Original Research Paper

Volume - 14 | Issue - 09 | September - 2024 | PRINT ISSN No. 2249 - 555X | DOI : 10.36106/ijar

Physics

AN IN-DEPTH STUDY ON THE FUSION OF CONCEPTS IN PHYSICS WITH THE COMPOSITION OF MUSIC

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ABSTRACT There is a close synergy between physics and music. This has been in existence since the time of Pythagoras, perhaps before. The documentation of this compatibility has been subsequently researched and written about. Physics is used extensively in acoustics and also concerning the materials used for various instruments. So much so that the new genres of music take specific care of the type of material that encompasses certain instruments so that the correct sound effect is achieved. **Research Question:** The paper will analyze the synergy between physics and the composition of music. What are the concepts in physics that are used extensively in music? How far does the knowledge of this science impact the understanding of music? Does this connection exist even today with the newer genres of music? Is the synergy between the two related to only instruments or does it extend to vocal music? These and other such questions would be attempted to be addressed in the course of this paper.

KEYWORDS : Standing waves, acoustics, frequency, amplitude, compression, rarefaction, timbre, diffraction, interference, quantum theory, superposition, entanglement.

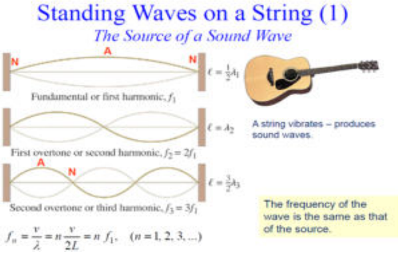
Introduction

Most people consider physics to be a highly mathematical-oriented subject, while music seems to be a subject that is taken up at any level to help relax and calm the individual. But there is a close relationship between the two as the core of music is the concept of sound. This obeys the laws of physics. Acoustic science, which is an extremely integral part of music, uses the concept of sound waves to understand how human perception is affected and also how musical notes are produced, transmitted, and interpreted.

The basic effect of music, which is sound, is a concept that explains how the longitudinal wave, which means that the particles of a medium vibrate parallel to the direction of the propagation of the wave. The sound wave that emerges out of a musical instrument, a loudspeaker, or even from a vocalist, pushes the air forward and backward as the sound propagates outward.

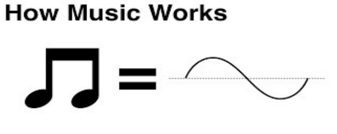
It is this vibration that is science-based and produces sounds that vary in pitch, volume, tempo, and rhythm. As far as musical instruments are concerned, the sound that emerges from them is again made possible because of standing waves which come from the constructive interference between waves traveling in both directions along a string or a tube

Figure 1. Standing waves emerge from string instruments



Source: Google images

Figure 2. A musical note is converted into a sound wave.



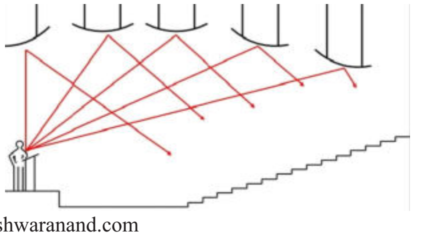
Source: Google Images

Figure 2 indicates the synergy and close relationship that music has with sound waves.

2. Historical origin of the discovery of the relationship between physics and music

Aristotle of the 4th century BCE, a tutor to Alexander the Great, explained the production and transmission of sound in terms of motion. From strings in a guitar to the resonance of an opera in a grand symphony hall, acoustic science is the basis of all fundamental principles of sound creation and transference. It is this field of science that has had a great influence on both the design and construction of musical instruments, as well as venues. Acoustic principles help architects and engineers design rooms that optimize sound quality, improving an audience's auditory experience.

Figure 3. Acoustic science used in an auditorium



Source: ishwaranand.com

Music is an art that permeates every human society. Throughout history, music has been an important adjunct to ritual and drama and has been credited with the capacity to reflect and influence human emotion. The ancient Greek philosopher Democritus denied any need for music "It was not a necessity, but it arose from the existing superfluity". The thought process at this time was that music, like other arts, is mere 'graces'.

It has been recognized that the power to move people has always been attributed to music. In India, music was used in the service of religion from the earliest. Much of the performances of artists are set to Indian traditional music, and a skillful singer rivals that of an instrumentalist.

In Western music, the vertical dimension of a chord structure affects the creation of sound tones.

In South Asian classical music, the division of an octave (intervals) is more numerous than in Western music. There is a spontaneous imitation that is carried on between an instrumentalist and a narrator, with the background being played by the rhythmic subtleties of the drums, which leads to an enormous measure of excitement.

Chinese music, like the music of India, has been part and parcel of a ceremony or narrative. According to Confucius, music and government are reflected in one another. He believed that only a superior man who can understand music is equipped to govern.

Music was virtually a department of mathematics for the philosopher Pythagoras, who was the first musical numerologist and who laid the foundation of acoustics. The Greeks discovered the correspondence between the pitch of a note and the length of a string, but they did not progress to the calculation of the pitch based on vibration.

Plato was a stern musical disciplinarian. He declared that music echoes divine harmony, rhythm, and melody, all reflecting the moral order of the universe. He valued music in its ethically approved form, his concern being with the effects of music. He regarded it as a psycho-sociological phenomenon.

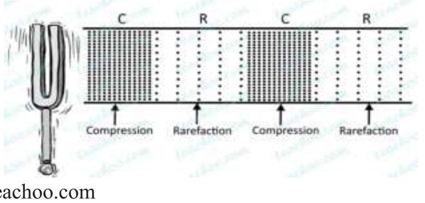
The role of music as a part of an accessory to words is clearly illustrated in the history of Christianity. Martin Luther insisted that music should be simple and direct, and an aid to piousness.

The origin of the study of the physics of sound, known as acoustics, is credited to Pythagoras, the Greek mathematician and philosopher. In the 6th century BC, Pythagoras conducted experiments to determine the properties of vibrating strings that produced musical sounds. In the 4th BC, Aristotle posited that sound waves propagate through the air due to the motion of the air.

CONCEPTS OF PHYSICS THAT ARE RELATED TO MUSIC

The two basic elements that are related are frequency and amplitude. Frequency is defined as the number of compressions per sound and this is directly related to the pitch of the sound: as the frequency increases, so does the pitch. The frequency is measured in Hertz (Hz). For example, the frequency and pitch is the note A above middle C which has a frequency of 440 Hertz. A similar characteristic of sound waves is their period, which refers to the time it takes for one cycle of the wave to complete and is the inverse of the frequency.

The second basic feature of sound waves is their amplitude, ie: the amount of pressure change that occurs between rarefactions and compressions. This translates to the loudness of the sound (frequency): as the amplitude increases, so does the loudness.



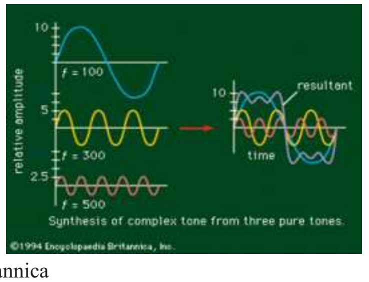
Source: teachoo.com

Figure 4. Visual representations of compressions and rarefactions.

COMPLEX SOUNDWAVES

TIMBRE

Figure 5. Complex soundwaves from pure tones (timbre)



Source: Britannica

Timbre can be defined as the resultant of three sin curves when their ordinates are added along the time scale. In an equation form, the amplitude y of the waveform at any time t would be represented by $y=10\sin(2\pi\ 100t)+5\sin(2\pi\ 300t)+2.5\sin(2\pi\ 500t)$. The timbre of this form is different from others that have a fundamental tone of 100 Hertz and a different harmonic amplitude.

In music, timbre is the tone of an instrument or voice that arises due to the reinforcement by individual singers or instruments of different harmonics, or overtones (q * v of a fundamental pitch). A nasal timbre stresses different overtones than a mellow timbre. The timbre of a tuning fork is clear and pure as the sound it produces is without overtones.

Timbre is determined by:

- An instrument's shape.
- Frequency range within which the instrument can produce overtones.
- Envelope of the instrument's sound.

The timbre of a singing voice is modified by contracting various parts of the vocal tract such as lips, tongue, or throat.

TONE

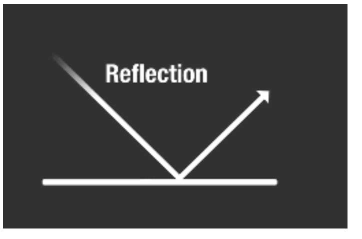
This is recognized by the regularity of vibration. A simple tone has only one frequency and a complex one consists of two or more simple tones called overtones. The frequency of the overtones could be in terms of multiples, for example, 2, 3, or 4, and these are known as harmonics. A combination of harmonic tones is pleasant to hear and therefore called a musical tone.

WAVE

These are a propagation of disturbances from place to place in a regular and organized way. Mechanical waves such as sound require a medium but electromagnetic waves do not require any medium. Waves can travel immense distances even though the oscillation at one point is small, for example, a thunderclap can be heard kilometers away yet the sound carried manifests itself at any point only as a minute compression or rarefaction of the air.

They display certain basic phenomena. In reflection, a wave encounters an obstacle and is reflected back. In refraction, a wave bends when it enters a medium and has a different speed. In diffraction, waves bend when they pass through small obstacles and spread out when they pass through small openings known as apertures. When two waves meet, they could create a wave with a larger amplitude than the original wave, or they could create a wave with a smaller amplitude, this is known as interference.

Figure 6. Visual representation of reflection of a wave.

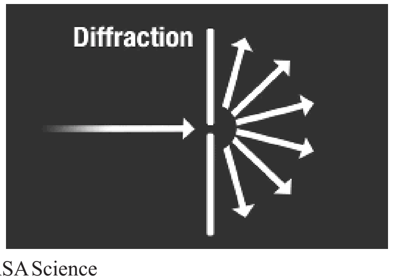


Source: NASA Science

Figure 7. Refraction of white light through a prism

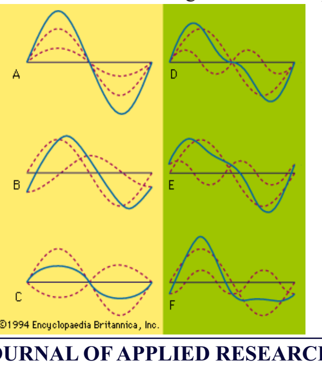
Source: Britannica

Figure 8. Visual representation of diffraction through a slit



Source: NASA Science

Figure 9. Interference of waves resulting in different amplitude



Source: Britannica

DOPPLER EFFECT

When the source of a wave moves relative to an observer, the observer notices a change in the frequency of the wave. This change is called the Doppler Effect, named after the Austrian physicist Christian Doppler. In sound, this effect is an everyday experience. When a blowing of a horn is passed on a highway, the observer notices that the pitch of the note seems to change.

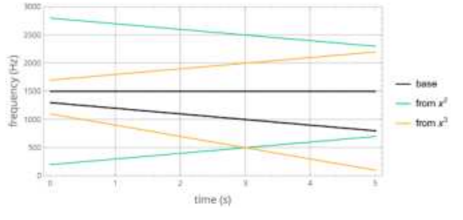
STANDING WAVES

If a wave is confined to a close space, it undergoes both reflection and interference. The periodic waves with frequencies are fixed by the boundary condition at the end of the tube. There are positions in the tube where the displacement of air is zero, this is known as standing waves. The positions of continuous zero displacement are known as nodes, and the positions for maximum displacement are known as anti-nodes.

COMBINATION TONES

This is a psycho-acoustic phenomenon, also known as resultant or subjective tone, that is artificially perceived when two real tones are sounded at the same time. There are two types of combination tones: sum tones whose frequencies are found by adding the frequencies of the real tone and difference tones whose frequencies are the difference between the frequencies of the real tones. Combination tones can be produced electronically by combining two signals in a circuit that has non-linear distortion, such as an amplifier, subject to clipping or a ring modulator.

Figure 10. Combination tone



Source: http://szhorvat.net/

PHANTOM TONES

The ear-brain system can be fooled in many ways giving rise to what are known as phantom tones. Under the right circumstances, listeners will perceive a frequency that is the difference between two frequencies:

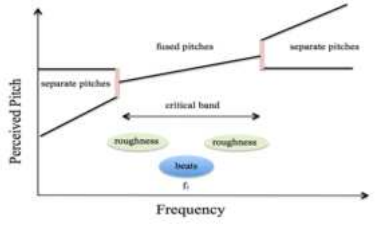
f=f1-f2

A similar effect can sometimes occur when the sum of two frequencies is heard instead of the two individual frequencies:

f=f1+f2

These combination tones are sometimes called Tartini tones. For example, a guitar string is tuned by comparing a note with a known pitch and tuning the string till the beats disappear. If the notes are a little further apart, one can hear a single note but it appears to be rough or wavering, and eventually one hears two separate notes instead of beats. The range of frequencies where the two are close enough to cause a single sound is known as a critical band.

Figure 11. Visual representation of the combination of perceived pitch and frequency



Source: phys.LibreTexts.org

SYNERGY BETWEEN MUSICAL INSTRUMENTS AND PHYSICS

All music emerges from the principles found in physics and mathematics. The structure of musical instruments shows an aesthetic, artistic look. The fixing of a sound post in a violin, and the mouth and finger holes in a flute are works of perfect engineering.

A musical instrument aims to provide excellent sound quality and an aesthetic look, as well as be easy to play and control. All sounds in the musical instrument originate through vibrations which create sound waves that move through the air. Resonance occurs when an object vibrates in response to sound waves of a certain frequency. In string instruments like the Veena, the strings are plucked and in a violin, the strings are bowed to produce sound. The vibration from the strings hits the hollow body, which is called the resonator of the instrument, and the bouncing of the resonator produces sound.

TYPES OF VIBRATION IN MUSIC

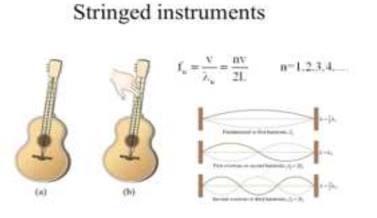
There are different types of vibration, e.g. vibration of strings, vibration of air, vibrations of reeds, vibrations of vocal chords, vibration of membranes, etc.

The mode of vibration is oscillating, reciprocating, and periodic.

EXAMPLES OF:

1. Stringed instruments - Veena, Violin, and Guitar.
2. Percussion instruments - Mridangam, Tabla, and Drums.
3. Wind instruments - Flute, Nagaswaram, and Clarinet.
4. Autophones - Cymbals and Bells.

Figure 12. Stringed instruments and harmonics



Source: Google image

LAWS OF VIBRATION

Laws of vibration of stringed instruments would depend upon:

1. LAW OF LENGTH - The frequency of vibration of a string is inversely proportional to the length of the vibrating string if the tension and mass per unit length are constant.

2. LAW OF TENSION - The frequency of vibration in a string is directly proportional to the square root of the tension if the vibrating length and mass per unit length are constant.

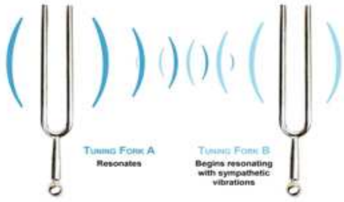
3. LAW OF LINEAR DENSITY - The frequency of vibration of a string is inversely proportional to the square root of mass per unit if the tension and vibrating length are constant.

Marsenne's Laws describe the frequency of oscillation of a stretched string or monochord useful in musical tuning and musical instrument construction, eg: a string half the length (1/2), four times the tension (4), or one quarter the mass per length (1/4), is an octave higher (2/1). A pattern of change over time is called an oscillation or vibration. It need not be necessarily regular or repetitive but there must be a series of oscillating changes that allow energy to travel, or change media, whether it is a sound wave or a sound signal.

RESONANCE

The principle of sound waves plays a crucial role in distinguishing sounds. In music, resonance amplifies the sound, like the soundboard in a piano, resonating with the vibrations of the strings, and a singer's body resonates with the vibrations of the vocal folds. Resonance is a special form of vibration that is equal to the machine's natural frequency. The natural frequency is defined as the square root of the ratio system stiffness divided by system mass. Resonance can result in a system failure, which is why it should be avoided.

Figure 13. Tuning forks showing resonance



Source: Median

In many cases vibration is undesirable, wasting energy, and creating unwanted sound, eg: vibration in the motions of engines, electric motors, or any mechanical device. This could be caused by an imbalance in the rotating parts, uneven friction, or the meshing of gear teeth. Careful designs minimize unwanted vibration. Sounds are generated by vibrating structures, eg: vocal chords. These pressure waves can induce the vibration of structures, eg: eardrums. Attempts to reduce noise are related to issues of vibration.

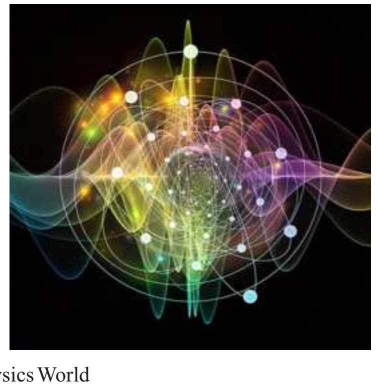
The geometry of the instruments will determine what harmonics of the sound wave will be amplified. The sound of the instruments would also be described by the amplitudes and the time of each of the harmonics present in the resulting sound. This group characteristic, frequency combination, and times are called tone, eg: the same note played by a horn sounds different when produced by a violin although the fundamental frequency of sound is the same, the harmonic frequencies are different. In the violin, a wide range of harmonics appear along with the fundamental sound. Rock and roll style songs have many high-pitched guitar sounds. Some people can create sounds with all types of materials, eg: a plastic bottle, a metal rod, or even a plastic bag can be used to create an instrument.

HAVE THESE CHANGED WITH THE GENRES OF MUSIC CHANGING?

The new theory in physics that has emerged with their relationship to music is the quantum theory. This theory gives rise to new ideas, possibilities, and ways of understanding musical development. Quantum theory is one where no music is present, it explains the logic of atoms, particles, and electrons obeying different rules than those indicated by the classical Newtonian world. Quantum music is a branch that looks at music and quantum physics. This new theory is a way of detecting sounds and forms that do not exist in the traditional (classical) approach to music. Words like 'vacuum', 'one particle', 'two particles', 'superposition', and 'entanglement' are titles in physics, but when applied to music, they give the audience a different aspect of approaching and understanding music.

Some composers have tried to use 'authentic' quantum sounds as a basis for music creation. The way that this is done is 1. to use the frequencies that can be measured in the quantum lab. If these frequencies were converted into the pitch of a musical note, it would be extremely high for the human ear to hear, Thus, this needs to be toned down many times to experience an oscillation of a detectable sound. 2. To use quantum information in a musical composition with probabilities. This is done by putting tones in quantum states in which the possibility of hearing one note and not another is a probability.

Figure 14. Artistic representation of the intersection of music and quantum physics



Source: Physics World

Music encompasses a realm that spans genres ranging from classic melodies to hip-hop rhythms and country tunes. Whatever the preference, music can bring joy and facilitate emotional release. It acts as a force that fosters a sense of belonging among people. Music also increases overall feeling of well-being and may decrease pain perceptions, the reason being that sound waves are ultimately vibrations. Listening to music releases dopamine, a chemical that is a part of the brain's reward system, and makes us feel good. Music does not emerge from random creative inspiration, it involves scientific structure, pattern, repetition, and other characteristics that make it recognizable to the human ear.

CONCLUSION

Music and physics are like two peas in a pod. Neither of them can exist without each other. They are both connected and depend on various laws and theories. Music is the basic engagement of the laws of sound: whether in the form of vocals or the playing of instruments. Even the place - auditorium, or stage - where concerts occur is concerned with sound physics. The instruments played are concerned with the materials that string instruments are made of and those used for percussion. It is not only a close synergy between vocals but also between all types of acoustics, ranging from vocals to auditoriums to materials with which the instruments are assembled. Both of them are intertwined and for an excellent rendition, they need to synchronize with each other.

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