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Sound of Silence – the Theological and Physical Interpretation of Sound

Summary: The article describes the notion "sound" from 2 different perspectives: theological and scientific – more precisely physical point of view. In biblical tradition, sound is the carrier of God's Word. In the Old Testament the Hebrew word קול (kol) does not play any special theological function. In the New Testament there are 3 Greek terms that convey the semantic circle of the notion sound: ἤχος (ēchos), φθόγγος (fthongos) and φωνή (fōnē). They are used in the context of God's revelation. In the Evangelical-Lutheran tradition, the Word is the only medium of God's grace. This is stated in the theological principle of *solum verbum*. The spoken word played a primary role in Martin Luther's theological reflection. Contemporary theology enables access to the voice and mutual communication between God and the people, as well as in human dialogue.

From a physical point of view, sound is a mechanical wave propagating in an elastic medium only. These are not only waves from a frequency range 20 to 20.000 hertz [Hz] to which the human ear is sensitive, but waves of frequency beneath 20 Hz down to 0,1 Hz and rarely to 0,001 Hz (infrasound, below 20 Hz) to much higher than the upper limit of audibility (ultrasound), i.e. from 20.000 Hz to the range above hundreds of GHz. The whole range is used and takes full advantage in various fields of human life. All this, briefly, is presented in the paper.

Keyword: Sound, Silence, Word, *solum verbum*, Liturgy, Acoustic, Physics, Wave

Streszczenie: Dźwięk ciszy – teologiczna i fizyczna interpretacja dźwięku

Artykuł ukazuje rozumienie pojęcia „dźwięk” z dwóch różnych perspektyw naukowych: teologicznej oraz fizycznej. W tradycji biblijnej, dźwięk jest nośnikiem Bożego Słowa. W Nowym Testamencie występują trzy greckie terminy oddające krąg znaczeniowy terminu dźwięk: ἤχος (ēchos), φθόγγος (fthongos) oraz φωνή (fōnē). W tradycji ewangelickiej, to Słowo jest jedynym medium Bożej łaski. Ujmuje to zasada teologiczna *solum verbum*. Dla teologicznej refleksji Marcina Lutra prymarną rolę pełniło Słowo mówione. Współczesna teologia widzi szczególną rolę głosu we wzajemnej komunikacji pomiędzy Bogiem i ludźmi, jak też w ogólnoludzkim dialogu.

Z fizycznego punktu widzenia dźwięk to fala mechaniczna rozprzestrzeniająca się tylko w środowisku materialnym. To nie tylko fale o częstotliwości od 20 do 20.000 herców [Hz], na które czule jest ludzkie ucho, ale fale od częstotliwości ułamków Hz (infradźwięki) do dużo wyższych niż górna granicą słyszalności (ultradźwięki) tzn. od 20.000 Hz do zakresu powyżej setek GHz. Cały ten zakres używany jest i wykorzystywany w różnych dziedzinach życia człowieka. To wszystko, w wielkim skrócie przedstawione jest w niniejszym artykule.

Słowa kluczowe: Dźwięk, cisza, Slowo, solum verbum, liturgia, akustyka, fizyka, fala

The sound of not only Silence - Introduction

The 14th of January 2019 was one of the most tragic days in the present history of Gdansk. The mayor of the city, Paweł Adamowicz was stabbed during the charitable action “The Great Orchestra of the Christmas Charity” (“Wielka Orkiestra Świątecznej Pomocy”) and then died in hospital¹. The following days, both in the Tricity and all over Poland, brought about the time of mourning and reflection. One of the impressive motives of the social celebration of this horrible occurrence was the song “The sound of Silence” originally performed by Paul Simon and Art Garfunkel in 1965, during the ecumenical commemoration of Paweł Adamowicz performed by David Draiman, the Vocalist of the metal group *Disturbed* in acapella version. In the first months of 2019 the life and death of Paweł Adamowicz were the inspiration to many personal reminiscences² and to a huge number of essays which interpreted this fact in the bright political and philosophical perspective³. Also the lyrics of the song – hymn of those days inspired thousands of people of Gdansk to reflect on the way of human life as well as on the power of sound of silence. The song has originally the title Sounds of Silence which was later changed into Sound of Silence. This tragic episode of Pomeranian and Polish history was also an attempt to brighter reflection about the role of sound and silence in the life of a human being. Does the Silence have only one sound or a lot of sounds? Is it possible to impress positive and negative emotions without the Sound, but only in Silence? This study’s aim is to describe the phenomenon of sound in the theological and physical interpretation.

¹ *Gdansk Mayor Pawel Adamowicz in Poland fatally stabbed on stage at charity event (January 14, 2019)*, www.cbsnews.com/news/poland-gdansk-mayor-pawel-adamowicz-stabbed-great-orchestra-of-christmas-charity-event/ (2019.08.10).

² From protestant point of view: M. Hintz, *Wspomnienie o Pawle Adamowiczu*, „Zwiastun Ewangelicki” 3/2019, 14–15.

³ T. Lis, *Umrzeć za Gdańsk. 12 rozmów o Pawle Adamowiczu, wolności i magii Gdańska*, Warszawa 2019.

Sound in the biblical perspective

The creation of the World according to the first book of the Bible, i.e. the 1st Book of Moses, also called *Genesis* or in the Hebrew tradition known as *Beresbit* (בְּרֵאשִׁית) started with the words of God's activity. In the second Verse we find the relation of the spirit *ruah* (רוּחַ) of God which is translated also as wind or breath. In the Old Testament tradition there is no significant reflection on such abstract phenomenon as the sound⁴. The Hebrew Bible Canon called *Tanakh* (תַּנְ"ךְ) from the first letters of 3 parts of this collection of books means: *Tora* (Teaching), *Neviim* (Prophets), *Ketuvim* (Writings). The *Tanakh* is the textual source for the Christian Old Testament, however it has a different order of books and the translations of Protestant Bible essentially divide the same material into 39 books. We have to underline that this division reflected in the notion of *Tanakh* is more often used in the literature of the Rabbinic period. The former title of Hebrew Bible was *Mikra* (מִקְרָא) which means 'reading' or 'that which should be read'. For the analysis of the term "sound" this remark has a big importance while the texts of the Holy Scripture – of the Words of God were in this period primary read publicly⁵. The sound, the voice of reader was a carrier of God's Will.

German Theologian Gerhard von Rad marginally describes the Israel's understanding of sound in the context of language. Also Werner H. Schmidt in the analysis of the Old Testament Faith conducts no separated analysis of the Israel's understanding of language or sound. The understanding of the physical World in *Tanakh* was evaluated in a very long process⁶.

The Hebrew's word קול or קל – kol (sound, voice)⁷ is used in that verbal context. In the *Biblical Concordance* of the OT there are 61 occurrences of the word "sound"⁸. In the common interpretation, God speaks to his chosen nation, Israel and the sound is a form of His communication with them. God

⁴ G. von Rad, *Old Testament Theology*, Vol. I: *The Theology of Israel's Historical Traditions*, Vol. 1: *The Theology of Israel's Prophetic Traditions*, Vols. 1 and 2, with an introduction by W. Brueggemann, Westminster John Knox, Louisville 2001.

⁵ W. Brueggemann, *An introduction to the Old Testament: the Canon and Christian Imagination*, John Knox Press, Westminster 2012, 76.

⁶ W. H. Schmidt, *Alttestamentlicher Glaube in seiner Geschichte*, Berlin 1976, 10.

⁷ P. Briks, *Podręczny słownik hebrajsko-polski I aramejsko-polski Starego Testamentu*, Warszawa 1999, 308.

⁸ *Bible Concordance*, <https://www.artbible.info/concordance/s/703-1.html> (2019.08.10).

speaks to human kind primarily without a medium of scripture. This kind of God's activity is for the biblical authors something understandable by itself. In the description of the Creation (Gen 1,1-2,25) can we show a quite a big number of association with acoustic meaning. First entry about the sound can we find already in the 2nd Verse of the Bible, when the Elohist's Author writes about "wind from God swept over the face of the waters"⁹. The first place where the word kol "sound" is found is in the Exodus in the description of Vestments of Priesthood. "And it shall be upon Aaron to minister: and his sound shall be heard when he goeth in unto the holy place before the LORD, and when he cometh out, that he die not" (Ex 28,35)¹⁰.

God speaks to his Nation with the words: בַּת קוֹל (literally: "daughter of voice", voice of God). According to the Jewish Encyclopedia: "The characteristic attributes of the *Bat Kol* are the invisibility of the speaker and a certain remarkable quality in the sound, regardless of its strength or weakness. A sound proceeding from some invisible source was considered a heavenly voice, since the revelation on Sinai was given in that way"¹¹. Proclaiming his will, Gods speaks also using natural phenomena, for example He speaks "out of the fire" (Dtn 4,12). Gods spoke and the people could see no form, no exposition of the Lord.

Much more impulses to the understanding of sound can be found in the second part of Hebrew *Tanakh* that is by the Prophets. They would speak the Word of God to the whole nation, but seldom to individual person or persons. God is closer to his Nation in the time of the prophets. The procedure of calling for a prophet is always God's own activity: He calls his servants with an external voice. The voice of God spoken by the prophets was the medium of the Holy Spirit who rested upon the Prophets and the relation was personal and very intimate. The prophecy was a special gift of the Lord which was possessed not only by the prophets, but was also given to other people. The motive of silence is present in a special form in the Book of Jonah the Prophet. The sound of his prayer is reaching God even when pronounced from the belly of a fish (Jon 2,1)¹².

⁹ Translation: NRSV – *The Holy Bible. New Revised Standard Version*, New York 1989.

¹⁰ Translation: KJV – *King James Version*.

¹¹ K. Kohler, L. Bau, *BAT KOL*, <http://jewishencyclopedia.com/articles/2651-bat-kol#anchor2> (2019.08.10).

¹² L. Boase, S. Agnew, *Whispered in the Sound of Silence: Traumatizing the Book of Jonah*, "Bible and Critical Theory" 12 (2016), 4–22.

In liturgical life of the Jerusalem temple and later, in the diaspora situation, in the synagogue celebration, the Sound was a form of human praise of the Lord and in the prayer as an expression of human thoughts to the Lord.

The New Testament generally follows the understanding of natural phenomena described in *Tanakh*. The words ηχος (ēchos) φθογγος (fhoggos) and φωνη (fōnē) are used in the NT text giving the meaning of sound. According to the Greek-Polish Vocabulary, the word φωνη is used in the NT text 139 times, ηχος 4 times and φθογγος only 2 times by Paul¹³. The New Testament seldom uses the Hebrew formula “Voice of God”: Ἦλθεν οὖν φωνὴ ἐκ τοῦ οὐρανοῦ (John 12,28) – the voice from Heaven. The same words, but in different context (Baptizing of Jesus) in the synoptic tradition: Matth. 3,17; Mark 1,11; Luke 3,22. This is the Voice of God, the Father. The other contexts using the formula “voice from heaven” is found in the description of Transfiguration (Matth. 17,5; Mark 9,7 and Luke 9,35), there is no presence of the transfiguration in John Tradition. In John 12,28 the words are used shortly before the Passion¹⁴.

The resurrected Jesus speaks personally to Saul on the road to Damascus: “He [Saul] fell to the ground and heard a voice saying to him” (Acts 9,4). Saul answered and by His Voice Jesus introduces himself. This form of dialogue is taken from the prophets’ tradition when, for example, Isaiah speaks to God during his mission as the prophet of Israel (Isaiah 6,1-13). In the text of Acts we can find 3 other places connected with this event: Acts 22,7; Acts 26,14 In the pericope about Cornelius the centurion, Peter was instructed twice by the voice concerning the clean and the unclean, Acts 10,13 and 10,15.

The tradition of John underlines the divine dimension of Jesus Christ. The special function in this interpretation is played by the Logos Hymn in the first chapter of the 4th Gospel (John 1,1) where Jesus is presented as λόγος (the Word) through whom God created the world¹⁵. Jesus Christ as God’s incarnated Word came to the world as a human: “And the Word became flesh and

¹³ R. Popowski, *Wielki Słownik Grecko-Polski Nowego Testamentu*, Oficyna Wydawnicza Vocatio, Warszawa 1994, 265, 638, 647.

¹⁴ Voice, in: *International Standard Bible Encyclopedia*, www.internationalstandardbible.com/V/voice.html (2019.07.10).

¹⁵ A. Robert, A. Feuillet, *Introduction to the New Testament*, Desclee Company, New York–Rome–Paris–Tournai 1965, 615.

lived among us” (John 1,14). This is ontological difference between the presence of God’s Word (God’s voice) in the NT and in the OT. The sound of Jesus’ words is the sound of God. In the list of the messianic titles of Jesus we also find his prophetic identity¹⁶. For Jesus is fasting one of the most important moment in his way to self-understanding. The fast on the dessert is also a time of Silence (Matth. 4,1-11) and afterwards an attempt to temptation. In silence the person tries find a way to his interior and to God.

To recapitulate, there is no independent study or analysis of the essence of the sound in the Bible, we can underline that the New Testament continues the OT understanding of the usage of the word “sound” in the context of the Voice of God which proclaims his Will. In Jesus Christ the Word of God was present among the people.

Theological interpretation of Sound

Theological analysis of a dogmatic or doctrinal problem could be conducted from ecumenical or confessional perspective. For our research we have chosen a Protestant perspective where theology of the Word plays a central role.

The Greek notion λόγος was translated into Latin *verbum* and in this notation was used in the evangelical theology of the 16th century. The Reformation formulated theological principles which were a reduction of the system of medieval scholastic vision. *Sola scriptura*, *sola gratia et fide* and *solus Christus* summarized the Protestant understanding of God’s revelation. Luther’s teaching on justification by grace alone underlines the role of the Word (*verbum dei*) in the salvation process¹⁷. Luther’s theology was deeply rooted in St. Paul’s teaching, particularly in the *Letter to Romans*, where he found a gracious God.

In Martin Luther’s theology the Word of God has different forms, but the most important are the Bible and the Sermon. He gives the spoken word the primacy over the written Word. In Luther’s thinking God’s Word was the sermon first¹⁸. There is no special reflection on the phenomenon of “sound” in Luther’s theology as well as in the teachings of other leaders of the Wittenberg

¹⁶ L. Goppelt, *Theologie des Neuen Testaments*, Evangelische Verlagsanstalt, Berlin DDR 1983, 213.

¹⁷ K. G. Appold, *The Reformation. A Brief History*, Wiley & Sons 2011, 87.

¹⁸ H.–M. Barth, *Die Theologie Martin Luthers. Eine kritische Würdigung*, Gütersloher Verlagshaus, Gütersloh 2009, 149, 157.

and Swiss Reformation. For Luther and his collaborators, the Church was primarily a tool of God in the process of giving grace to human kind and the oral teaching was the main device to be used in this process.

For the Lutheran theology, the distinction between the visible and invisible Church was one of the most important descriptions of the Body of Christ. All confessional books of the Lutheran denominations published in 1580 as *Liber Concordia (the Book of Concord)* clearly followed this conception.

One of the most important dogmatic formula is found in the *Confessio Augustana (the Augsburg Confession)* from 1530, written by Philip Melancthon. The Article 7 defines the Church and teaches that there is one holy Christian church and it is found wherever the Gospel is preached in its truth and purity and the sacraments are administered according to the gospel. It means that CA VII describes only 2 possible *notae ecclesiae*. The most important function of the Church is teaching, using an oral form of communication. In the second part of this article of Faith we read: “Nor is it necessary that human traditions, that is, rites or ceremonies, instituted by men, should be everywhere alike. As Paul says: One faith, one Baptism, one God and Father of all, etc. Eph. 4,5-6”¹⁹. *Confessio Augustana* was publicly loudly read during the session of Reichstag of Augsburg, June 1530. The same form of oral activity was earlier Luther’s experience when he testified his faith by the Emperor Charles the Fifth during the interrogatory on Reichstag of Worms in 1521²⁰. In the Lutheran Orthodox Theology the Latin phrase *solum verbum* was the interpretation of the presence of God’s Word in the World. According to this doctrine the Words of God have only one medium of God’s Grace. The Word of God occurs in two forms only: spoken word and visible word – sacraments. Sacraments are the visible form of the Word²¹. The sound of God – the voice of the Lord is His presence in the Holy Scripture, in preaching and in teaching (catechesis) of the Church. We can also conclude that the Sermon and teaching of Catechism (religious lesson) is the presence of the sound in the Church.

The next generations of Protestant theologians added many aspects of a dogmatic pattern, but the role of an oral Word in the life and in day-to-day

¹⁹ *The Augsburg Confession* – CA, Article VII, <http://bookofconcord.org/augsburgconfession.php> (2019.03.20)

²⁰ H.–J. Abromeit, *The Luther Effect: What was the aim of the Reformer and what was the result?*, “Gdański Rocznik Ewangelicki” Vol. XI, 2017, 111.

²¹ M. Uglorz, *Marcin Luter. Ojciec reformacji*, Wydawnictwo Augustana, Bielsko–Biała 2006, 144–160.

practice of the Church has not changed since the 16th century. Nowadays, we cannot speak about the special, theological reflection or analysis of the sound phenomenon. The sound is seen as a transmission form between God and the human kind and in the prayer in opposite direction. Both the written and the oral form of the Word are present in the Church, which is the Body of Christ in a mystical form of its existence.

Physical interpretation of the Sound and Silence phenomenon

Acoustics, a term that reminds me of the conversation with Jan Fiutak, who in the year of establishment of the University of Gdańsk, wondered about admitting me to work at the Institute of Physics. Finally he hired me directing me to the Department of Acoustics managed by Antoni Śliwiński. I was a nuclear physicist, but could I work in the field of acoustics? At that time I had very little idea about acoustics. Today, after many years of work, I can share my knowledge in this field.

The designer of the “Penitential Temple of the Holy Family” cathedral in Barcelona (Sagrada Família)²² architect Antonio Gaudí²³ believed that the most important sense of faith is the sense of hearing, not sight²⁴. It seems obvious to me that the great architect was not very far from truth. Many people have auditory (echo) memory problems, especially those who are blind or visually impaired²⁵; these people would certainly agree with the great architect Gaudí.

In addition, many people attending churches and participating in religious services rather rarely read the Holy Bible. Almost all information about religious topics comes from a priest talking from the pulpit. So let’s learn more about acoustics and its huge role in human life as well as in scientific research.

The formation of acoustics, as an important branch of modern physics, began long before the beginning of written history. It is clear that sound arises

²² <https://sagradafamilia.org> (2019.09.04).

²³ <https://www.britannica.com/biography/Antoni-Gaudi> (2019.09.04).

²⁴ R. Makarewicz, *Dźwięki i fale*, Wydawnictwo UAM, Poznań 2004.

²⁵ See: E. Bogusz G. Mroziak, E. Skrodzka, *Investigation of Vibratory Detection Thresholds on Proximal Phalange and Wrist in Blind and Visually Impaired Teenagers*, “Acta Physica Polonica” 2012, A 121(1A), A19–A23; Furmann A., Skrodzka E., Giżewski P., Nowotny Ł., *Effect of sound reproduction method on performance in sound source localization tasks by visually impaired and normal sighted subjects*, “Acta Physica Polonica” 2013, A 123(6), 988–994.

from the beating of an object against an object and the vibrations of various bodies are one of the oldest elements in shaping the scientific picture of the world. An important stage in the development of acoustics was the emergence of music. Some archaeological findings indicate visualization of a musical instrument made of bone with side holes almost forty thousand years ago. Nearly two thousand years before Christ, a system of sound sources was made by dividing the octave into twelve time intervals²⁶. In the monography there are first acoustic recommendations for the construction of apartments in the Old Testament²⁷.

The origin of acoustics can be traced back to ancient times. It is impossible to determine exactly when a primitive man first noticed that the sounds of nature can be pleasant to the ear. It can be speculated that this observation was the basis for the creation of musical art. Otherwise, a human being would not have invented musical instruments. Thus, he had created musical instruments for many thousands of years before he became interested in the study of the nature of musical sounds.

Ancient musical instruments are much older than the first extant information about acoustics. It seems that the most ancient musical instruments are wind instruments. Various whistles and pipes of animal horns and shells are in the excavations of the Paleolithic – ancient stone age. The time of occurrence of the ancient flute and trumpet-shells is estimated around 80.000-13.000 BC. Flutes with the holes appeared around 5000-2000 BC.

The earliest string instruments, such as a harp, are known from drawings found during archaeological excavations in Ancient Egypt. Knowledge of the ancient acoustics is rather speculative and to a large extent has a mystical character.

The Chinese mythological philosopher Fokhi [佛希] who lived three thousand years BC, thought about the relation of the sound pitch to the elements of nature: earth, water, air, fire and wind. What relation the Chinese philosopher managed to establish — history is silent about. Although the term “acoustics” was introduced only in the 18th by J. Sauveur²⁸ the understanding of the wave character of the sound dates back to the 17th century.

²⁶ D. R. Raichel, *The Science and Applications of Acoustics*, Springer 2006.

²⁷ *Ibidem*.

²⁸ J.W. Strutt (Lord Rayleigh), *Theory of sound. from English* (Russian translation). Vol. 1–2, State publishing house of technical and theoretical literature 1940.

Today the genesis of the science of acoustics is generally attributed to the Greek philosopher Pythagoras (6th century BC) who had experimented on the properties of vibrating strings that produced pleasing musical intervals. This led to the creation of a customization (tuning) system bearing his name.

Aristotle (4th century BC) rightly (correctly) suggested that the sound wave propagates in the air, through the movement of air – a hypothesis based more on philosophy than on experimental physics; however, he wrongly assumed that high frequencies propagated faster than low frequencies – a bug that persisted for many centuries.

The foundations of classical acoustics were created by many scholars, including Galileo and Mersenne – the 17th century (the issue of pitch and speed of sound). At that time, the view was established that sound propagation requires a material medium. Famous acousticians worked at that time: Otto von Guericke, Huygens, Newton, Hooke, Bernouli, Fresnel, Helmholtz, Kirchhoff, Kundt and above all Lord Rayleigh whose *Theory of Sound*, written in 1877-78, is called the Bible of classical acoustics. Many scholars consider the work of Herman Helmholtz *Die Lehre von Tonempfindungen* from 1870 as the beginning of crystallization of acoustics in a separate field and the work of Lord Rayleigh from 1888 mentioned herein above. Then the process of transformation of acoustics into a separate scientific discipline took place going beyond the branch of theoretical and experimental physics.

In the past classical acoustics was defined as the science of sound, its generation, transmission and reception. It was limited to a frequency range heard by people. Thus, it was understood as a branch of physics dealing with voice, i.e. longitudinal waves of compressed and decompressed air felt by the human ear. The separation of so defined range of acoustics is equivalent to the separation of optics, originally also referred to as the section of physics dealing with the study of visible light. Yes, also today, it is associated by an average person with something that is perceived by his sense of hearing.

Everyone is faced with the phenomena of acoustics. Let's listen to the world around us. We suddenly begin to hear sounds that we have paid no attention to. The clock is ticking, music is playing somewhere, the wind is whistling, a bird is chirping in the distance. In addition it is also difficult not to mention the field of technology that would not encounter acoustic issues: manufacturers of musical instruments are looking for ways to improve the acoustic properties of their products, builders are busy striving to reduce environmental and industrial noise, acoustic methods of research allow to establish the quality

of a detail without destruction, measuring the acoustics set within several minutes will give you full information on the work of details in the engine of the car or machine engine - and this important knowledge is obtained on the basis of sound wave analysis²⁹.

And where does the acoustic wave come from? If a vibrating body - a tuning fork, string, membrane, etc. - is placed in an elastic medium, it will put in oscillatory motion the elements of the medium which are in contact with the body. As a result, parts of the medium adjacent to the body (substance) will undergo periodic deformations (compression or stretching) and elastic forces appear in the medium, aiming to restore it to an equilibrium state. Due to the interaction of elements of the medium, the elastic deformations will be transferred from one element to another, more distant from the vibrating body. Periodic deformations caused anywhere in the elastic medium (in a vacuum such mechanical disturbances do not propagate) will spread in the medium at a certain velocity „v” depending on the physical properties of the medium.

$$v = \sqrt{\frac{1}{\beta * \rho}}$$

where: β - compressibility coefficient, ρ - density.

The particles of the medium vibrate around their equilibrium positions. Only the deformation state will spread in the medium. The process of vibration propagation in the medium is called a wave process or simply a wave. Depending on the nature of the elastic deformations, transverse and longitudinal waves are distinguished. In longitudinal waves, vibrations of medium particles occur along the line defining a direction of wave propagation, Fig. 2. In transverse waves, vibrations of medium particles are perpendicular to the direction of wave propagation, Fig. 1.

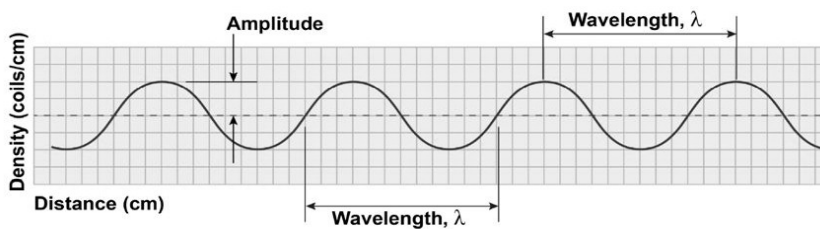


Fig. 1. Transverse wave propagating in x direction³⁰.

²⁹ <http://pianomax.ru/istorija-akustiki> (2019.09.05).

³⁰ <https://www.bing.com/images/search?q=longitudinal+waves&qpv=longitudinal+waves&FORM=IGRE> (2019. 09.04).

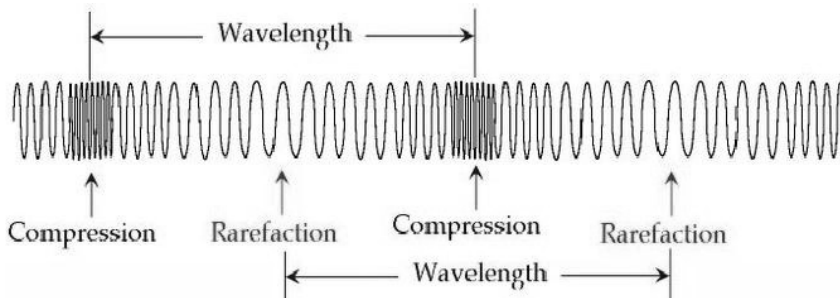


Fig. 2. Longitudinal wave³¹.

Liquid and gaseous media do not have shape elasticity. Therefore longitudinal waves can only be excited in them. They propagate in the form of alternating compression and rarefaction of a medium. In solids both longitudinal and transverse waves can be generated.

The equation describing the diagrams presented above (Fig. 1 and 2) is the typical sinusoidal wave function:

$$y(x, t) = A \cos(kx - \omega t)$$

where : k – wave number ($2\pi/\lambda$), ω - angular frequency, t – time.

Many interesting phenomena are related to acoustics.

Doppler effect

The Doppler effect is one of the remarkable discoveries in the study of the properties of wave phenomena. Its universal character is determined by the fact that today thousands upon thousands of different devices in different spheres of human activity are based on it. The phenomenon which was then named after its discoverer, an Austrian physicist Christian Doppler was first described in the mid-nineteenth century.

When the observer moves towards a resting sound source, he hears the sound at a higher frequency than when he is at rest (not moving). In the case when the observer moves away from a stationary source he hears a sound of a lower frequency. It looks similar to a moving source. The carrier harmonic signal pitch increases when approaching and decreases as you move away.

This phenomenon was postulated by Christian Doppler in 1842 stating that the colour of a luminous object should change with the relative movement of the observer and the moving body.

³¹ Ibidem.

$$f_l = \frac{u \pm u_l}{u \mp u_s} f_s$$

where: f – frequency, u – sound velocity, u_l – listener velocity, u_s – source velocity.

This phenomenon occurs in all types of waves and Doppler himself believed that the phenomenon he had discovered should also apply to acoustic waves. Buy Ballot proved it in acoustics in 1845, Fig. 3.

The Doppler effect is widely used in medicine. Devices for ultrasonic diagnostics work on the basis of the Doppler phenomenon. There is a separate technique in ultrasound called Doppler.

The Doppler effect is also used in optics, acoustics, electronics, astronomy, radar devices. The discovery of the Doppler effect played an important role in the development of modern physics. One of the confirmations of the Big Bang theory is based on this effect. How do the Doppler effect and the Big Bang relate? According to the Big Bang theory, the universe is expanding.

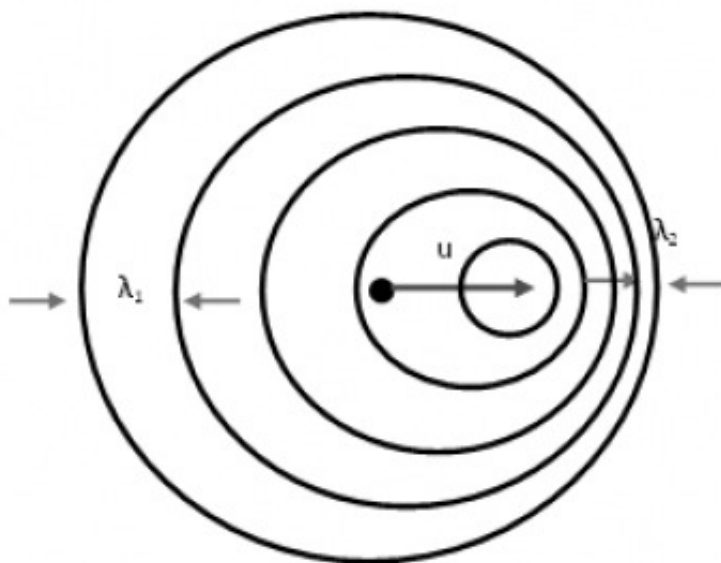


Fig. 3. The scheme of the Doppler phenomenon shown when the source is moving to the right with the velocity u . To the observer on the right, the wavelength λ_2 shortens (wave frequency increases), on the left λ_1 becomes longer (the wave frequency decreases).

Crossing the sound barrier, Mach angle (Mach number) Mach cone

The source of sound waves in gas (liquids) can be any body moving in it. This body, moving in a stationary gas, creates in front of it an area of increased

pressure. This generates elastic waves. The shape of these waves depends on the velocity of the body.

If the velocity of the listener u_l or the source u_s is greater than the velocity of sound v , the formulas describing the Doppler phenomenon must be modified and the result obtained will be completely different. In this case, the body producing the wave will overtake the wave it produces.

$$\frac{v}{v_s} > 1 = M$$

The path the body travels during t ($l = v_s t$) is greater than the distance traveled by the acoustic wave, i.e. at the speed of sound v ($R = vt$), Fig. 4.

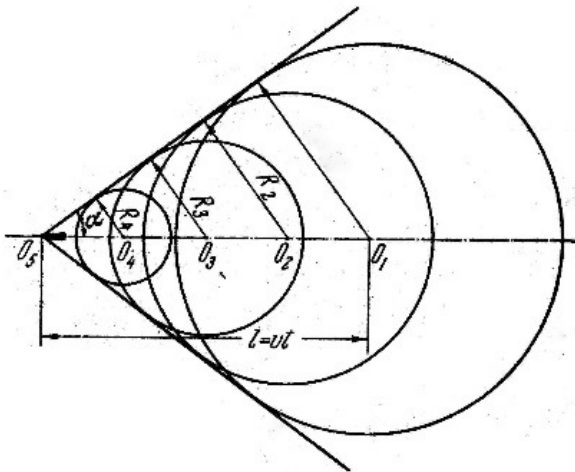


Figure 4. Mach cone

The figure 4 shows that the body was initially at the point O_1 and caused a sound wave. After the unit of time has elapsed, the body will overtake the wave front and reach the O_2 point, generate another wave there, etc. After 4 time units, the body will be at O_5 ahead of all waves that were created by the body during its movement. In this case, the waves created by the body during its movement are a family of spherical surfaces contained in the cone. At its top is the source. This cone is called the cone of weak perturbations or Mach (discoverer of this phenomenon) cone. The value of the flat angle α of the cone can be determined from Fig. 4.

$$\sin \alpha = \frac{R}{l} = \frac{v}{v_s} = 1 - M.$$

where: M – Mach number.

To an average person, the world of acoustics is associated with a signal that is perceived by his sense of hearing, i.e. in the frequency range from about

20 Hz to 20.000 Hz. It should be added that we also have other frequency ranges that are of interest to acoustic scientists, i.e. below 20 Hz called infrasound and above 20.000 Hz, i.e. above upper human perception threshold called ultra- or hyper-sound. These frequency ranges, especially the range of ultra- and hyper-sounds are used in many fields of science: physics, chemistry, medicine, biology and many others.

Ultrasound

The history of ultrasound goes back 200 years. Its birth can be considered the moment of its artificial generation with the help of a siren built by the French scientist C. Cagniard de la Tour in 1919.

More attention to ultrasound was paid during the First World War. We are talking about high frequencies. Their corresponding wavelengths are very short (for 100 kilohertz (kHz) - about 3 mm in the air). Therefore, they are not subject to as much bending as audible acoustic waves and therefore behave similarly to light waves. In particular, they propagate along straight lines and form directional beams (application similar to radar). In addition, it is possible to produce ultrasonic waves of very high intensity.

The moment when the upper limit of audibility was experimentally determined by Galton in 1883 with the help of a pipe he constructed, was of significant practical importance in the development of ultrasound. The Galton pipe had for many years been the master source of ultrasound in the 50 kHz range and served as an instrument in very many major studies conducted with ultrasound in the late 19th and in the first half of the 20th century. A breakthrough in practical application of ultrasound was the work of Langevin (1917) who used the piezoelectric effect in a crystal to generate and detect ultrasonic waves in liquids.

The piezoelectric effect is based on an observation that when a properly cut quartz plate is subject to pressure, electric charges are generated on its surface, i.e. an electric field will be created in the plate. This effect was discovered by the brothers James and Peter Curie in 1880. The following year 1881, the brothers discovered the reverse piezoelectric phenomenon - alternating electric field acting on the same plate in the proper direction evokes a variable linear deformation in the plate. Thus, in the case of the application of alternating voltage at a frequency of 60 kilohertz (kHz) the plate begins to vibrate at the same frequency. Langevin used ultrasound at sea to detect icebergs and

submarines. Thus, he gave rise to hydrolocation applications and the development of hydroacoustics.

Ultrasound generation and detection devices using the piezoelectric effect allowed their generation in the region of relatively high (radio) frequencies and high intensity. The phenomena of electrostriction and magnetostriction are also used to generate ultrasound. These two phenomena use the deformation of materials under the influence of electric or magnetic field.

Ultrasound applications are very broad and are usually divided into two areas: passive and active applications, depending on the way of interaction with the environment in which they are propagated. As far as passive applications are concerned one should mention the following: ultrasonic spectroscopy³² and flaw detection, photoacoustics³³, acousto-optics³⁴, musical instruments³⁵, medical ultrasound diagnostics, hydroacoustics³⁶. In regard to active applications of ultrasound it is necessary to mention: medical ultrasound therapy, coagulation and ultrasonic dispersion, cavitation, sonoluminescence, sonochemistry, fragmentation (e.g. kidney stones) and the formation of rigid centers, welding and soldering, washing, extraction and drying of substances and many more.

The importance of sound in today's world confirms the activities of UNESCO, International Commission for Acoustics (ICA) and La Semaine du Son (LSdS). ICA and LSdS have signed a Memorandum of Understanding and will cooperate to achieve international recognition of the goals of UNESCO

³² B.B.J. Linde, N.B. Lezhnev, *The effect of bond saturation in five-membered hetero-cyclic compounds upon their acoustic properties-VT energy migration rate*, "Ultrasonics" 1998, 36 9, 959-966.

³³ B.B.J. Linde, N.B. Lezhnev, *Absorption and velocity of ultrasonic waves in thiophene, o-, p-xylenes and their mixtures*, "Journal of molecular structure" 2005, 754 (1), 111-115.

³⁴ V.I. Balakshy, B.B.J. Linde, A.N. Vostrikova, *Acousto-optic interaction in a non-homogeneous acoustic field excited by a wedge-shaped transducer*, "Ultrasonics" 2008, 48, 5, 351-356

³⁵ E. Skrodzka, A. Krupa, E. Rosenfeld et al., *Mechanical and optical investigation of dynamic behavior of violins at modal frequencies*, Conference: 10th International Spring School on Acousto-Optics Location: Sopot, POLAND Date: MAY, 2008, "Applied Optics" 2009, 48, 7, C165-C170; E. Skrodzka, B.B.J. Linde, A. Krupa, *Modal parameters of two violins with different varnish layers and subjective evaluation of their sound quality*, "Archives of Acoustics" 2013, 38 (1), 75-81.

³⁶ D.B. Kilfoyle, A.B. Baggeroer, *The state of the art in underwater acoustic telemetry*, IEEE J. Oceanic English 2000, 25, 4-27.

Resolution 39 C/49 25 September 2017 on “The Importance of Sound in Today’s World: “Promoting Best Practices” in the framework of the International Year of Sound 2020 (IYS 2020)³⁷.

To the common understanding of Sound – Theological and physical conclusions

We cannot imagine the existence of human kind without sound. For theological understanding of the World the sound is recognized as voice or whisper, also as noise or sough. For the Protestant theological attempt the only way of communication between God and man is a verbal one. The transmission of God’s Words is his voice, also present in written form in the Bible. The primal way of God’s monologue or dialogue has an oral form, later written in *Tanakh* and in the New Testament – the witness of his Revelation. Without the medium of sound this communication could not be established. In the Christian tradition, the prayer is the dialogue between man and God but the premise for it is the Silence. In the moment of silence, there is a space for the discourse between the creature and the Creator. One of the important moment in the human self-understanding is fast. The fast is also a time of Silence. In silence the person try to find a way to his interior.

In the postmodern World however there is much more noise, hum or sough than the real personal communication. The biblical tradition testifies to the dialogue between God and human kind and within the humanity.

Modern science describes the phenomenon of sound in different categories. The language of acoustic is based on mathematical pattern. The theoretical side of physics has found a practical solution in many forms of human life. Their birth of ultrasound has a special role in human history in the last 200 years. What we human being understand as silence is not always in the language of Physics. We do not hear the waves different from a frequency range 20 to 20.000 Hz to which the human ear is sensitive. We are not able to use our technical things and find solution without the theory of sound. The Silence is not a proper way to solve human problems. It could only be a step, a breakthrough in a further dialogue. The voice is the proper medium of communication not violence. This is also an experience which was given for the citizens of Gdańsk in January 2019.

³⁷ <http://www.icacommission.org/index.html> (2019.09.04).

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