a desired shape. A low mechanical strength in the dried semi-finished products is undesirable since they are liable to be damaged during the subsequent production stages. To reduce the amount of damage, various modifying additives are added to the casting slip in order to improve the plasticity and mechanical strength of the semi-finished ceramic products.

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The paper presents the results of preliminary investigations of the effect of modifiers on the elastic properties of raw and fired kaolin. The investigations were performed using non-destructive acoustical methods: a pulse one [1] and a resonance one [2]. The measurements were performed at the Institute of Fundamental Technological Research of the Polish Academy of Sciences. The samples were prepared at the Institute of Glass and Ceramics at Pruszków.

## 2. Sample preparation

The samples to be tested were prepared from KOC kaolin of the following physical and chemical properties:

(a) chemical composition [%]

| | | | |
|---|---|---|---|
| firing losses | 11.54 | CaO | 0.36 |
| $SiO_2$ | 52.95 | MgO | 0.48 |
| $Al_2O_3$ | 33.15 | $Na_2O$ | 0.06 |
| $Fe_2O_3$ | 0.58 | $K_2O$ | 0.69 |
| $TiO_2$ | 0.49 | | |

(b) mineral composition [%]

| | |
|---|---|
| clay minerals | 83.28 |
| quartz | 12.04 |
| feldspar | 4.68 |

(c) particle-size analysis

| dimension [μm] | [%] | dimension [μm] | [%] |
|---|---|---|---|
| > 60 | 1 | 7-5 | 94.0 |
| 60-30 | 99 | 5-3 | 77.1 |
| 30-20 | 98.7 | 3-2 | 67.2 |
| 20-10 | 94.0 | > 2 | 56.7 |

The following modifiers were added to the KOC kaolin:

(a) Rokrysol WF-1 (coagulum manufactured by "Rokita", Brzeg),

(b) Glycocel (carboxymethylcellulose sodium),

(c) Ground bentonite (Milowice).

The casting slip was prepared by first pouring the modifier into water. After mixing, dry KOC kaolin was added, mixed for 2 hours with a stirrer and left to stand for 24 hours. The suspension thus prepared was mixed, separated from the sludge using No. 1 Sieve (3600 holes/cm$^2$) and filtered using a laboratory filter press operated at a pressure of $10^6$ N/m$^2$. The discs obtained were de-aerated in a vacuum press to homogenize the composition and next formed in the shape of samples in the same press. Next the samples were dried at 110°C to the surface-dry state. After drying, some of the samples were fired in a silit chamber kiln at 1250°C.

### 3. Measurement method

The investigated samples had the form of rods several centimeters long and a square cross-section of about 1 ×1 cm. Such a form for the samples made it possible to perform the measurements on both a concrete tester and a resonance elastometer. In some cases the form of the samples deviated markedly from the cubicoid. However, in spite of that, meaningful preliminary results were obtained on the effect of some additives on the mechanical properties of kaolin.

Raw samples were examined using a BI-8R-M66 Ultrasonic Concrete Tester manufactured by "Radiotechnika" (Wrocław). The measurements were performed using a transmission method at frequencies of 250 kHz and 500 kHz generated by G-250 and G-500 heads. The fired samples were tested using a Unipan 541 Material Tester and 100 kHz 100 LBN1 ultrasonic heads. The samples were coupled with transducers using "Epidian 5" epoxyadhesive.

In making the measurements by an acoustical resonance method a modern version of a resonancee elastometer, produced by IFTR PAS (Warsaw), was used [3]. This instrument is provided with capacitance type, contactless electroacoustic transducers and, therefore, the ceramic samples to be examined were covered with a thin silver layer. The layer is several micrometers thick and does not affect the measurement results. The samples excited in a longitudinal mode. The principle of the measurement is illustrated in Fig. 1. A transmitting electrode

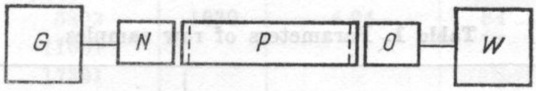


Fig. 1. Schematic diagram of the resonance elastometer
$G$ – generator, $N$ – transmitting transducer, $P$ – sample, $O$ – receiving transducer $W$ – amplifier

$N$ is biased with a D. C. voltage and fed with a signal from a variable frequency sine wave generator $G$. By varying the generator frequency $f$ one can excite successive resonances in the sample (cf. Table 3). The oscillations of the sample $P$ are detected by a receiving transducer $O$. Next the signal from the transducer is supplied to an amplifier $W$. The frequency of the resonance oscillation is measured with a digital frequencymeter built into the measuring system. The propagation velocity in the samples is determined from the relation

$$c = \lambda_n f_n, \tag{1}$$

where $c$ is the velocity of the elastic wave, $\lambda_n$ — the wavelength, and $f_n$ — the frequency of the $n$-th resonance.

The wavelength in the case of longitudinal modes is

$$\lambda_n = \frac{2}{n} l, \tag{2}$$

where $n$ is the order of the resonance, and $l$ — the sample length.

In the case of slender samples where the length $l$ is much greater than the transverse dimension and the latter is much smaller than the wavelength, the propagation velocity is expressed by the relation

$$C = \sqrt{\frac{E}{\varrho}}, \tag{3}$$

where $E$ is the Young's modulus, and $\varrho$ — the specific density of the material.

## 4. Results

The results of measurements and the parameters of samples are summarized in Tables 1-4 and in Figs. 2 and 3. The results obtained indicate that the additives denoted in the figures by $R$ (rokrysol), $G$ (glycocel) and $B$ (bentonite) affect the propagation velocity, and thus the Young's modulus, to various degrees. Agreement between the results obtained by the different measurement methods (the pulse method and the resonance method) is good.

The measurements performed on the raw samples reveal a dispersion of the ultrasonic wave velocity brought about by the unfavourable ratio of the transverse dimension of the samples and the wavelength [4]. The dispersion of the ultrasonic wave velocity observed is also due to the large inhomogeneity of the structure.

**Table 1.** Parameters of raw samples

| Sample No | Dimensions $l$ [m] | $b \times h$ [m] | $\varrho$ [kg·m$^{-3}$] | Materials |
|---|---|---|---|---|
| 1 | 0.1475 | 0.011 × 0.11 | 1480 | kaolin |
| | | | | kaolin |
| 2 | 0.1353 | 0.011 × 0.011 | 1610 | +0.2 % rokrysol |
| 3 | 0.1298 | 0.011 × 0.011 | 1500 | +0.5 % rokrysol |
| 4 | 0.1407 | 0.011 × 0.011 | 1430 | +1.0 % rokrysol |
| 5 | 0.1404 | 0.011 × 0.011 | 1520 | +0.2 % glycocel |
| 6 | 0.1525 | 0.011 × 0.011 | 1590 | +0.5 % glycocel |
| 7 | 0.1521 | 0.011 × 0.011 | 1510 | +1.0 % glycocel |
| 8 | 0.1187 | 0.011 × 0.011 | 1560 | +0.2 % bentonite |
| 9 | 0.1488 | 0.011 × 0.011 | 1540 | +0.5 % bentonite |
| 10 | 0.0947 | 0.011 × 0.011 | 1530 | +1.0 % bentonite |

**Table 2.** Parameters of fired samples (firing temperature $1523 \pm 20$ K)

| Sample No | Dimensions: $l$ [m] | Dimensions: $b \times h$ [m] | Dimensions: $\varrho$ [kg·m$^{-3}$] | Materials |
|---|---|---|---|---|
| 1 | 0.0547 | $0.0096 \times 0.0096$ | 2270 | kaolin |
| | | | | kaolin |
| 2 | 0.1260 | $0.0097 \times 0.0101$ | 1910 | +0.2 % rokrysol |
| 3 | 0.0708 | $0.0097 \times 0.0101$ | 1780 | +0.5 % rokrysol |
| 4 | 0.1283 | $0.0097 \times 0.0098$ | 1730 | +1.0 % rokrysol |
| 5 | 0.0588 | $0.0096 \times 0.0099$ | 1830 | +0.2 % glycocel |
| 6 | 0.1416 | $0.0099 \times 0.0099$ | 1830 | +0.5 % glycocel |
| 7 | 0.0826 | $0.0099 \times 0.0099$ | 1740 | +1.0 % glycocel |
| 8 | 0.1099 | $0.0099 \times 0.0100$ | 1840 | +0.2 % bentonite |
| 9 | 0.1388 | $0.0099 \times 0.0100$ | 1820 | +0.5 % bentonite |
| 10 | 0.0875 | $0.0099 \times 0.0100$ | 1910 | +1.0 % bentonite |

**Table 3.** The results of measurements on the raw samples

| Sample No | Resonance method: Resonance frequency [Hz] | Resonance method: $c^*_{av}$ [m/s] | Pulse method $f = 250$ kHz: $E$ [N/m$^2$]·10$^9$ | Pulse method: $\tau$ [$\mu$s] | Pulse method: $c$ [m/s] |
|---|---|---|---|---|---|
| 1 | 5018<br>10072<br>15106 | 1485 | 3.26 | 98 | 1505 |
| 2 | 6406<br>12728<br>19078 | 1725 | 4.80 | 78 | 1735 |
| 3 | 5885<br>11798<br>17636 | 1530 | 3.51 | 50 | 1550 |
| 4 | 5229<br>10452<br>15724 | 1470 | 3.10 | 94 | 1495 |
| 5 | 5803<br>11661<br>17391 | 1630 | 4.04 | 84 | 1670 |
| 6 | 5964<br>11904<br>17845 | 1815 | 5.24 | 82 | 1860 |
| 7 | 5967<br>11841<br>17755 | 1805 | 4.92 | 83 | 1830 |
| 8 | 6293<br>12437<br>18744 | 1485 | 3.44 | 76 | 1560 |
| 9 | 5434<br>10805<br>16230 | 1605 | 3.90 | 90 | 1655 |
| 10 | 8970<br>17935<br>26679 | 1695 | 4.39 | 56 | 1690 |

* $c_{av}$ was determined as the mean value for the three modes

**Table 4.** The results of measurements on the fired samples (firing temperature 1523 ± 20 K). The results were obtained by the pulse method at a frequency of 100 kHz

| Sample No | $\tau$ [μs] | $c$ [m/s] | $E$ [N/m²]·10⁹ |
|---|---|---|---|
| 1 | 12.5 | 4370 | 43.3 |
| 2 | 27.9 | 4515 | 38.9 |
| 3 | 16.4 | 4315 | 33.1 |
| 4 | 31.2 | 4110 | 29.2 |
| 5 | 13.4 | 4375 | 35.2 |
| 6 | 32.1 | 4410 | 35.6 |
| 7 | 19.6 | 4225 | 31.1 |
| 8 | 26.5 | 4145 | 31.6 |
| 9 | 33.7 | 4120 | 30.9 |
| 10 | 20.0 | 4310 | 35.5 |

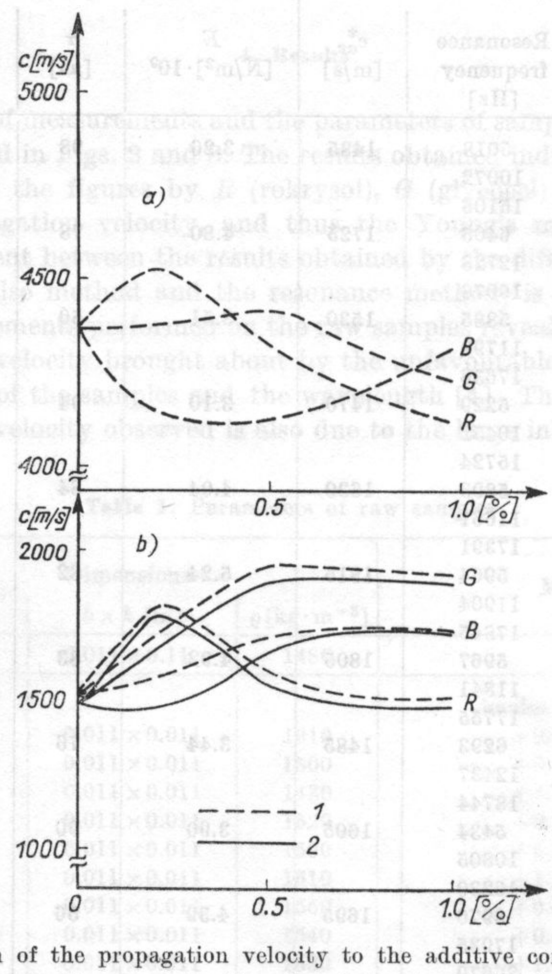


Fig. 2. The relation of the propagation velocity to the additive concentration in kaolin
a) fired samples, b) raw samples; $R$ – rokrysol, $G$ – glycocel, $B$ – bentonite

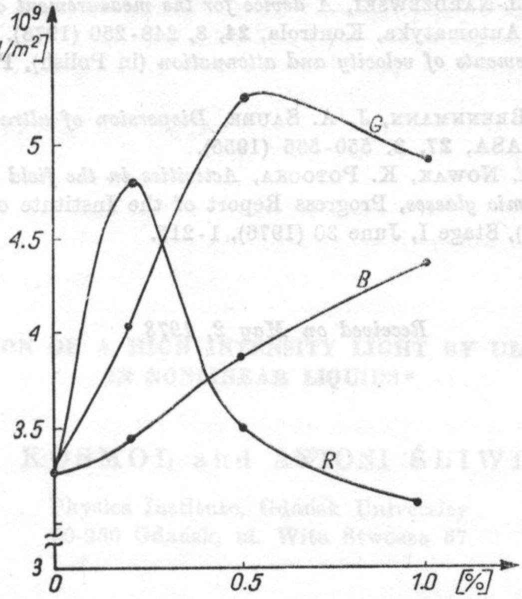


Fig. 3. The relation of value of Young's modulus $E$ to the amount of modifier in the raw samples, determined by the acoustic resonance method
$R$ – rokrysol, $G$ – glycocel, $B$ – bentonite

In the resonance method the measurements are performed in a range in which the transverse dimension of the sample is much smaller than the wavelength and, therefore, one can assume that the wave propagation in the sample is of the rod type [3].

#### 4. Conclusions

The investigations performed indicate that acoustical methods and, in particular, the acoustic resonance method can be used for the determintation of the strength characteristics of ceramic clay materials in the raw state.

The results of the Young modulus mesaurements obtained by acoustical methods agree with the results of plasticity measurements performed in the Laboratory of Rheological Investigations of the Institute of Glass and Ceramics, Pruszków Branch [6].

#### References


[1] L. Filipczyński, Z. Pawłowski, J. Wehr, *Ultrasonic methods of material testing* (in Polish), PWT, Warszawa 1959, 76-105.

[2] J. Ryll-Nardzewski, *Reasonance elastometer, A set for the investigation of elasticity constants* (in Polish), Pomiary, Automatyka, Kontrola, **15**, 5, 207-210 (1969).

[3] A. Kulik, J. Ryll-Nardzewski, *A device for the measurement of elastic properties* (in Polish), Pomiary, Automatyka, Kontrola, **24**, 8, 248-250 (1978).

[4] J. Wehr, *Measurements of velocity and attenuation* (in Polish), PWN, Warszawa 1972, 47-54.

[5] L. Y. Tu, J. N. Brennmann, J. A. Sauer, *Dispersion of ultrasonic pulse velocity in cylindrical rods*, JASA, **27**, 3, 550-555 (1955).

[6] B. Kaczmarek, A. Nowak, K. Potocka, *Activities in the field of the rheology of raw materials and ceramic glasses*, Progress Report of the Institute of Glass and Ceramics (Pruszków Branch), Stage I, June 30 (1976), 1-215.

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4, 2, 117-130 (1979)

# DIFFRACTION OF A HIGH INTENSITY LIGHT BY ULTRASOUND IN NONLINEAR LIQUIDS*

MAREK KOSMOL and ANTONI ŚLIWIŃSKI

Physics Institute, Gdańsk University
80-950 Gdańsk, ul. Wita Stwosza 57

The paper presents some experimental and theoretical results obtained in the examination of high power light diffraction ($Nd^{3+}$ laser) by ultrasound (4 MHz) in nonlinear liquids. The diffraction patterns differ from the usual results for the light of small intensity. The distributions of the light can be explained by the influence of the optical nonlinearity of the medium (3-rd harmonic light generation and frequency mixing). The theoretical description proposed appears to explain the experimental results.

## 1. Introduction

Since coherent sources of light of high intensity became available, many experimental and theoretical papers have appeared on the nonlinear effects accompanying light propagation in material media. One of the phenomena, the diffraction of high intensity light by ultrasound was first examined in 1971 [8] and has been further investigated [9, 11, 12, 13]. This paper gives a review of the topic, including some new results and theoretical explanations. We start with a description of some elements of nonlinear optics required for further acousto-optic considerations.

The intensities of classical sources of light are small (0.1-100 W/cm²), but in laser sources intensities from some mW/cm² to some decades of GW/cm² [14] are available experimentally, depending on the kind of the laser device used. The electric field intensities of the optical vector corresponding to such

* This work was carried out in the MR.I.24 research programme.

light energy densities are $10^5$ V/cm to $10^8$ V/cm (by comparison, the electric field intensity of sun light is barely 10 V/cm) [10]. Such high electric field strengths are comparable to the electric fields existing in the interior of matter (e.g. the electric field from the nucleus on an electron in a hydrogen atom is of the order of $10^9$ V/cm, internal fields in crystals are of the order of $10^8$ V/cm, in liquids $10^5$-$10^7$ V/cm).

Thus, one can see that in the strong electric fields created with laser beams some properties of atoms and molecules and, consequently, of the whole material media can be changed during the propagation of light through them. Under such conditions the electric polarization of a medium is no longer proportional to $\boldsymbol{E}$, i.e. the relation

$$\boldsymbol{P}_L(\boldsymbol{r}, t) = \chi_1^e \boldsymbol{E}(\boldsymbol{r}, t) \tag{1}$$

is not adequate for a description of physical phenomena. An additional nonlinear polarization $\boldsymbol{P}_{NL}$ occurs and

$$\boldsymbol{P}_{NL}(\boldsymbol{r}, t) = \chi_2^e : \boldsymbol{E}^2(\boldsymbol{r}, t) + \chi_3^e : \boldsymbol{E}^3(\boldsymbol{r}, t) + \ldots, \tag{2}$$

where $\chi_1^e$, $\chi_2^e$ and $\chi_3^e$ are tensors of the electric susceptibility of the first, second and third rank, respectively.

In linear optics the refractive index of a medium for light has a constant value, and in the range of linear phenomena the principle of superposition is valid, i.e. no interaction among various light beams takes place. The electric fields of very intense light cause changes in the refractive index of the medium and nonlinear optical effects occur. In this case the principle of superposition is not valid: the electric fields of different light beams interact with one another, and they also interact with the material medium in which they are propagating (the nonlinear polarization mentioned above).

A special effect in nonlinear phenomena consists in the generation of higher harmonics of $2\omega, 3\omega, \ldots$, where $\omega$ is the frequency of the fundamental component. These harmonics correspond to the consecutive orders of nonlinearity of the electric polarization of the medium in formula (2).

It may be shown [10] that the tensor of the electric susceptibility of the second rank, $\chi_2^e$, has components different from zero only in the case of crystals belonging to the crystallographic classes which have no centre of symmetry. For crystals possessing a centre of symmetry and for isotropic bodies the second order nonlinear phenomena do not occur, but at very high light intensities the cubic nonlinearity plays a dominant role. For the last case one can write the dependence of polarization on the electric field as follows:

$$\boldsymbol{P} = \chi_1^e \cdot \boldsymbol{E}(\boldsymbol{r}, t) + \chi_3^e : \boldsymbol{E}^3(\boldsymbol{r}, t) + \ldots \tag{3}$$

For isotropic media this gives

$$P = \alpha E + \beta E^3 + \ldots, \tag{4}$$

where $\alpha$ and $\beta$ denote coefficients corresponding to $\chi_1^e$ and $\chi_2^e$ for isotropic media.

Thus, in a medium with 3-rd order nonlinearity the 3-rd harmonic of light can be generated during propagation. This results from the following consideration.

If the original beam has the form

$$\boldsymbol{E} = \boldsymbol{E}_0 \cos(\boldsymbol{kr} - \omega t), \tag{5}$$

where $\boldsymbol{E}_0$ is the amplitude of light, $\boldsymbol{k}$ – wave vector, $\boldsymbol{r}$ – vector of coordinates, $\omega$ – fundamental frequency, $t$ – time, then, due to the nonlinear interaction, the 3-rd order polarization will occur:

$$\boldsymbol{P}^{(3)} = \beta \boldsymbol{E}_0^3 \cos^3(\boldsymbol{kr} - \omega t). \tag{6}$$

Formula (6) may be written as the sum of two terms (in view of the relation $\cos^3 x = \frac{1}{4}(3\cos x + \cos 3x)$):

$$\boldsymbol{P}^{(3)} = \tfrac{3}{4}\beta \boldsymbol{E}_0^3 \cos(\boldsymbol{kr} - \omega t) + \tfrac{1}{4}\beta \boldsymbol{E}_0^3 \cos(3\boldsymbol{kr} - 3\omega t). \tag{7}$$

Using this formula one can estimate the change in refractive index introduced by the nonlinear polarization.

Generally, for the electric induction $D$ in the medium, we have

$$D = D_0 + P, \tag{8}$$

where $D_0 = \varepsilon_0 \boldsymbol{E}$ is the electric induction in a vacuum, $\varepsilon_0$ – permeability of a vacuum. From the definition one can write

$$\varepsilon_E \varepsilon_0 = \frac{dD}{dE}, \tag{9}$$

where $\varepsilon_E$ is the electric permeability which is a function of the electric field $E$. From (9), using (8) and (7), we get

$$n_E = n + \gamma E^2 \quad \text{or} \quad \Delta n = n_E - n = \gamma E^2, \tag{10}$$

where $\gamma = 3\beta/2\varepsilon_0 n$, $n = \sqrt{\varepsilon}$, $n_E = \sqrt{\varepsilon_E}$.

Thus the variation of refractive index due to the 3-rd harmonic is proportional to the squared amplitude of the fundamental. $\gamma$ is the characteristic constant responsible for the 3-rd order nonlinear polarization of the medium.

In the literature [9] the electrostriction of the medium is considered as the main reason for the nonlinear polarization and the coefficient $\gamma$ is expressed by the formula

$$\gamma = \frac{\varrho(\partial\varepsilon/\partial\varrho)_s \beta_s}{16\pi n_0}, \tag{11}$$

where $\varrho$ is the density, $\beta_s$ – the adiabatic compressibility, $\varepsilon$ – the electric permeability, $n$ – the refractive index of the undisturbed medium.

The quantities $\beta_s$ and $\varrho(\partial\varepsilon/\partial\varrho)_s$ are known for many substances and it was possible to calculate $\Delta n$ from formulae (10) and (11) for a chosen value of $E$. For a laser beam of power density $10^{12}$ W/cm², corresponding to $E = 2.7\cdot 10^7$ V/m, $\gamma$ and $\Delta n$ were calculated for a few liquids. Results are presented in paper [9] (see Table 1).

**Table 1**

| Substance | $n_0$ | $\varrho\cdot 10^3$ [kg/m³] | $\varrho(\partial\varepsilon/\partial\varrho)_s$ | $\beta_s\cdot 10^{13}$ [N/m²] | $\gamma\cdot 10^{20}$ [m²/V²] | $\Delta n\cdot 10^6$ |
|---|---|---|---|---|---|---|
| water | 1.3397[c] | 0.997[c] | 0.82[c] | 45.7[c] | 0.06 | 0.44 (0.38)[a] |
| carbon disulfide | 1.674[a] | 1.262[a] | 2.39[a] | 49.5[a] | 0.42 | 3.19 (2.91)[a] |
| benzene | 1.522[a] | 0.879[a] | 1.56[a] | 52.6[a] | 0.21 | 1.61 (0.04)[a] |
| carbon tetrachloride | 1.4720[c] | 1.595[c] | 1.15[a] | 58.0[c] | 0.14 | 0.99 |
| toluene | 1.5130[c] | 0.865[c] | 1.60[c] | 70.0[c] | 0.30 | 2.24 |
| ethyl alcohol | 1.369[c] | 0.789[c] | 0.95[c] | 92.8[c] | 0.15 | 1.14 |
| methyl alcohol | 1.338[c] | 0.791[c] | 0.82[c] | 100.5[c] | 0.14 | 0.95 |
| nitrobenzene | 1.553[b] | 1.203[a] | 40.0[a] | 34.8[a] | 2.21 | 670.0 |

*a* – [22], *b* – [23], *c* – [24]

### 2. Conditions for the third harmonic generation

The conditions required for the 3-rd harmonic generation [1] are the following:

a. The isotropic medium must be nonactive optically.

b. The electronic absorption of light must be absent or very small.

c. Performance of phase matching conditions must be present, i.e. the value of the phase velocity for the fundamental and the 3-rd harmonic of light in the medium must be the same, i.e. $\Delta k \approx 0$, in the relation

$$\Delta k = k_{3\omega} - 3k_{\omega} = \frac{3\omega}{c}(n_{3\omega} - n_{\omega}), \tag{12}$$

where $n_{3\omega}$, $n_{\omega}$ and $k_{3\omega}$, $k_{\omega}$ are the refractive indices and the wave numbers for the 3-rd harmonic and the fundamental one, respectively.

d. There must be an interaction along the coherence length:

$$l_s = \frac{\pi}{\Delta k}.$$

The formula for the intensity of the 3-rd harmonic of light is as follows [1]:

$$I(3\omega, l) = (\chi_{xxyy}^{3\omega})^2 \left\{ \frac{r\sin\frac{1}{2}l\Delta k}{\frac{1}{2}\Delta k} \right\}^2 I^3. \tag{14}$$

The first experimental steps in obtaining the 3-rd harmonic generation were performed by TERHUME et al. [15] in 1962. They used a ruby laser and a crystal of calcite. In 1969 GOLBERG and SCHUUR [7] examined the 3-rd harmonic generation in liquids, particularly in liquid crystals. The change in the refractive index and other interesting nonlinear effects were described by BUCKINGHAM [4] and BLOMBERGEN [3].

Condition b may be achieved by introducing an abnormal dispersion for the frequency range between the fundamental and harmonic [6] as was first experimentally realized by BEY et al. [2] (see Fig. 3).

The first calculations on the diffraction of intense light generating the 3-rd harmonic by ultrasound were performed in 1969-72 by JÓZEFOWSKA et al. [8, 9] (see Figs. 1 and 2). The amplitude distributions are described by the formulae

$$E(\omega, l, x, t) = \exp(2\pi i\nu t)\sum_{k=-\infty}^{+\infty} \Phi_k^0(a)\exp\left(-i\frac{n_0}{\delta n}a\right)\exp\left(2\pi ik\frac{x}{\Lambda}\right)\times$$

$$\times\exp(-2\pi iNt)+\exp[3(2\pi i\nu t)]\sum_{k'=-\infty}^{+\infty}[\Phi_{k'}^1(3a)+A_{k'}(a)]\times \qquad (15)$$

$$\times\exp\left[-i\frac{n_0}{\delta n}\cdot 3a\right]\exp\left(2\pi ik'\frac{x}{\Lambda}\right)\exp(-2\pi iNt) \quad \text{for } k'=3k,$$

where $\nu$ and $\lambda$ are the frequency and wavelength of light, respectively, $N$ and $\Lambda$ are the frequency and wavelength of the ultrasound, $n_0$ is the optical refractive index for the undisturbed medium, $\delta n$ is the amplitude of variation in the index due to the ultrasound and is proportional to the acoustic pressure of the wave, $t$ is the time, $\Phi_k^0(a)$ are Bessel functions of argument $a = 2\pi\delta nl/\lambda$, $\Phi_{k'}^1(3a)$ are Bessel functions of argument $3a$, and $A_{k'}$ are complicated linear combinations of the products of Bessel functions of different orders [8].

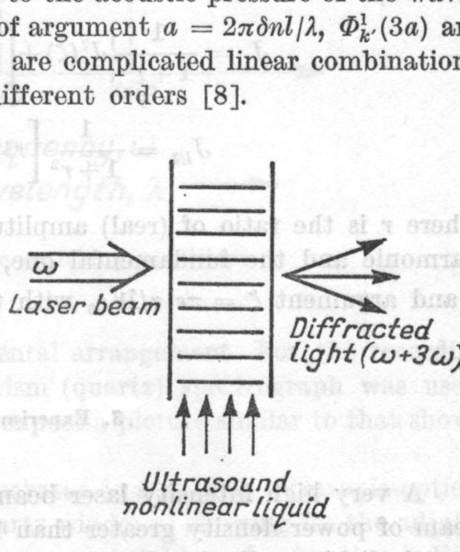


Fig. 1. Geometrical situation of the diffraction of light by ultrasound generating the 3-rd harmonic in a nonlinear liquid medium

The light intensity distributions are given by

$$J_0 = (1-r)^2 \Phi_0 \Phi^* + E^2 r^2 [\Phi_0(3a) + A_0(a)][\Phi_0(3a) + A_0(a)]^* \tag{16}$$

(* denotes the complex conjugate) and for the 3-rd harmonic for the orders $k' = \pm 1, \pm 2, \ldots$ we have

$$J_{\pm 1} = E^2 r^2 [\Phi_{\pm 1}(3a) + A_{\pm 1}(a)][\Phi_{\pm 1}(3a) + A_{\pm 1}(a)]^*. \tag{17}$$

Some experimental work on this problem was performed by KOSMOL [11].

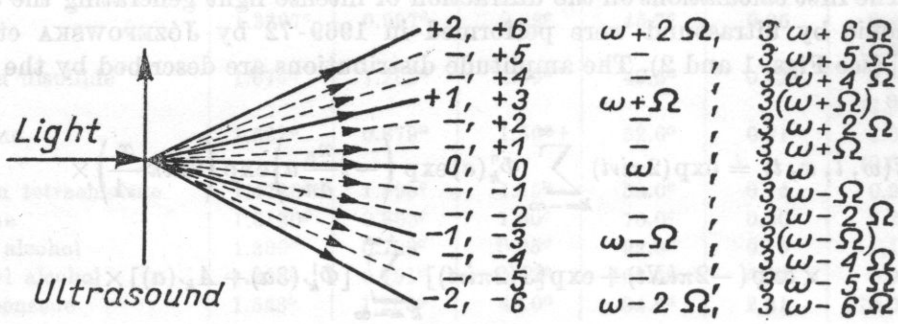


Fig. 2. Spectrum of diffraction pattern in the phenomenon of the diffraction of light by ultrasound in a nonlinear liquid medium

Lastly, MERTENS and LEROY [13] recalculated the results of Józefowska et al. and obtained an exact solution using a generating function method which gave simple expressions for the intensities of the fringes in the diffraction pattern,

$$J_j = \frac{1}{1+r^2}\left\{J_j^2(\zeta) + \left[r^2 + \frac{9\beta^2\zeta^2}{\varepsilon^2(1+r^2)^2}\right] J_{3j}^2(3\zeta)\right\}, \tag{18}$$

$$J_{l/3} = \frac{1}{1+r^2}\left[r^2 + \frac{9\beta^2\zeta^2}{\varepsilon_1^2(1+r^2)^2}\right] J_l^2(3\zeta), \tag{19}$$

where $r$ is the ratio of (real) amplitudes of the light for the generated third harmonic and the fundamental one, and $J_j(\zeta)$ is a Bessel function of order $j$ and argument $\zeta = \pi\varepsilon_1 z / \lambda\sqrt{\varepsilon_0}$ with the condition $l \neq 3j$.

### 3. Experimental conditions

A very high intensity laser beam is required in the experiments. A laser beam of power density greater than $10^{12}$ W/m² was used, corresponding to an electric field amplitude of the light wave in the beam of $2.7 \cdot 10^7$ V/m. As our first investigations with a ruby laser $\lambda = 6943$ Å, and the 3-rd harmonic at about 2300 Å, were not satisfactory, we used an Nd-glass laser with $\lambda = 10600$ Å (and the 3-rd harmonic about 35300 Å) which proved more convenient for the experiment. Using a switching cell with an Eastman Kodak Q-switch 9860, we obtained gigantic laser pulses of tens of nanoseconds duration.

Material suitable for the 3-rd harmonic generation must be relatively transparent both for the fundamental and for the 3-rd harmonic. The generation takes place along the coherence length of the light beam $l_s$, given by the formula (derived from [12] and [13])

$$l_s = \frac{\lambda_\omega}{6\,(n_{3\omega} - n_\omega)}, \tag{20}$$

where $\lambda_\omega$ is the wavelength for the fundamental, and $n_{3\omega}$ and $n_\omega$ are the refractive indices of the fundamental and the 3-rd harmonic, respectively.

Conditions for matching after FRANKEN et al. [6] are presented in Fig. 3. An ultrasonic wave of 4 MHz was used in the experiments.

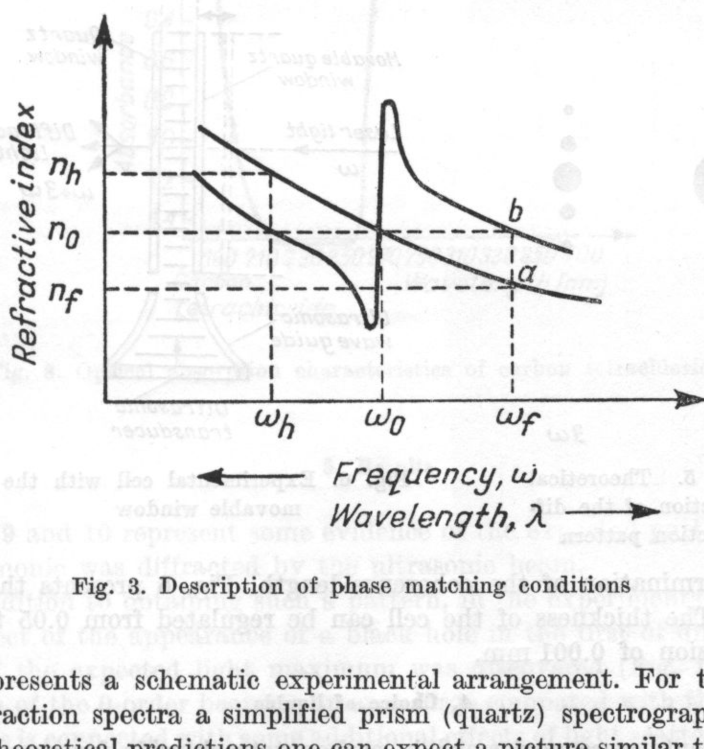


Fig. 3. Description of phase matching conditions

Fig. 4 presents a schematic experimental arrangement. For the recording of the diffraction spectra a simplified prism (quartz) spectrograph was used. From the theoretical predictions one can expect a picture similar to that shown in Fig. 5.

The most important part of the apparatus is a special ultrasonic-optical cell which has parallel movable walls (quartz windows) allowing for the adjustment of the interaction distance for the proper matching of refractive indices

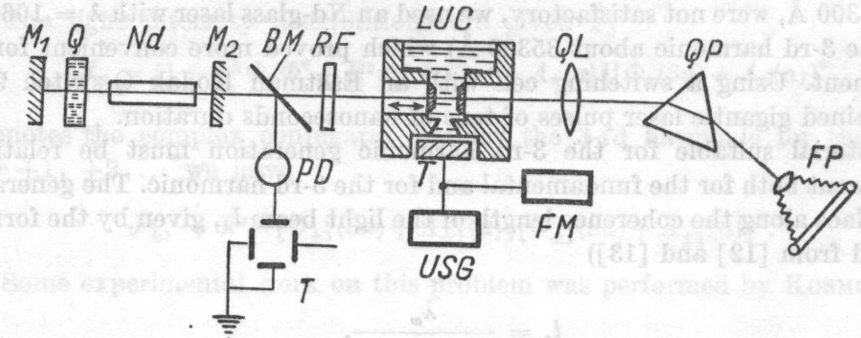


Fig. 4. Experimental arrangement

$M_1$ – mirror $R = 100\,\%$ $M_2$ – mirror $R = 50\,\%$, $Q$ – $Q$-switcher, $Nd$ – $Nd^{3+}$ glass laser, $BM$ – beam-splitter, $PD$ – photodiode, $RF$ – red filter $LUC$ – light ultrasonic cell with liquid, $T$ – piezoelectric transducer, $USG$ – ultrasonic supply generator, $FM$ – frequency meter, $QL$ – quartz lens, $QP$ – quartz prism spectrograph, $FP$ – photographic plate

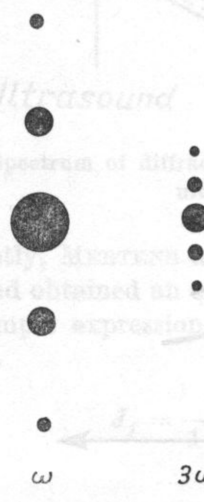


Fig. 5. Theoretical prediction of the diffraction pattern

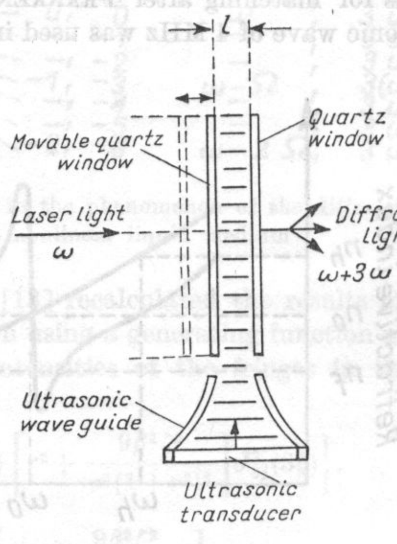


Fig. 6. Experimental cell with the movable window

and for determination of the coherence length. Fig. 6 presents the structure of the cell. The thickness of the cell can be regulated from 0.05 to 6.27 mm with a precision of 0.001 mm.

### 4. Choice of liquids

Experiments were performed in carbon tetrachloride for comparison wih the calculations in [9] and in a 130 g/liter solution of methylene blue (the substance used in [5]) in methyl alcohol. Figs. 7 and 8 show the absorption characteristics for these substances, obtained with a Carl Zeiss Jena Specord 71 and 72 IR.

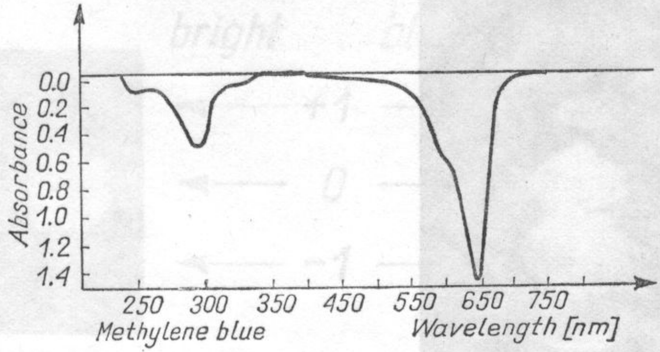


Fig. 7. Optical absorption characteristics of methylene blue

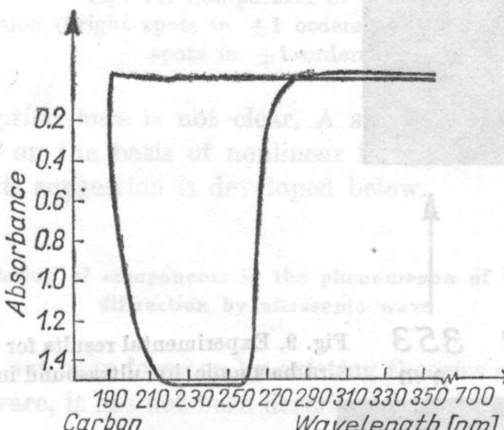


Fig. 8. Optical absorption characteristics of carbon tetrachloride

## 5. Results

Figs. 9 and 10 represent some evidence of the expected pattern, where the third harmonic was diffracted by the ultrasonic beam.

In addition to obtaining such a pattern, in the experiments of M. Kosmol a new effect of the appearance of a black hole in the first of diffraction order instead of the expected light maximum was discovered (Fig. 11, a, b). (The diffraction of the 0-order beam to an area large compared with those of the ±1 order spots is connected with some additional effects of light scattering associated with obtaining a letter collimation of pulse beam with a duration of about 40 ns.)

The situation is closely analogous to the observation of absorption lines in a light spectrum, e.g. Fraunhofer lines in the spectrum of the sun. The reason

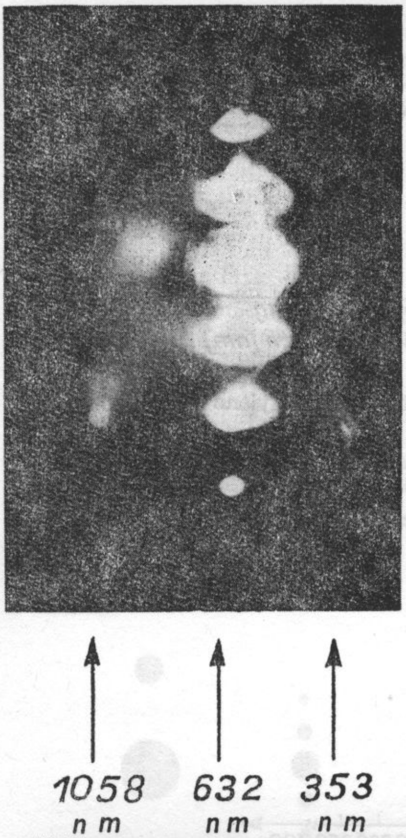


Fig. 9. Experimental results for the diffraction of the 3-rd harmonic by ultrasound in carbon tetrachloride

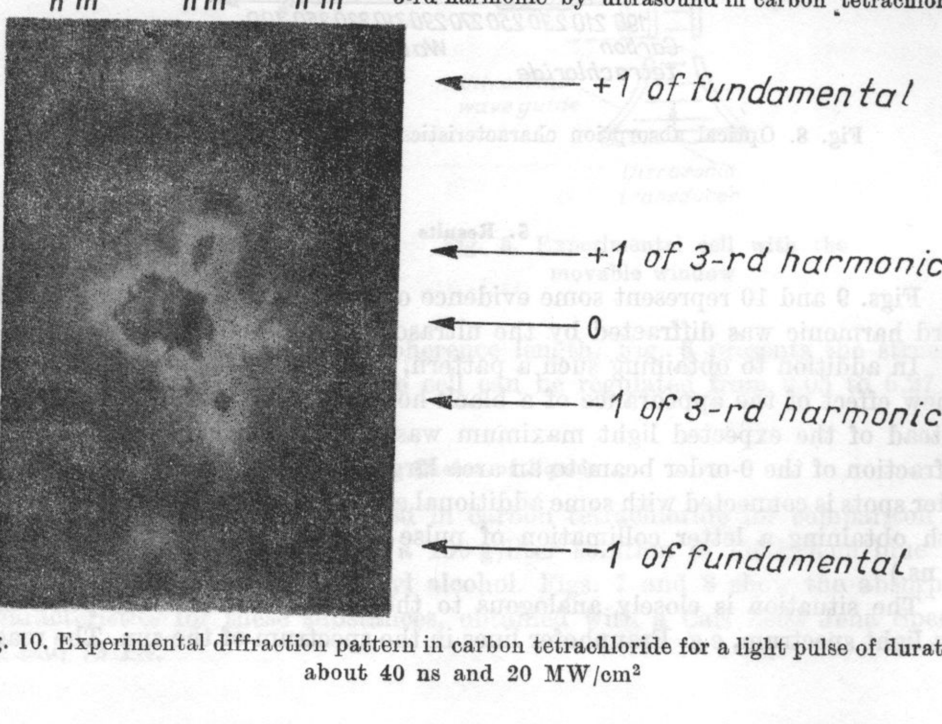


Fig. 10. Experimental diffraction pattern in carbon tetrachloride for a light pulse of duration about 40 ns and 20 MW/cm$^2$

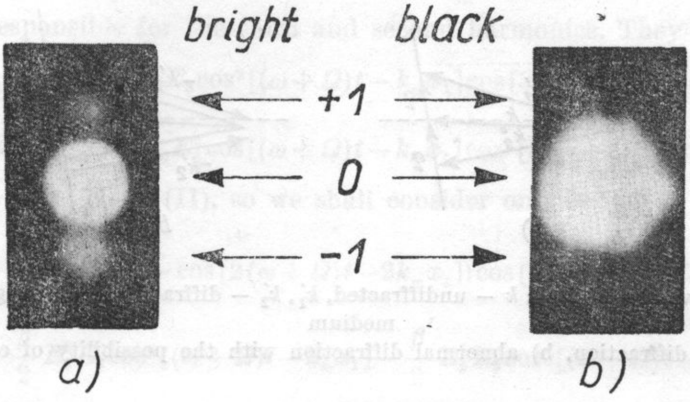


Fig. 11. Comparison of two patterns
a) for normal diffraction (bright spots in $\pm 1$ orders), b) for abnormal diffraction (black spots in $\pm 1$ orders)

for such an absorption here is not clear. A suggestion has been proposed to explain this effect on the basis of nonlinear interaction in a multidiffraction effect [12], and this suggestion is developed below.

#### 6. Selective annihilation of components in the phenomenon of high-power light pulse diffraction by ultrasonic wave

The effect has not been foreseen by existing theories and, as far as the present authors are aware, it has not been described in the literature.

**6.1.** *An attempt at an explanation.* The fact of the cancellation of coherent beams diffracted at angles corresponding to the $\pm 1$ orders may be interpreted only as a result of the appearance of other coherent beams propagating at the same angles but in opposite direction and with phases able to cancel the emission line, thus giving an absorption line (the medium is absorbing this wave) (Fig. 12).

Let us consider the generation of the third harmonic in a nonlinear medium with the 3-rd order nonlinearity and the diffraction of the light of this harmonic into the first order ($\pm 1$ order), for instance.

Further, let us assume that the $+1$ (or $-1$) beam has still sufficiently high power to interact nonlinearly with the medium: in particular, the 3-rd harmonic beam will interact with the fundamental. Assuming that the light diffraction by ultrasound can be multiple (reiterated) as Brillouin suggested in 1922, we may consider an intermediate plane in the ultrasonic beam (Fig. 13), where there is a second process of diffraction. The vibrations of the light vectors of the overlapping and interacting beams of the fundamental and the 3-harmonic must there satisfy the formula

$$E^3_{\pm 1} = \beta [E^{(+1)}_{\omega} + E^{(+2)}_{2\omega}]^3 = E^{(+1)^3}_{\omega} + E^{(+3)^3}_{3\omega} + 3E^{(+1)^2}_{\omega} E^{(+3)}_{3\omega} + 3E^{(+1)}_{\omega} E^{(+3)^2}_{3\omega}. \quad (21)$$

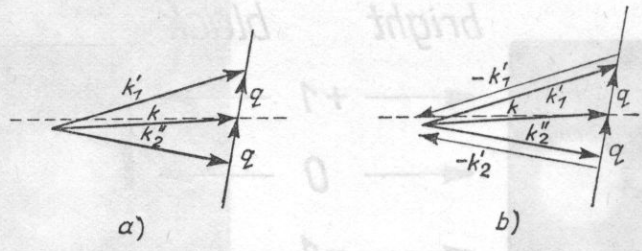


Fig. 12. Wave vectors of light: $k$ — undiffracted, $k_1'$, $k_2'$ — diffracted interacting in a nonlinear medium

a) normal diffraction, b) abnormal diffraction with the possibility of cancellation

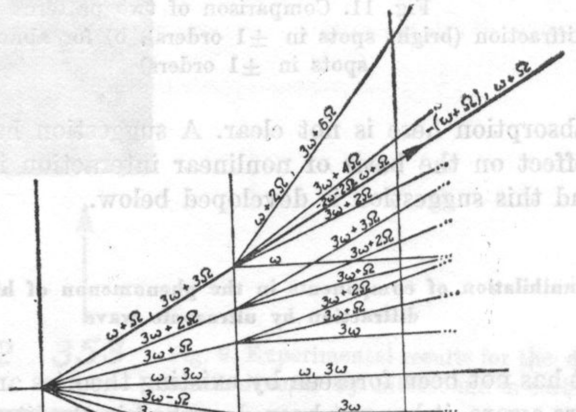


Fig. 13. Diffraction of a very high power light beam by an ultrasonic wave when the third harmonic of the light is generated as a multiple (reiterated) process considered for two-fold case

Putting

$$E_{\omega}^{(+1)} = E_0 \cos[(\omega+\Omega)t - k_{\omega} x_{+1}],$$
$$E_{\omega}^{(+3)} = E_3 \cos[3(\omega+\Omega)t - k_{3\omega} x_{+1}], \tag{22}$$

where $k_{3\omega} = 3k_{\omega}$, we obtain (among others) expressions such as

$$\cos^3 x = \tfrac{1}{4}(3\cos x + \cos 3x), \qquad \cos^2 x = \tfrac{1}{2}(1-\cos 2x),$$

which are responsible for the third and second harmonics. They are:

$$\text{(I)}\ E_\omega^2 \cdot E_{3\omega} = \beta E_0^2 \cdot E_3 \cos^2[(\omega+\Omega)t - k_\omega x_1]\cos[3(\omega+\Omega)t - 3k_\omega x_1], \quad (23)$$

$$\text{(II)}\ E_\omega \cdot E_{3\omega}^2 = \beta E_0 E_3^2 \cos[(\omega+\Omega)t - k_\omega x_1]\cos^2[3(\omega+\Omega)t \cdot 3k_\omega x_1]. \quad (24)$$

But we have (I) $\gg$ (II), so we shall consider only

$$\text{(I)} = \frac{\beta}{2} E_0^2 E_3 \{(1-\cos[2(\omega+\Omega)t - 2k_\omega x_1])\cos[3(\omega+\Omega)t - 3k_\omega x_1]\}$$

$$= \frac{\beta}{2} E_0^2 E_3 \cos^3[(\omega+\Omega)t - k_\omega x_1] - \frac{\beta}{2} E_0^2 E_3 \cos^2[(\omega+\Omega)t - k_\omega x_1] \times$$
$$\times \cos 3[(\omega+\Omega)t - k_\omega x_1]. \quad (25)$$

Since

$$\cos\alpha\cos\beta = \tfrac{1}{2}[\cos(\alpha+\beta)+\cos(\alpha-\beta)], \quad \text{where } x = [(\omega+\Omega)t - k_\omega x_1],$$

we have

$$\cos 2[(\omega+\Omega)t - k_\omega x_1]\cos 3[(\omega+\Omega)t - k_\omega x_1] \Rightarrow$$
$$\Rightarrow \cos\{2[(\omega+\Omega)t - k_\omega x_1] + 3[(\omega+\Omega)t - k_\omega x_1]\} +$$
$$+ \cos\{2[(\omega+\Omega)t - k_\omega x_1] - 3[(\omega+\Omega)t - k_\omega x_1]\} \Rightarrow$$
$$\cos 5[(\omega+\Omega)t - k_\omega x_1] + \cos\{-[(\omega+\Omega)t - k_\omega x_1]\} \Rightarrow$$
$$\Rightarrow \cos 5[(\omega+\Omega)t - k_\omega x_1] + \cos\{-[(\omega+\Omega)t + k_\omega x_1]\} =$$
$$= \cos 5[(\omega+\Omega)t - k_\omega x_1] + \cos[(\omega+\Omega)t + k_\omega x_1]. \quad (26)$$

A similar result may be obtained for (II).

Returning to Fig. 12 (b) and attributing the expressions for the wave numbers $k_1'$ and $-k_1'$,

$$\left.\begin{aligned} k_1' &\Rightarrow \cos[(\omega+\Omega)t - k_\omega x_{+1}] \\ -k_1' &\Rightarrow \cos[(\omega+\Omega)t + k_\omega x_{+1} s] \end{aligned}\right\} +1, \quad (27)$$

$$\left.\begin{aligned} k_2' &\Rightarrow \cos[(\omega-\Omega)t - k_\omega x_{-1}] \\ -k_2' &\Rightarrow \cos[(\omega-\Omega)t + k_\omega x_{-1}] \end{aligned}\right| -1 \text{ order}, \quad (28)$$

we see that the beams which can cancell one another appear as a result of the nonlinearity of the medium.

**6.2.** *Discussion and conclusions.* It is worthwhile to consider the physical mechanism of this interaction. Let us consider the induced Mandelsztam-Brillouin effect as a possible explanation. Under the influence of light nonlinear polarization, the density of a medium is changed due to an electrostrictive effect (see formula (11)) and, as a consequence, an elastic wave (M. B. effect) is induced.

The energy from a light beam of frequency $\omega + \Omega$ is pumped into the ultrasonic wave of frequency $\Omega$ (this corresponds to the vector $\boldsymbol{q}$ in Fig. 12) but with opposite phase, thus giving the strong absorption of this particular component. We can also say that this light induced (pumped) elastic energy forms an elastic wave propagating in the opposite direction $(-\boldsymbol{q})$ which gives the appearance of a light beam in exactly the opposite direction (opposite in phase) which is coherent to the first beam and is cancelling it out. The first beam gives the emission line (or bright spot) but the second transformed beam gives the absorption line (or black spot) as the result of its interaction with the first beam.

This is only a qualitative conception, which requires much more examination both in experiment as in theory to evaluate the effect quantitatively.

## References


[1] C. A. Akhmanov, P. B. Khokhotov, *Problemy nieliniejnoj optiki*, Moskva **1964**.
[2] P. P. Bey, J. F. Giuliani, H. Rabin, Phys. Rev. Lett., **19**, 819 (1967).
[3] N. Blombergen, *Nonlinear optics*, New York **1965**.
[4] A. D. Buckingham, Proc. Phys. Soc., **B 69, 344 (1956)**.
[5] R. K. Lee Chang, K. Galbraith, Phys. Rev., **175**, 3, 170 (1968).
[6] P. A. Franken, J. F. Ward, Rev. Mod. Phys., **175**, 3, 170 (1963).
[7] L. S. Golberg, J. M. Schuur, Appl. Phys. Lett., **14**, 306 (1969).
[8] J. Józefowska, A. Śliwiński, Proc. 7th Int. Congr. Acoust., Budapest, 21, U5 (1971).
[9] J. Józefowska, M. Kosmol, A. Śliwiński, Jour. Phys., C6, supp. XI-XII **23**, 239 (1972).
[10] S. Kielich, *Molekularna optyka nieliniowa*, PWN, Warszawa – Poznań **1977**.
[11] M. Kosmol, Acta Phys. Polon., **A 50**, 375 (1976).
[12] M. Kosmol, A. Śliwiński, Acoustics Lett., **1**, 17-20 (1977).
[13] R. Mertens, O. Leroy, *Diffraction of intense laser light by an ultrasonic wave in the case of large ultrasonic wavelengths*, Proc. of U. I. Brighton (1977).
[14] J. F. Ready, *Effects of high-power laser radiation*, Ac. Press, New York 1971.
[15] R. W. Terhune, P. D. Maker, C. M. Savage, Phys. Rev. Lett., **8**, 404 (1962).


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# HOW THE STRUCTURE OF A MEDIUM IS SEEN BY AN ACOUSTIC WAVE*

IGNACY MALECKI

Institute of Fundamental Technological Research
00-049 Warszawa, ul. Świętokrzyska 21

Division of heterogeneous media into three types, depending on the dimensions of heterogeneities. Media with macroheterogeneities occurring naturally and in technological materials. Chraracterization of microheterogeneities. Frequency and energy transport ranges requiring quantum representation of waves in media with heterogeneities caused by crystal structure defects. Quantum phenomena and background noise for audible sounds. Density of phonons occurring in acoustic impulses. Quantum phenomena possible in biological substances.

## 1. Introduction

The acoustic wave is a unique source of information concerning the medium in which it propagates. For many centuries only waves in continuous and homogeneous media have drawn the attention of scientists. Even before the second world war investigation of the influence of the structure and heterogeneity of a medium on the propagation of acoustic waves had begun. However it is only in the last decade that considerable progress in the investigation of this problem has been made; many laboratories have concentrated their activities on the study of this subject. This situation justified the choice of the problem of the correlation between the structure of media and bodies and acoustic waves propagation as the focal point of the second FASE Congress.

The sessions of the first and second sections are dedicated to this problem, while the third section constitutes their logical complement: moving from the physical phenomena to their perception by man. I think that this is sufficient

* FASE-78, invited paper, unpublished in the Proceedings.

reason for me to dedicate the opening lecture of the Congress to certain general aspects of the influence of media structure on the acoustic field.

The acoustic wave "sees" the heterogeneity of the medium if its length is commensurable with the dimensions of the heterogeneities or with the distance between them. For a longer wave the medium "appears" to be homogeneous; however, the heterogeneities influence the value of the attenuation coefficient and, therefore, the acoustic wave gives indirect information about their nature. As far as the dimensions are concerned, we may differentiate three ranges of heterogeneities connected, respectively, with the macrostructure, microstructure and molecular-atomic structure of a medium. The rather trivial definitions of the limits between these ranges will be omitted from my considerations.

In the majority of media all the three ranges of heterogeneities exist; it is the length of the wave that determines the one that we perceive. Of course, every material medium has heterogeneities due to its molecular-atomic structure and we should therefore pay a special attention to them. The macroscopic heterogeneities may be natural or caused by technological processes. In Table 1

**Table 1.** The frequencies related to the macroscopic heterogeneities

| Medium | Size of heterogeneities | Related frequency |
|---|---|---|
| Rocks | 1-10 m | 0.5-5 kHz |
| Water in ocean | 0.5-1 m | 1.5-3 kHz |
| Reinforced concerete | 0.5-1 cm | 0.25-1 MHz |
| Organic tissue | 0.1-1 cm | 0.2-2 MHz |
| Porous porcelain | 0.5 mm | 40 MHz |

some examples are given of media of this kind and the frequencies corresponding to the wavelengths commensurable with the dimensions of the heterogeneities.

The microheterogeneities have until lately been almost exclusively of natural origin and technological processes have influenced them only indirectly. The situation has recently changed with the introduction of microcomposites, e.g. in the form of whiskers.

In Table 2 the data pertaining to the microstructure of typical media, analogous to those given in Table 1, are presented.

**Table 2.** The frequencies related to the microscopic heterogeneities

| Nature of heterogeneities | Size of heterogeneities [μm] | Related frequency [GHz] |
|---|---|---|
| Magnetic domains | 10-100 | 0.05-0.5 |
| Dislocations in a monocrystal | 10 | 0.5 |
| Erythrocytes in blood | 4-8 | 0.2-0.4 |
| Grains in a polycrystal | 1-5 | 1-5 |
| Punctual defects | 0.1 | 50 |

Both ranges of heterogeneities have one essential feature in common: the medium must be treated as heterogeneous but still continuous; we deal here with an acoustic wave in the traditional sense. It allows us to use common methods of description for both of these ranges.

The essential feature is the structure of the heterogeneity; the dimensions are related to the wavelength, and thus relative parameters are dependent on the frequency. We may differentiate two basic types of the structure. On the one hand – the medium with strong heterogeneities, i.e. of markedly different acoustic impedances. Usually in such a case we deal with heterogeneities in the form of inclusions in a continuous matrix. These are called *grainy media*.

On the other hand, we have granular media with weak heterogeneities, i.e. of acoustic impedances not much different from one another. Most often heterogeneities are close to one another, so that here there is no distinct matrix.

Differences in structure necessitate different mathematical methods for determining the field distribution in media of the two types. For grainy media we usually adopt the method of imaginary sources, while in granular media the method of a small parameter is used. Depending on the degree of the structural irregularity we may or may not introduce statistical methods.

In Table 2, examples of both types of heterogeneity are given.

## 2. Molecular-atomic heterogeneities

The image of the acoustical phenomena changes deeply, once we descend to the molecular-atomic range. The traditional view of the acoustic wave make sense only in connection with the movement of matter, but the space between

**Table 3.** Examples of two types of heterogeneities

| Grainy media | Granular media |
|---|---|
| $Z_0 \lessgtr Z_i,\ D \gg l$ | $Z_0 \cong Z_i,\ D \ll l$ |
| Reinforced concrete | Water in ocean |
| Porous porcelain | Organic tissue |
| Crystal lattice | Polycrystal |

the molecules in fluids or the atoms in solids is not filled with a material medium. The acoustic wave is, therefore, a collection of vibrations of discretely distributed particles; this is often disregarded in technological acoustics. There is an important difference here, when compared with the electromagnetic wave, which – regardless of frequency – propagates is space in a continuous manner. The concept of the acoustic wave-length loses its physical sense in this range, becoming a formal quantity, since the same distribution of oscillations of particles may be obtained for a number of wavelengths (Fig. 1). We must, therefore, look for another solution.

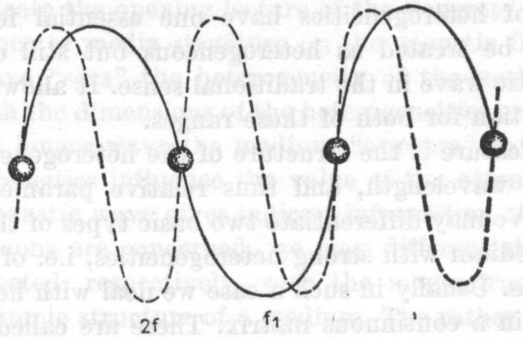


Fig. 1. Varied concept of wavelength for a chain of particles

Let us consider (Fig. 2) a simple chain of identical oscillators of masses $m_{a0}$, elasticities $K_0$ and distances $a$ between them; the oscillator has displacement $u_l$ and momentum $P_l$. Using Fourier analysis we find the displacements $U_{km}$ and momenta $P_{km}$ for the $k_m$ mode of oscillation:

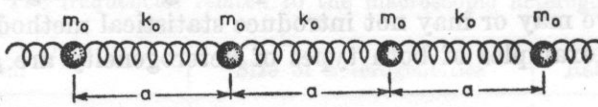


Fig. 2. A chain of oscillators of masses $m_0$ and elasticities $K_0$ between them

$$U_{km} = \frac{1}{\sqrt{Na}} \sum_{l=1}^{N} u_l e^{ik_m al},$$

$$P_{km} = \frac{1}{\sqrt{Na}} \sum_{l=1}^{N} P_l e^{-ik_m al}. \tag{1}$$

This mode of oscillation may be represented in the reciprocal space of wave vectors as a so-called *modal oscillator* moving with a velocity $c_m$ (Fig. 3). This operation is performed on the basis of classical mechanics, but the energy transport in the chain of oscillators, representing the acoustic wave, is subject to the same universal law as the energy flux of electromagnetic wave: it does not occur in a continuous manner but in quanta of energy given by the formula

$$E = \hbar\omega\left(n + \frac{1}{2}\right), \tag{2}$$

where $\hbar$ is the universal Planck constant, and $n$ is the number of the energy levels, i.e. the number of phonons.

The energy of the modal oscillator consists therefore of indivisible quasi-particles called, as we know, phonons; these quasi-particles are analogous to light photons, though their properties are slightly different.

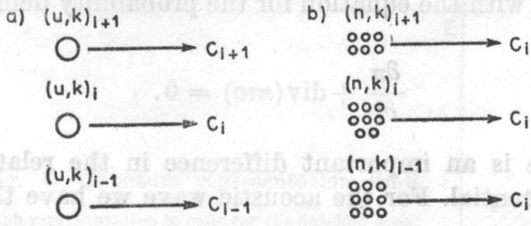


Fig. 3a. Representation of a chain of oscillators by a number of $k$ oscillators with a velocity $c_m$
Fig. 3b. Representation of a chain of $k$ oscillators as a flux of phonons $nk_i$

Therefore we shall present the moving modal oscillator as a flux of phonons of the same velocity $c_m$ (Fig. 3), consequently entering the field of quantum acoustics. The probability $\pi$ of the phonon of energy $E$, being in a given position at a given moment of time, is defined by the wave function

$$\psi = \sqrt{\pi} \cdot e^{iS}, \tag{3}$$

where $S = Et$ (energy of the system $\times$ time).

For phonons not dispersed by external factors this function fulfils the Schroedinger equation in the form

$$i\hbar \frac{\partial \psi}{\partial t} + \frac{\hbar^2}{2m_f} \nabla^2 \psi = 0, \tag{4}$$

where $m$ is the effective mass of the phonon.

This is compatible with the equation for the potential of an acoustic wave in a non-dissipative medium:

$$\frac{\partial^2 \Phi}{\partial t^2} - c^2 \nabla^2 \Phi = 0. \tag{4a}$$

It is evident that the quantum equation is of the first order, while the acoustic equation is of the second order; the quantum equation describes the flux of phonons moving with velocity $w$,

$$w = \frac{1}{m_f} \operatorname{grad} S, \quad m_f = \frac{\hbar k}{w}, \tag{5}$$

while the classical equation concerns the local movement of real particles of instantaneous velocity:

$$v = -\operatorname{grad} \Phi. \tag{5a}$$

The continuity of flux equation in a continuous medium, describing the instantaneous density $\varrho$ of the medium,

$$\frac{\partial \varrho}{\partial t} + \operatorname{div}(\varrho v) = 0, \tag{6}$$

is formally identical with the equation for the probability density of the phonon distribution:

$$\frac{\partial \pi}{\partial t} + \operatorname{div}(\pi w) = 0. \tag{6a}$$

However, there is an important difference in the relations between the velocity and the potential. For the acoustic wave we have the Euler equation

$$\varrho \frac{dv}{dt} + \operatorname{grad} p = 0, \tag{7}$$

and for the phonon flux the quantum acoustical equation

$$m_f \frac{dw}{dt} + \operatorname{grad} Q = 0, \tag{7a}$$

where $Q$ is the quantum potential:

$$Q = -\frac{\hbar^2}{2m_f} \frac{\nabla^2 \sqrt{\pi}}{\sqrt{\pi}}. \tag{8}$$

The gradient of the quantum potential defines the uncertainty of the position of the phonons, that is the dispersion of their flux. In the case of the flux of classical particles, having precisely determined positions, the quantum potential is obviously equal to zero.

The relations presented are an illustration of the degree of similarity and at the same time of difference of the phenomena occurring in the micro- and macroworlds. The acoustician crossing the boundary between these two worlds must be fully aware of the complexity of the problems which he tackles.

The energy of a single phonon is given by formula

$$E_f = \hbar \omega_f. \tag{9}$$

In light flux the scintillations corresponding to the individual photons had been observed by the beginning of our century. It must be expected that in view of the development of the technology of hypersound, for which a single phonon has a relatively high energy (for instance, for a frequency of $f = 10^{12}$ Hz, the energy $E = 10^{-15}$ erg), a similar observation of individual phonons will be possible. However, this does not seem to be possible at lower frequencies, since we deal there with enormous number of phonons. For instance, the weakest audible sound impulse at a frequency of 4000 Hz and with a duration of 1 msec carriers $10^{11}$ phonons. We have, therefore, a double quantum limitation on the range of applicability of traditional acoustics. The quantization in space occurs when the wavelength is commensurable with the distance between the oscillators, and in the case of a spatial system — commensurable with the mean free path of the phonon. It is independent of the wave energy and thus on the $(\omega, E)$-diagram the limit is a vertical line (Fig. 4).

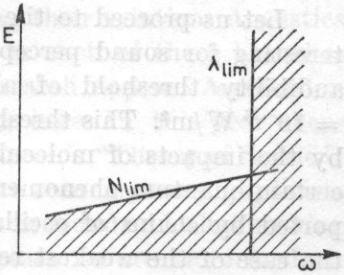


Fig. 4. Quantum representation limit

Such representation is valid for the hatched area; coordinates: $\omega$ – frequency, $E$ – system transported energy

As for the quantization of energy, it may be sensed only at low intensities, when the number $n$ is small, e.g. equal to 10. Then the limit on the $(\omega, E)$-diagram is an oblique straight line.

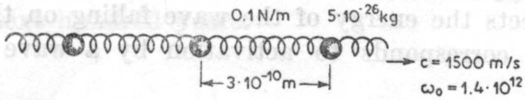


Fig. 5. Vibration transport in the internal ear represented by a chain of oscillators

For the chain of oscillators previously presented (Fig. 5) the limit of quantization thus defined corresponds to a transported power of

$$N_{\lim} \cong [10^{-26}\,\omega_0^2 \sin k_m^a] \quad \text{W}, \tag{10}$$

where $\omega_0 = \sqrt{k_0/m_0}$ is the frequency of natural oscillation of the resonator, and $k_m = \omega m/c$.

The distance between the molecules or atoms and, therefore, the limiting frequency depends on the temperature and pressure. In Table 4 some characteristic examples are given.

In gases the molecules are moving at random, there is no order and the mean free path of the molecule is the determining factor. In liquids there is a close order, while in solids – a distant order; the mean free path of the phonon is determined in this case.

**Table 4.** Limit frequency as function of the molecular structure

| Medium | Temperature $T$ [K] | Pressure $P$ [atm] | Mean free path $l$ [m·10⁻⁷] | Limit frequency $f$ [GHz] |
|---|---|---|---|---|
| | 300 | 1 | 2 | 2 |
| Ideal gas | 100 | 1 | 0.7 | 6 |
| | 20 | 1 | 0.1 | 40 |
| Liquids | | | | |
| $CO_2$ | 273 | 70 | 480 | 0.05 |
| $CS_2$ | 298 | 1 | 7.4 | 3.25 |
| $SO_2$ | 273 | 10 | 34 | 0.7 |
| $C_6H_6$ | 273 | 1 | 6.5 | 3.7 |
| $CH_3Cl$ | 273 | 1 | 17 | 1.43 |

Let us proceed to the quantum limitation of energy — it is especially interesting for sound perception. A man of very keen hearing has a minimum audibility threshold of about $p_{tr} = 2\cdot 10^{-6}$ N/m² at 4000 Hz; hence $i_{tr} = 10^{-14}$ W/m². This threshold coincides with the level of thermal noise caused by the impacts of molecules of air against the ear-drum. On the other hand, certain quantum phenomena also occur in the internal ear, the energy is transported by chains of oscillators composed of molecules of lymphatic fluid. In the case of the weakest received signal one such chain is activated. The data of such a chain are the following: $m_0 = 5\cdot 10^{-26}$ kg, $K_0 = 0.1$ N/m, $\omega_0 = 1.4\cdot 10^{12}$ Hz, $a = 3\cdot 10^{-10}$ m, $c = 15000$ m/s. Introducing these parameters into formula (10) for a signal of frequency $\omega/2\pi = 4000$ Hz, we obtain for the limiting power $N_{\lim}$, transported by the chain of molecules, a value of $3.3\cdot 10^{-18}$ W.

This chain collects the energy of the wave falling on the ear-drum. The limiting power $N_{\lim}$ corresponds to activation by a wave of intensity $i_{\lim} = 1.7\cdot 10^{-14}$ W/m².

**Table 5.** Limit frequency as function of the atomic structure

| Medium | Temperature $T$ [K] | Mean free path $l$ [m] | Limit frequency $f$ [GHz] |
|---|---|---|---|
| Si | 273 | $6.8\cdot 10^{-9}$ | 214 |
| | 77 | $4.3\cdot 10^{-7}$ | 3.4 |
| | 20 | $6.5\cdot 10^{-7}$ | 0.023 |
| $SiO_2$ | 273 | $1.8\cdot 10^{-9}$ | 590 |
| | 77 | $2.4\cdot 10^{-8}$ | 38 |
| | 20 | $1.3\cdot 10^{-5}$ | 0.076 |
| Ge | 273 | $5.2\cdot 10^{-9}$ | 164 |
| | 77 | $5.2\cdot 10^{-8}$ | 16.4 |
| | 20 | $7.1\cdot 10^{-6}$ | 0.12 |
| $CaF_2$ | 273 | $1.4\cdot 10^{-9}$ | 818 |
| | 77 | $1.6\cdot 10^{-8}$ | 58.7 |
| | 20 | $1.6\cdot 10^{-6}$ | 0.587 |
| NaCl | 273 | $1.07\cdot 10^{-9}$ | 710 |
| | 77 | $0.8\cdot 10^{-8}$ | 95 |
| | 20 | $3.7\cdot 10^{-}$ | 2.05 |

The convergence of that quantity with the audibility threshold $i_{tr}$ confirms the universal character of the quantum limitation.

The phenomena of oscillation transport by the biomolecules of the nervous system is as yet unexplored to the full.

The natural frequencies of the biomolecules are considerably lower than those of the lymphatic liquid and are of the order of $10^8$-$10^9$ Hz, and this fact affects the oscillatory processes in the neurons.

I have mentioned several problems still awaiting their solution. Acoustics is still being developed, it developes branches and in each of these branches new problems worthy of scientific and technical research appear. A reflexion taken from the past seems to be particularly fitting here. In this year there occurs the centenary of the publication of Lord RAYLEIGH's "Theory of Sound". Shortly after this book had been published one of the contemporary physicists said that it contained everything that could be written on sound and that nothing was left to be done in acoustics. After a hundred years we are more modest. In Europe alone there are several journals dedicated solely to acoustics and the papers on our speciality are dispersed in journals of many disciplines, beginning with linguistics and musicology and ending with architecture and metallurgy. I think that both we and our successors will have enough subjects to pursue for at least the next hundred years.

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# EMISSION, ABSORPTION AND PROPAGATION OF ACOUSTIC THz-WAVES IN SOLIDS*

W. EISENMENGER

Physikalisches Institut der Universität Stuttgart, Teilinstitut 1
(Pfaffenwaldring 57, 7000 Stuttgart 80, FRG)

Recent experimental developments in generation and detection of THz acoustical phonons have led to studies of phonon emission, propagation and absorption in solids. New results of this acoustical phonon spectroscopy concern phonon interactions with collective excitations (phonons, photons, magnons), localized excitations (resonant scattering of impurities, radiationless transitions) and electronic excitations in metals, superconductors and semiconductors. The different experimental methods and their applications to phonon interaction studies are discussed.

## Introduction

During the past ten years several new methods have been developed extending the classical range of ultrasound and microwave acoustics in solids into the range of THz ($10^{12}$ Hz) and higher frequencies. The reason for this was an increasing interest in energy transport properties in solids in the range of thermal lattice vibration frequencies. Typical questions are: the mechanisms of heat generation or the emission of phonons by excited electrons and the resonance absorption and emission of mechanical vibrations or phonons by impurities in dielectric crystals. In analogy to optical spectroscopy this kind of investigation is called *phonon spectroscopy* in the sense of an acoustical emission and absorption spectroscopy. Since phonons and photons as Bose-particles are subject to the same quantum statistics, the well-known close analogy of waves between acoustics and microwave technique extends also into the range of THz frequencies. But also the quantum laws of radiation transitions, as for instance

* FASE-78, invited paper, unpublished in the Proceedings.

valid for atomic emission, photoeffect or bremsstrahlung are as valid for phonons as for photons. In consequence of the short wavelength of 10 Å to 100 Å a coherent detection in ultrasonics and microwave acoustics is not possible any more.

In the following we report on the progress in spectroscopy with acoustical phonons in the THz-frequency range. We discuss different experimental methods and the phonon interactions which have been investigated.

### Inelastic neutron scattering

From the Bragg scattering of monochromatic thermal neutrons by thermal sound waves or sound waves due to quantum mechanical zero-point oscillations the total $\omega(k)$-relation or dispersion curve of the possible lattice vibrations of the crystal is obtained, as shown in Fig. 1. By the presently available high neutron densities in high flux reactors a frequency resolution of 50 GHz

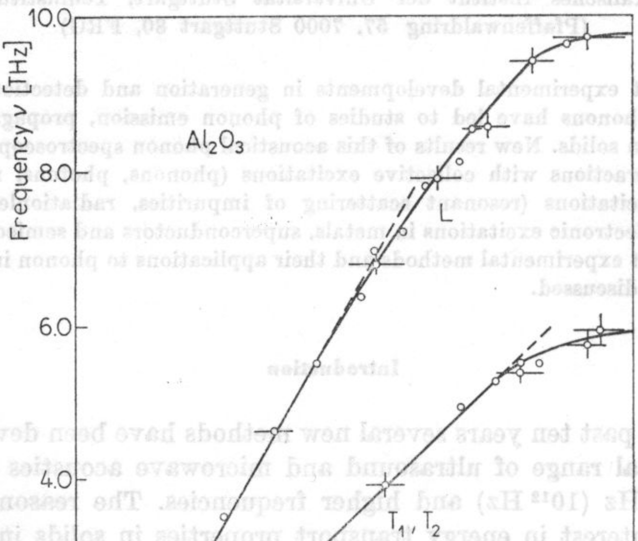


Fig. 1. Dispersion of acoustical phonons in $Al_2O_3$ obtained from neutron scattering (H. Bialas et al., Phys. Lett. 43, 97, 1973)

is attainable. In consequence of this high resolution it is meanwhile possible, as shown in Fig. 2, to detect the influence of localized lattice vibrations [1] on the dispersion curve resulting from high concentrations of impurity atoms. Under the influence of localized oscillations the dispersion curve splits at the frequency of the impurity resonance. While the method of neutron scattering is superior to any other method for the determination of the acoustic dispersion,

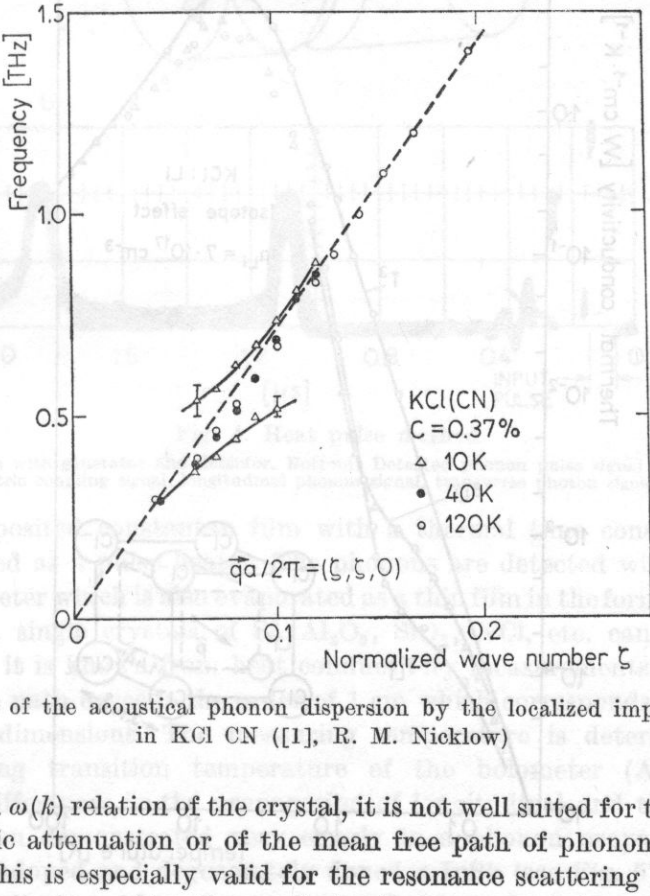


Fig. 2. Splitting of the acoustical phonon dispersion by the localized impurity resonance in KCl CN ([1], R. M. Nicklow)

i.e. the phonon $\omega(k)$ relation of the crystal, it is not well suited for the determination of acoustic attenuation or of the mean free path of phonons propagating in the solid. This is especially valid for the resonance scattering by impurities of lower concentration. Also the analysis of phonon emission spectra is very difficult in consequence of the low sensitivity.

### Thermal conductivity and phonon pulse measurements

One of the best known and simplest methods to determine the scattering of THz phonons in solids is the measurement of heat conduction, especially in the range of low temperatures. Beside the influence of sample geometry and elastic scattering, especially Rayleigh-scattering, on the phonon mean free path, information on inelastic phonon scattering (Umklapp-processes) and electron scattering can be obtained. In addition, minima in the heat conductivity as function of temperature show the influence of resonant phonon scattering by impurities as e.g. paraelectric systems [2], i.e., KCl : Li (as shown in Fig. 3), paramagnetic ions and ions with splitting of the electronic energy

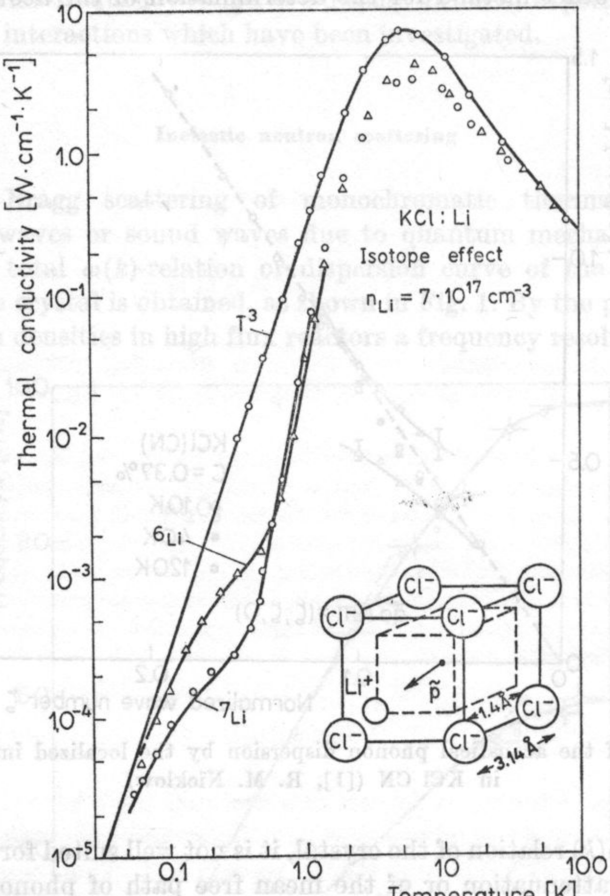


Fig. 3. Tunneling resonance of Li in KCl observed in thermal conductivity [2]

states by crystal field effects [3] (i.e. $Al_2O_3 : V^{3+}$, $Al_2O_3 : Ti^{3+}$). The frequency resolution of these measurements is very poor, also the mode dependence of the phonon scattering cannot be determined.

A significant progress was possible by the introduction of the heat pulse method [4] by v. Gutfeld and Nethercot. In this method (see Fig. 4) a separate measurement of the propagation of longitudinal and transverse phonon pulses is possible. In addition, the contribution of diffusely scattered phonons can be determined. For the generation of phonon pulses in heat pulse experiments

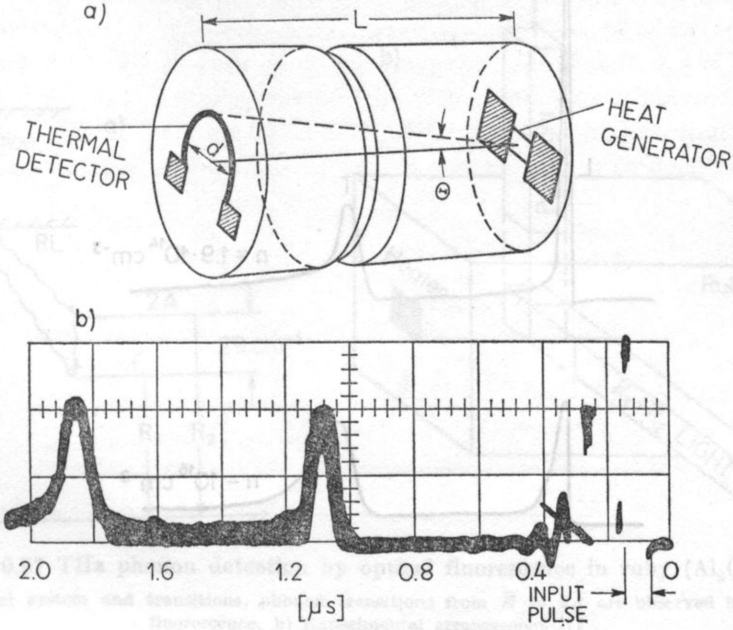


Fig. 4. Heat pulse method

Top: crystal sample with generator and detector. Bottom: Detected phonon pulse signal. From right to left, electric coupling signal, longitudinal phonon signal, transverse photon signal [4]

a vacuum deposited constantan film with a thermal time constant of about $10^{-8}$ sec is used as a pulse heater. The phonons are detected with a superconducting bolometer which is also evaporated as a thin film in the form of a meander. As substrates, single crystals of Si, $Al_2O_3$, $SiO_2$, KCl, etc. can be used. For these crystals it is known from heat conductivity measurements that the phonon mean free path exceeds the order of 1 cm which corresponds to the mostly used sample dimensions. The measuring temperature is determined by the superconducting transition temperature of the bolometer (Al : 1.2 K; Sn: 3.7 K). The differences in the propagation of longitudinal and transverse phonons have been demonstrated very clearly in a phonon propagation experiment [5] in undoped and degenerately doped *n*-InSb (see Fig. 5). While longitudinal and transverse phonons propagate almost undamped in undoped InSb (mean free path 1 cm), the longitudinal wave is strongly attenuated in degenerate *n*-doped InSb by inelastic electron scattering at the spherical Fermi surface. Heat pulse measurements have been very valuable in investigations of phonon propagation velocities and of phonon focussing [6] by anisotropy of the sound velocity as well as in phonon scattering measurements. Since phonon generation by heaters and detection by bolometers are experimentally uncomplicated, these techniques are often used in connection with other detection or phonon generation methods. The high maximum phonon radiation power of the generator and the great sensitivity of the detector, as well as the fact that

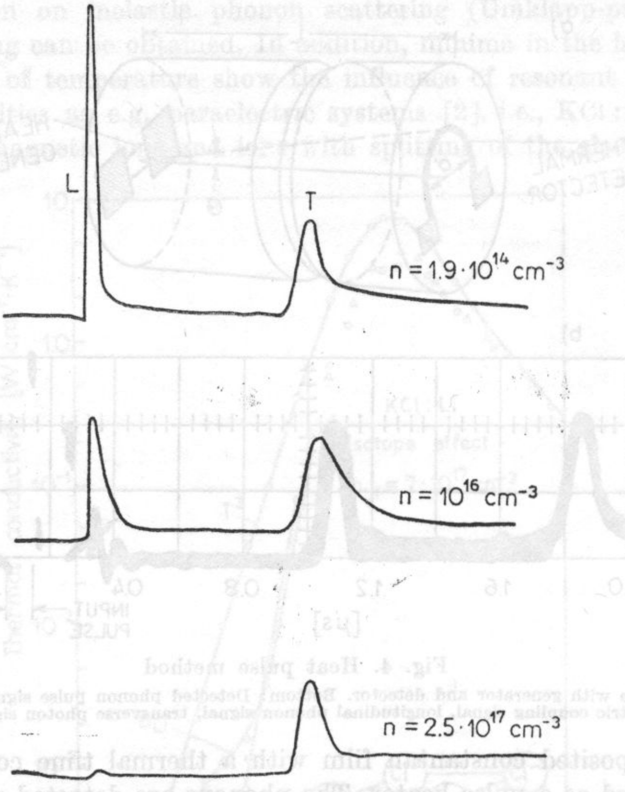


**Fig. 5. Attenuation of longitudinal heat pulses in the degenerately doped *n*-InSb with increasing carrier concentration [5]**

thin metal layers can be evaporated on arbitrary crystal surfaces which have been polished, are of great advantage.

To a certain extent, frequency information, however, with poor resolution can be obtained as in heat conduction measurements by variation of the heater power or the heater temperature.

**Frequency selective phonon detection by induced optical fluorescence of crystal ions**

The first successful frequency selective phonon detection in the THz range by influencing the optical fluorescence was reported by RENK and DEISENHOFER [7] who used the system $Al_2O_3 : Cr^{3+}$. In this experiment (see Fig. 6) the splitting of the metastable ruby laser levels in the so-called $\bar{E}$ and $2\bar{A}$-states with a spacing of 29 cm$^{-1}$, corresponding to 0.87 THz, is used. Using ultraviolet excitation of the crystal at low temperatures the optical fluorescence is mainly observed from the lower $\bar{E}$-level. The $2\bar{A}$-level is weakly populated in consequence of fast radiationless transitions to the $\bar{E}$-level. Phonon radiation

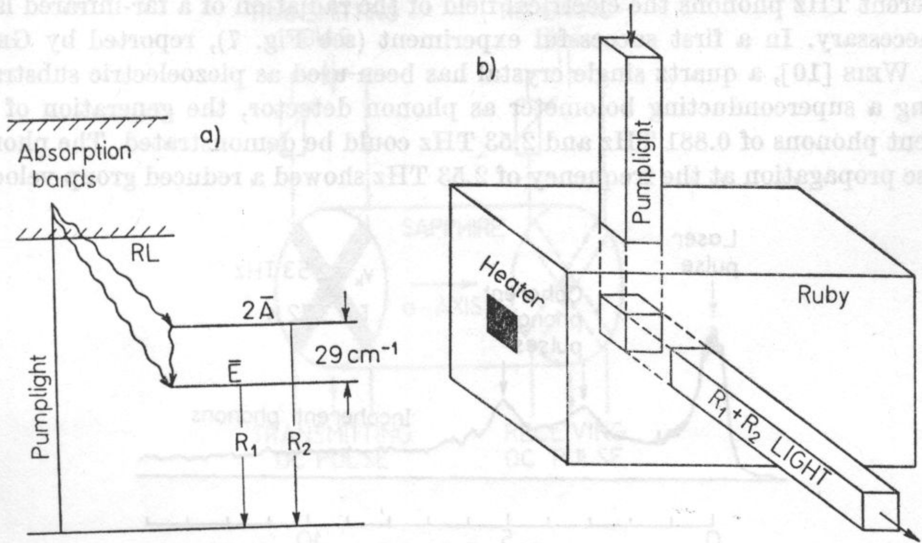


Fig. 6. 0.87 THz phonon detection by optical fluorescence in ruby ($Al_2O_3 : Cr^{3+}$)

a) Energy level system and transitions, phonon transitions from $\bar{E}$ to $2\bar{A}$ are observed by enhanced $R_2$ fluorescence. b) Experimental arrangement [7]

at 0.87 THz increases the population of the $2\bar{A}$-level by additional transitions from the $\bar{E}$-level under phonon absorption. Correspondingly, the phonon population at the frequency of 0.87 THz can be determined by observing the $R_2$-fluorescence intensity. Heat pulse experiments demonstrated the possibility of a fast and sensitive phonon detection. In addition, phonon trapping and the coupling of metastable states in the phonon field could be investigated. Recent experiments have also been performed with the system $CaF_2 : Eu^{2+}$. This system shows a pressure-dependent level splitting [8] of radiationless transitions in the frequency range from 0 to 80 $cm^{-1}$ corresponding to the frequency range from 0 to 2.4 THz. In principle, systems of this kind are well suited for monochromatic phonon detection and also for generating incoherent phonons. A further possibility of optical phonon detection and phonon generation lies in the application of vibronic side lines of fluorescence transitions [9] of rare earth ions. In this respect the system $SrF_2 : Eu^{2+}$ has been used for an analysis of the phonon spectrum radiated from a pulse heater. These optical methods have so far been applied to special systems, an extension to other substrates appears possible if special coupling methods or surface doping are used.

### Coherent surface excitation of THz phonons

The methods discussed so far concerned the detection and generation of incoherent phonons. In contrast, coherent phonons can be generated by surface excitation of piezoelectric crystals in the field of microwaves. For generating coherent THz phonons the electrical field of the radiation of a far-infrared laser is necessary. In a first successful experiment (see Fig. 7), reported by GRILL and WEIS [10], a quartz single crystal has been used as piezoelectric substrate. Using a superconducting bolometer as phonon detector, the generation of coherent phonons of 0.881 THz and 2.53 THz could be demonstrated. The phonon pulse propagation at the frequency of 2.53 THz showed a reduced group velocity

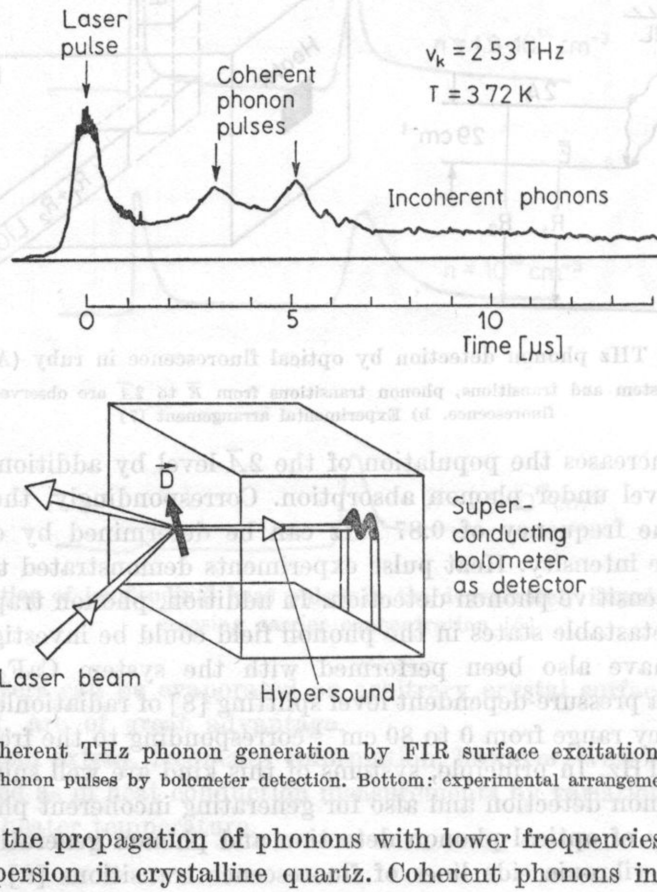


Fig. 7. Coherent THz phonon generation by FIR surface excitation of quartz
Top: phonon pulses by bolometer detection. Bottom: experimental arrangement [10]

compared to the propagation of phonons with lower frequencies in agreement with the dispersion in crystalline quartz. Coherent phonons in the THz frequency range can be used for the investigation of saturation and other high intensity effects. A spectroscopy with coherent acoustical phonons necessitates continuously tunable far-infrared laser sources.

### Phonon spectroscopy with superconducting tunneling junctions

For a versatile spectroscopy with acoustic phonons in the THz range it is necessary for the phonon generator and detector to be easily deposited on the substrate surface (see Fig. 8) (as e.g. by vacuum evaporation) and that, in ad-

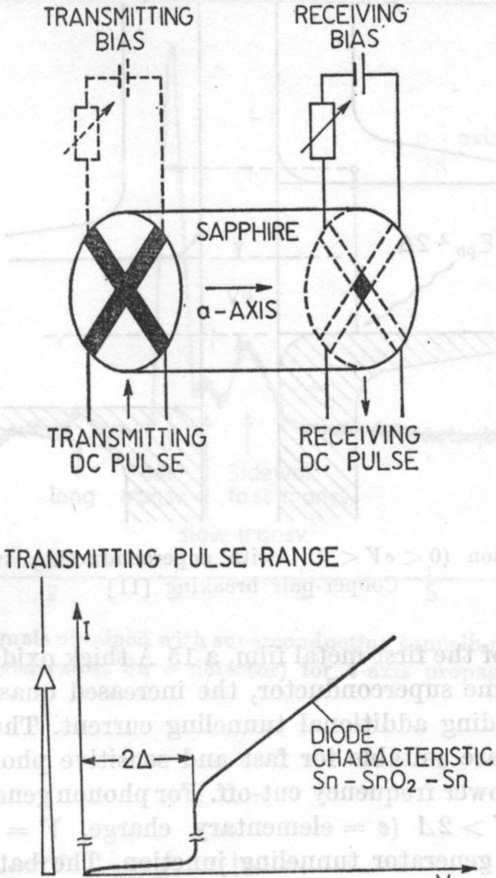


**Fig. 8.** Phonon generation and detection with superconducting tunneling junctions
Top: experimental arrangement. Bottom: Tunneling *I-V* characteristic with detection and transmitting bias range [11]

dition, generator or detector can be tuned. These conditions are fulfilled to a wide extent for superconducting tunneling junctions [11]. Phonon detection (see Fig. 9) is analogous to the internal photoelectric effect. Phonons having a minimum energy of $2\Delta$ ($\Delta$ = energy gap) excite electrons from the superconducting ground state by breaking-off Cooper-pairs. The mean free phonon path for this process is of the order of 1000 Å at frequencies corresponding to $h\nu = 2\Delta$ ($2\Delta_{Al} = 0.38$ meV or 90 GHz, $2\Delta_{Sn} = 1.2$ meV or 290 GHz; $2\Delta_{Pb} = 2.7$ meV or 650 GHz). In a vacuum deposited superconducting film of appr. 2000 Å thickness phonons of the energy exceeding $2\Delta$ are, therefore, nearly completely absorbed leading to an increase of the electron or quasiparticle density exceeding the thermal occupation. In a superconducting tunneling

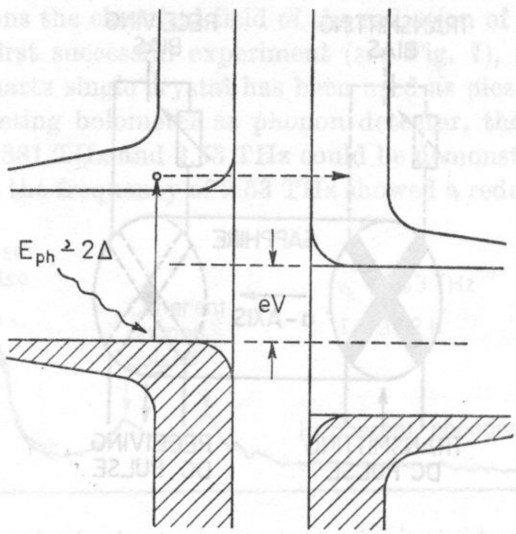


Fig. 9. Phonon detection ($0 < eV < 2\Delta$) with superconducting tunneling junctions by Cooper-pair breaking [11]

junction, consisting of the first metal film, a 15 Å thick oxide layer and a second metal film of the same superconductor, the increased quasiparticle population leads to a corresponding additional tunneling current. Thus, superconducting tunneling junctions are suitable for fast and sensitive phonon pulse detection (see Fig. 10) with a lower frequency cut-off. For phonon generation a DC-voltage corresponding to $eV > 2\Delta$ ($e$ = elementary charge, $V$ = battery voltage) is applied to a similar generator tunneling junction. The battery voltage is sufficient for the breaking of Cooper-pairs in the so-called single particle tunneling process (see Fig. 11) with a necessary energy of $2\Delta$. The excess energy $eV - 2\Delta$ is essentially converted into kinetic energy of the quasiparticles. This excess energy can be emitted by quasiparticle relaxation to the gap edge $\Delta$ in the form of relaxation phonons. This process is analogous to the X-ray bremsstrahlung. After the relaxation decay the quasiparticles recombine again to Cooper-pairs emitting phonons of the fixed frequency corresponding to $h\nu = 2\Delta$. The energy distribution of the relaxation phonons exhibits a sharp upper limit at $eV - 2\Delta$. The special form of the quasiparticle density of states in the superconductor leads to a nearly rectangular spectral distribution at this cut-off frequency. For the spectroscopy [12] with phonons (see Fig. 12) it is now essential that using a modulation of the generator voltage $V \pm \delta V$ leads only to a spectral change at the frequency $\nu = (eV - 2\Delta) : h$ in a narrow band of the width $\delta\nu = \pm\, \delta eV : h$. The resulting modulation of the detector signal, therefore, contains only the signal contributions from this narrow frequency band which is tunable by varying the generator voltage. In this way a spectroscopy with quasimonochromatic phonons is possible which meanwhile has found several

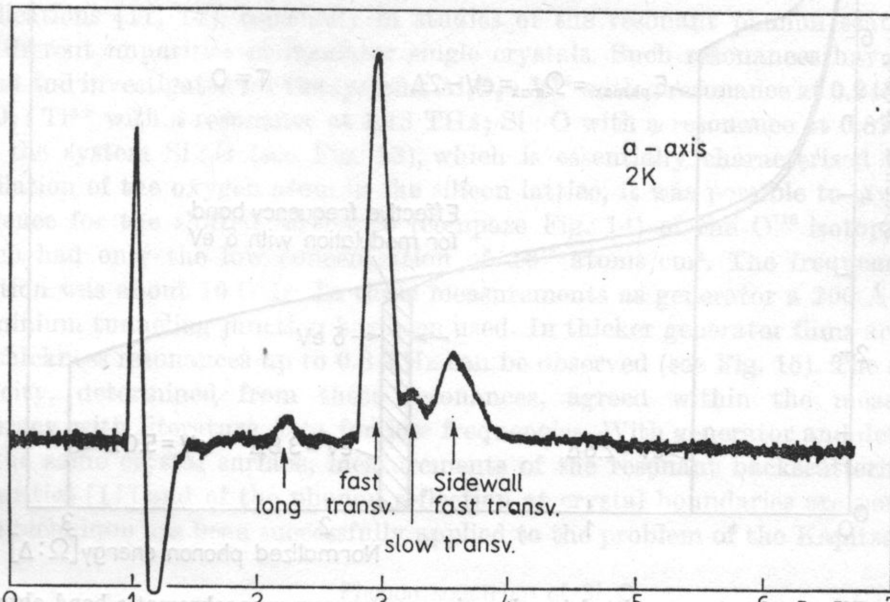


**Fig. 10.** Phonon pulse signals obtained with superconducting tunneling junctions as generator and detector (Pb – generator, Sn – detector) for *a*-axis propagation in $Al_2O_3$ [11]

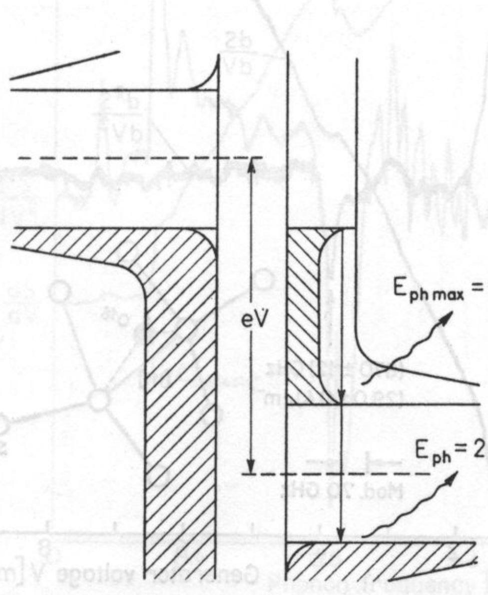


**Fig. 11.** Phonon frequency ($eV \geqslant 2\Delta$) in superconducting tunneling junctions
Relaxation: $E_{\mathrm{phmax}} = eV - 2\Delta$. Recombination: $E_{\mathrm{ph}} = 2\Delta$ [11]

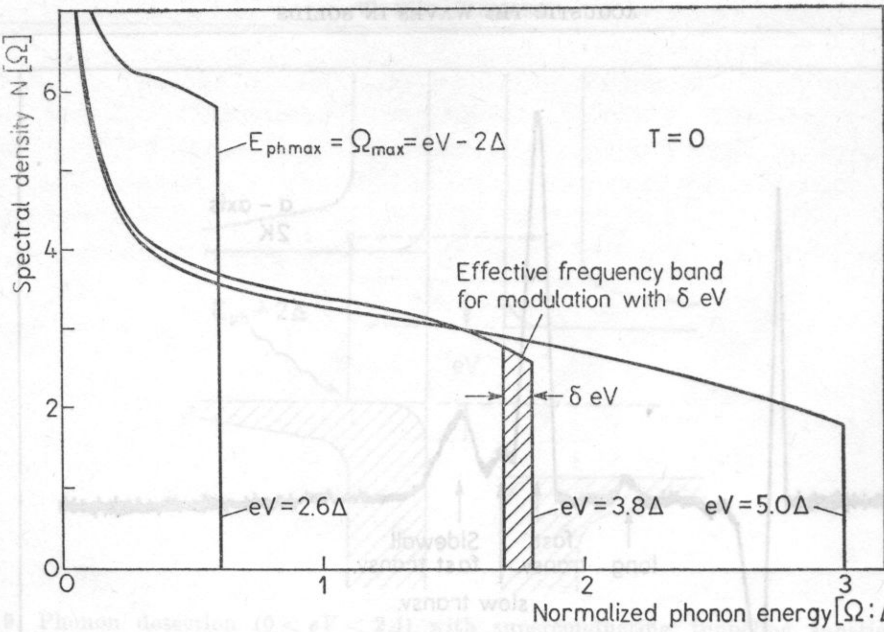


**Fig. 12. Phonon spectrum emitted in relaxation and narrow monochromatic band obtained by modulation [11, 12]**

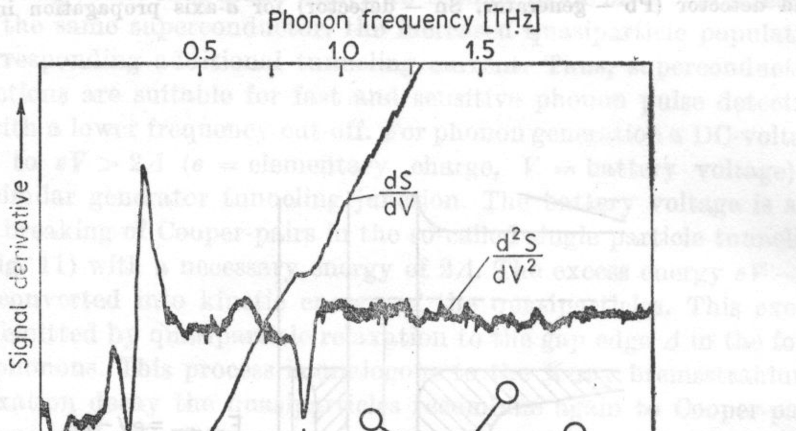


**Fig. 13. 870 GHz phonon absorption by oxygen in Si**

$dS/dV$ = first detector-generator derivative or direct modulation signal; $d^2S/dV^2$ = second detector – generator derivative or second harmonic modulation signal applications [11, 14], especially in studies of the resonant phonon scattering of different impurities in insulator single crystals. Such resonances have been found and investigated for the systems $Al_2O_3 : V^{3+}$ with a resonance at 0.248THz; $Al_2O_3 : Ti^{3+}$ with a resonance at 1.13 THz; Si : O with a resonance at 0.87 THz. For the system Si : O (see Fig. 13), which is essentially characterized by an oscillation of the oxygen atom in the silicon lattice, it was possible to give also evidence for the shifted resonance (compare Fig. 14) of the $O^{118}$ isotope [13] which had only the low concentration of $10^{18}$ atoms/cm³. The frequency resolution was about 10 GHz. In these measurements as generator a 200 Å thick aluminium tunneling junction has been used. In thicker generator films acoustical thickness resonances up to 0.8 THz can be observed (see Fig. 15). The sound velocity, determined from these resonances, agreed within the measuring accuracy with literature data for low frequencies. With generator and detector on the same crystal surface, measurements of the resonant backscattering by impurities [14] and of the phonon reflection at crystal boundaries are possible. This technique has been successfully applied to the problem of the Kapitza-ano-

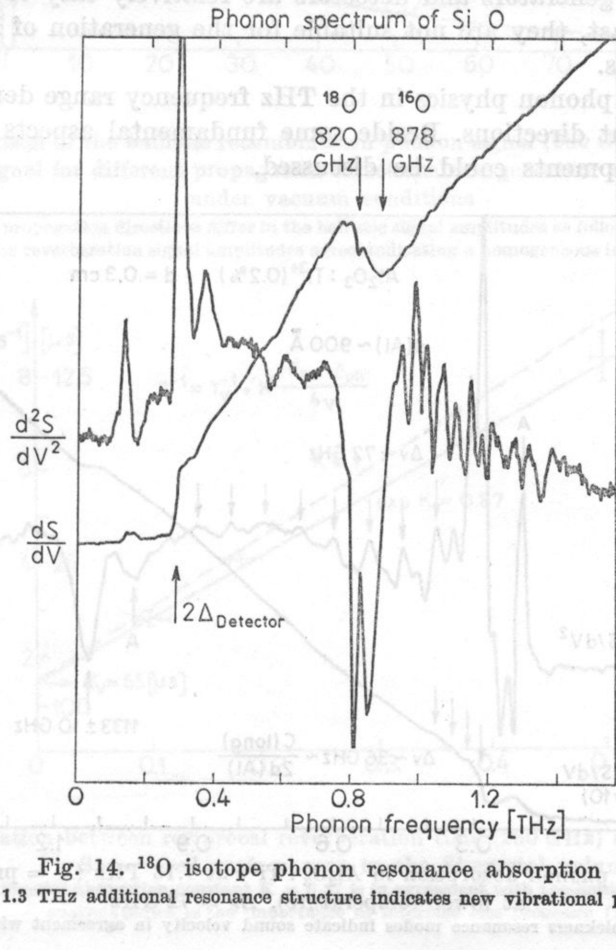


Fig. 14. $^{18}O$ isotope phonon resonance absorption

**In the range 0.9 to 1.3 THz additional resonance structure indicates new vibrational processes [13]**

maly, i.e. the transmission of phonons from the crystal into liquid helium [15]. In addition, the phonon emission spectrum [16, 13] of superconducting tunneling junctions could be investigated in detail confirming the predictions of the theory of superconductivity. Measurements of the phonon intensities emitted by recombination of quasiparticles to Cooper-pairs indicated that even for ideal crystals and crystal surfaces the total absorption of phonons amounts to about 90%. Terahertz phonon reverberation measurements [17] in the crystal substrate analogous to the room acoustical reverberation method (see Figs. 16 and 17) showed that the responsible phonon absorption processes are not localized in the crystal volume, but at the interface between the superconducting tunneling junction and the crystal substrate. In this process THz phonons decay in a wide frequency range spontaneously into low energy acoustical phonons. Other investigations concerned insulators, semiconductors, metals and superconductors, by which new results with respect to the phonon interaction with impurities, magnons and electrons have been obtained.

Beside their tunability discussed above, superconducting tunneling junctions as phonon generators and detectors are relatively easy to fabricate and to use. In contrast, they are not suitable for the generation of high intensity coherent phonons.

The field of phonon physics in the THz frequency range develops already in many different directions. Beside some fundamental aspects only some of the main developments could be discussed.

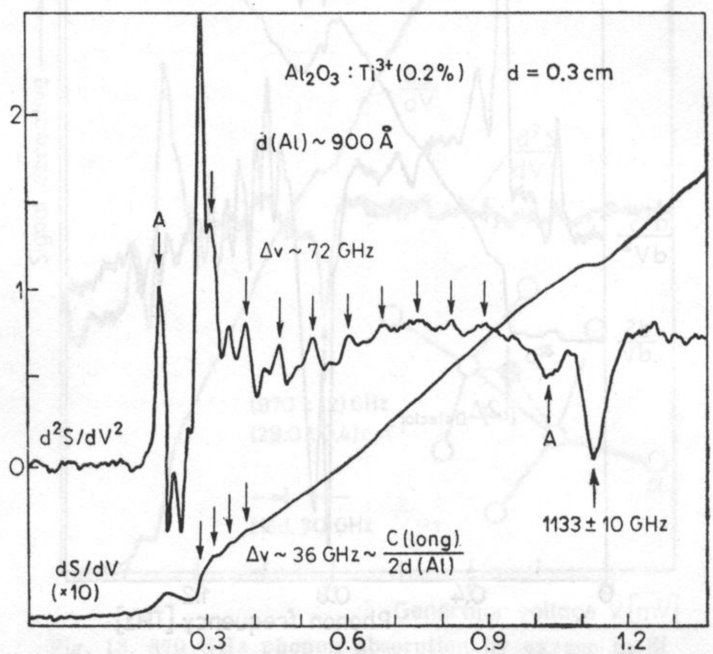


Fig. 15. Acoustical phonon absorption in $Al_2O_3 : Ti^{3+}$ at 1.13 THz ($A$ = precursor, reduced at lower temperature), $\Delta\nu$ = 72 GHz

Generator film thickness resonance modes indicate sound velocity in agreement with bulk values

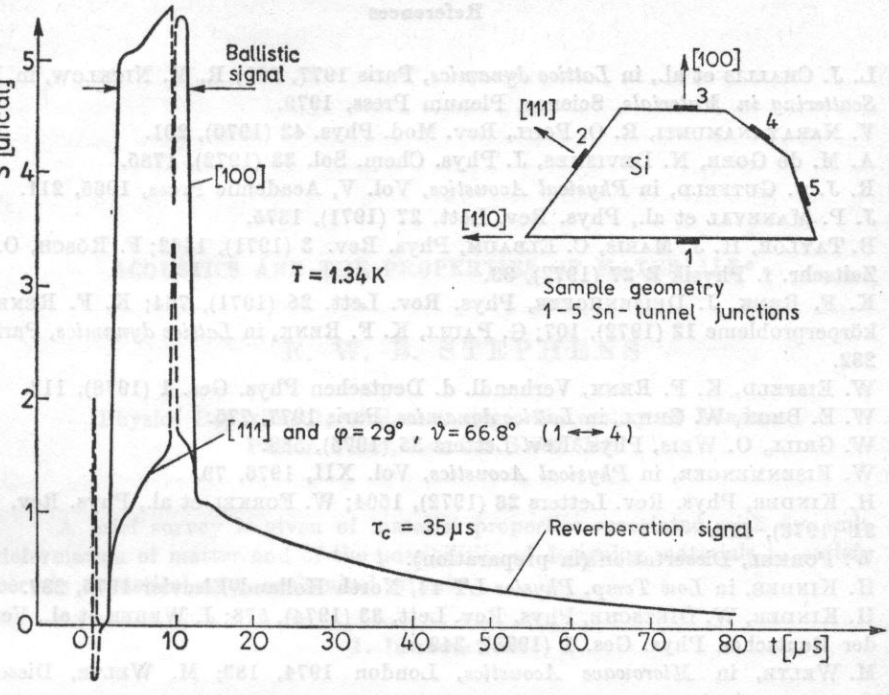


**Fig. 16. Comparison of the ballistic recombination phonon signal (280 GHz) and the phonon reverberation signal for different propagation directions and generator or detector positions under vacuum conditions**

**The (100) and (111) propagation directions differ in the ballistic signal amplitudes as follows from different phonon focussing factors. The reverberation signal amplitudes agree, indicating a homogeneous intensity distribution [17]**

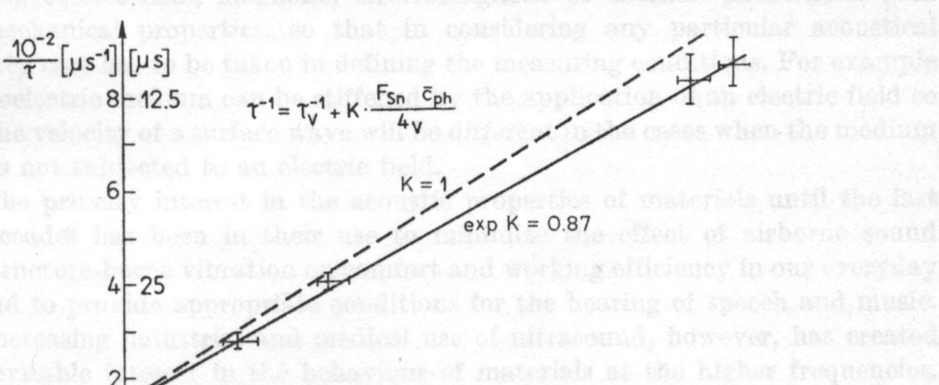


**Fig. 17. The relation between reciprocal reverberation time (280 GHz) and the ratio of the Sn-covered surface area to the Si-crystal volume**

**The resulting experimental absorption constant $K = 0.87$ is in agreement with the ballistic experiments. Further analysis indicates the importance of interface loss processes [17]**

## References


[1] L. J. Challis et al., in *Lattice dynamics*, Paris 1977, 261; R. M. Nicklow, in *Neutron Scattering in Materials*, Science, Plenum Press, 1979.

[2] V. Narayanamurti, R. O. Pohl, Rev. Mod. Phys. **42** (1970), 201.

[3] A. M. de Goer, N. Devismes, J. Phys. Chem. Sol. **33** (1972), 1785.

[4] R. J. v. Gutfeld, in *Physical Acoustics*, Vol. V, Academic Press, 1965, 211.

[5] J. P. Maneval et al., Phys. Rev. Lett. **27** (1971), 1375.

[6] B. Taylor, H. J. Maris, C. Elbaum, Phys. Rev. **3** (1971), 1462; F. Rösch, O. Weis, Zeitschr. f. Physik **B 27** (1977), 33.

[7] K. F. Renk, J. Deisenhofer, Phys. Rev. Lett. **26** (1971), 764; K. F. Renk, Festkörperprobleme **12** (1972), 107; G. Pauli, K. F. Renk, in *Lattice dynamics*, Paris 1977, 232.

[8] W. Eisfeld, K. F. Renk, Verhandl. d. Deutschen Phys. Ges. **1** (1978), 112.

[9] W. E. Bron, W. Grill, in *Lattice dynamics*, Paris 1977, 775.

[10] W. Grill, O. Weis, Phys. Rev. Letters **35** (1975), 588.

[11] W. Eisenmenger, in *Physical Acoustics*, Vol. XII, 1976, 79.

[12] H. Kinder, Phys. Rev. Letters **28** (1972), 1564; W. Forkel et al., Phys. Rev. Letters **31** (1973), 215.

[13] W. Forkel, Dissertation (in preparation).

[14] H. Kinder, in *Low Temp. Physics* LT 14, North Holland/Elsevier 1975, 287.

[15] H. Kinder, W. Dietsche, Phys. Rev. Lett. **33** (1974), 578; J. Weber et al., Verhandl. der Deutschen Phys. Ges. **1** (1978), 349.

[16] M. Welte, in *Microwave Acoustics*, London 1974, 183; M. Welte, Dissertation (in preparation).

[17] H. J. Trumpp, W. Eisenmenger, Z. Physik, **B 28** (1977), 159.


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# ACOUSTICS AND THE PROPERTIES OF MATERIALS*

R. W. B. STEPHENS

Physics Department, Chelsea College, University of London
Pulton Place, London SW6 5PR

A brief survey is given of material properties associated with dynamic deformation of matter and of the possibilities of designing materials to satisfy certain acoustical and mechanical criteria.

## 1. Introduction

The purpose of this paper is to collect together in perspective the existing knowledge of material properties which are involved in the study of acoustics, and so our concern is essentially related with the dynamic properties of a medium. However, these properties can be affected by external agencies through the coupling of electrical, magnetic, electromagnetic or thermal phenomena with the mechanical properties, so that in considering any particular acoustical property care has to be taken in defining the measuring conditions. For example a piezoelectric medium can be stiffened by the application of an electric field so that the velocity of a surface wave will be different in the cases when the medium is or is not subjected to an electric field.

The primary interest in the acoustic properties of materials until the last few decades has been in their use to minimize the effect of airborne sound and structure-borne vibration on comfort and working efficiency in our everyday life and to provide appropriate conditions for the hearing of speech and music. The increasing industrial and medical use of ultrasound, however, has created an inevitable interest in the behaviour of materials at the higher frequencies. At the kernel of such an activity is the piezoelectric transducer and its mechanical properties, and those of the coupling medium to the system under investigations are of vital concern. The bonding medium must possess the optimum acoustical properties for the transmission of the maximum acoustical power

* FASE-78, invited paper, unpublished in the Proceedings.

from the transducer to the test medium and additionally must possess adequate mechanical strength to withstand the applied alternating stresses and temperature cycles. The development of space research has increased the upper limits of the working temperatures required of vibrational-isolating materials and also the need for their mechanical stability at the very high sound pressure levels, i.e. 160 dB or greater, created by rocket engines.

The theoretical understanding of the dynamic mechanical properties of materials may be discussed either phenomenologically or from the atomic or molecular aspect and both points of view are completely understandable only within the range of perfect elasticity, i.e. the material obeys Hooke's law, stress and strain are time independent and strain is completely and instantaneously recoverable upon the release of load. Elasticity theory enables the medium to be completely characterized by a set of elastic moduli to give a satisfactory phenomenological interpretation.

The theoretical calculation of the elastic constants of metals and of ionic crystals from interatomic forces has been carried out and good agreement obtained with experiment only for the simpler solids, but it would seem that the difficulties are of technique and not of principle. More complex are time-dependent phenomena, anelasticity in metals and viscoelasticity in organic materials and glasses, and we are concerned here with stress relaxation, creep and internal friction at very low stresses. It should be stated that the nonlinearity of the stress-strain curves (shear) due to time effects must be distinguished from an inherent non-linearity of stress to strain. Phenomenological theory in the anelastic range appears satisfactory but there is a great difficulty in relating anelastic properties to interatomic forces.

A great deal of progress has been made in relating the viscoelastic properties of polymers to chemical structure, to molecular configuration and to the formation and breaking of bonds and, likewise, the anelastic properties of glass are reasonably understood. Rubber behaves rather uniquely and is described quite successfully by a statistical theory which depends on the analysis of the configurational response of a series of mesh points connected by flexible chains of varying length.

The significant characteristics of the plasticity behaviour of solids is the inherent non-linearity of the shear stress to shear strain together with the large permanent deformations. The time-dependent phenomena of creep and stress-relaxation in the plastic region are time-wise similar to viscoelastic behaviour but not with respect to stress. Large applied stresses often result in a permanent change of material properties referred to as strain or work hardening. The yield stress observed is much lower than theoretically predicted from the forces concerned in the slip and glide of a perfect crystal, and by way of explanation of this divergence the concept of dislocations was proposed and has been used to correlate a number of mechanical properties, although limited in its quantitative aspect. Fracture and strength of a material are probably those mechanical properties about which we have least understanding and it is uncertain whether strength can be described in terms of a true material constant, while fracture is a complicated phenomenon as various processes could lead to disintegration [1].

The liquid state has received less theoretical attention than that of solids as regards structural aspects but there is an increasing interest academically and in industrial and medical applications. The use of sonar and underwater communications in general require a knowledge of the ocean path as regards depth, salinity and temperature pattern, and internal waves could play the part of dislocations in solids and influence beam scattering. A brief mention is only possible of the significance of acoustics in liquid structure. Of all pure liquids only ordinary and heavy water has a positive velocity temperature coefficient, $dV/dT$, at ordinary temperatures, but at 74°C the coefficient has decreased to zero and subsequently becomes negative as for other liquids. This anomalous behaviour is explained as due to the dual presence of a non-associated and close packed form and to an associated form or cluster. According to HALL [2] the compressibility of the latter under acoustic compression is mainly due to the breaking of the hydrogen bonds creating a partial destruction of the associated bulk structure while the compression of the free-space amongst the non-associated water molecules gives the second contribution to the compressibility. On raising the temperature the structural component of the compressibility decreases due to the falling fraction occupied by the cluster state but the other compressibility rises due to increasing inter-distance between molecules, thus leading to a compressibility minimum while at a slightly different temperature a maximum occurs in the sound velocity. Similar cluster phenomena have been observed by LEE KIN TAT [3] in ultrasonic measurements with liquid mercury amalgams (Fig. 1). Air bubbles in water increase the com-

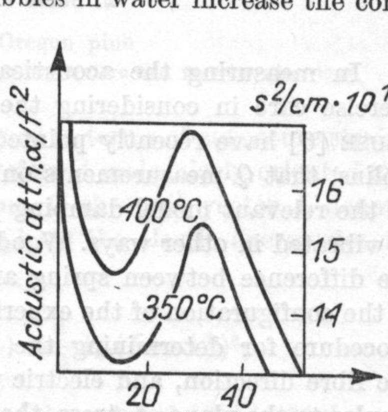


Fig. 1. Cluster phenomena observed in ultrasonic measurements with liquid mercury amalgams

pressibility [5] so that at 50 % concentration the sound velocity reaches a minimum value of 20 $ms^{-1}$ (Fig. 2).

Acoustic relaxation phenomena occur in all forms of matter and the mole-

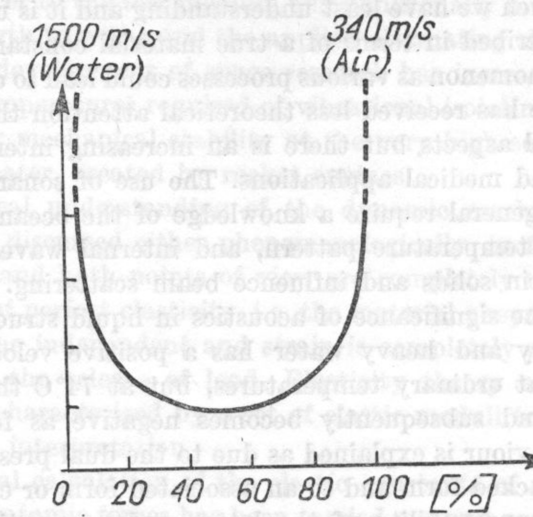


Fig. 2. Velocity of sound in water containing bubbles (after KARPLUS)

cular interaction of oxygen and water vapour is an interesting illustration. The resulting acoustic damping, due to this cause, begins to strongly complete, at around 4 kHz, with the wall and audience absorption in a concert hall. The effect has to be taken into account in experimental acoustic model simulation of auditoria [1, 4].

## 2. Some experimental considerations

In measuring the acoustical parameters of materials it is necessary to exercise care in considering the geometrical aspects. MCINTYRE and WOODHOUSE [6] have recently pointed out, in connection with the construction of violins, that $Q$ measurements on bars are not sufficient by themselves to give all the relevant model damping properties of an isotropic material which is to be vibrated in other ways. Wood is anisotropic and also inhomogeneous due to the difference between spring and summer growths, so care has to be taken in the configuration of the experimental specimen. Fig. 3 indicates the general procedure for determining the piezoelectric polarisation where the $z$-axis is the fibre direction, and electric polarisation takes place in a direction perpendicular to the plane of stress, the sign reversing with the direction of the applied shear. The rectangular coordinates assigned to wood structure are shown in Fig. 3, where $x$ is the radial and $y$ is the tangential direction in tree trunk. The anisotropy of Oregon pine is shown in Fig. 4. Nematic liquid crystals contain unique mobile filaments, so-called *disinclinations* (cf. dislocations of a solid), and optically behave as a uniaxial medium with a centre of symmetry,

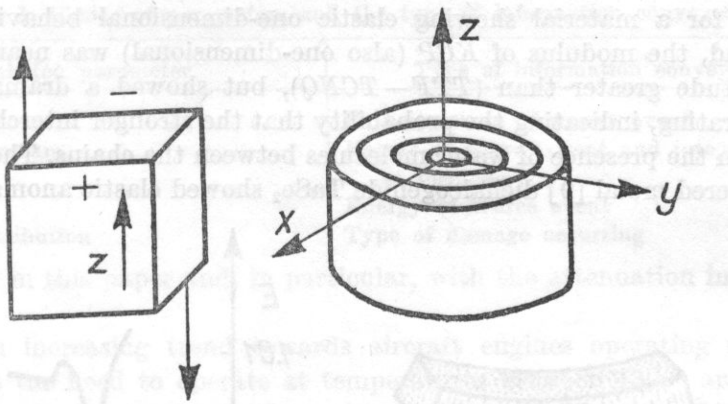


Fig. 3. Piezoelectric polarization rectangular coordinates for wood

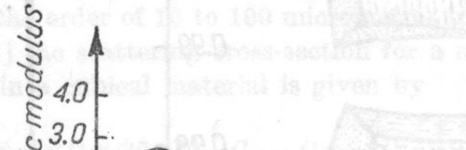


Fig. 4. The anisotropy of Oregon pine

*a* — spring growth, *b* — summer growth, *Φ* is the angle between fibre and pressure directions

so the piezoelectric properties have to be explained in terms of curvature strains. These arise from the spatial variation of the preferred molecularly oriented axis and its departure from its equilibrium position. If the unit vector $L$ denotes the molecular orientation at any point, then [7, 8] the elastic energy density of a deformed nematic is

$$E = \frac{1}{2} k_{11} (\operatorname{div} L)^2 + \frac{1}{2} k_{22} (L \operatorname{curl} L) + \frac{1}{2} k_{33} (L \operatorname{curl} L)^2 ,$$

where $k_{11}$, $k_{22}$ and $k_{33}$ are the elastic constants (of the order of $10^{-5}$ to $10^{-6}$ dyne) of splay, twist and bend, respectively (Fig. 5).

Because of the difficulty of preparing one- and two-dimensional compounds in bulk, BARMATZ employed the vibrating reed technique for determining their elastic constants. The low Young's modulus measured for the one-dimensional ($TTF - TCNQ$) system is consistent with the concept of weak interchain coupling expected for a material showing elastic one-dimensional behaviour. On the other hand, the modulus of *KCP* (also one-dimensional) was nearly one order of magnitude greater than (*TTF – TCNQ*), but showed a dramatic decrease on dehydrating, indicating the probability that the stronger interchain coupling arose from the presence of water molecules between the chains. The two-dimensional layered metal [9] dichalcogenide $TaSe_2$ showed elastic anomalies (Fig. 6),

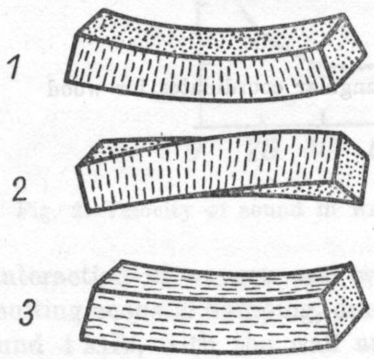


Fig. 5. Distinct curvature of a liquid crystal
1 – splay, 2 – twist, 3 – bend

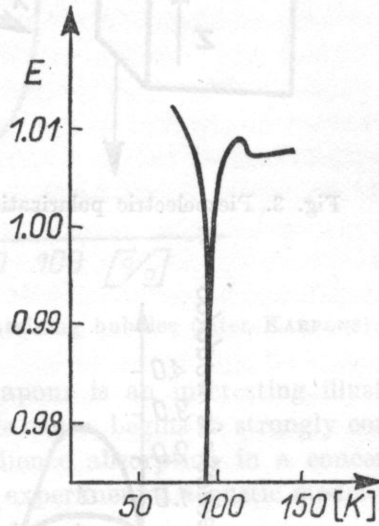


Fig. 6. $E$ modulus normalized to $E_{3000K}$

which were explained in terms of charge density waves, i.e. the periodic variation of the amplitude of conduction electron density coupled to a lattice distortion of the same period.

It is significant to point out that ultrasonic, i.e. dynamic, methods of measurement are made in such short cycling times that negligible creep or plastic strain can occur, which is particularly advantageous for high temperature experiments. However, from an engineering point of view, care has to be exercised in using the data since usually only very small strain amplitudes are employed.

The choice of experimental parameters to be used determines the type of information conveyed as exemplified by those relating to acoustic emission signals [10] as given in Table 1.

### 3. Ultrasonic attenuation in solids

Ultrasonic propagation in crystalline solids may be conveniently divided into two groups, the intrinsic – which is inherent in all solids and involves interaction with phonons and with conduction electrons, and the extrinsic mechanism involving interaction with material defects. It is essentially with the latter that

**Table 1.** Choice of parameters and the type of information conveyed

| Emission parameter | Type of information conveyed |
|---|---|
| Waveform | Fine structure of source event |
| Frequency spectrum | Nature of source event and integrity of specimen |
| Amplitude | Energy of source event |
| Amplitude distribution | Type of damage occurring |

we deal with in this paper and, in particular, with the attenuation in ceramics [11, 12].

With an increasing trend towards aircraft engines operating at higher temperatures the need to operate at temperatures between 1300° and 1400°C demands use of ceramic materials such as silicon nitride or carbide, which possess high strength and thermal shock resistance and also good resistance against oxidation. The problem posed to the acoustics *N.D.T.* operator is how to test defects of the order of 10 to 100 micrometres in the ceramics. According to PAPADAKIS [13] the scattering cross-section for a spherical cross-section for a spherical grain in a cubical material is given by

$$\beta = (8\pi^2 r^6 f^4 p^2/375E^4)\left\{(C_{11}-C_{12}-2C_{44})^2\left[2+3\left(\frac{E}{\mu}\right)^{5/2}\right]\right\},$$

where $C_{ij}$ are the single crystal elastic constants, $f$ is the frequency, $\mu$ — the shear modulus, $p$ — the density, and $E$ — Young's modulus. The equivalent scattering cross-section for a pore is given by YING and TRUELL [14] as

$$\beta = \left(\frac{64}{9}\pi^5\right)\frac{g_c f^4 p^2 r^6}{E^2},$$

where $g_c$ is a function of the elastic properties of the material and has typically values between 5 and 30. It is evident that there is a very strong dependence of attenuation in ceramics on grain or pore radius ($r$) so that the scattering will be dominated by the very large value extreme of the grain or pore size distributions. In comparing pores and grains of equivalent size it is seen from the equations that porosity is likely to be a dominating source of attenuation, also the high modulus and low density of the majority of ceramics help to moderate the attenuation problem. The experiments carried out by TITTMANN [15] on fine grained and fully dense $Si_3N_4$ and SiC indicate that the attenuation is still acceptable at frequencies up to 400 MHz and the frequency dependence is generally smaller than the $f^4$ relation of Rayleigh scattering.

#### 4. Shock waves in solids

This work has so far been concerned essentially with low intensity sound waves but the changed character of the propagation and the response of the medium have long been utilised for investigating molecular phenomena in gases [1]. The generation of shocks in solids, except for some polymeric media [16], requires necessarily the detonation of an explosive in contact with it or the impact of a projec tileon its surface. The step-pressure pulse generated changes shape during propagation as a result of inertial forces derived from the mechanical properties of the medium and these changes have to be interpreted in terms of the properties, analogous somewhat to the use of an electrical pulse to determine the parameters of an electrical network. The use of plane-wave loading simplifies the interpretation of observations, for there is the possibility of phase transformations in the solid also being induced by shock waves, and it was Johnson et al. [17] whose shock experiments first revealed a triple point in the pressure-temperature phase diagrams of iron (Fig. 7).

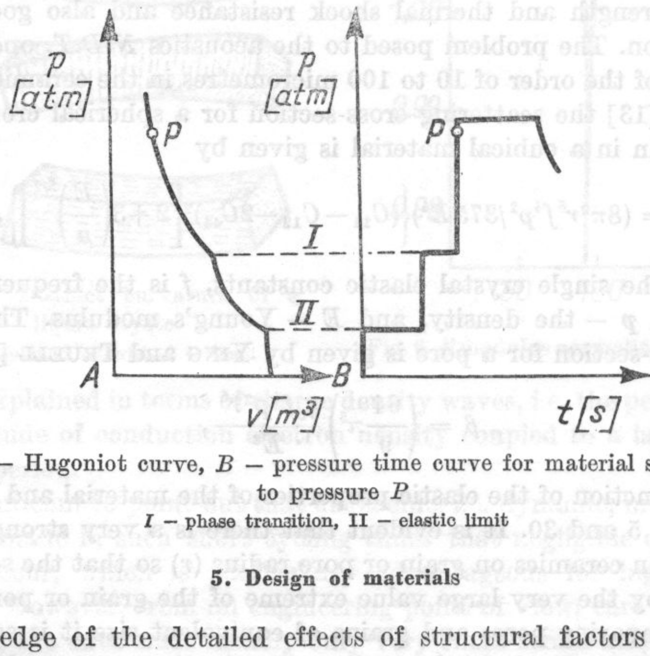


Fig. 7. *A* – Hugoniot curve, *B* – pressure time curve for material shock-excited to pressure *P*
*I* – phase transition, II – elastic limit

### 5. Design of materials

A knowledge of the detailed effects of structural factors upon physical properties can often enable materials to be designed to satisfy particular acoustical requirements, and in Table 2 some possible means are given, whereby temporary or permanent changes can be brought about in the normal behaviour of a material.

As pointed out recently by WIRT [34] bulk absorbing materials are not very suitable, for example in aircraft, with its specific constraints of high temperature, vibration and space. He has suggested new forms of sound absorbing structure employing a number of acoustical elements in both parallel and series. Amongst the various new materials that offer exciting possibilities let us mention metallic glasses which are effectively metals in which the atoms have the random structure of a liquid but retain the close packing of a solid. They are generally extremely hard with tensile strengths greater than good stainless steels. The absence of grain boundaries is evident in their low ultrasonic attenuation [35].

**Table 2.** Means of bringing about changes in behaviour of a material

| Process or agency | Application |
|---|---|
| Stressing of solid | Hardening of material (increase of elastic modulus), also inducement of residual compressive stresses for alleviation of fretting fatigue [1] |
| Nuclear irradiation | Gamma irradiation of polyethylene changes structure to rubbery and, with increased dosage, to brittle solid [18, 19] |
| Ion implantation | Applied to surface wave devices crystalline structure is disturbed and causes velocity change, of opposite sign in quartz and lithium niobate (Fig. 8) [20, 21] |
| Varying crystal growth rate | Control of $Q$ of synthetic quartz crystal (Fig. 9) [22] |
| Use of external agencies | Illumination of acoustic amplifier semi-conductor to control electron velocity. Modifying acoustic propagation in liquid crystal by applied electric field [23] |
| Temperature variation | Changes velocity, acoustic impedance etc. Utilised in BELL's acoustic thermometer [24] |
| Compounding of media | Carbon fibres in plastic change acoustic character as well as mechanical strength and density. Also use of Cork particles in rubber isolator [26, 25] (Fig. 10) |
| Introduction of a second phase | Varying carbon content in steel alters acoustic damping. Damping in water also increased by presence of salts [27, 28] |
| Graded material | In absorbers for underwater use the medium is modified in a gradual manner through its thickness, e.g. by mixing a rubberlike material with fillers like graphite and air-containing substances like sawdust [29] |
| Monomolecular layers | Formation on liquid surfaces leads to increased damping of surface waves [30] |
| By change of material geometry | The addition of ribs to vibration isolators increases their stiffness. Also compounding of vibration absorption mountings. Use of wedges in anechoic rooms [32]. Rubber tubing containing air for pressure release absorbers [33, 31] |

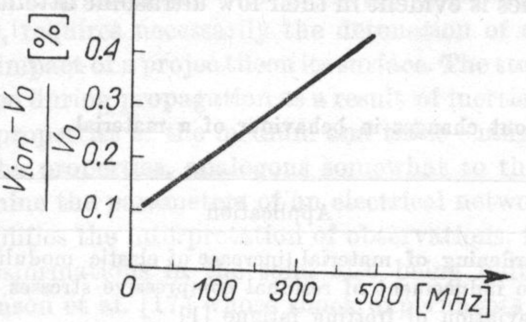


**Fig. 8. He and Li ions in quartz**

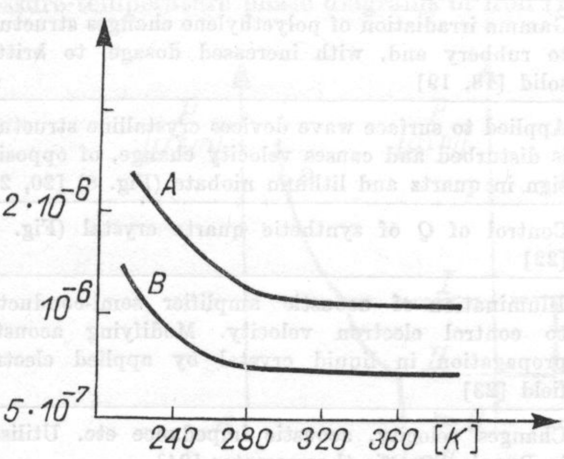


**Fig. 9. $Q^{-1}$ of synthetic quartz and growth rate**

**curve $A$ – 0.55 mm per day, curve $B$ – 0.25 mm per day (Jones and Brown)**

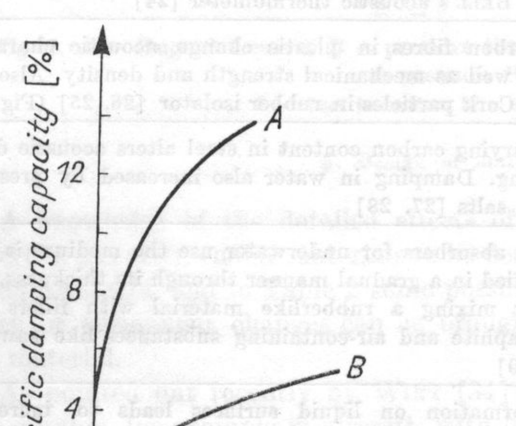


**Fig. 10. Damping in cast irons (Fox and Adams)**

**$A$ – coarse flake graphite, $B$ – fine flake graphite, $C$ – modular graphite**

## General References

[1] Ultrasonic Methods in Solid State Physics; TRUELL, ELBAUM and CHICK, Academic Press: *Physics of Rubber Elasticity*; TRELOAR, Oxford Univ. Press: *Structural Characteristics of Materials*; Elsevier Pubn. Co.; *Anelastic Relaxation in Crystalline Solids*; NOWICK and BERRY, Academic Press: *Acoustics and Vibrational Physics*; STEPHENS and BATE, Arnold Ltd.: *Liquid Crystals*; CHANDRASEKHAR, Cam. Univ. Press: *The Structure of Matter*; CHRISTY and PYTTE, Benjamin Inc.: *Internal Friction of Structural Defects in Crystalline Solids*; BATIST, North Holland Pubn.: *Physical Ultrasonics*; BEYER and LETCHER, Academic Press: *Elasticity and Anelasticity of Metals*; ZENER, Univ. of Chicago Press.

## Special References

[2] L. HALL, Phys. Rev., **73**, 772 (1948); O. NOMOTO and H. ENDO, Chem. Soc. Japan, **43**, 2715 (1970).
[3] LEE KIN TAT and R. W. B. STEPHENS, *Ultrasonic Intl.*, London 1973.
[4] V. O. KNUDSEN, JASA, **5**, 112 (1933), H. O. KNESER, Z. Tech. Phys., **16**, 213 (1935).
[5] H. B. KARPLUS and J. M. CLINCH, JASA, **36**, 1040 (1964).
[6] M. E. McINTYRE and J. WOODHOUSE, Acustica, **39**, 209 (1978).
[7] E. FUKADA, Wood Science and Techy., **2**, 299 (1968).
[8] T. F. NORTH, W. G. B. BRITTON and R. W. B. STEPHENS, *Ultrasonics Intl. Proc.*, 1975.
[9] M. BARMATZ, I. E. E. E., Ultrasonics Symp. Proc. 1974.
[10] R. W. B. STEPHENS and A. A. POLLOCK, JASA, **50**, 904 (1971).
[11] L. ELBAUM, Ultrasonics, **7**, 113 (1969).
[12] B. and H. JAFFE and W. R. COOK, *Piezoelectric ceramics*, Academic Press, 1971.
[13] E. M. PAPADAKIS, JASA, **37**, 711 (1965).
[14] C. S. YING and R. TRUELL, J. App. Phys., **27**, 1086 (1956).
[15] B. R. TITTMANN et al., IEEE Ultrasonics Symp. Proc. 1976, 653.
[16] G. E. DUVALL and R. A. GRAHAM, Rev. Modern Physics, **49**, 523 (1977).
[17] P. C. JOHNSON, B. A. STEIN and R. S. DAVIS, J. App. Phys., **33**, 557 (1962).
[18] A. CHARLESBY and E. FUKADA, *Rheology of elastometers*, Pergamon Press.
[19] A. RADY, Ph. D. Thesis, 1956 (Univ. of London).
[20] P. HARTEMANN and M. MORIZOT, I. E. E. E. Ultrasonics Symp. 1974.
[21] HANG-SHEN TUAN, I. E. E. E. Trans. Sonics, S-U **23**, 4, 232 (1976).
[22] C. K. JONES and C. S. BROWN, Proc. Phys. Soc., **79**, 930 (1962).
[23] A. R. HUTSON and D. L. WHITE, J. Appl. Phys., **33**, 40 (1962).
[24] J. W. F. BELL, Ultrasonics, **6**, 11 (1968).
[25] D. E. W. STONE and B. CLARKE, N. D. Testing J., **8**, 137 (1975).
[26] *Noise and Vibration Control*, ed. L. L. BERANEK, McGraw-Hill.
[27] M. A. O. FOX and R. D. ADAMS, J. Iron and Steel Inst., 527 (1972).
[28] L. N. LIEBERMANN, JASA, **20**, 868 (1948).
[29] K. TAMM, *Technical aspects of sound*, Vol. II, Elsevier, 1957.
[30] J. C. SCOTT and R. W. B. STEPHENS, JASA, **52**, 3 (1972).
[31] J. C. SNOWDON, *Vibn. and shock in damped mechanical systems*, Wiley.
[32] J. W. HEAD, Brit. J. Appl. Physics., **16**, 1009 (1965).
[33] U. ULKU, D. I. C. Thesis, Imperial College, 1967.
[34] L. S. WIRT, JASA, **57**, 1 (1975).
[35] G. and D. TAYLOR, New Scientist, 12 Aug. 1976.

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# CERTAIN PROBLEMS OF NOISE ANNOYANCE*

AURELIAN STAN

Acoustical Committee, Rumanian Academy of Sciences
Calea Victoriei 125, Bucharest, Romania

Of many objective and subjective problems connected with noise annoyance the present paper presents the results of investigations concerning the following issues:

1. Dependence of the effectiveness of an acoustic baffle on the kind of closed space in which it has been placed.
2. Economic effects of measures taken to diminish noise inside a closed space.
3. Correlation between certain annoyance indices TNI and LNP and $\sigma$, and the presentation of results of statistical traffic noise measurements.

Many theoretical and experimental works have discussed the diminution of the sound level by acoustic baffles placed in free space. It seems sufficient to mention here only a synthetic review work [1] and the proceedings of a seminar on the acoustic protection of residential zones with baffles [2]. Much less research has been devoted to baffle activity in closed rooms [3-5]. In order to determine baffle efficiency in open and closed spaces, one should consider equation (1) for the baffle attenuation in a free field,

$$\Delta L_e = 10\lg\frac{|P_E^2|}{P_D^2} = 10\lg\frac{4}{N^2} = 6-10\lg N^2, \tag{1}$$

where $P_E$ and $P_D$ are the acoustic pressures measured at the same point with baffle and without it,

$$N^2 = \{[C(u_2)-C(u_1)]^2+[S(u_2)-S(u_1)]^2\}\times \times\{[C(v_2)-C(v_1)]^2+[S(v_2)-S(v_1)]^2\}, \tag{2}$$

$$u = y\sqrt{\frac{2}{\lambda}\cdot\frac{1}{x_r}},\quad v = z\sqrt{\frac{2}{\lambda}\cdot\frac{1}{x_r}},$$

* FASE-78, invited paper, unpublished in the Proceedings.

$C$ and $S$ being the Fresnel functions, $u$ and $v$ — the Fresnel parameters and $x_r$ — the distance (Fig. 1) defined by the relation

$$\frac{1}{x_r} = \frac{1}{x_s} + \frac{1}{x_0}$$

and $\lambda$ denoting the wavelength.

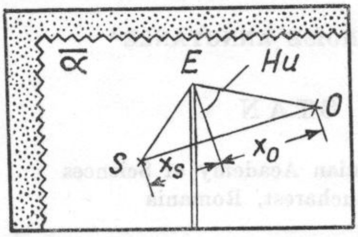


Fig. 1. A baffle in a closed space

In a closed space the insertion attenuation of a baffle $E$ placed between a source $S$ and an observer $O$ can be expressed [3] by

$$\Delta L_r = 10\lg\frac{I_{\rm d}+I_{\rm rev}}{I_{\rm dif}+I_{\rm rev}}, \tag{3}$$

where $I_{\rm d}+I_{\rm rev}$ is the acoustic intensity measured at an observation point without the baffle, as the sum of the sound intensity from the direct field $I_{\rm d}$ and the intensity from the reverberent field $I_{\rm rev}$, which have the following values:

$$I_{\rm d} = \frac{P}{4\pi(x_s+x_0)^2}, \quad I_{\rm rev} = \frac{4}{\pi}P.$$

The sum of $I_{\rm dif}+I_{\rm rev}$ is the sound level at the same point with the baffle and consists of a diffracted wave field intensity

$$I_{\rm dif} = I_e\left(\frac{x_r}{2x_0}N\right)^2$$

and a reverberent field sound intensity for the changed conditions of $I_{\rm rev}$, $I_e$ being the sound intensity in front of the baffle, $P$ — the sound power of the source, and $R = S\alpha/(1-\alpha)$ is the acoustic absorption of the enclosure (room).

One can thus write relation (3) in the following way:

$$\Delta L_r = 10\lg\frac{4}{N^2}\,\frac{1+4\pi(x_s+x_0)^2/R}{1+16(x_s+x_0)^2/N^2R}. \tag{4}$$

Since equation $10\lg(4/N^2) = \Delta L_e$ is the baffle insertion loss attenuation in a free field (1), relation (4) may be written as

$$\Delta L_r = \Delta L_e - \Delta L_c, \tag{5}$$

where $\Delta L_c$ is the insertion attenuation loss correction of a baffle in a closed space:

$$\Delta L_c = 10\lg \frac{1+4\pi(x_s+x_0)^2/R}{1+16(x_s+x_0)^2/N^2} \frac{\varrho}{R}. \tag{6}$$

From relation (6) one can draw the following conclusions:

a. In an anechoic chamber ($\alpha = 1$, $R = \infty$), $\Delta L_c = 0$, the acoustic conditions correspond to those in a free field in which

$$L_r = L_e. \tag{7}$$

b. In the case of a reverberent space ($\alpha = 0$, $R = 0$)

$$\Delta L_c = -10\lg \frac{4}{N^2} = \Delta L_e,$$

therefore $\Delta L_r = 0$, and thus the baffle causes no additional attenuation.

In order to show changes in the attenuation correction for a semi-infinite baffle placed in a semi-reverberent chamber, the value of this parameter was calculated for various values of $R$ in the range of 50-1000 m² and for different distances $SO$ between the source and the observer, $SO = x_0 + x_s$ in the range of 2-14 m. The results of these calculations are shown in Figs. 2 and 3. The

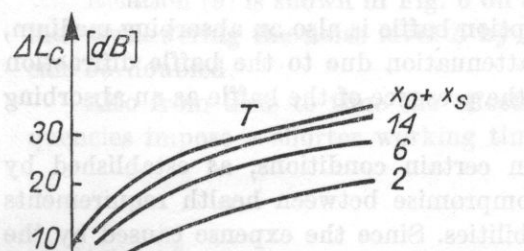


Fig. 2. Correction $\Delta L_c$ as a function of the parameter $V$, $R = 1000$ m²

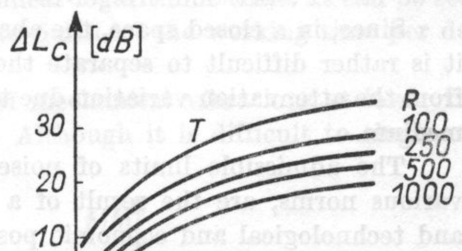


Fig. 3. Correction $\Delta L_c$ as a function of $V$ for $x_s + x_0 = 2m$ and various values of $R$

values calculated for the expression $N^2$, as a function of the parameter $V$, are given in Table 1.

It follows from Fig. 2 that for given values of $R$ and $V$ the correction $\Delta L_c$ increases with increasing distance between the source and the observer, whereas

**Table 1.** Values calculated for the expression $N^2$ as a function of the parameter $V$

| $V$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N^2$ | 0166 | 0050 | 00224 | 00126 | 000795 | 00055 | 000417 | 00316 | 00251 | 000198 | 000158 |

it follows from Fig. 3 that for a fixed distance $SO$ and a given value of $V$, the correction $\Delta L_c$ decreases with increasing $R$. Fig. 4 shows the attenuation variation $\Delta L$ as a function of various parameters. Thus, for long distances between the source and the observer, the attenuation is almost independent of the acoustic absorption of a room, whereas for, short distances $x_0+x_s$, the attenuation $\Delta L$ increases rapidly with increasing $R$.

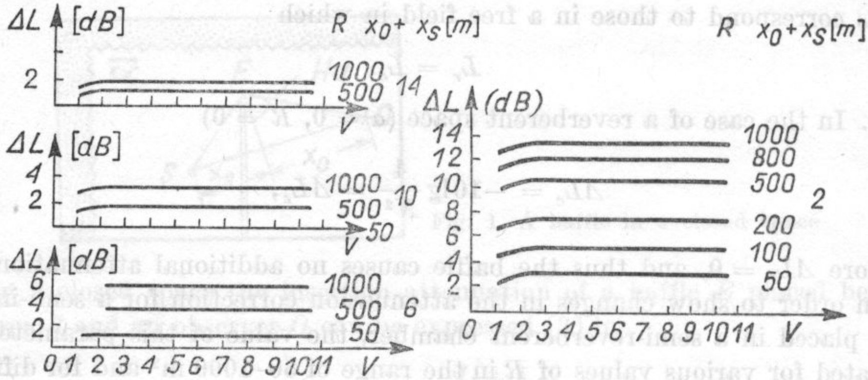


Fig. 4. Attenuation correction $\Delta L$ as a function of $V$, $R$, for various distances between the source and the observer

Since, in a closed space, the absorption baffle is also an absorbing medium, it is rather difficult to separate the attenuation due to the baffle diffraction from the attenuation variation due to the presence of the baffle as an absorbing medium.

The admissible limits of noise in certain conditions, as established by various norms, are the result of a compromise between health requirements and technological and economic possibilities. Since the expense caused by the effects of noise is very large, noise also has to be analyzed from an economic point of view. There are general, direct and indirect expenses [7-9], including:

expenses for the periodic checking of the level of noise and vibration in different places of work, comprising the cost of adequate apparatus and trained personnel;

time wasted by skilled personel who are employed in medical check up, as well as the shortage and variation of staff due to the changing of jobs to those that are less noisy;

a loss of capital invested in the former and new jobs;

sums paid as allowances for work in very noisy conditions, premature pensions or damages for possible accidents on the job due to the effect of noise and vibration.

These sums should be enlarged by losses due to a lower output on the job and a poorer quality of product. There are still a number of machines and equipment whose operational noise cannot be lowered to the limits established by the various norms without large expense. The cost of solutions leading to improving the acoustic conditions of such a job may be represented as the cost of diminishing the noise by 1 dB as a result of the solution adopted or by comparison of the expense necessary to lower the noise and vibration level to the overall investment cost.

It seems that in the analysis of economic issues other factors should also be considered, e.g. the diminished percentage of hearing loss risk (Fig. 5), the increase of effective working time due to diminished noise, and increased production following increased individual output. The measures taken to lower the level of equivalent noise decrease the hearing loss risk, which has not only social, but also economic significance.

The admissible value of the noise level for an 8-hour day is known to be the level $L_{eq}$ equal to 90 dB(A). If the noise level $L > 90$ dB(A) for 8 working hours, the time of exposure to noise should be shortened to make the danger to hearing the same as that at 90 dB(A).

The relation between the noise level $L$ and the exposure time $t$, in hours, can be expressed by

$$L = L_{eq} + \Delta L = 90 + k \lg \frac{8}{t}, \tag{9}$$

where $10 \leqslant k \leqslant 20$.

Relation (9) is shown in Fig. 6 on a linear-logarithmic scale. It can be seen that by lowering the noise level $L$ by 3 to 5 dB(A), the working time per day can be doubled.

Also from time to time the effects of mechanical vibrations at lower frequencies impose a shorter working time. Although it is difficult to single out

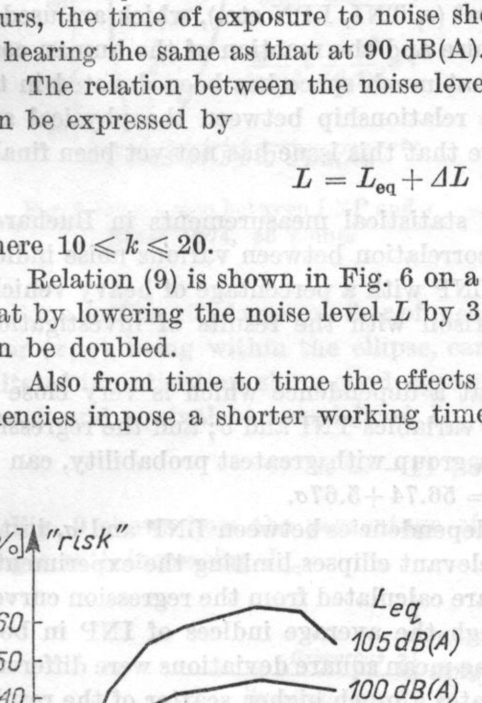


Fig. 5. The variation of the hearing loss risk

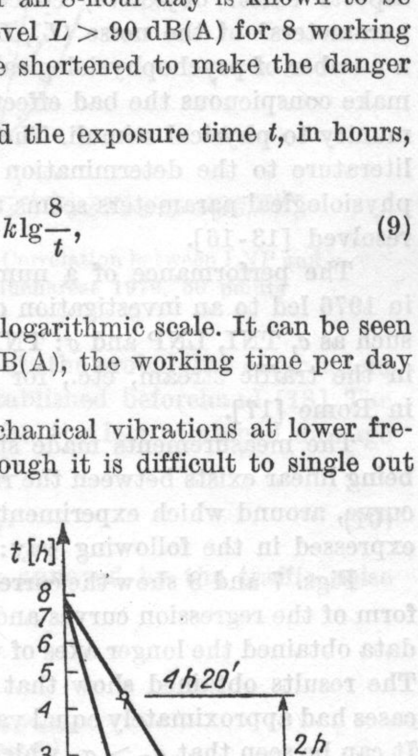


Fig. 6. Relation between the noise level $L$ and the admissible working time $t$

productivity from the set of factors occurring in the process of material production, nevertheless, our investigations have given some interesting results concerning this issue. Thus, in a weaving plant room, where the total noise intensity was 100 dB, an increase in productivity of 2-3% was achieved, together with working time lengthened by over 3 hours.

In summary, it should be stated that in order to correctly estimate the economic efficiency of the measures taken to diminish noise and vibration, one should also take into consideration the increased production due both to a higher productivity and a longer working day in the noise, as well as the diminished hearing loss risk.

In the analysis of problems posed by transport noise the two following aspects exist: objective, concerning the determination of certain physical parameters[1] of the noise ($L_i, L_{10}, L_{50}, L_{eq}, \sigma$) and subjective, connected with a number of psychophysiological factors[2] ($c$, TNI, LPN etc.), which are used to make conspicuous the bad effects of noise and the reaction of the human community to physical stimuli. The fact that much space has been devoted in the literature to the determination of the relationship between the physical and physiological parameters seems to prove that this issue has not yet been finally resolved [13-16].

The performance of a number of statistical measurements in Bucharest in 1976 led to an investigation of the correlation between various noise indices such as $c$, TNI, LNP and $\sigma$: TNI and LNP with a percentage of heavy vehicles in the traffic stream, etc., for comparison with the results of investigations in Rome [17].

The measurements made show that a dependence which is very close to being linear exists between the random variables TNI and $\sigma$; and the regression curve, around which experimental data group with greatest probability, can be expressed in the following way: TNI $= 56.74 + 5.67\sigma$.

Figs. 7 and 8 show the correlative dependencies between LNP and $\sigma$, in the form of the regression curves and the relevant ellipses limiting the experimental data obtained the longer axes of which are calculated from the regression curves. The results obtained show that although the average indices of INP in both cases had approximately equal values, the mean square deviations were different. It can be seen that $\sigma_B > \sigma_R$ which indicates a much higher scatter of the results in the first case. It may have been caused by a greater variety of vehicle types, their technical defects or by vehicles travelling without a synchronized traffic light system, the so called "green wave".

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[1] $L_i$ is noise level exceeding respectively $i$ % of the measurement time,

$$L_{eq} = 10\lg[\Sigma f_j 10 L_j/10], \text{ where } f_j = \left(\sum t_j\right)/T,$$

$\sum t_j$ being the total time for which the noise level belongs to class $j$, and $T$ — the total measurement time.

[2] $c = L_{10} - L_{90}$; TNI $= L_{90} + 4c - 30$; LNP $= L_{50} + c + c^2/50$.

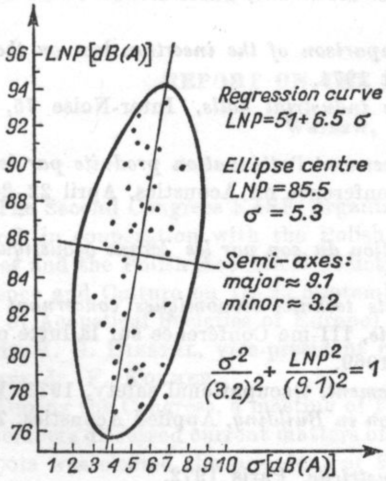


Fig. 7. Correlation between LNP and $\sigma$, Rome 1974, 46 points

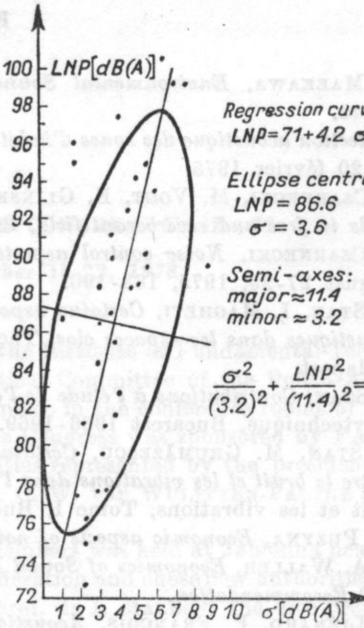


Fig. 8. Correlation between LNP and $\sigma$, Bucharest 1976, 60 points

For a sufficiently large number of measurements the probability of a random vector $(x, y)$, being within the ellipse, can be established beforehand [18]. The results of investigation show good agreement with the law combined damage index $R$ and equivalent sound level $L_{\mathrm{eq}}$ [19, 20]:

$$R = -11 + 8.3 \lg L_{\mathrm{eq}}. \tag{10}$$

Fig. 9 shows how the percentage of people annoyed by the traffic noise changes with increasing $L_{\mathrm{eq}}$.

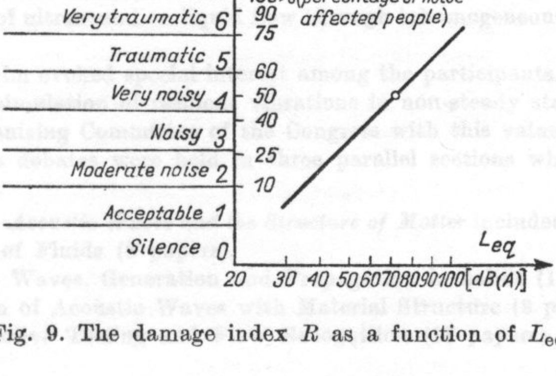


Fig. 9. The damage index $R$ as a function of $L_{\mathrm{eq}}$

**References**

[1] Z. Maekawa, *Environmental Sound Propagation*, ICA 8 (1974), Invited Lectures, 29-46.

[2] *Protection acoustique des zones d'habitation par des écrans*, Table Ronde CNRS Marseille, 18-20 février 1975.

[3] S. Czarnecki, M. Vogt, E. Glińska, *Comparison of the insertion loss on the barrier walls in free and reverberant field*, Budapest 1974.

[4] S. Czarnecki, *Noise control aspects inside industrial halls*, Inter-Noise 75, Sendai, August 27-29, 1975, 183-190.

[5] A. Stan, I. Magheti, *Certains aspects concernant l'atténuation produite par les écrans acoustiques dans les espaces clos*, The 6th Conference on Acoustics, April 22-26, 1976, Budapest.

[6] A. Stan, *Contributions à l'étude de l'atténuation du son par les écrans acoustiques*, Inst. Polytechnique, Bucarest 1966-1969.

[7] A. Stan, M. Grumăzescu, *Certains aspects technico-économiques concernant la lutte contre le bruit et les vibrations dans l'industrie*, III-me Conférence sur la lutte contre le bruit et les vibrations, Tome I, Bucarest 1969.

[8] Cz. Puzyna, *Economic aspects of noise abatement*, Occupational safety, 1973, Warsaw.

[9] R. A. Waller, *Economics of Sound Reduction in Building*, Applied Acoustics, **7** (1968).

[10] *ISO-Recommendation.*

[11] P. Liénard, P. François, *Acoustique industrielle*, Paris 1972.

[12] *ISO-Recommendation*, 2631-1974.

[13] I. D. Griffiths, F. J. Langedon, *Subjective response to rock traffic noise*, Building Research Station, Paper 37, 38, 1968.

[14] D. R. Aubrée, *La gêne causée par le bruit de circulation à Paris*, 7 Congress ICA, Budapest 1971.

[15] G. L. Fuchs, *Objective and subjective evaluation of rooms*, 9 Congress ICA, Madrid 1977.

[16] G. Vulkan, *Traffic noise index*, Journal of Sound Vibration, **11**, 475-476.

[17] C. B. Cannelli, *Traffic noise pollution in Roma*, Applied Acoustics, **7**, 2 (1974).

[18] A. Stan, T. Stănăsilă, *Quelques aspects concernant le degré de gêne du bruit produit par le traffic*, ETAN XXI Jugoslovenska Konferencija Banja-Luka, 6-10, 1977.

[19] M. de Silva, *Urban noise evaluation*, 9 Congress ICA, Madrid 1977.

[20] R. Gambard, *The Meaning of Correlation Coefficients in Annoyance*, Acoustica, **33**, 351-352 (1975).

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## REPORT ON THE SECOND CONGRESS FASE - 78

**Warsaw, September 18-22, 1978**

The Second Congress FASE, organized by the Institute of Fundamental Technological Research in cooperation with the Polish Acoustical Committee of the Polish Academy of Sciences and the Polish Acoustical Society took place in the conference rooms of the Palace of Science and Culture on 18-22 September. The Congress was sponsored by FASE (Federation of Acoustical Societies of Europe) authorities represented by the president of FASE prof. dr. H. G. Diestel, vice-president prof. dr. O. W. van Wulfften-Palthe and FASE secretary dr. F. Kolmer.

During the Congress, a meeting of FASE members was held at Jabłonna near Warsaw. The members discussed current matters of the Federation and chose new authorities. Dr. Paul François was elected the president of FASE, prof. dr I. Malecki the vice-president and dr. F. Kolmer was reelected as the secretary.

320 scientists from all over the world participated in the Congress. They represented 22 countries namely: Great Britain, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, France, Greece, GDR, GFR, Holland, Hungary, Iran, Italy, Japan, Poland, Roumania, Spain, Sweden, USA, USSR and Yugoslavia.

The number of the Polish participants amounted to 153 persons, the number of foreign participants — to 167 persons.

The number of papers amounted to 174 including 1 plenary, 11 invited, 118 contributed and 44 poster form papers.

During the opening ceremony, chaired by the President of the Congress prof. dr. Stefan Czarnecki, several speeches were presented by: prof. dr Ignacy Malecki, vice-president of the Polish Academy of Sciences prof. dr. A. Trautman and FASE president prof. dr. H. G. Diestel. Finally, prof. dr. I. Malecki presented a plenary paper entitled "How the structure of matter is seen by the acoustic waves".

After the opening ceremony the participants saw three films:

1. Fragments of 9th ICA Congress, Madrid, 1977.
2. Computer simulation of elastic waves from transducer: a) longitudinal waves, b) transversal waves — K. Harumi, T. Saito, T. Fujimori (Japan).
3. Influence of ultrasound on liquid flow through inhomogeneous media — H. V. Fairbanks (USA).

The second film evoked special interest among the participants. It presented, in a demonstrative way, simulation of resilient vibrations in non-steady state. The Japanese side presented the Organizing Committee of the Congress with this valuable film.

The Congress debates were held in three parallel sections which were divided into particular sessions.

Section I — *Acoustic Waves and the Structure of Matter* included the following session:

1. Acoustics of Fluids (8 papers).
2. Ultrasonic Waves. Generation and Propagation in Solids (15 papers).
3. Interaction of Acoustic Waves with Material Structure (8 papers).
4. Nondestructive Testing and Flaw Recognition (13 papers).

5. Materials characterization (15 papers).

Section II – *Ultrasonic Methods of Location and Recognition* was divided into following sessions:

1. Wave Propagation.
2. Ultrasonic Diagnostic Methods.
3. Holography and Optical Methods in Acoustics.
4. Underwater Acoustics (4 papers).
5. Geoacoustics (5 papers).
6. Transducers (8 papers).

Section III – *Objective and Subjective Evaluation of Sound in Limited Space* dealt with the following groups of problems:

1. Concert Halls and Auditoria (18 papers).
2. Industrial Halls (8 papers).
3. Urban Areas (16 papers).
4. Methods of Measurements and Subjective Evaluation (11 papers).

Broadly understood problems of nondestructive testing were the most popular among the participants of Section I and the topics discussed involved not only flaw recognition of material macrostructure but also attempts at quantitative evaluation of it and analysis of physical state of materials.

The problem of material cracking was another important subject of Section I.

Moreover, Section I dealt with development of research on generation of acousto-electric waves and phenomena accompanying it as well as with investigations of liquid relaxation and generation of acoustic waves by means of lasers.

In Section II the greatest attention was devoted to the theme of ultrasonic diagnostic methods, understood in a broad sense. It not only included new methods of this quickly developing scientific field but also a number of fundamental problems in the field of ultrasonic waves propagation in biological media as well as construction of piezoelectric transducers.

The popularity of this theme is justified by both tradition of Polish research which has investigated this field for several years as well as rapid progress of ultrasonic diagnostic methods all over the world. According to current prospects these methods will be soon as widely used in medicine as X-ray methods nowadays.

Several interesting papers dealing with underwater acoustics and geoacoustics completed the section forming a synthetic view of ultrasonic methods applied in detection and recognition of objects of different kinds.

During the debates of Section III a series of lectures were devoted to the problems which joined psychoacoustics and interior acoustics. They presented interrelation of objective measurement methods and subjective evaluation. Such interrelation is especially important when acoustical conditions differ from the statistic theory. Most of the papers touching the problem of subjective evaluation dealt with speech for which it was easier, compared with music for example, to have a selection of quantitative criteria.

Significant development of research based on computer simulation and the latest measurement methods were characteristic factors of the III Section lectures.

## Section I

### Acoustics of Fluids

L. M. Liamshev, *Laser Generated Sound in Liquid* (invited paper).

R. Płowiec, *Viscoelastic Relaxation Region in some Natural and Synthetic Oils* (poster form).

E. Soczkiewicz, *Propagation of Ultrasound and Hole Volumes in the Hole Theory of Liquids.*

K. Takagi, K. Negishi, *Study of Vibrational Relaxation in Liquid Pyridine by High-Resolution Bragg Reflection Method.*

E. Yaronis, A. Voleisis, B. Voleisiene, *Interferometric Studies of Ultrasound Velocity Dispersion in Aqueous Solutions of Lanthanide Salts.*

A. Juszkiewicz, J. Kopyłowicz, Z. Kozłowski, *Measurements of some Anomalies in the Propagation of Ultrasonic Waves in Pure Water.*

L. Werlban, L. Skubiszak, *Properties of Mixtures of Gamma-Butyrolactone with Selected Ethers and Water Fixed by Ultrasonic Methods.*

## Materials Characterization

R. W. B. Stephens, *Acoustics and Material Properties* (invited paper).

L. Fröhlich, W. Morgner, Z. Pawłowski, *Applications of Acoustic Methods to Assess Material Structure* (poster form).

S. Kozakowski, *Effect of Internal Stresses in Castings on the Changes in Ultrasonic Wave Velocities* (poster form).

A. Kulik, J. Ryll-Nardzewski, *Applications of Flexural Vibrations of Thick Circular Plates in Physical Examinations of Solids* (poster form).

H. Gawda, *Ultrasonic Investigations of the Mechanical Properties of Stalks of Wheat* (poster form).

A. Brokowski, *Remarks upon the Lateral Displacement at Rayleigh and Lamb Critical Angle* (poster form).

A. Pilarski, Z. Pawłowski, *Bond Strength Evaluation with Ultrasonic Method* (poster form).

B. Peńsko, L. Filipczyński, *Ultrasonic Method and Apparatus for Fatigue Testing of Steal Wires* (poster form).

K. A. Kunert, Z. Kozłowski, *Ultrasonic Investigation of Cross-Linked Polyethylene* (poster form).

J. Lewandowski, J. Ranachowski, E. Ryll-Nardzewska, *Ultrasonic Method of Mechanical Properties Estimation of Ceramic Materials.*

Z. Pawłowski, G. Funke, *Evaluation of Fracture Risk with Ultrasonic Method.*

Z. T. Kurlandzka, *Brittle Fracture of Elastic Dielectric in Presence of Electromagnetic Forces.*

K. Elek, J. Granat, P. Pfeliegel, *Measurement of the Complex Young's Modulus on Samples of Annular Discs, e.g. Grinding Wheels.*

J. Lewandowski, *Scattering of Compression Acoustic Waves in Inhomogeneous Media.*

## Ultrasonic Waves. Generation and Propagation in Solids

D. Sette, *Sound in Liquid Crystals* (invited paper).

R. Leć, *Piezoelectric Properties of $LiIO_3$ Crystals* (poster form).

V. K. Nguyen, W. Pajewski, *Generation of the Acoustoelectric Wave by Means of the Shear Vibrations Source* (poster form).

A. Byszewski, A. Drzewiecka, M. Szustakowski, *Applications of Optical Reflected Method for Surface Acoustic Waves.*

W. Ciurapiński, K. Goździk, M. Szustakowski, B. Swietlicki, *Acousto-optic Diffraction of Light in Thin Plates of Lithium Niobate Single Crystals.*

L. Solarz, *Diffraction of Surface Waves on a Waveguide.*

T. S. Liem, *Electromagnetic Acoustic Transducer in Non-Destructive Testing of Metals.*

S. Kolnik, J. Klimko, *Electromagnetic Generation of Ultrasonic Surface Waves a Perturbed Boundary Conditions.*

P. Loranc, M. Szustakowski, *Some Remarks on Causes of Damage in* $LiIO_3$ *Piezoelectric Transducers.*

E. Danicki, *Theory of Generation of SAW Bulk Waves and Plate Modes by ITD.*

K. Regiński, *Quasi-Continuous Description of the Acoustic and Optical Vibrations in Ionic Crystals.*

J. Berger, F. Plique, K. Rousseau, A. Zarembowitch, *Ultrasonic and Brillouin Scattering Investigation of the Structural Phase Transition of Antiferro-distorsive Crystals.*

M. Fischer, B. Perrin, A. Zarembowitch, *Acoustical Investigation of Anharmonic Behaviour of Crystal Showing Structural Phase Transition.*

D. Holz, *Problems on Measuring Mechanical Data Important for Acoustics of Inhomogeneous Anisotropic Material.*

## Interaction of Acoustic Waves with Material Structure

W. Eisenmenger, *Emission, Absorption and Propagation of Acoustic THZ Waves int Solids* (invited paper).

P. Boch, A. Danger, C. Gault, *Ultrasonic Investigation of the Formation of Guinier. Preston Zones in Aluminium-Magnesium Alloys* (poster form).

L. Lipiński, *Modulus Defect Stimulated by Ultrasonic Excitation in Polycrystalline Metal Samples* (poster form).

W. Chomka, D. Somatowicz, *Influence of Sodium Oxide on Internal Friction in Iron-Metaphosphate Glass* (poster from).

J. Deputat, *Temperature Dependence of Dislocation Internal Friction in Sodium Chloride* (poster form).

B. Fay, *Calculation of the Density of Scattering Centres.*

L. Opilska, A. Opilski, *Acoustical Method of the Energy Gap Determination in Semiconductors.*

J. A. Gallego-Juarez, E. Rieva, *Ultrasonic Aggregation of Micron Aerosol Particles.*

## Nondestructive Testing and Flaw Recognition

J. Obraz, *Some New Achievements in Ultrasonic Nondestructive Testing* (invited paper)

M. Przybyłowicz, J. Karle, *Digital Evaluation of the Flaw Size in Ultrasonic Nondestructive Testing* (poster form).

Z. Pawłowski, J. Gorzny, J. Szelążek, *Experience in Ultrasonic Testing of Pipeline Weld* (poster form).

L. Adler, *Selected Problems in Quantitive Nondestructive Evaluation.*

T. R. Licht, *Developments in Acoustic Emission Instrumentation.*

C. Gazanhes, *Targets Transfer Functions and Impulse Responses.*

T. Pritz, *Transfer Function Method for Determining Complex Modulus of Viscoelastic Materials.*

A. Jungman, F. Cohen-Tenoudji, B. R. Tittmann, *Characterization of Surface Flow by Wideband Spectrum Analysis.*

A. F. Brown, E. A. Lloyd, *Broad-Band Ultrasound in Non-Destructive Testing.*

J. P. Sessarego, *Bojarski's Identity – Application to the Target Recognition.*

J. Łoziński, *Study of Temperature Variation within the Heat-Seal Zone. The Ultrasonic Heat Sealing of Polycarbonate Film Depending on the Physical Parameters of the Process.*

A. Erhard, H. Wüstenberg, E. Mundry, *Detection of Near-Surface Cracks with Creeping Waves.*

B. Audenard, P. Pomes, *Acoustic Emission Applications during Pressure Testing of Vessels.*

K. Pellant, *Results of Measurements of Artificial Resin Elastic Moduli.*

J. Łoziński, W. Oliferuk, T. Piotrowski, *Application of Infrared Radiation in Studying the Ultrasonic Heat-Seal Zone of Polycarbonate Film.*

I. Grabec, *Insensitivity of Acoustic Emission to Shock Loading.*

**Section II**

## Holography and Optical Methods

P. Greguss, *Ultrasonic Methods of Material Recognition* (invited paper).

F. I. Braginskaya, Y. I. Varshavski, *Problems in the Use of Ultrasonic Holography in Medical Diagnostics* (poster form).

E. Yaronis, A. Voleisis, K. Kundrotas, V. Sukackas, *System of Ultrasonic Digital Interferometers* (poster form).

R. Reibold, *Calibration of Ultrasonic Probe Transducers by Means of Holographic Interferometry.*

P. Kwiek, O. Leroy, A. Śliwiński, *Verification of the Theory of Ultrasonic Light Diffraction by Adjacent Ultrasonic Beams.*

P. Kaczmarski, A. Leszczyński, J. Narkiewicz-Jodko, P. Rajchert, *Frequency Characteristics of the Laser Beam Acoustooptic Deflector Utilizing* $LiIO_3$ *Piezoelectric Transducer.*

J. Narkiewicz-Jodko, A. Leszczyński, P. Rajchert, P. Kaczmarski, *Laser Beam Acoustooptic Deflector – Experimental Models.*

R. O. Prudhomme, *Les Spectres de Sonoluminescences.*

S. Sajauskas, V. Domarkas, *Laser Meter of Pulse Response of Ultrasonic Transmitters*

## Wave Propagation

A. P. Sarvazyan, *Velocity of Ultrasound in Biological Tissues* (poster form).

R. C. Chivers, R. J. Parry, *Ultrasonic Modelling of Human Tissue. A Prototype Foetal Head.*

K. P. Richter, R. Millner, *Ultrasonic-Pulse-Spectroscopy and Tissue-Backscattering of Human Liver in Vitro.*

W. H. Round, R. C. Chivers, *Ultrasonic Propagation in the Human Eye: Parameter Measurement and Beam Profiles.*

L. Filipczyński, *Temperature Effect in Soft Tissue – Estimated and Measured.*

G. Yaroniene, *Response of Biological Systems to Low Intensity Ultrasonic Waves.*

W. H. Round, R. C. Chivers, J. K. Zieniuk, *Influence of the Human Eye on an Ultrasonic Beam: A Ray Tracing Approach.*

E. A. Vasiltsov, V. I. Koronchentsev, *Field Problems of Acoustic Antenna Arrays on Cylindrical Screens.*

R. C. Chivers, *Amplitude and Phase Fluctuations in the Propagation of Longitudinal Waves in Inhomogeneous Media.*

T. Salava, *Heart Sound Analysis in Computer Assisted Systems.*

V. T. Koronchentsev, *Synthesis of Acoustic Arrays in Impedance Screen.*

R. J. Parry, R. C. Chivers, *Sampling of Fast Waveforms in Ultrasonic Materials Science.*

H. Toda, H. Fukuoka, *Analysis of Wave Mode in Composite Cylinder.*

R. Dyba, *Perturbation and Taylor Series Approach to Finite-Amplitude Problems in the Case of Intermediate Mach Numbers.*

### Ultrasonic Diagnostic Methods

I. HRAZDIRA, *Biophysical Aspects of Ultrasonic Tissue Characterization* (invited paper).

J. LASKARIS, K. KIRKOU-IATRIDOU, D. KATSIMANTIS, *Value of Ultrasonography in Cytologic Diagnosis of Cancer in Abdominal Organs* (poster form).

A. HADIDI, *Ultrasonography of Echinococcal Liver Cysts* (poster form).

A. HADIDI, *Sonographic Evaluation of Jaundiced Patients* (poster form).

T. POWAŁOWSKI, *Real Time Automatic Transcutaneous Determination of Blood Velocity by Means of c.w. Doppler Method Eliminating Angle Dependence* (poster form).

G. ŁYPACEWICZ, T. POWAŁOWSKI, K. ŁUKOWSKA, *Ultrasonic Examinations of Breast Tumours with Doppler Method* (poster form).

K. ILMURZYŃSKA, J. SAŁKOWSKI, *Heart Visualization in Real Time for Diagnosis of Hyperthropic Cardiomyopathy* (poster form).

J. ETIENNE, L. FILIPCZYŃSKI, J. GRONIOWSKI, J. KRETOWICZ, A. NOWICKI, *Three Ultrasonic Methods of Placenta Location.*

A. M. HADIDI, *Contribution of the Echography to the Clinical Thyroidology.*

J. GRYMIŃSKI, G. ŁYPACEWICZ, *Use of Ultrasonic Guiding Transducer for Monitoring Thoracocentesis.*

A. M. HADIDI, *Pancreatic Sonography.*

J. PREISOVA, *New Approach to Interpretation of A-Scan Echograms of Orbital Tumours.*

J. CZAJKOWSKI, J. ETIENNE, Z. KRAWCZYKOWA, *Blood Flow Estimation in Carotid and Ophthalmic Arteries by Means of Doppler Technique.*

K. IWASZKIEWICZ-GIŻYCKA, A. CHROŚCICKI, T. POWAŁOWSKI, J. GRUCHALSKI, Z. MALEC, *Role of Transcutaneous Ultrasonic Doppler Method in Diagnosis of Potency of Congenital and Surgical Shunts between Aorta and Pulmonary Artery.*

R. KUBAK, *One- and Two-Dimensional Pulsed Doppler Echography: Signal Processing and Cardiovascular Applications.*

M. PARDEMANN, *Ultrasonic c.w. Doppler Technique in Stomatology.*

A. WAGNER, T. POWAŁOWSKI, Z. PAMPUCH, *Ultrasound Analysis of Peripheral Blood Flow – Vascular Resistance and Their Changes in Children.*

A. CHROŚCICKI, T. POWAŁOWSKI, *Cardiac Flow Measurements in Right Heart by Means of Ultrasonic Pulse Doppler Technique.*

### Transducers

C. RANZ-GUERRA, *Analysis of Sandwich Structures as Sonic Sources* (invited paper).

K. BRENDEL, G. LUDWIG, *Vibracoax – a Pressure Sensor for Measurements in Ultrasonic Cleaning Equipments* (poster form).

K. VAMMEN, *Revolving Transducer Real Time Ultrasonic Scanning System* (poster form).

W. PAJEWSKI, *Method of Measurements of Electromechanical Coupling Factor for Thickness Vibrations.*

A. MARKIEWICZ, *Transient Performance of Piezoelectric Transducers for Medical Diagnostics.*

K. P. RICHTER, R. MILLNER, I. DANZ, *Properties of Ultrasonic-Broadband-Transducers with a Multi-layer Matching to Water.*

T. MARUK, *Analysis of Dynamic Focusing with Ring Transducers.*

A. LUKOSEVICIUS, R. J. KAZYS, *Wideband Ultrasound Technique: Some Different Design Approaches.*

### Geoacoustics

A. J. BERKHOUT, *Exploration Seismology – The Use of Sound in the Search for Oil and Gas* (invited paper).

A. JAROSZEWSKA, W. KOŁTOŃSKI, I. PLEŚNIAK, B. PRZYGODZKA, *Sonic Testing of the Freezing Process in Rock Formations* (poster form).

J. ADAMCZYK, *Determination of Solid Compactibility Index by Seismic Waves.*

R. KUNTZMANN, *Some Results Achieved by the Development of Ultrasonic Modular Probe USS Applied to Shallow Well Measurements.*

G. I. PIETKIEVITCH, *Acoustic Indexes of Heterogeneity of Geological Media.*

Underwater Acoustics

R. SALAMON, A. STEPNOWSKI, *Directional Properties of Broadband Acoustical Beamformer* (poster session).

Z. JAGODZIŃSKI, *Frequency Optimization in Sonar Systems.*

A. STEPNOWSKI, R. SALAMON, J. BURCZYŃSKI, *New Method of an Echo Integrator Calibration in the Acoustic System of Fish Biomass Estimation.*

P. A. LEWIN, O. V. OLESEN, *Evaluation of Electroacoustic Underwater Transducer.*

**Section III**

Concert Halls and Auditoria

H. HARAJDA, *Changes in Amplitude of Violin Sounds in a Concert Hall* (poster form).

E. HOJAN, *Objective Evaluation of Acoustic Field of Loudspeakers by Impulse Technique* (poster form).

J. MEYER, *Acoustics of Haydn's Concert Halls.*

H. WINKLER, *Raumakustische Massnahmen im Grossen Saal des Palastes der Republik.*

P. HUHN, *Festlegung der Raumproportionen Kleiner Studiotechnischer Räume zur Optimierung der Eigenfrequenzverteilung bei tiefen Frequenzen.*

H. RYFFERT, E. OZIMEK, L. JUGOWAR, J. KONIECZNY, *Evaluation of Signal Frequency Changes during Its Decay Process.*

R. MAKAREWICZ, H. RYFFERT, *Phenomenological Description of the Perception of Monochromatic Signals in the Diffusion Room.*

H. FASTL, *Reverberation and Post-Masking.*

T. HOUTGAST, H. J. STEENEKEN, *Predicting Speech Intelligibility from the Modulation Transfer Function, I: General Room Acoustics.*

R. PLOMP, H. J. M. STEENEKEN, *Predicting Speech Intelligibility from the Modulation Transfer Function, II: Geometrical Room Acoustics.*

D. de VRIES, W. BEENTJES, *Behaviour of Various Speech Intelligibility Prediction Methods in Sound Fields with Double Decay Reverberation.*

I. JANUŠKA, *Speech Loudness – Possibilities of the Subjective Rating and Objective Prediction.*

J. NOVAK, *Sub(ective Perception and an Objective Prediction of Speech Loudness.*

J. BLAUERT, *Some Aspects of Three-Dimensional Hearing in Rooms.*

W. SCHMIDT, *Vergleich der Objektiven Kriterien zur Messung des Akustischen Raumeindrucks.*

E. OZIMEK, *Determination of Irregularity of Frequency Rsponse of a Room.*

A. ILLENYI, *About a Comparison of Studio Monitoring Luodspeakers with Objective and Subjective Measuring Methods.*

A. MELKA, *Experimental Comparison of Five Methods for Subjective Evaluation of Sound-Reproduction Quality.*

Industrial Halls

S. CZARNECKI, E. KOTARBIŃSKA, *How to Use Absorbing Materials in a Shallow Room for the Optimal Condition of Noise Reduction* (poster form).

G. GRAZZINI, R. POMPOLI, *Sound Propagation inside Industrial Halls.*

O. BSCHORR, *Computation of Noise Distribution in Industrial Environment.*

A. COCCHI, R. POMPOLI, *On the Evaluation of Noise Level Reduction Obtainable with Absorbing Acoustic Materials.*

P. DOČKAL, *Noise Control by Means of Room Acoustics in Large Industry Halls with Many Sound Sources.*

Ch. PRITZKOW, *Sound Screens in Rooms.*

J. P. NAGY, A. J. KORONKAI, *Noise Reduction by Barriers in a Small Compressor Building.*

R. BOTROS, *Design Considerations in a Large-Group Telephone.*

## Urban Areas

R. JOSSE, *Traffic Noise in Urban Areas* (invited paper).

A. STAN, *Pollution Acoustique* (invited paper).

B. RUDNO-RUDZIŃSKA, J. ZALEWSKI, *Prediction of Community Noise Using the Digital Simulation Method* (poster form).

M. WOJCIECHOWSKA, R. KUCHARSKI, *Prognostical Acoustic Map of the Areas around the Projected Fast Railway City Line* (poster form).

J. GRABEK, R. KUCHARSKI, *Rules of Predicting the Acoustic Protecting Zones around Noisy Railway Objects* (poster form).

R. KUCHARSKI, *Motorway Noise Propagation from Elevated Roads and Two-Level-Crossings, Empirical Investigation* (poster form).

S. CZARNECKI, J. SZUBA, *Local Means of Traffic Noise Control inside Residence Interiors* (poster form).

U. LEHMANN, *Planungsunterlagen und Verfahren zum Lärmschutz beim Städtebau.*

M. STAWICKA-WAŁKOWSKA, *Acoustic Characteristics of the Areas Adjacent to Express Routes.*

B. BUNA, L. VEREB, *Effect of Vehicle Categories and Speeds on Noise Level of Urban Expressways.*

M. BITE, *Design of Highway Noise Shielding Establishments Using Computers.*

E. BUCHTA, J. KASTKA, *Annoyance from Highway Road and Factory Noise.*

J. CECHURA, *Sound Levels in Building Exposed to External Noise.*

A. J. KORONKAI, J. P. NAGY, *Method for Designing of Sound Insulation of Façades.*

B. SZUDROWICZ, J. RUTKOWSKI, *Influence of Built-in Trafo Stations on Acoustical Climate of Dwelling.*

K. D. GÖBEL, *Beispiele der Anwendung Künstlicher Hindernisse unter Berücksichtigung örtlicher Gegebenheiten zur Verringerung der Lärmbelastigung für Anlieger.*

## Methods of Measurements and Subjective Evaluation

S. CZARNECKI, Z. ENGEL, A. MIELNICKA, *Paths of Sound Propagation through the Barriers* (poster form).

M. RABIEGA, J. ZALEWSKI, *Echo Parameters Evaluation in the Tone-Burst Technique of Sound Absorption Measurements* (poster form).

M. KIERZKOWSKI, M. MADEJSKI, *Automatic Computer System for Measuring Acoustic Properties of Building Partitions* (poster form).

A. RUDIK, *Proposal for Extremal Noise Limitation Inside the Cabin of Various Types of Aircraft* (poster form).

T. WALASIAK, J. MIAZGA, *Audibility of Warning Signals by Truck Drivers* (poster from).

V, MELLERT R. WEBER, *Artificial Head with Corrected Frequency Response for Frontal Sound Incidence.*

R. WEBER, V. MELLERT, *Comparative Study of Transportation Noise: Correlation of Subjective Evaluation with Physical Parameters.*

Z. DUKIEWICZ, *Application of the Coherence Function to Random Structure-Born Sound Measurements.*

W. ZIPPE, *Bildung von Räumlichen Mittelwerten dēs Schallpegels mit Hilfe eines integrierenden Schallpegelmessers.*

A. BALDACCONI, G. SPADA, *Quantification of Industrial Halls-Generated Noise Exposure According to Italian Legislation of Insurance.*

I. BARDUCCI, M. COSA, *Problems Concerning the Evaluation of Occupational Noise Exposure.*

The papers of particular sections were presented in three forms: as invited papers given by relevant personalities in the field of acoustics – the papers dealt with subjects suggested by the Organizing Committee of FASE (45 minutes); as contributed papers submitted by the participants and accepted by the Organizing Committee (15 minutes and 5 minutes' discussion); as poster form papers (5 minutes) to present the basic thesis and results and two sessions of one hour duration to present the papers in details and to discuss them in boxes with the help of posters prepared by the authors.

The poster form was highly appreciated by the participants of the Congress. Dr. Paul François, in his letter form France sent after the Congress, wrote: "The poster form session which was for the first time introduced to scientific conferences of FASE is very effective and makes a perfect complement to the papers presented in a traditional way".

The plenary meeting chaired by dr. F. Kolmer took place after the end of section debates. The results of the Congress were summed up by the FASE president dr. Paul François. The debates were closed by the president of the Organizing Committee prof. dr. Stefan Czarnecki.

After the official part the participants met in rooms of Palace of Science and Culture to have a glass of wine, exchanged their opinions for the last time and sum up their talks on future cooperation.

The Congress was accompanied by an exhibition of acoustical research equipment and materials. The following firms presented their products: Brüel and Kjaer from Denmark, Medata AB from Sweden, INCO from Poland, TECHPAN from Poland, and UNIPAN from Poland.

In addition to the scientific programme the Congress participants took part in social events. The events included reception at National Museum, which was preceded by visiting some of the most valuable Museum displays. They also saw the performance of Verdi's "Mask Ball" in the Warsaw Opera.

*S. Czarnecki (Warszawa)*

## REPORT ON PROCEEDINGS OF THE 25TH OPEN SEMINAR ON ACOUSTICS

**Błażejewko, near Kórnik, 14-16 September, 1978**

The 25th Open Seminar on Acoustics which has annually gathered Polish acousticians and foreign guests on many years, was organized by the Poznań Division of the Polish Acoustical Society, Committee on Acoustics of the Polish Academy of Sciences, and the Department of Acoustics of the Adam Mickiewicz University, Poznań.

More than 200 participants, research workers from higher educational institutions and ministerial institutes currently engaged in acoustics, took part in the seminar. There were also 15 foreign guests representing centres of acoustics in France, Great Britain, Holland, Denmark and Czechoslovakia.

It is worth noting the participation of the chairman of the Federation of European Acoustical Societies, Dr. Paul François from France and Dr. E. F. Evans from England (Keele), a well-known specialist in the field of psychophysiological acoustics, who came to Poland for the first time, invited by the organizers of the seminar.

The seminar was opened by the chairman of the Organizing Committee and the chairman of the Polish Acoustical Society, Prof. dr. hab. Halina Ryffert who presented a general outline of the history of the seminars, of the way in which their form and range of subjects had developed.

Next, during the official opening of the seminar, Dr. Paul François took the floor, on behalf of GALF, Groupement des Acousticiens de Langue Française, to present in a systematized way the development of contacts between acousticians from Poland and France, which led to the signing in 1975 of the agreement on scientific co-operation between GALF and Polish Acoustical Society. This year it was included in the governmental agreement on cultural co-operation between Poland and France.

Despite the shortened duration of the seminar, the Organizing Committee decided to change in some way the form of the sessions and include the issues part of the seminar within the framework of round-table meetings which took place in the mornings. The reviewing part consisted of short papers and communiqués from different branches of acoustics in three parallel sections in the afternoon sessions. The content of the discussion at the round-table meetings was closely connected with the directions of the investigations of the Poznań centre, comprising the following issues:

modern methods of analysis and processing of acoustic signals,
current directions of investigations in psychoacoustics,
elements of physiology in psychoacoustics.

The 25th Open Seminar on Acoustics included three roundtable meetings.

The 1st meeting took place on September 13, opening with a paper by prof. B. Escudié (France) entitled "Etat actuel du traitement des signaux acoustiques propa gésdans l'atmosphère et des applications à l'imagérie spatiofréquentielle des bruiteurs".

The 2nd meeting took place on September 15, opening with an introductory paper by prof. L. Pimonov (France) entitled "Le Facteur Temps en Audition".

The 3rd meeting took place on September 16, opening with an introductory paper by prof. E. F. Evans entitled "Studies of Peripheral Physiological Mechanisms Underlying Analysis of Complex Sounds".

The meetings enjoyed considerable interest as shown not only by very large audiences, but also by unexpectedly lively discussions, despite the specialist character of the subjects. Nevertheless, it was here that the interdisciplinary character of this branch of knowledge – acoustics – became conspicuous, since many persons engaged in other branches found certain aspects of the subjects discussed also of interest to them.

The meetings were in turn chaired by doc. dr. hab. Edward Ozimek – in place of prof. B. Escudié from France, who sent in his paper, being unable to take part in the seminar, the next by prof. Leonid Pimonov from France, and the third in turn by prof. E. F. Evans from England.

The afternoon sessions were generally connected with subjects from several branches of acoustics, including mainly:
– acoustics of speech, music and psychoacoustics,
– physical and ultrasonic acoustics,
– technical and community acoustics.

Of the 94 papers and communiqués contributed and published in Proceedings of the 25th Open Seminar on Acoustics, 87 were presented during the sessions.

**Section I. Acoustics of speech, music and psychoacoustics**

M. T. ROTH, *Etude des variations acoustiques de la voyelle dans les monosyllabes en français.*

G. MERCIER, P. QUINTON, R. VIVES, *Dialogue homme-machine avec Kéal.*

J. JARYCKI, A. PAWLAK, Z. WOROBIEC, *Measurement of a Power Density Spectrum Based on the "Speech Chorus" Method for Continuous Speech and Language Tests.*

R. SIWANOWICZ, J. SOBKOWSKI, *Spectrum Analysis of Voice Signals in Terms of Walsh Functions.*

B. W. KULESZA, B. ROGALA, J. SOBOLEWSKI, *Investigations of the Statistical Properties of Sound.*

A. PAWLAK, J. JARYCKI, Z. WOROBIEC, *Application of Simulating Methods to the Automatic Classification of Larynx Transducers.*

P. BIEŃKOWSKI, W. MYŚLECKI, Z. WOROBIEC, *Method of Synthetic Speech Quality Evaluation.*

K. MUSIALIK, *Grammars Generating a Fixed Set of Messages by Means of a Computer Voice Response System* (CVRS).

J. ZIELIŃSKI, W. MYŚLECKI, *Parametrical Generation of Basic Intonation Functions for the Synthesis of Polish Speech Phrases.*

H. HARAJDA, J. FRYK, *Zonality of Melodic Intervals as Reproduced by an Average Gifted Child.*

A. PREIS, *Timbre of Complex Tones and their Spectral Envelopes.*

A. PODRES, *Comparison of a Human Observer with an Energy Detector in the Signal Detection Process.*

S. PRUS, *Does Psychometric Function Behaviour Confirm the Classical Detection Theory?*

K. MLICKA, *Detection Probability Determination of a Continuous Signal Parameter Change Evoking a Blurred Change of Loudness.*

K. MLICKA, S. PRUS, *Detection Probability Determination of a Continuous Signal Parameter Change Evoking a Blurred Change of Pitch.*

J. FLORKOWSKI, *Utilization of Headphone Listening in the Investigation of Sound Source Localization by the Minimum Audible Angle Method.*

Cz. PUZYNA, *Results of the Investigation of the Obstacle Perception by the Blind.*

K. RUDNO-RUDZIŃSKI, *Perception of Distortions that Result from Different Distances to Woofer and Tweeter.*

**Section II. Physical and ultrasonic acoustics**

A. BERGASSOLI, *Interaction des acoustiques dans un guide.*

W. RDZANEK, *Mutual Acoustic Impedance of Circular Panels with the Bessel Distribution of Vibration Velocity.*

M. CZECHOWICZ, T. SOBOL, S. CZARNECKI, *Acoustical Feedback in the Process of Edgetone Generation.*

A. JAROCH, H. IDCZAK, *Scattering of the Sound Wave on the Rigid Surface with Pseudo-Random Irregularities.*

R. DYBA, B. ŻÓŁTOGÓRSKI, *Acoustic Noise Nonlinear Transformation Caused by Moving Boundary Condition Effect.*

T. ZAMORSKI, R. WYRZYKOWSKI, *Hyperbolic Horns of Annular Cross-Section.*

W. BANDERA, *Determination of the Complex Young's Modulus for Some Viscoelastic Materials.*

S. NUCKOWSKI, J. SZYMBOR, *On the Accuracy of a Nonlinear System Multidimensional Transfer Function.*

J. ANTONOWICZ, M. GAŁAŻEWSKA, J. TABIN, *Field of a Partially Deteriorated Ultrasonic Focusing Head.*

J. Tabin, B. Sikora, *Influence of Power Dissipation in the Transducer on Ultrasonic Attenuation Measurements with the Diverging Beam.*

E. Kozaczka, J. Morawiec, *Investigation of the Sensitivity of Cylindrical Piezoelectric Transducers.*

J. Golanowski, T. Gudra, *Ultrasonic "Planar" Type Transducer.*

B. J. Kibort, *Method of Measurement of Transmission Loss in Ultrasonic Communication in Structural Elements.*

A. Dyka, *Digital Underwater Echo Integrator.*

L. Kilian, *Side Scan Sonar Equation for the Detection of Bottom Targets.*

E. Kozaczka, *Investigation of Sound Generated by Cavitating Ship Propellers.*

S. Weyna, *Designation of Vibration and Acoustic Parameters of Ship Accomodation Bulkhead Properties.*

A. Kowalski, *Measurement of the Target Strength of a Skin Diver.*

Z. Klusek, *Dependence of the Spectral Level of the Ambient Sea Noise in the South Baltic on Wind Speed.*

M. Holec, J. Ratowski, *Vertical Sound Speed Distribution and Gradients in the Baltic Sea and their Seasonal Variation.*

J. Ratowski, M. Holec, *Influence of Sound Speech Changes in the Baltic Sea on Hydrographic Measurement Accuracy.*

J. Berdowski, M. Strozik, *Arrangements for the Investigation and Visualization of Surface Acoustic Wave Fields.*

J. Finak, A. Krzesiński, M. Tomaszewski, *Capabilities of the Application of Piezoelectric ZnO Films to Present-Day Acoustooptic Devices.*

Z. Kleszczewski, A. Mleczko, M. Strozik, H. Delewicz, *Practical Application of the Acousto-optic Modulation of the Laser Light.*

Z. Tylczyński, *Propagation of a Quasi-Longitudinal Ultrasonic Wave into the b Plane of TGS Crystals.*

J. Mizera, *Influence of Ultrasonic Fiel don the Electrochemical Oxidation Process of Phenol Solutions.*

J. Bednarek, T. Ciszewski, Z. Talarczyk, *On Some Problems in the Ultrasonic Measurement of the Level of Loose Materials.*

L. F. Lipińska, *Effect of Ultrasound on Internal Friction in Polycrystals.*

M. Konarska, *Criteria for Industrial Exposure to Airborne Ultrasound.*

D. Lewandowska, C. Lewa, S. Łętowski, *Influence of Gas Admixtures on Shear Viscosity in Liquids.*

**Section III. Technical and community acoustics**

K. Berezowska-Apolinarska, *Acoustic Field in Some Urban Structures of Different Geometry.*

K. Berezowska-Apolinarska, W. Kołaski, *Influence of Central Quarter Development on Noise Propagation.*

R. Makarewicz, *Intensity of the Sound Field Generated by a Moving Source in a Semispace Filled by a Stratifield Medium.*

L. Jugowar, *Method of Analysis of Dynamic Changes of Phase and Sound Frequency under Non-Steady State Conditions.*

A. Rudiuk, *Acoustic Field in an Aircraft Cabin.*

B. Szulc, J. Szczepański, B. Plebański, *Methods for Investigating Vibrations and Noise in Trams and the Criteria for their Estimation.*

R. J. Kucharski, *Problem of Choosing a Road Traffic Noise Index Suitable for the Wide Recognition of the Acoustic Climate.*

M. Wojciechowska, R. J. Kucharski, *Method of Predicting Railway Noise.*

B. Szulc, J. Szczepański, B. Plebański, *Estimation of Noise in Railway Vehicles.*

W. Rybarczyk, *Statistical Distribution of the Mean Noise Intensity at Work Stands in Working Rooms.*

D. Trynkowska, R. Michalski, *Classification and Matching of Ear Hearing Protectors.*

W. Tyrchan, *Substitution Acoustic Mass of the Nozzle and Diffusor System.*

W. Tyrchan, *Aerodynamic Noise in the Free Inlet Stream to the Nozzle and Diffusor System.*

L. Rutkowski, *Acoustic Analysis of the System with Several Degrees of Freedom under Non-Steady State Conditions.*

W. Bartelmus, A. Studziński, *Comparison of States in Acoustic and Vibratory Methods of Diagnosing Machines.*

E. Hojan, J. Florkowski, G. Kienitz, *Testing Device for Vibrating Systems Using the R. F. S. Method.*

J. Morański, *Computer Simulation of Frequency Response and Electrical Impedance for some Loudspeaker Systems.*

J. Koralewski, *Influence of the Magnetic Field of Voice Coil on the Parameters of Loudspeakers.*

M. Niewiarowicz, *Influence of the Acoustical Loading of a Membrane on the Value of its Mechano-acoustical Parameters.*

Z. Dobrucki, *Impulse Response of an Electromechanical Moving Coil Transducer.*

E. Hojan, M. Niewiarowicz, J. Florkowski, *Method of Optical Enlargement in Testing the Vibrations of Electroacoustic Transducers.*

P. Żarnecki, *Multi-channel Signal Processing System Applied to the Time-Frequency Analysis of Acoustical Data.*

A. Puch, *Method for Transfer Matrix Measurements on Acoustic Filters.*

J. Frenkiel, *New Polish Standard for Tape Recorders for Domestic Use.*

J. Kamiński, J. Jurkiewicz, K. Baściuk, *Synchronous Extraction of Identification Signals.*

Z. Engel, W. Stanek, *Acoustical Characteristics of a Multilayer Beam.*

D. Nitecki, J. Smurzyński, *Investigation of the Application of Vibro-Dampers of the "Powar" Type as Elements for Decreasing the Noise Level in Accomodation.*

The participants of the seminar expressed satisfaction with the proceedings of the 25th Open Seminar on Acoustics and appreciatively accepted its new character which is the expression of the search by our acoustic community for still better forms of creating an adequate plane for presenting the latest accomplishments and investigation results and for deep and inquisitive scientific discussion. The foreign guests also, in warm words, expressed their appreciation of both the academic aspect of the session, the pleasant atmosphere and the organizational efficiency.

14 papers were entered during the seminar for the M. Kwiek competition for the best paper, the academic and formal aspects of which had been estimated by relevant reviewers.

The participants of the seminar had the opportunity of seeing exhibitions of measuring devices manufactured by Brüel & Kjaer and of electroacoustic equipment from the Loudspeaker Factory "Tonsil" at Września.

It should be added that the jubilee 25th Open Seminar on Acoustics coincided with the 15th anniversary of the Polish Acoustical Society and, in this connection, on Wednesday, September 13, there was a solemn gathering of member-founders of the Society, which proceeded in an atmosphere of many interesting reminiscences and reflections.

On the eve of the seminar, on September 13, there was the 16th Congress of the Polish Acoustical Society Delegates, which elected the Society leadership.

*E. Ozimek (Poznań)*