Chapter - 1

Sound & Music

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Sound, is the physical basis of music. To begin with therefore, let us discuss the nature of sound, its various aspects, its mode of propagation and its effect on the human ears from a scientific point of view.

It is a matter of common knowledge that any physical sound is the result of vibrations. Some part of the other of the object producing sound *(whether it is a vocal chord, a string of a musical instrument or simply a nonmusical bang)* must vibrate. Some times the vibrations are visible, as in the case of a violently plucked string of a Tamboora or a strongly vibrating tuning fork.

Even after the vibrations of tuning fork have become invisible they can be felt by lightly touching its prongs with the fingers. In other cases the vibrations are so feeble that they can be neither seen nor felt by the fingers but can be detected by more sensitive instruments. In the case of a flute, the vibrating substance is the air column contained in the pipe comprising the body of the flute.

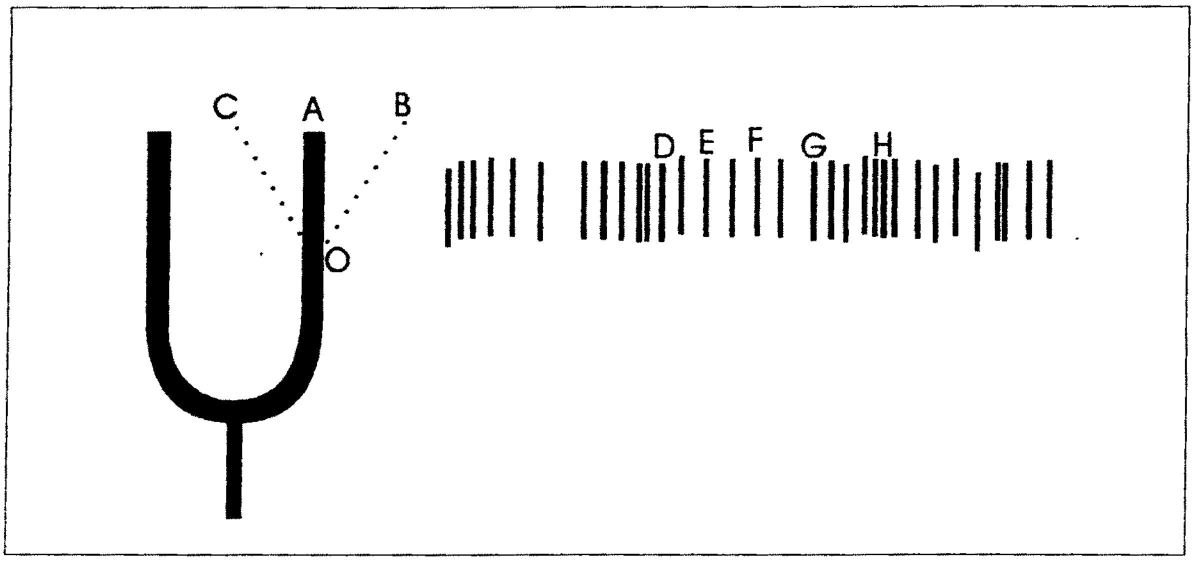
The converse of the above, however, is not true in the ordinary sense; all vibrating objects may not produce sound detectable by human ears. This is owing to the limitations of human ears. If the frequency of vibrations is less than 30 cycles per second, the sound produced cannot be detected by most human ears. Such a sound is termed as Infrasonic. This is why a rubber manually vibrated to and fro or a pendulum does not appear to produce any sound.

Technically speaking, a sound is produced, but the vibrations being only a few times per second, it fails to register on the ear drums. Similarly, when the vibrations are more than 30,000 cycles per second, the sound produced are unable to stimulate the ear drum. Such sounds are called ultrasonic. Examples of ultrasonic are the sounds produced by bats which are inaudible to the human ears but which help the bats to detect the existence of obstacles in their way.

Thus vibrations in any substance like stretched string, elastic rod, or air columns are the origin of sound. However, the sound must travel upto the ears also. For the propagation of sound, an intervening medium is necessary. In ordinary experience, this medium is the atmosphere.

How the sound produced by a vibrating tuning fork is propagated through the air is shown in *Diagram I.*

Diagram-1.



The arm AO of the tuning fork is vibrating alternately between the positions BO and CO. When the arm moves to the position BO from AO, the air in the neighbourhood is compressed. Similarly when the arm is in the position CO, the air on the right is rarefied. Waves of compressions and rarefactions move along the direction indicated by the arrow much in the same way as the bang of a railway engine *(and pull)* against the first carriage travels to the last carriage, being passed on by each carriage in succession to the next one. In the example of compressions and rarefactions produced in the air by a vibrating tuning fork, the air molecules do not actually travel upto the ear drum. They simply vibrate to and fro about their mean position while the compressions and rarefactions travel from the tuning fork to the ear with a velocity depending upon the properties of the air. This kind of propagation is called *"Wave propagation"* in which energy *(here sound)* is transferred from particles to particle. Wave propagation is possible only in an elastic intervening medium *(air, in this case)*.

When the compressions and rarefactions produced by a vibrating object travel upto the ear drum, the ear drum also vibrates. These vibrations, communicated to the brain by the auditory nerve, are perceived by the brain as sensations of sound. The question now arises, what distinguishes one kind of sound from another ? It must depend upon the modes of vibrations of the source of sound. Let us discuss these aspects in slightly greater detail. The motion of a plucked stretched string or a simple swinging pendulum are known as simple harmonic motion.

A simple harmonic motion of a vibrating particle is distinguished by the amplitude *(maximum displacement of the particle from the mean position)* and frequency *(number of complete vibrations per second)* while a particular stage of displacement of the particle at any given time is distinguished by what is known as the phase angle.

Returning to *Diagram-1*, in the case of a vibration tuning fork, the amplitude is AB or AC, frequency is the number of complete vibrations per second *(one vibration being counted as the cycle from B to C and back to B)* and the phase of the particle is the stage of displacement at any time, where the particle may be anywhere between B and C. The same amplitude and frequency govern the simple harmonic motion performed by the particles of air intervening between the tuning fork and the ear. However, a snap of all the particles would show that the phase of every particle was different. The air particle just adjacent to the arm of the tuning fork has the phase same as that of the corresponding point on the tuning fork. As one moves to the right, the phase goes on decreasing uniformly because it takes some time for the motion to be transferred from one particle to the next.

Hence every particle of air at a distance from the arm of the tuning fork is lagging behind in phase as compared to the point on the tuning fork and would attain the same phase when the wave starting from the tuning fork reaches the particle in question. The time lag depends upon the velocity of sound waves and the distance of the particle from the source of sound. The particular stage of compression or rarefaction at any point is reached by another particle on its right in *Diagram-I* after a time lag. That is how waves of compression and rarefactions travel away from the source of sound with the velocity of sound.

The distance between two consecutive compressions or rarefactions, or any two particles in the same phase is called wave length and is denoted by . It is evident that during the time in which the tuning fork completes one vibration, sound waves travel a distance equal to.

Any sound, musical or otherwise, is distinguished by three features
1). *Loudness*
2). *Pitch* and
3). *Quality*.
Let us discuss these properties one by one.

1. LOUDNESS

This does not really need much discussion. Everyone knows what distinguishes a murmur from the roar of a lion or how sound changes on operating the volume knob of a radio. Loudness, or the intensity of sound, is related to the energy flowing through the intervening medium per unit volume. This depends upon the amplitude of the vibrations mentioned earlier. It is not difficult to verify this. In a vibrating tuning fork, the amplitude of vibrations can be easily seen by the blurred outlines of the vibrating arm. When the amplitude is large, the sound produced is loud. As the amplitude diminishes, the loudness of the sound also decreases until the amplitude is no longer visible to the eye, but can be still felt with the fingers. The sound of the tuning fork also becomes very feeble then. the same can be verified in the case of a vibrating plucked string of musical instrument like Tamboora of sitar or a vibrating drum. Scientifically, loudness is measured in units called decibels. The loudness of sound encountered in common experience is given decibels in *Table 1.*

Table No.1

Threshold of hearing	0 *decibels.*
Quiet room	20 *decibels.*
Quiet street	40 *decibels.*
Quiet Conversation	50 *decibels.*
Loud Conversation	70 *decibels.*
Busy typing room	90 *decibels.*
Near loud motor horn	100 *decibels.*
Near airplane engine	120 *decibels.*
Threshold of pain	130 *decibels.*

2. PITCH

The second feature of the sound *viz.* **Pitch** is more important for our purpose. The *pitch or note* of a sound makes an impression of a different nature independently of loudness. In a musical scale Sa Re Ga Ma Pa Dha Ni, the pitch steadily increases from Sa to Ni. In a vibrating tuning fork, the loudness goes on decreasing with the passage of time but the pitch remains unchanged throughout. As the loudness of a sound depends upon the amplitude of vibrations, the pitch or the note depends upon the frequency of the vibrations measured in terms of cycles per second. Taking the frequency of the note Sa as 240 *(cycles per second)*, the frequency of a sound is called *"Swara"* of a *"Nad" (sound)*.

The frequency of vibrations of a freely vibrating instrument does not depend upon how it is plucked, but it only depends upon the physical properties including elasticity of the vibrating portion of the instrument. The chords of musical instruments are tuned to the desired note *(frequency)* by adjusting the tension by shifting the bridges or by tightening or loosening the pegs on which string are fastened In the case of a Tamboora, for example, the main adjustment is done by adjusting the tension and finer adjustments are done by shifting small beads to alter the length of the vibrating portion of the chord. A note or *"Swara"* can thus be defined as the frequency in cycles per second or the length of a given chord subject to a given tension. The latter method was adopted by the early musician.

3. QUALITY

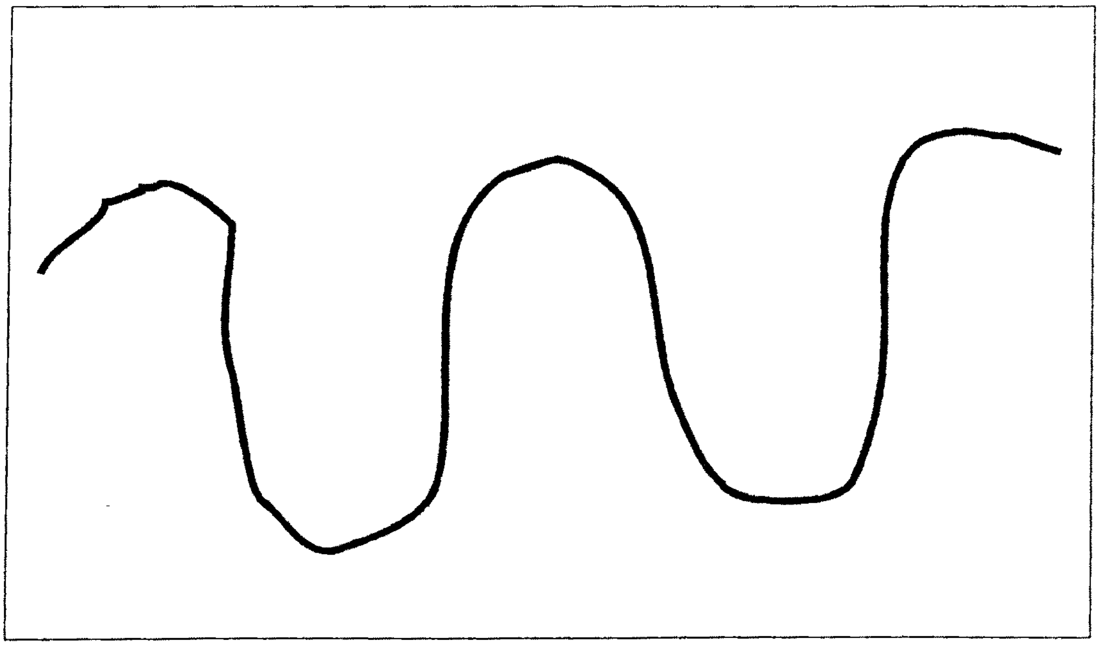
The third feature of a sound viz, quality is what essentially draws a distinction between musical and non musical sounds. Two sounds may have the same loudness and the same note and yet one of them may be musical, *(pleasant to the ears)* and the other non musical. The distinction between these two sounds would be that of quality.

It is not the loudness or pitch but the quality of sound that enables us to recognize the voice of our friend. A male singer and a female singer may be singing a duet on the same notes equally aloud, but the difference in the quality of sound produced is at once noticeable.

Any regular listener can easily discern whether the instrument being played in a radio recital is Sitar, Sarod or Veena. The difference is that of quality. Again the sound of truck horn, the call of a crow, the sound of a falling utensil may have the same general pitch as a musical instrument or a singer's voice, but it is the difference in the quality which categorizes the former sounds as *"noise"* rather than music. It is, therefore, basically quality and not loudness or pitch which distinguishes a musical sound from noise and which also distinguishes between various kinds of musical sounds or voices. Of course loudness and pitch also have an important role to play. Too loud a sound cannot be pleasant to ears. Similarly, very high pitch or note may appear too shrill or a very low note may appear too harsh to the ears; but the limits of loudness or frequency are owing to the limitations of human ears, while the difference of quality are more fundamental.

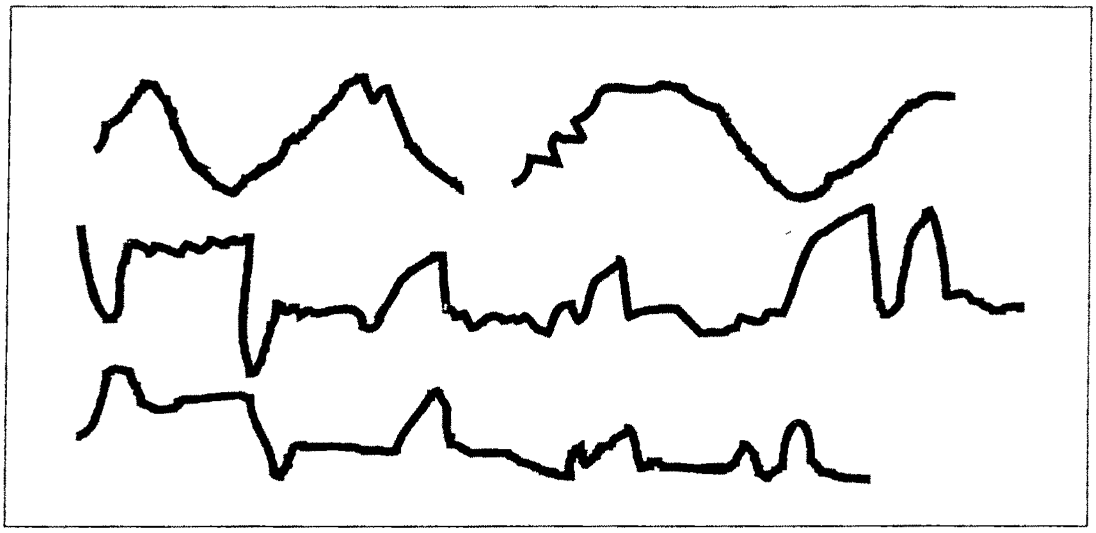
Let us now see what quality means scientifically.
The graphic representation of simple harmonic vibration
is of the form of a sine curve of the shape given in Diagram 2.

Pure simple harmonic vibrations
Diagram 2



But hardly any object or instrument in practice vibrates in perfect simple harmonic motion. Actual vibrations of a source of sound have a general form of sine curve but have a more detailed structure. A few examples of the graphic representations of sounds actually produced are shown in Diagram 3.

Diagram-3

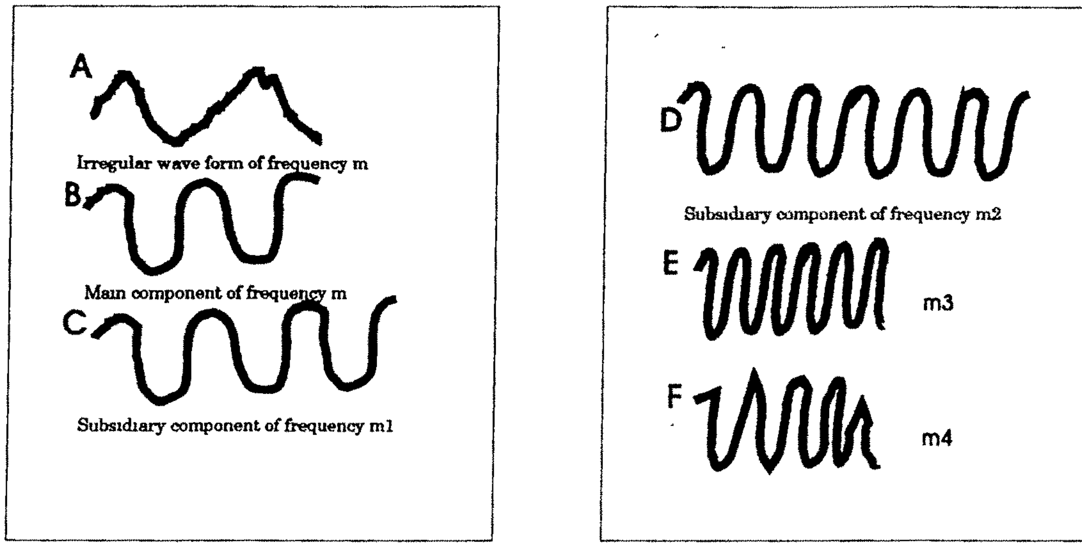


The vibrations in the sources of sound are periodic *(possession a define cycle and therefore frequency)* but they seldom conform exactly to the theoretical curve of simple harmonic motion. These differences in the wave forms constitute the differences in quality.

Quality, then is determined by the shape of the curve depicting the vibrations graphically. some of the wave forms appear pleasant to the ears and are classed as musical while others appear unpleasant and are rejected as noise. the distinction will become even more clear after a further analysis of an irregular wave form.

It follows from a famous theorem of mathematics named after its inventor Fourier, that any wave form of an irregular structure *(such as shown in Diagram 3)* can be regarded as a mixture of pure sine curves of different frequencies.

Diagram-4



If the Wave form corresponds closely to a pure sine curve, the frequency of this pure sine curve would predominate in the mixture and other frequencies will be much less prominent *(their amplitude will be small)*. As the wave form grows more and more irregular, the frequencies other than the main frequency become more and more prominent *(their amplitudes become comparable to that of the main frequency)*. Thus the parent wave form such as may be actually produced by a musical instrument has been shown in *(Diagram 4a).* Fourier's analysis shows that it can be broken up into a number of pure sine curves (pure frequencies of different frequencies m m 1 m 2 which contain, apart from the parent frequency m, other frequencies m 2 m 3 etc. It will be seen that the component *(Diagram 4B)* with the frequency same as the general frequency of the original frequency predominates, having a large amplitude. Other frequencies shown in diagram 4C, 4D, 4E etc. decrease rapidly in amplitude as the frequency becomes more and more different from the original frequency of the wave form. If the original wave form resembles less with a pure sine curve, the frequencies other than the main frequency become more prominent. On he other hand, if the wave form exactly coincides with a pure sine curve., *(Diagram 2)* other frequencies are totally absent. The Fourier's analysis can be applied to any periodic curve, however irregular.

Thus, any sound produced by a vibrating source is a *"compound note"* which is an admixture containing the main note and many other notes in decreasing properties. The composition of such compound notes into constituent notes was studied by Helmholtz who used the term *"tone"* to define a pure frequency and *"note"* to describe a compound note.

The quality of a sound is determined by the composition of this admixture of pure tones into which the original sound can be broken up following Fourier's analysis. When the admixture contains notes or frequencies of musical scale *(which will be defined and discussed later)* the sound appears pleasant and is recognized as music, otherwise it remains non musical. It will be explained in a later chapter that certain notes, in combination of a fundamental note produce harmony, producing a pleasing effect on the ear. Such notes belong to a musical note. On the contrary, notes which, when combined with a fundamental note do not produce harmony are not pleasant to ears. When a compound note contains notes belonging to a musical scale *(producing harmony)*, the effect is pleasant to ears.

As an example from common experience where some of the overtones can be rather distinctly heard, we can cite the ringing of a bell. As the bell is struck, one can make out, along with the main loud note, a number of fainter shrill notes which are the overtones having twice or thrice the frequency of the fundamental note. In musical instruments, the overtones are particularly noticeable in bow instruments. A violent often produces *"controlled harmonics"* from his instrument by lightly touching the vibrating string with his fingers and thereby creating or accentuating partial nodes at the points of contact. The resulting sound has soft flute-like quality.

Thus we have seen that any musical note is not a pure tone or single frequency but a superposition of different frequencies in which the predominant tone is called the fundamental tone and others are called harmonies or partial tones. What pleases the ear is the particular blend of these different notes rather than the purity of the note. One might imagine that the presence of partial tones is a kind of impurity in the main note and a *"perfect"* musical instrument should be the one which succeeds in avoiding all the partial tones and maintains a pure tone containing a single frequency. This is just not so. The human ear does not enjoy a pure tone which appears rather pungent like the drone of a mosquito. One can easily verify this by listening to a tuning fork and deciding for himself how pleasant it is as compared to a sitar, Sarod or even a Tamboora.

Before concluding this chapter, let us briefly discuss how the ear responds to different notes. It has been established that the ear perceives ratios of frequencies rather than differences. If notes having frequencies 100, 200, 400, 800, 1600 etc. were sounded in succession they would appear equally spaced to the ears in the frequency spectrum.

On the other hand, if notes having frequencies 100, 200, 300, 400, 500 etc. were so sounded, ears would find the *"spacing"* between them diminishing gradually. Thus, equal ratios, rather than equal differences of frequencies are judged as equal intervals, by the ears. This quality of ears is often mathematically expressed by saying that the frequency response of the ears is logarithmic.

A logarithm of any number x with base A is given by the following formula.

$X = a^y$

Where Y is the logarithm of X with base a and is written log a.

Thus the logarithm of a given number with a given base is the number by the power of which the base number must be raised in order to yield the given number. Usually, logarithms of base 10 are used in practical applications.

Thus if Y = Log 10 x

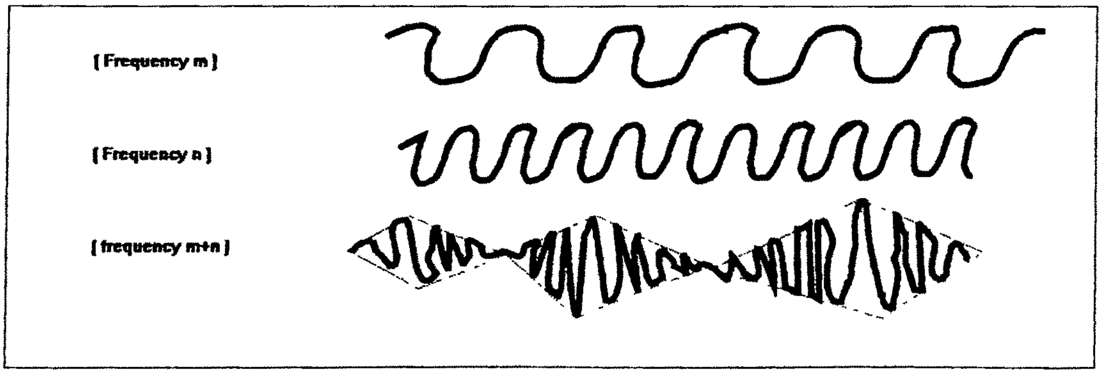
then, $X = 10^{y}$

It can be easily seen that log A + log B = log A/B. Hence ratios of numbers are reflected as additions of their logarithms. Therefore, if logarithms of frequencies are used instead of frequencies equal ratios of frequencies will correspond to equal differences of the logarithms of frequencies and will be perceived as equal intervals by human ears. Equal differences of logarithmic response of the ears. Because of the above property of human ears, the notes of any musical scale are chosen so as to belong to a geometric sequence *(with a fixed ratio)* rather than an arithmetic sequence *(with a common difference)*.

There is however, a special case when the ear is able to detect a minute difference between two frequencies with a remarkable accuracy. This happens when two very nearly equal frequencies are sounded simultaneously. The sound resulting form the superposition of two nearly equal frequencies mid way between the two constituent frequencies but its amplitude waxes and wanes many times in a second with a frequency which is equal to the difference of the difference of the two frequencies.

Graphically, the superposition of two vibrations with equal amplitude and frequencies equal to m and n is shown in Diagram 5.

Diagram 5



It is seen from the continuous curve in diagram 5 C that the frequency of resultant vibration is $(m+n)/2$ and its amplitude is not constant but fluctuates between a certain maximum and zero. The variation of amplitude is represented by the dotted curve enveloping the continuous curve. If the amplitude of the initial vibrations had been unequal, the general nature of the resultant curve would have remained the same except that the minimum amplitude would have been different from zero.

Thanks to the phenomenon of beats, it is possible for the human ear to detect a small difference of frequencies of two notes sounded simultaneously. As an experiment, we may take two identical tuning forks of the same frequency. Now the frequency of one of them can be made slightly different by loading its prongs with soft wax. If the two tuning forks are sounded together, beats will be heard as fluctuations in the intensity of the sound, the number of beats per second being equal to the difference in the frequencies of the two tuning forks.

When this difference is large, the number of beats per second is too large to be detected clearly by the ears. As the difference becomes smaller and smaller, the beats become more and more pronounced; because the smaller the number of fluctuations per second, the more clearly the beats can be noticed by the ears. Hence the accuracy of the ears to detect a small difference of frequencies when two approximately equal notes are sounded simultaneously, is indefinitely high; for the smaller the difference of frequency, the more pronounced are the beats heard by the ears.

The above property is utilized to tune musical instruments. The string of the musical instrument to be tuned is compared with a standard note and the tension or the length of the string is adjusted so that the two notes are roughly equal and beats are heard. Now the fine adjustment of tension or length is adjusted in such a way that number of beats per second decreases and finally, beats disappear altogether. When no beats are heard on sounding the string and the standard note simultaneously, their frequencies are exactly equal and the string has been tuned.

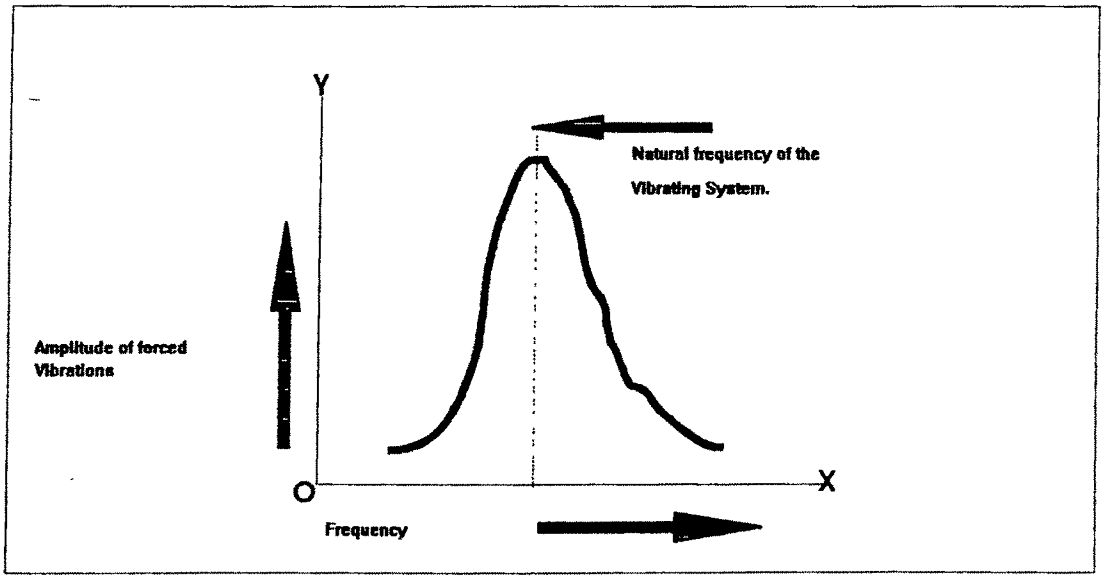
Thus the efficiency of the human ear to detect even the slightest difference of frequencies of two notes played simultaneously is remarkable. but is must be remembered that this is possible only if the two notes are heard simultaneously *(so that their superposition is possible)*. If the same notes are heard at different times, the ears would be sensitive to the ratio of their frequencies rather than the difference, and may not be able to detect them as different notes if the ratio is very close to 1. On the contrary, when the ratio of the frequencies of two notes heard at different times is significantly different from 1 so that the notes are distinguished when the same notes are heard simultaneously since their difference may be too large.

Thus, human ears are sensitive to ratios of the frequencies of two notes when the notes are heard at different times and to their difference when they are heard simultaneously, the sensitivity in the former case is much less as compared to the latter case.

There is another phenomenon which is useful while tuning musical instruments although to a much lesser extent than the phenomenon of beats. This is the phenomenon of resonance. To explain it, let us first put forward the concept of forced vibration distinguished from natural or free vibrations. So far, we have talked about only the latter in which force is applied only in the beginning to effect a certain displacement about only the latter in which force is applied only in the beginning to effect a certain displacement about the mean position of the vibrating instrument to start the vibrations. After starting the vibrations, the force is withdrawn and the system is left free to vibrate under its own elasticity. In such cases, the frequency of vibrations is quite independent of the displacement initially applied but depends only upon the inertia and elasticity of the vibrating system. Such a frequency is called the natural frequency of the vibrating system.

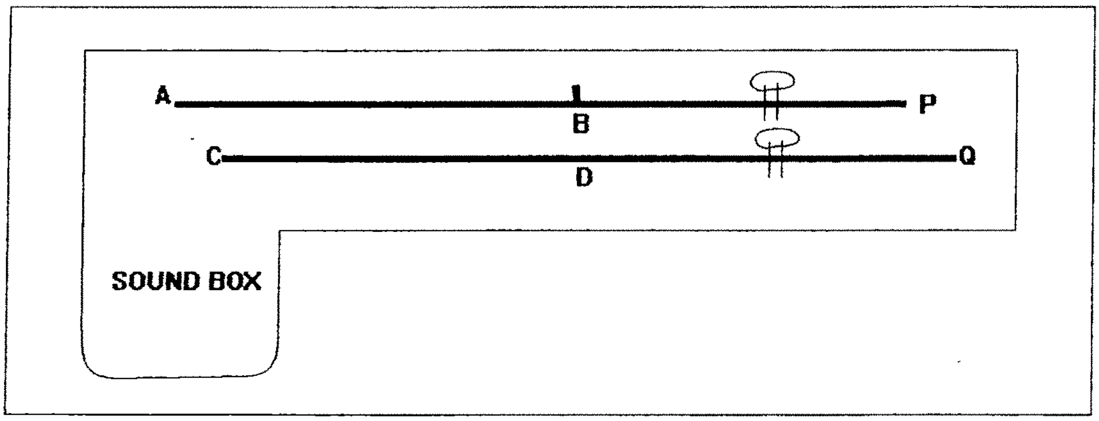
The situation becomes quite different when a periodic disturbing force is continuously applied on a vibrating system. The system is then forced to vibrate in the frequency of the force applied rather than its natural frequency. Such vibrations are called forced vibrations. However, since there is a conflict between the frequency of force and the natural frequency of the system, the amplitude of forced vibration is very small. When the frequency of forced vibrations is equal to the natural frequency of the system, suddenly the amplitude rises very high This is called the phenomenon of resonance. the graph shown in diagram 6 makes clear how the amplitude of forced vibrations varies with the frequency of vibrations and rises sharply when this frequency equals the natural frequency of the vibrating system.

Diagram 6



Let us now see how this phenomenon is useful while tuning the musical instrument.

Diagram 7



Let AB and CD be two strings of a musical instrument say a Tamboora and AB has already been tuned to the desired frequency, CD being out of tune. Now when AB is vibrated by plucking the string, the vibrations pass into the sound box and vibrate the large volume of air inside *(so that the sound is amplified)*. These vibrations again tend to vibrate CD *(forced)* with the frequency of AB. The amplitude of the vibration of CD us very small when CD is out of tune. Now the tension of CD is adjusted until the vibrations of AB also resonate CD. When the frequency of AB and CD are equal, the vibration of AB set CD into resonant vibration in which the amplitude of vibrations is easily visible. The phenomena of resonance and beats is well known to musicians who make use of them while tuning the instruments. Tuning with the help of beats, however, is extremely accurate.

To sum up, sound, musical or otherwise, is the result of periodic vibrations distinguished by amplitude *(loudness)*, frequency *(pitch)* and quality *(shape of the wave from or the degree of predominance of partial tones over and above the fundamental tone)*. Basically, it is the quality rather than amplitude of frequency, which distinguishes noise from music and which enables us to recognize the sound as coming from a particular vocalist or instrument. The exact composition of the compound determines how pleasant the sound will be to the ears.

When notes are heard one after the other, human ears detect the ratio of their frequencies rather than their difference. when this ratio is very closely equal to 1, ears are unable to distinguish the notes as distinct *(when sounded one after the other)*. However, when two notes having very nearly the same frequency are heard simultaneously their difference can be very accurately detected by the ears owing to the production of beats *(rise and fall in the intensity of sound)*. When the two notes, exactly equal are sounded simultaneously, the ears can detect this unison by the phenomenon of resonance, or more accurately, by total disappearance of beats.

Having gone into the general characteristics of sound and some basic phenomena, in the next chapter, we shall discuss the relationships of one note with others and distinguish when their relationships are musical and when they are not. Then we shall go into the origin of musical scales and different systems of musical scales.