DOI: 10.61782/fa.2025.0113

FORUM ACUSTICUM EURONOISE 2025

AL-ÁNDALUS. SPREADING ACOUSTIC KNOWLEDGE FROM SPAIN TO WESTERN EUROPE

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ABSTRACT

During the Early Middle Ages, while in Western Europe science was almost forbidden, in al-Ándalus scientific knowledge flourished, not only for translating Greek philosophers into Arabic, but also for being free to practice art and technology. The first transference from there was the ten digits numeral system adopted in the 11th century, and the milestone is the translation from Arabic to Latin of Euclid's Elements book. In those years the study of sound waves was embedded in music or mathematics, it was not a separate discipline, then to understand their achievements in acoustics a closer look at their writings is needed, of which the few that survived are in the library of *El Escorial*. In al-Ándalus, there were several schools of music, and some of the teachers were craftsmen who made musical instruments, many of them required skills and acoustic knowledge to be designed. The list of scientific contributions made by Moorish Spain to the West is almost endless, and this paper will focus on how they interpreted the translations of the Greeks and their learning and development of the sound wave physics, which became part of the acoustical knowledge.

Keywords: *history of science, al-Ándalus, acoustics, music.*

1. INTRODUCTION

The Iberian Peninsula was militarily occupied by the Muslims in 711, who later introduced, in addition to their religion, the practice and theory of knowledge that the Arabs philosophers had, some of it taken from the writings of the Greek philosophers, whose reading was forbidden in Western Europe. This article only mentions that the study of ancient Greek philosophy was forbidden in Western Europe, it will not go deeper, nor will it comment on the political and/or religious situations that motivated such prohibitions for centuries, a period that until a few years ago was pejoratively called the "Dark Ages," which is now known as the "Early Middle Ages," a historical interval that spans from the fall of the Roman Empire to the 10th century. These occupied territories took the name of al-Ándalus, being Córdoba the city that stood out in the arts and sciences, which sheltered libraries with documents brought from Turkey, Persia, and the rest of the Arab world, among them the translated writings of the Greek philosophers in Arabic.

Regardless of the coexistence between Christianity, Judaism and Islam, which certainly did not have social and/or economic equality in those occupied territories [1], here it will be highlighted those areas in which sound and music were developed in al-Ándalus as a means of cultural expression and human knowledge.

This article is a meta-analysis based on firsthand secondary sources (free available from the Internet), and it is part of a side research started later in 2022, which is conducted by the author who is publishing the history of the acoustics in Spain, in the Acoustics Journal of the *Spanish Acoustical Society*.

2. SOUND AS A PART OF MUSIC INSIDE OF THE QUADRIVIUM

The *Quadrivium* comprised arithmetic, geometry, astronomy and music, and this article is focused on highlighting the scientific contributions that were made in al-Ándalus, in the field of wave phenomena from music, because in the Early Middle Ages physics, and much less acoustics, were not individualized as knowledge since its

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theoretical content is embedded in the texts of practical and/or theoretical music written by the Arabs, it is not possible to pinpoint a right place of their theories, and here is shared a summary of what could be unearthed from the main music's treatises known in al-Ándalus, by the most prominent thinkers who subsequently were spread in Western Europe, which ultimately shaped the science that prevailed in the Renaissance and the Enlightenment.

All Arabs books and manuscripts on music include writings which in modern words we could identify as behavior of waves, some translated from Greek texts (and corrected or expanded) and many others elucidated by the Arabs themselves. Those writings were brought mostly from Persia and Turkey to al-Ándalus, as books and treatises written in Arabic were gradually translated into Latin – mostly at Toledo– first spread them from al-Ándalus to Bath and Oxford (in England), and later to France and the rest of medieval Europe.

Certainly, the Arabic thinkers analyzed here, using craft techniques of "trial and error" applied to improve the loudness of musical instruments, accumulated basic knowledge of musical acoustics (in modern words) that is revealed in their writings, i.e., they did not describe a section on physics, but rather the explanation of wave physics is deeply inserted in their musical treatises.

3. MUSIC AND SOUND TREATISES IN AL-ÁNDALUS

One of the firsts books which highlight the Arab legacy on Western culture, was published in 1875 under the title "The intellectual development of Europe," where is discussed the crucial role that Arab scholar played in the preservation and translation of ancient knowledge, protecting many Greeks and Romans texts (mostly at Egyptians, Persians and Turkish libraries) that might have otherwise been lost [2]. This book emphasizes that the Arab world not only preserved those texts but also expanded upon them, making significant contributions to various fields, and discusses the influence of Arab music on European culture.

Also, it highlights how Arab musical traditions and instruments significantly impacted on Western European music, during the Early Middle Ages and beyond. Arab instruments such as the lute ('ud in Arabic), the guitar (qitār), and the rebec (rabāb) were introduced and became integral to European musical development. Besides, it notes that the transmission of these musical elements occurred through cultural exchanges between Iberian Peninsula and other regions which enriched European music, contributing to its diversity and evolution [2].

In the opinion of the author of this article, four are the most important personalities who would be highlighted as the main thinkers of the Arab world in producing philosophical treatises on music and sound (which was used in al-Ándalus), in chronological order they are: Ziryab, al- Kindī, al-Fārābī, and Avicenna.

3.1 Ziryab and the school of music at Córdoba, the first in Europe

Abulhasán Ali ben Nafi (789–857), nicknamed Ziryab, was born in Baghdad. He arrived in al-Ándalus circa 822 and settled in Córdoba city, where he started a revolutionary age of several cultural changes. Among dozens of contributions, he made significant ones in the field of sound physics, particularly musical theory domain and instruments design.

According to the Royal Academy of History of Spain[1], his major contributions were in the art of music: "He made some modifications in the construction technique of the lute, adding a fifth string and reducing its weight with thinner woods with better resonance" [6]. He improved the sound quality of the lute and some other chordophone instruments by using new materials, not only for their frames or bodies, but also for the strings.

He created around 850 in Córdoba, what is considered the first school of music in the world, which was revolutionary both in its time and today, because it was open, did not depend on any religion, and people of both sexes studied.

From some sources [7] [8] [9] it is possible to outline that his direct contributions to acoustics may not be easy to pinpoint, his innovations in designing musical instruments and performance techniques likely had implications for sound production and perception; he concentrated on the theory of composition, chords, rhythms, etc., so that music were pleasant to hear for the human mind.

Regarding musical acoustics, it is credited that Zyrab improved the *nuba* (*nawba*) style, by introducing a structured suite based on modal principles, distinct rhythmic cycles within movements that feature tempo acceleration, and integration of instrumental and vocal elements. Then, these can be understood as a move towards structured musical sequences within a modal framework. Acoustically, the nuba results in a musical form with a defined harmonic color, rhythmic complexity, dynamic contrast, and a rich timbral environment.

His emphasis on the quality of sound and the nuances of musical expression suggests an understanding of basic

[1] In 1738, thanks to the enlightened action of various eighteenth-century personalities, the *Royal Academy of History of Spain* was founded.

acoustic principles; for example, the lengthening of the neck of the lute contributed to the improvement of other stringed instruments, it's likely that Ziryab's modifications were informed by an understanding of acoustic principles, such as string tension, resonance, and sound projection.
While specific details about Ziryab's direct contributions to the field of sound physics and musical notation, may be limited due to historical context, his innovations in musical theory and instrument design had an impact on the understanding and appreciation of waves behavior.

3.2 Works of al-Kindī

According to the Stanford Encyclopedia of Philosophy, *Abu Yusuf Ya'qub ibn Ishaq al-Kindī* (800–873 C.E.) was the first self-identified philosopher in the Arabic tradition (and one of the most prolific writers), and the first to translate Aristotle into Arab. Although he initially borrowed ideas from the Greeks on music and wave physics, he developed, deepened and went beyond what they contributed, improving the theory of sound and its perception.
As it is cited in [3], contrary to the Greeks, he proposed that sound is a form of wave motion "similar to how waves form when you throw a pebble into a pond;" al-Kindī theorized that when an object vibrates, it causes the air around it to also vibrate, and these vibrations spread outwards in a spherical pattern, forming waves of compressed and rarefied air. He recognized that air acts as the medium for these sound waves, transmitting them from the source to our ears. Al-Kindī's theories were remarkably accurate for its time (considering technological limitations), he also theorized that when these sound waves reach our ears, they cause our eardrums to vibrate; then, those vibrations are then translated into signals that our brains interpret as sound [3].
A brief summary of his works on music theory (he wrote at least seven treatises) is presented in [4], where is described how al-Kindī found a scientific approach as well, because one of his aims was "to find a logical explanation of the peculiarities of sound grouping;" he also observed "how harmony is produced by the arrangement of specific notes." Al-Kindī "noticed that each note carries a precise pitch and that those notes with a very high or a very low pitch do not fit in a harmonious manner." Then, he concluded that it is necessary to create an explanation on how to establish a pitch, a revolutionary thought at that time, formalizing the use of the notes by alphabetic names which opened the scientific description of musical instruments by means of the instrumental tablature, the basis of manufacturing instruments, and centuries later this was the most important tool for the tempered system.
Links between music and mathematics are deeply analyzed in [5], where it is explained that al-Kindī reached a blend of scientific observation and mathematical reasoning, when he explored the relationship between the pitch of a sound and the length of the string that produces it. By the available means of his time, he meticulously calculated the precise mathematical ratios that correspond to different musical intervals, developing a system for tuning musical instruments, particularly the 'ud (the lute), being a pioneering acoustical tool, because he came up with his own ideas. It is important to mention that he used for all mathematical reasoning the Hindu numeral system.
Al-Kindī's thoughts on sound physics (music) were accurate for the 9th century, and it laid the foundation for later medieval philosophers to further develop the understanding of acoustics. While he didn't have sophisticated tools that we have today to study sound waves, his logical reasoning and observations led him to a groundbreaking discovery.

3.3 "The great book of music" of al-Fārābī

Perhaps the most relevant and influential treatise on sound and music from the Arab world, was written by *Abū Naṣr Muḥammad ibn al-Faraj al-Fārābī* (870–950 C.E.) titled *Kitāb al-Mūsīqā al-Kabīr* (The great book of music), which the only surviving copy is in custody at *El Escorial* (part of the Spanish National Library–BNE). There are three other musical treatises in other European libraries.
It is important to highlight that al-Fārābī for the Arab world is considered as "The second thinker," being Aristotle the first one. He wrote extensively on music theory, exploring the mathematical and physical principles underlying musical sounds.
According to [10] [11] al-Fārābī writings are being reviewed and revisited, in order to make a distinction among what he borrowed from the Greeks, what he corrected and what are his own contribution to the field of music and sound, because the fact that he gave detailed information about instruments and surpassed the Greeks in the field of sound physics gave him a place in the history of music [11].
Al-Fārābī's work on the physics of sound built upon the knowledge of earlier Greek philosophers like Aristotle, but he is the thinker least influenced by the ideas about music and sound of Pythagoras or Plato [11]. Criticizing the Pythagorean concept of music, he discussed the distinction between practical and theoretical music and emphasized the importance of understanding the physical foundations of sound, because he recognized the significance of sound as a

physical phenomenon; then, he recognized the significance of a sensory foundation for theoretical music.

According to a philosophy of music research on al- Fārābī's work [12], he discusses the relationship between practice and theory of music, and also between the composition and performance of music, and the justification that he gives about that in modern words could be said to belong to psychoacoustics, since "the fact that theories come after sensory experience in the temporal sense does not render reason completely useless or trivial in musical analysis" [12]; then, he expanded on his analysis, including distinctions between sensation, imagination, and reasoning in classical theories of the soul in the study of music (as Greeks did it).

As a music theorist, al-Fārābī conceptualized that music brings together many aural experiences, because tones, melodies, and intervals are indeed dependent on sensation and imagination, meaning that both the inductive method (melody has rational principles), and the deductive method (taking the principles to the individual melodies), both have to be used. This last statement has a deep meaning to human knowledge: It was one of the first times that it was proposed to have the reasoning of the Scientific Method.

While not explicitly focusing on modern physics, his insights into propagation and nature of sound were significant for his time. A few key points on the physics of al-Fārābī's on sound: He realized that sound originates from vibrations, whether produced by the human voice, musical instruments, or natural phenomena. He described how these vibrations travel through the air, creating sound waves. He understood that a medium, such as air or water, is necessary for the transmission of sound, he explained that the denser the medium, the faster sound travels.

While al-Fārābī's contributions to acoustics are significant, it's important to note that his work primarily focused on the theoretical aspects of music rather than practical acoustics or physics of sound. However, his exploration of the nature of sound and its relationship to the human psyche laid the groundwork for future developments.

As a general summary of al-Fārābī's work, he examines the production and perception of sound, contributing to the understanding of the underlying principles of music, writing extensively on music theory, including the physical properties of sound, the mathematical relationships between notes, and the psychological effects of music.

Al-Fārābī left a lasting legacy in the field by moving away from mystical explanations of music and focusing (in modern words) on the physical principles that govern sound.

3.4 Ibn Sina (Avicenna) and his "Book of healing"

Abū 'Alī al-Husayn ibn 'Abd Allāh ibn Sīnā (980–1037 C.E.) or Avicenna, highly influenced by al-Fārābī's, he made significant contributions to the understanding of sound propagation and acoustics, Avicenna works on the nature of sound and its transmission through different mediums helped to lay the foundation for many developments in acoustics. His writings on music theory, such as the *Kitāb al-Shifā'* ("Book of Healing" or "The physics of the healing" for some translators), explored the relationship between music, mathematics, and the natural world [13], and it is a comprehensive encyclopedia which covers a vast range of subjects [14] [15], including medicine, philosophy, astronomy, music and physics.

He discussed the mathematical principles underlying musical scales and intervals, as well as the physiological and psychological effects of music on the human body. It's important to note that Avicenna's primary focus was on music theory and its philosophical implications on human behavior (following the al-Fārābī's work). His insights into sound propagation, including reflection and refraction, were likely integrated within his broader understanding of acoustics and their relation to music and human experience.

Avicenna describes sound as a form of vibration that travels through the air, explaining that sound is produced when an object moves and creates a disturbance in the surrounding medium, typically air, then, sound waves propagate through different media, highlighting that the speed and quality of sound can vary depending on the medium it travels through, such as air, water, or solid materials; all of his explanations were primarily qualitative rather than quantitative.

Avicenna also discusses the phenomena of sound reflection (echoes) and refraction (bending of sound waves), demonstrating his understanding of how sound waves interact with different surfaces and materials, providing a framework to understand that sound as a wave-like disturbance.

Avicenna was interested in movement phenomena and its measurement; he based his analysis on two concepts: rapidity and slowness. As cited in [16] he distinguished between the speed of light and of sound: "Thunder can be seen and heard. Thunder (lightning) is seen at one time, but heard at another, after it (the sound) has moved in the air and gradually reached the hearing." In other words, he established the difference in the speeds of the two forms of movement of matter.

It's important to note that much of Avicenna's work on sound is linked to his philosophical and musical investigations. He explored the relationship between sound, music, and the human soul, considering how music can

evoke emotions and affect the human body (In modern words: a journey between musical acoustics and psychoacoustics), and while his explanations may differ from modern scientific concepts.
Avicenna's work played a significant role in the history of acoustics.

4. EARLIEST WESTERN PHILOSOPHERS WHO USED TRANSLATED ARABIC TEXTS

As cited in [17], the first known translation of philosophical manuscripts from Arab to Latin were made by Adelard of Bath, an English philosopher, during the 12th century introducing ancient Greek texts which had only existed in Arabic form to Western Europe. Among his translations, the most influential work was of Euclid's Elements (text used for eight centuries), and the second is the introduction of the Hindu ten digits numeral system and the zero.
Roger Bacon (1214–1292) is the most prominent philosopher and thinker in disseminating the contributions of the Greeks, which he made known through his great philosophical works with translations into Latin that were made in al-Ándalus, or by translating himself directly from Arabic. Concerning the interpretation of the texts that he translated into Latin, they were not always correct, Bacon himself shared an anecdote about the misinterpretations of the translations: "When I lectured on this in my classes but did not know how to explain it, as was required, my Spanish students derided me. I later learned from them that [the name] was not Arabic, as all the doctors believe, but Spanish, and [the plant] is seed of henbane" [18].
Based on al-Kindī's treatises on Hindu-Arabic numerical notation, Roger Bacon is one of the first to promote its use to leave aside the Roman one (which used letters), saying that it is good for science and academic learning. As cited in [19], Roger Bacon along Robert Grosseteste (1175–1253), based mostly on al-Fārābī's work, they were the first to conceptualize the importance of practice and experimental actions in science, merging the mathematical method with the experimental one, thus beginning the qualitative method in scientific research centuries before Francis Bacon.
Concerning sound physics [20], Bacon applied the term "algorithm"[2] to explain the step-by-step resolution of mathematical problems with algebra (to elucidate sound refraction and other matters), and the result obtained through these procedures he identified as *secundum computistas* (computed afterwards).
Although Greeks wrote about a grammar in music, later improved by Arabs, it was Roger Bacon who gave it a scientific form by incorporating mathematical logic, initiating the idea of meter and rhythm in music in Western Europe, saying that sound is part of music (reinforcing the Quadrivium); at the same time, it can be established that Roger Bacon in the 13th century is the first philosopher who grants the study of sound the entity of a scientific nature.
Among several of his contributions, Roger Bacon formalized the study of sound waves by stating that they do not propagate like a ray because do not have a linear pathway, but he did conceptualize that sound "can be studied as the path of a ray" [20] [21]. *Note*: Roger Bacon use the word "species" to describe rays.

5. DISCUSSION

It is well known that in the Early Middle Ages in Western Europe, the reading of Greek philosophers was forbidden (it was considered as pagan literature), then their writings were completely unknown; the opposite happened in Arab culture. Henry G. Farmer, a renowned researcher on Arabian music, in 1930 stated that the musical treatises of Greeks thinkers were well known among Islamic intellectual circles, and this familiarity was expressed in many of their writings, since Arab thinkers borrowed some ideas from the Greeks, but this does not take away from the originality of their contributions to scientific knowledge, and "al-Fārābī's treatment of physical and physiological principles of sound and music, is certainly an advance on that of Greeks" [22].
The Moorish culture were not mere transmitters of Greek heritage, but rather refiners and creators, who considerably contributed to the foundations of the later Western science, because scholars from European regions went to al-Ándalus (Spain) to study or seek books at Toledo's libraries, then they disseminated to the West the knowledge kept there.
Arabs' theories were accurate in those years and laid the foundation for later thinkers and philosophers of Western Europe (those that emerged in the Renaissance and the Enlightenment) to further develop our understanding of sound waves and acoustics. While they didn't have sophisticated tools that we have today to study sound waves. Their logical reasoning and observations led them to groundbreaking discoveries in the acoustics field. Therefore, it is important to understand that the concept of

[2] Word derived from Al-Khwarizmi, the Arab thinker who introduced the idea of solving arithmetic problems by methodical, step-by-step approach.

waves they had was not understood in the same way then, as it is now.

For some researchers it might seem that many of the contributions made by Ziryab, al-Kindī, al-Fārābī, and Avicenna, they are more focused on musical acoustics than on the physics of waves themselves, but it is important (once more) not to forget that until the Enlightenment sound itself was part of the music, not an individual entity.

All the sources consulted for writing this article agree on one thing: al-Fārābī was the first to give a scientific explanation of sound and to draw up rules for the construction of musical instruments, and "Fārābī made a valuable contribution to physiological acoustics which was not touched by the Greeks" [23]

As mentioned in this article, manuscripts translated from Greek-Arabic and Arabic-Latin are being revisited, not only to better decide how these texts were originally written, but also to find out what contributions were made by Arab philosophers; also, many are being translated directly into English from Arab [24]. Therefore, in the coming years it will be possible to update what is known about the contributions of the Arabs to the science and knowledge.

The way of interpreting the teachings that the Moors had in al-Ándalus had a great impact on the Iberian populations, because when, in the 13th century, the first kingdom of the future Spain could be formed, in order to establish its political power, King Alfonso X *El Sabio* (The Wise) created the first Spanish university in 1254 at Salamanca, which was also the first university that was not dependent on the Catholic Church, like the other three at that time, and also the first to have a Chair of Music [25].

6. CONCLUSION

Unlike the study of medicine, law, astronomy, and other disciplines, that were individualized in the Early Middle Ages, sound and wave physics were not studied separately (acoustics did not even exist as a field of knowledge). Since the study of sound and the behavior of elastic waves were not independent matters during those years, in the texts written by Arabs philosophers these theories are embedded and deeply rooted in their musical treatises, and to a lesser extent in medical ones (those who studied the curative use of music), perhaps for this reason an in-depth study and analysis of those writings is still pending.

Although not strictly "acoustics" in the modern sense, works of these Arabs scholars were an exploration of the physical manifestations of sound, and in essence, advanced the understanding of sound and acoustics by:

- Applying mathematical principles to music theory.
- Exploring the physical and psychological effects of music.
- Systematizing musical knowledge and practice.
- Contributing to the development of musical instruments.

The purpose of this article is to begin this discussion because **ultimately music is part of the creation of sounds**, and also, in a way, to recognize the contributions of those Arab thinkers whose works on music were translated in al-Andalus (from Arab into Latin), and whose ideas spread from Spain to Western Europe through European scholar's sway, leading to the Renaissance and the Enlightenment.

Acknowledgement. The author wants to thank to Prof. Eng. Federico Miyara (University of Rosario, Argentina), his review and comments on this article.

Disclaimer. The author has no feelings against any religion or culture; this article was written under the sole agenda of History of Science. Research and the writing of this paper were not funded and were done in the author's free time.

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