Engineering Physics 1

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Module-02
Lecture-04
Acoustics of Buildings - Part I

This is the fourth lecture of this five lecture series on Acoustics. In the last lecture, we studied ultrasonic waves, methods of their production and their applications which are quite varied and cover many areas.

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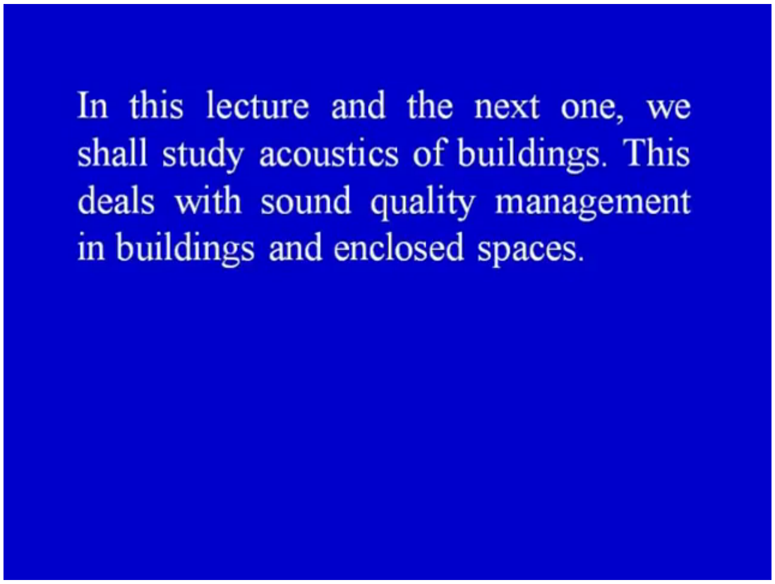

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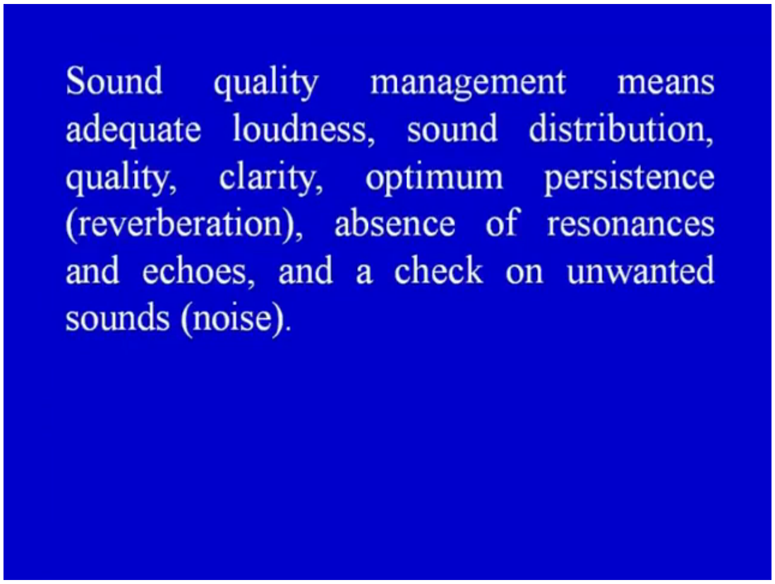

Sound quality management means adequate loudness, sound distribution, quality, clarity, optimum persistence (reverberation), absence of resonances and echoes, and a check on unwanted sounds (noise).

Sound quality management means adequate loudness, sound distribution, quality, clarity, optimum persistence reverberation, absence of resonances and echoes and a check on unwanted sounds which is just the noise.

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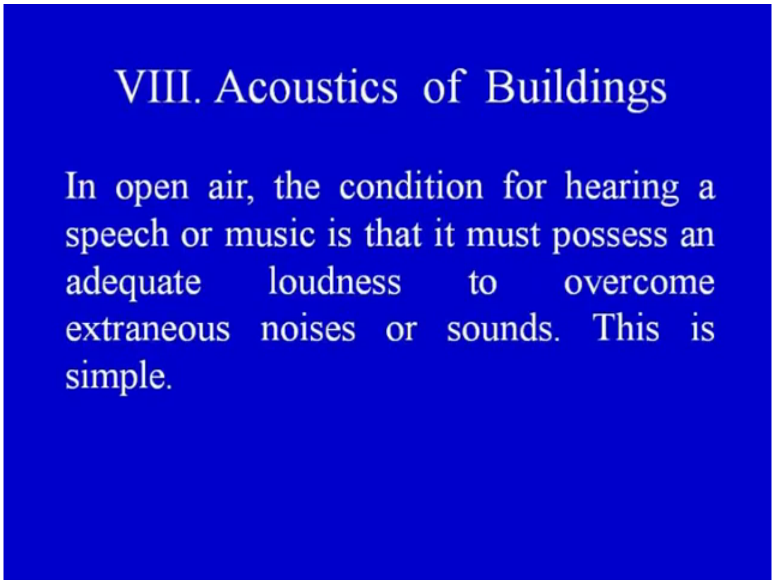

VIII. Acoustics of Buildings

In open air, the condition for hearing a speech or music is that it must possess an adequate loudness to overcome extraneous noises or sounds. This is simple.

In open air, the condition for hearing or speech or music is that it must possess an adequate loudness to overcome extraneous noises or sounds. This is quite simple.

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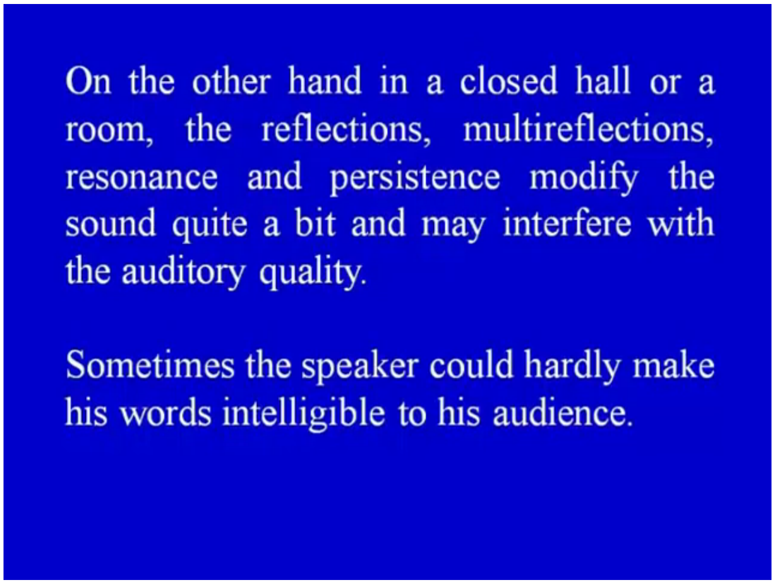

On the other hand in a closed hall or a room, the reflections, multireflections, resonance and persistence modify the sound quite a bit and may interfere with the auditory quality.

Sometimes the speaker could hardly make his words intelligible to his audience.

On the other hand, in a closed hall or a room the reflections, multireflections, resonance and persistence modify the sound quite a bit and may interfere with the auditory quality. Sometimes the speaker could hardly make his words intelligible to his audience.

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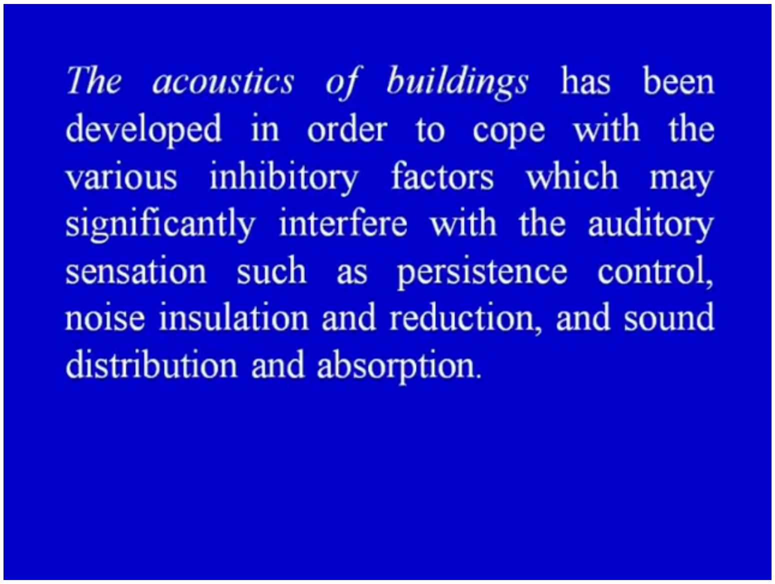

The acoustics of buildings has been developed in order to cope with the various inhibitory factors which may significantly interfere with the auditory sensation such as persistence control, noise insulation and reduction, and sound distribution and absorption.

The acoustics of buildings has been developed in order to cope with the various inhibitory factors which may significantly interfere with the auditory sensation such as persistence control, noise insulation and reduction and sound distribution and absorption.

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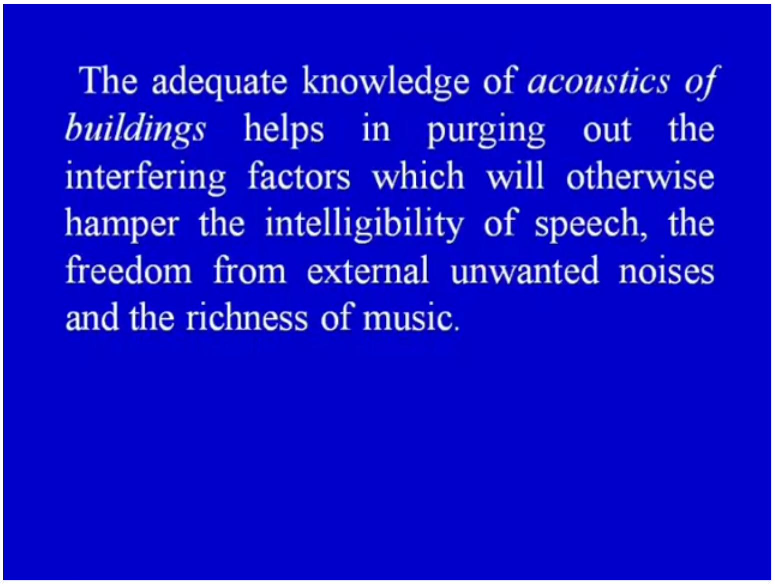

The adequate knowledge of *acoustics of buildings* helps in purging out the interfering factors which will otherwise hamper the intelligibility of speech, the freedom from external unwanted noises and the richness of music.

The adequate knowledge of acoustics of buildings helps in purging out with interfering factors which will otherwise hamper the intelligibility of speech, the freedom from external unwanted noises and richness of music.

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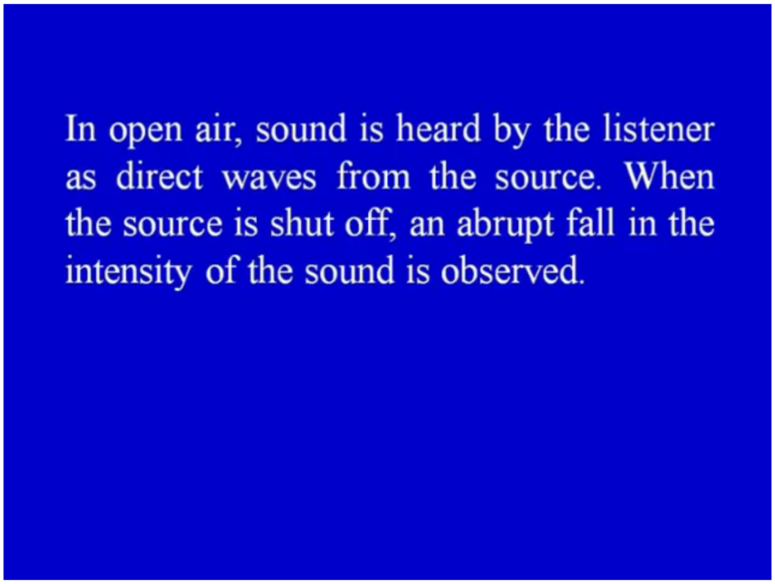

In open air, sound is heard by the listener as direct waves from the source. When the source is shut off, an abrupt fall in the intensity of the sound is observed.

In open air sounded heard by the listener as direct waves from the source. When the source is shut off, an abrupt fall in the intensity of the sound is observed.

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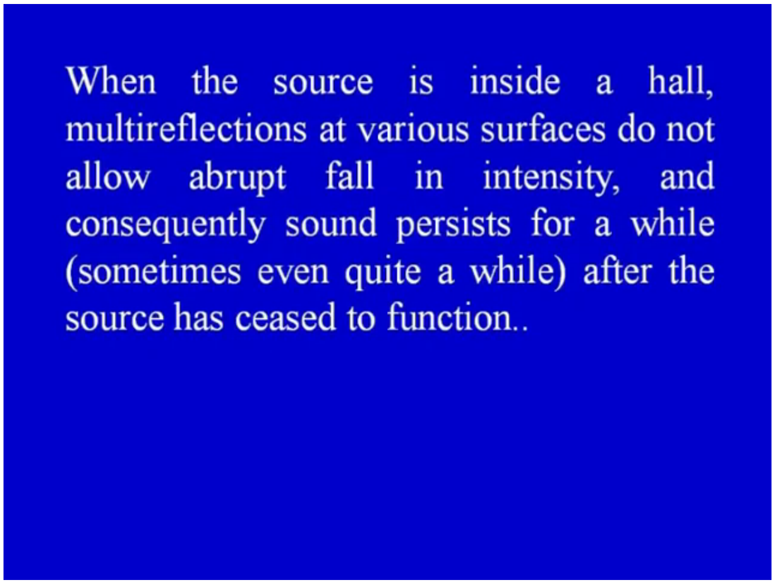

When the source is inside a hall, multireflections at various surfaces do not allow abrupt fall in intensity, and consequently sound persists for a while (sometimes even quite a while) after the source has ceased to function..

When the source is inside a hall, multireflections at various surfaces do not allow abrupt fall and intensity and consequently, sound persists for a while, sometimes even quite a while after the source has ceased to function.

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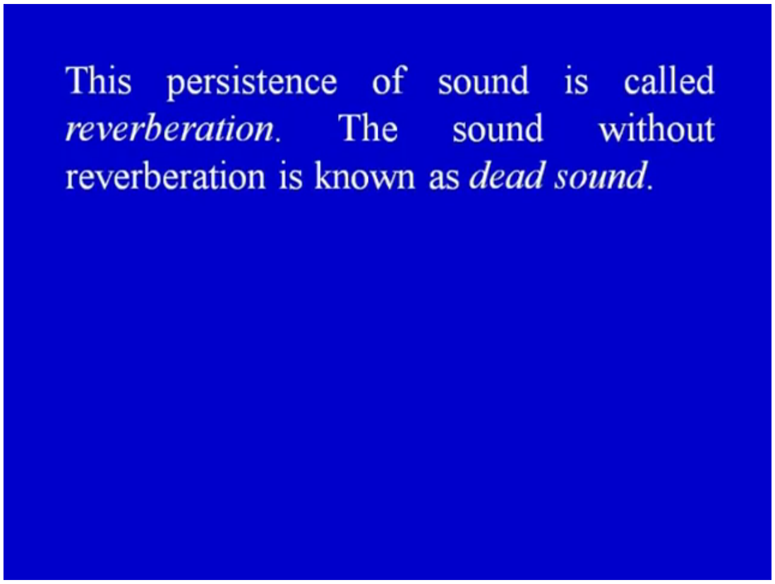

This persistence of sound is called *reverberation*. The sound without reverberation is known as *dead sound*.

This persistence of sound is called reverberation. The sound without reverberation is known as dead sound.

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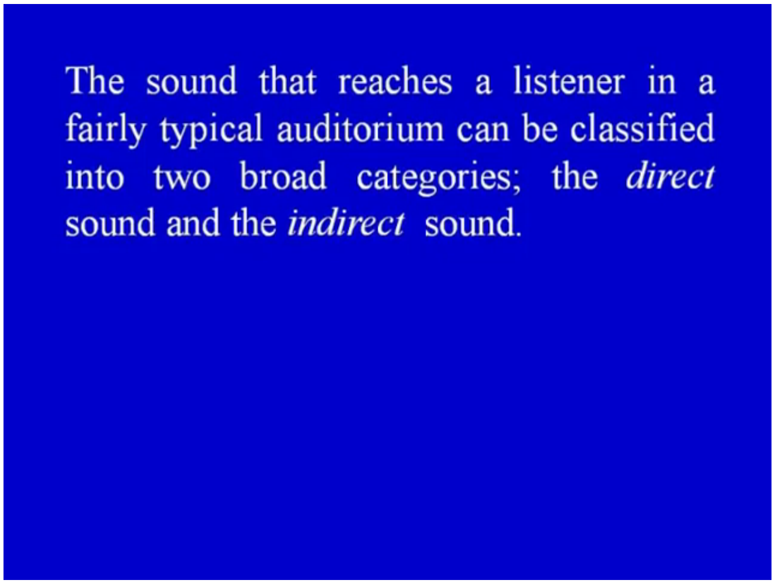

The sound that reaches a listener in a fairly typical auditorium can be classified into two broad categories; the *direct* sound and the *indirect* sound.

The sound that reaches the listener in a fairly tyPical auditorium or a room can be classified into two broad categories: the direct sound and the indirect sound.

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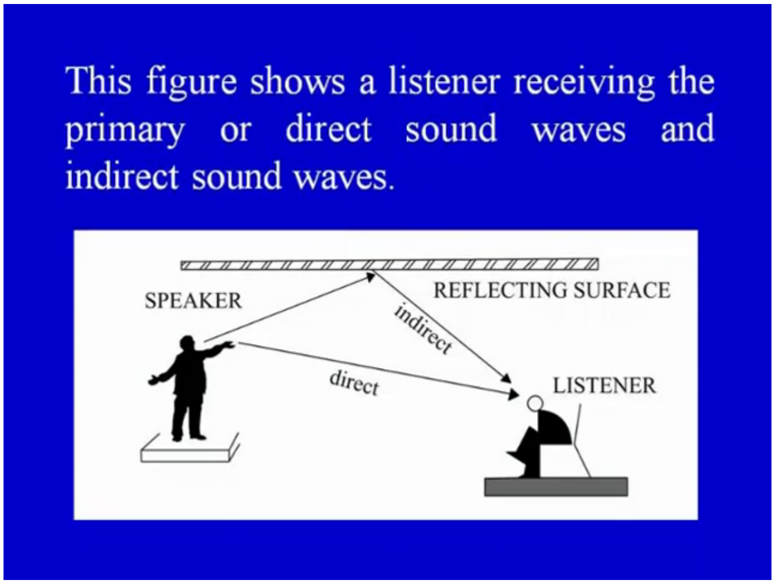

This figure shows a listener receiving the primary or direct sound waves and indirect sound waves.

This figure shows the listener receiving the primary or the direct sound; sound waves and indirect sound waves.

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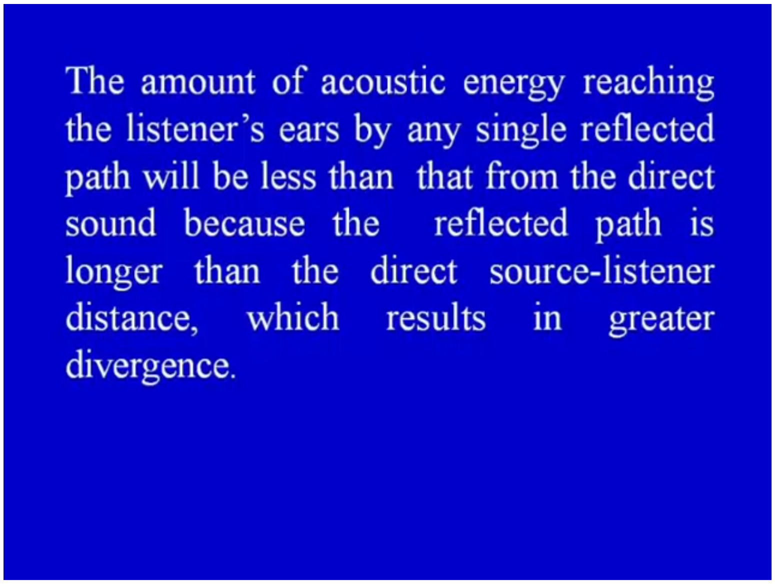

The amount of acoustic energy reaching the listener's ears by any single reflected path will be less than that from the direct sound because the reflected path is longer than the direct source-listener distance, which results in greater divergence.

The amount of acoustic energy reaching the listeners ears by any single reflected part, will be less than that from the direct sound because the deflected part is longer than the direct source listener distance which results in greater divergence and hence at greater loss.

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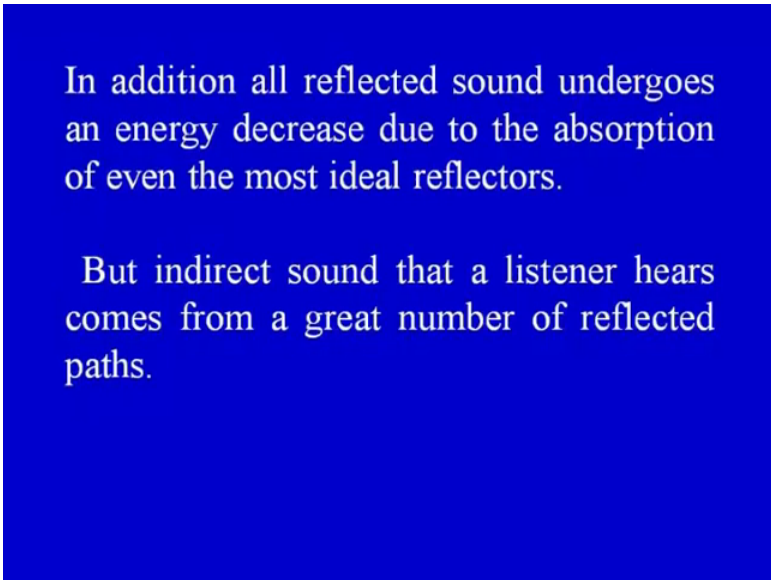

In addition all reflected sound undergoes an energy decrease due to the absorption of even the most ideal reflectors.

But indirect sound that a listener hears comes from a great number of reflected paths.

In addition, all reflected sound undergoes an energy decrease due to the absorption of even the most ideal reflectors. But indirect sound that a listener hears comes not from a single reflected path, comes from a great number of reflected parts.

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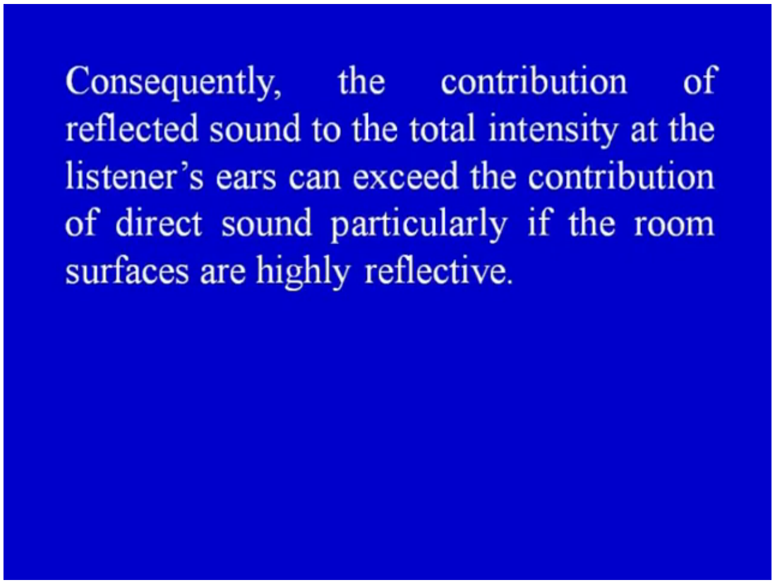

Consequently, the contribution of reflected sound to the total intensity at the listener's ears can exceed the contribution of direct sound particularly if the room surfaces are highly reflective.

And consequently the contribution of reflected sound to the total intensity at the listener's ears can exceed the contribution of direct sound particularly if the room surfaces are highly reflective.

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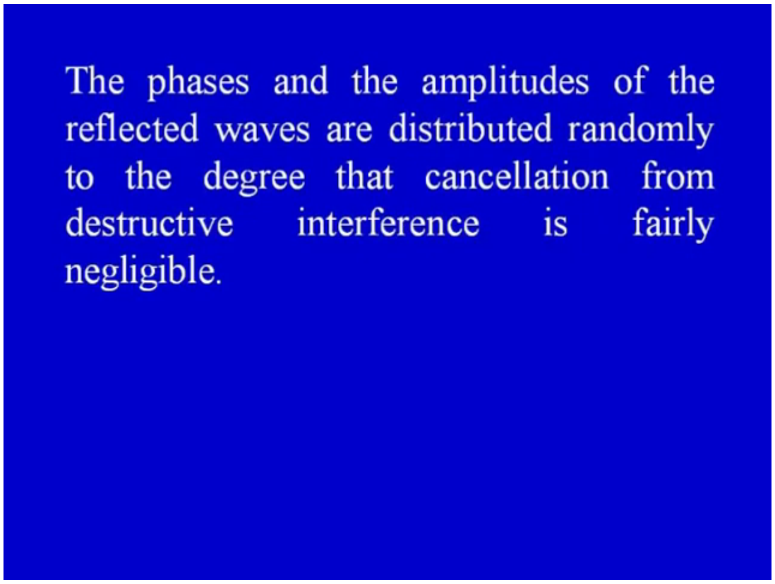

The phases and the amplitudes of the reflected waves are distributed randomly to the degree that cancellation from destructive interference is fairly negligible.

The phases and the amplitudes of the reflected waves are distributed randomly to the degree that insulation from destructive interference is fairly negligible.

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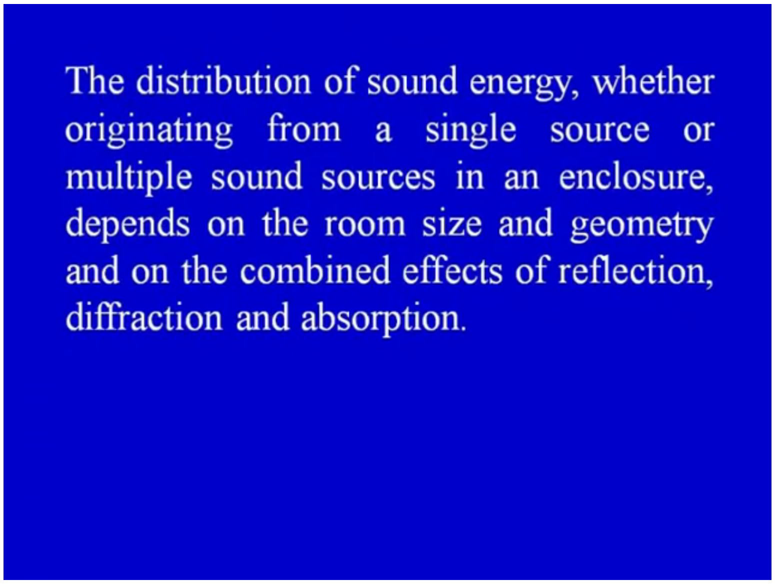
The distribution of sound energy, whether originating from a single source or multiple sound sources in an enclosure, depends on the room size and geometry and on the combined effects of reflection, diffraction and absorption.

The distribution of sound energy whether originating from a single source or multiple sound sources in an enclosure, depends on the room size and geometry and on the combined effects of reflection, diffraction and absorption.

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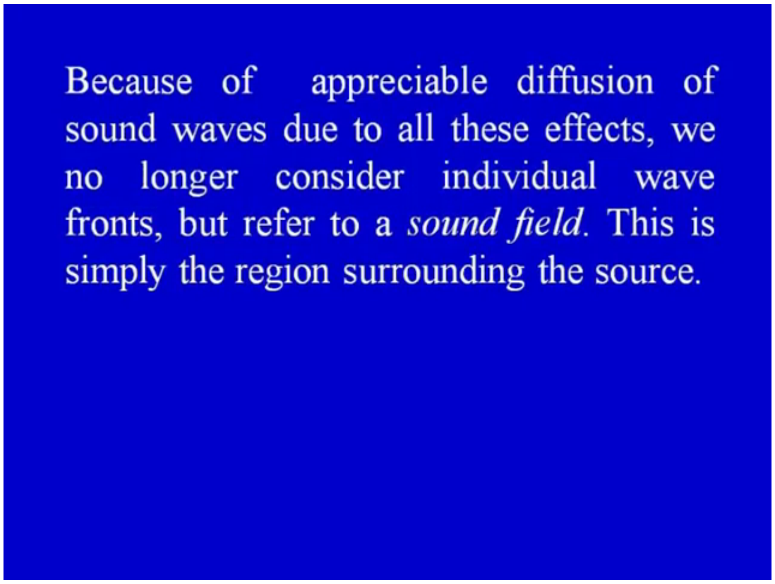
Because of appreciable diffusion of sound waves due to all these effects, we no longer consider individual wave fronts, but refer to a *sound field*. This is simply the region surrounding the source.

Because of appreciable diffusion of sound waves, due to all these effects, we no longer considered individual wave fronts no longer consider individual waves really; we considered what is called as a sound field. This is simply the regional region surrounding the source.

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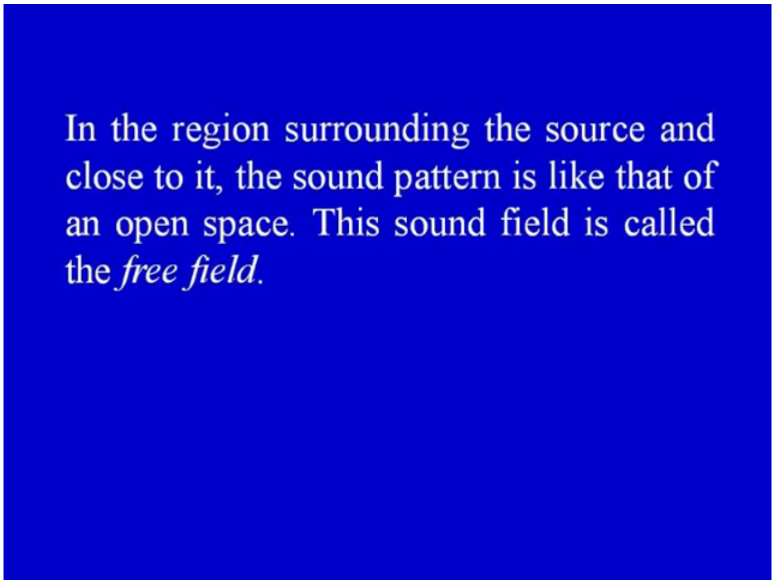

In the region surrounding the source and close to it, the sound pattern is like that of an open space. This sound field is called the *free field*.

In the region surrounding the source and close to it, the sound pattern is like that of an open space. This sound field close to the source is called free field.

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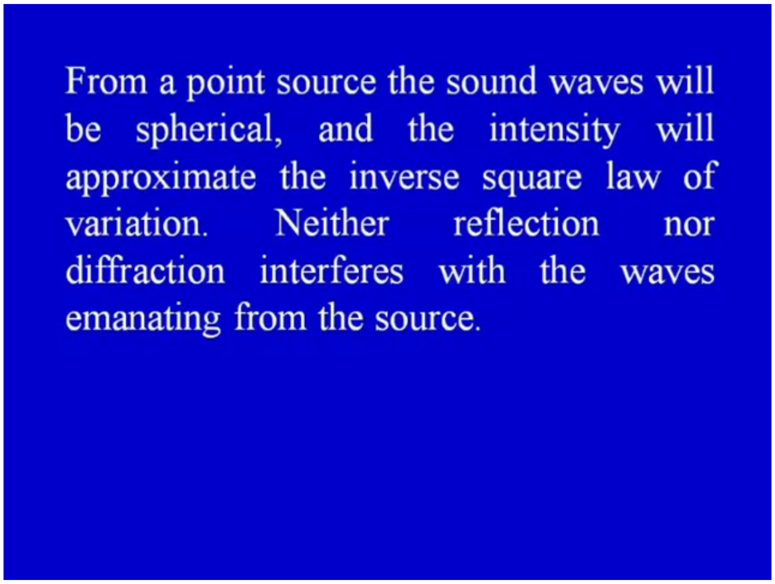

From a point source the sound waves will be spherical, and the intensity will approximate the inverse square law of variation. Neither reflection nor diffraction interferes with the waves emanating from the source.

From a point source the sound waves will be a spherical and the intensity will approximate the inverse square law of variation. Neither reflection nor diffraction interferes with the waves emanating from the source.

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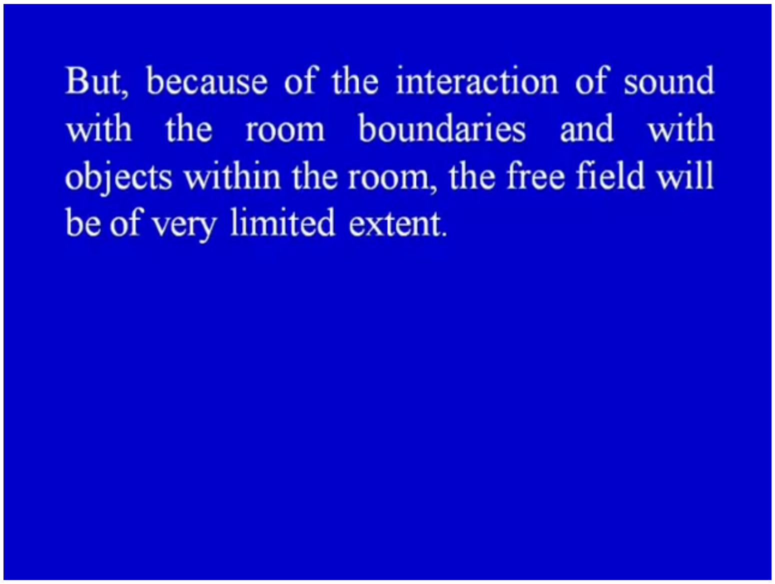

But, because of the interaction of sound with the room boundaries and with objects within the room, the free field will be of very limited extent.

But because of the interaction of sound with the room boundaries and with objects within the room the free field naturally will be a very limited extent.

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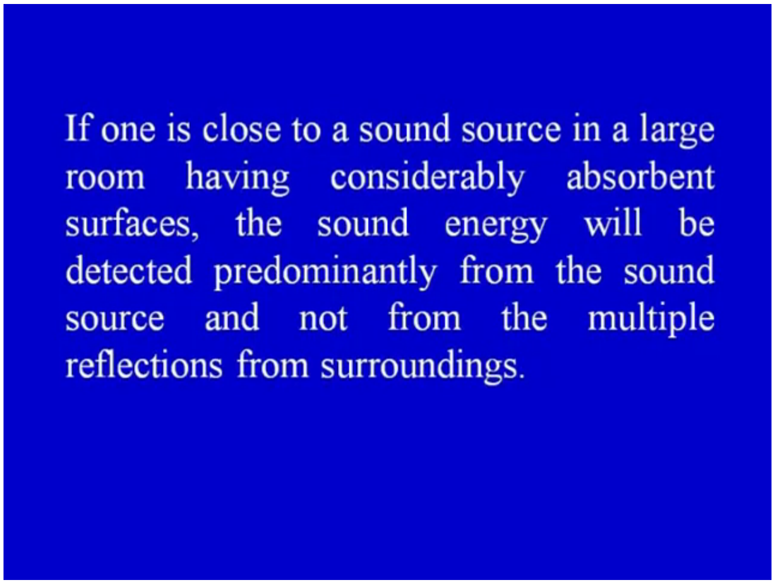

If one is close to a sound source in a large room having considerably absorbent surfaces, the sound energy will be detected predominantly from the sound source and not from the multiple reflections from surroundings.

But if one is close to a sound source in a large room having considerably absorbent surfaces the sound energy will be directly, directed dominantly from the sound source and not from the multiple reflections from the surroundings.

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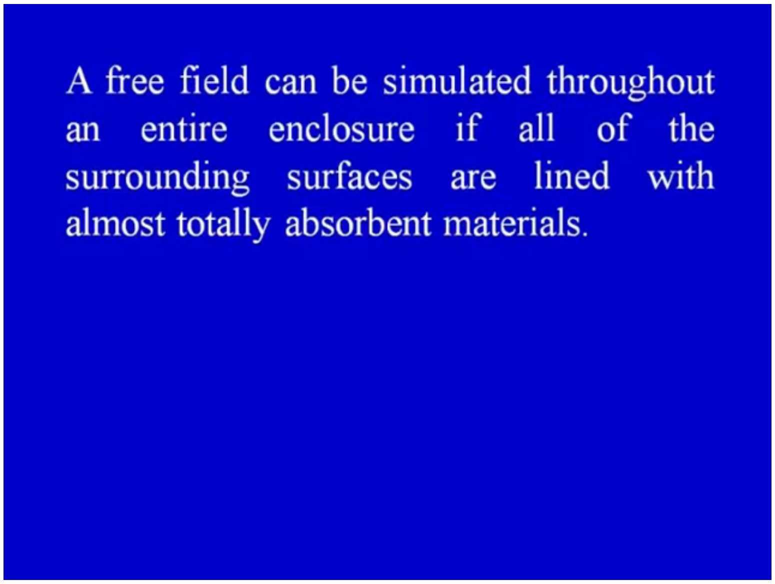

A free field can be simulated throughout an entire enclosure if all of the surrounding surfaces are lined with almost totally absorbent materials.

A free field can be simulated throughout an entire enclosure if all of the surrounding surfaces are lined with almost totally absorbent materials.

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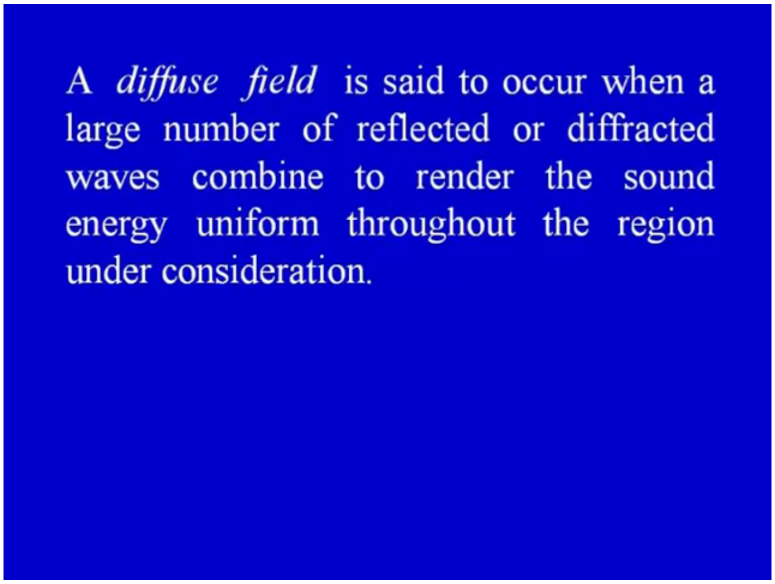

A *diffuse field* is said to occur when a large number of reflected or diffracted waves combine to render the sound energy uniform throughout the region under consideration.

A diffuse field is said to occur when a large number of reflected or diffracted waves combine to render the sound energy uniform that is important, uniform, throughout the region under consideration.

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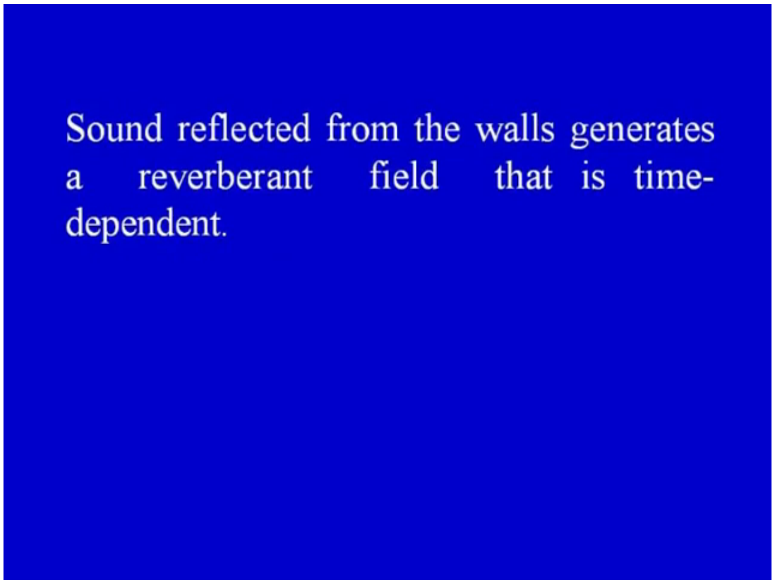

Sound reflected from the walls generates a reverberant field that is time-dependent.

Sound reflected from the walls generates a reverberant field that is naturally time dependent.

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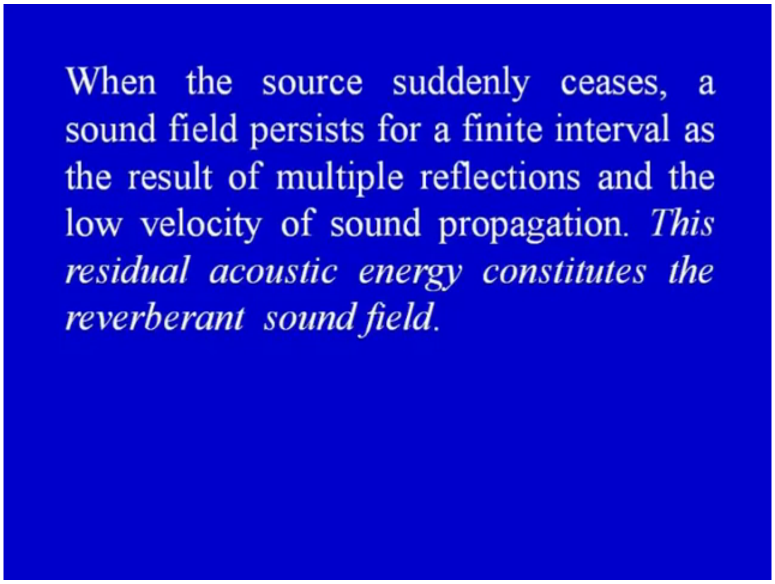

When the source suddenly ceases, a sound field persists for a finite interval as the result of multiple reflections and the low velocity of sound propagation. *This residual acoustic energy constitutes the reverberant sound field.*

When the source suddenly ceases, sound field persists for a finite interval as a result of multiple reflections and a low velocity of sound propagation. This residual acoustic energy constitutes the reverberant sound field.

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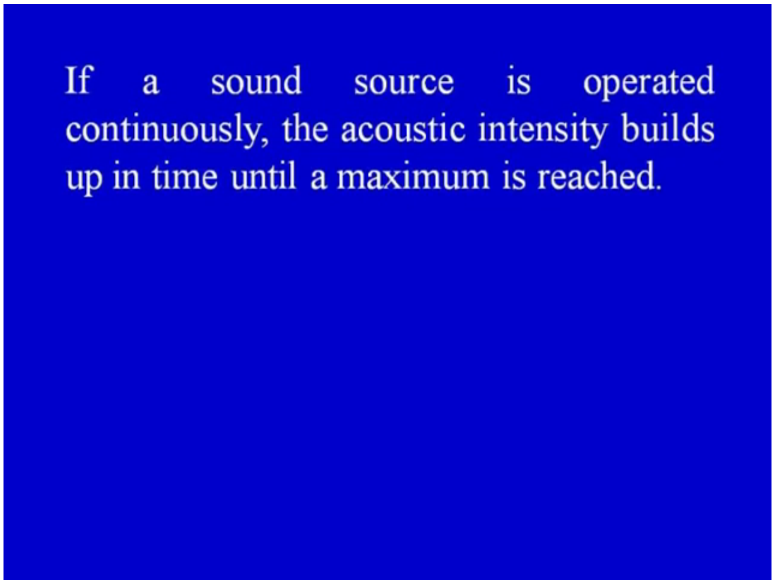

If a sound source is operated continuously, the acoustic intensity builds up in time until a maximum is reached.

If a sound source is operated continuously, the acoustic intensity builds up in time and the maximum is reached.

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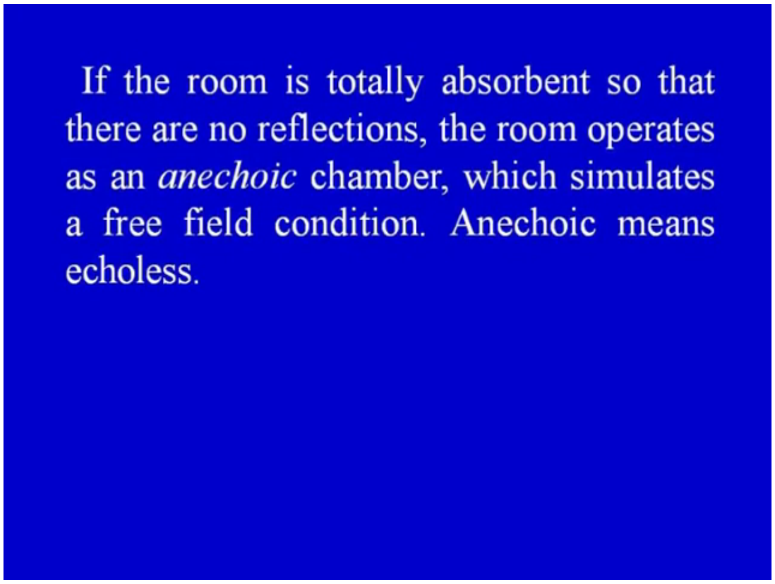

If the room is totally absorbent so that there are no reflections, the room operates as an *anechoic* chamber, which simulates a free field condition. Anechoic means echoless.

If the room is totally absorbent so that there are no reflections, the room operates as an anechoic chamber, simulates a free field condition. Anechoic means echoless.

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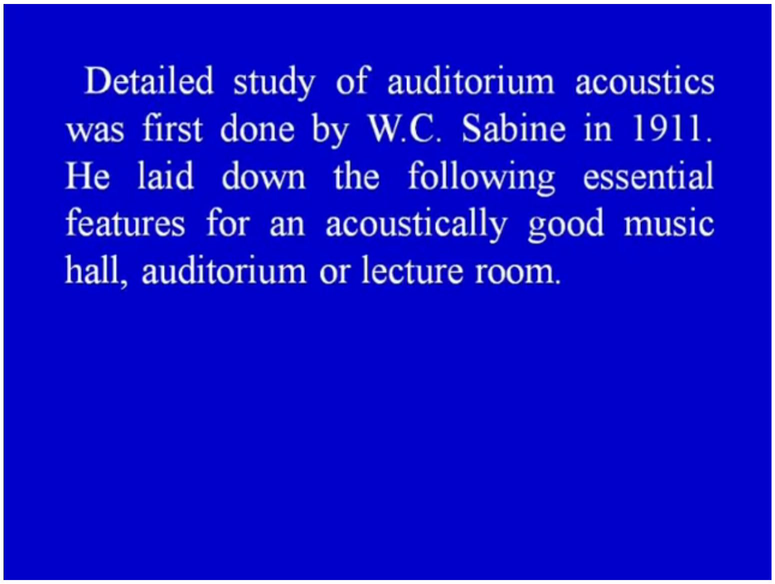

Detailed study of auditorium acoustics was first done by W.C. Sabine in 1911. He laid down the following essential features for an acoustically good music hall, auditorium or lecture room.

Now, detailed history of auditorium acoustics was first done by W C Sabine long back in 1911. He laid down the following essential features for an acoustically good music hall, auditorium or a lecture room.

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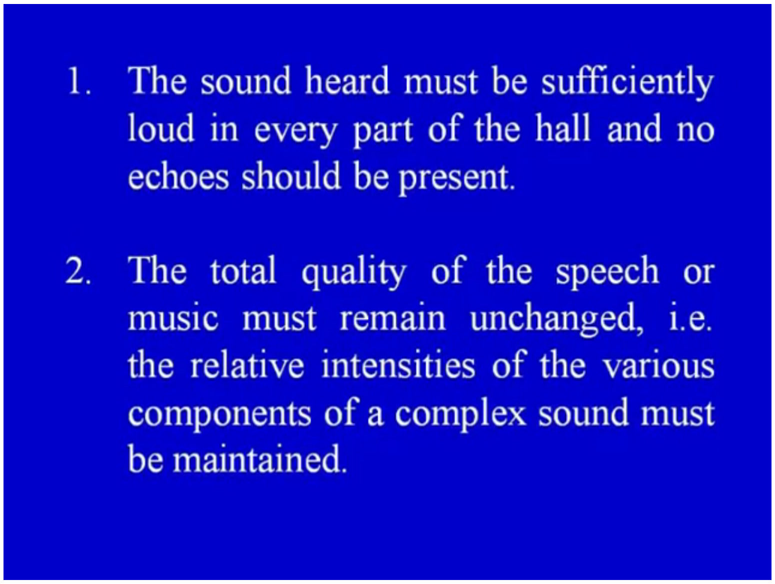

1. The sound heard must be sufficiently loud in every part of the hall and no echoes should be present.
2. The total quality of the speech or music must remain unchanged, i.e. the relative intensities of the various components of a complex sound must be maintained.

Number 1: The sound heard must be sufficiently loud in every part of the hall, every part of the hall and no echoes should present. Number 2: The total quality of the speech or music must remain unchanged that is the relative intensities of the various components of a complex sound must be maintained.

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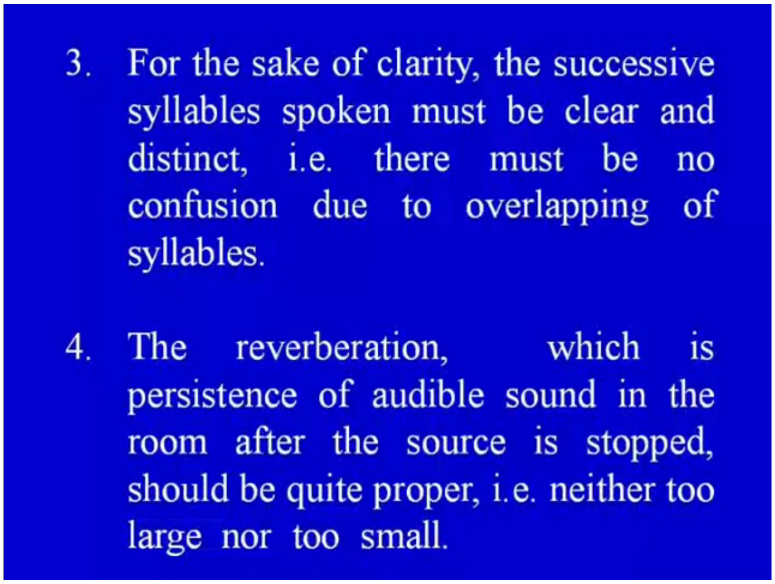
3. For the sake of clarity, the successive syllables spoken must be clear and distinct, i.e. there must be no confusion due to overlapping of syllables.

4. The reverberation, which is persistence of audible sound in the room after the source is stopped, should be quite proper, i.e. neither too large nor too small.

Number 3: For the sake of clarity successive syllables spoken must be clear and distinct. There must be no confusion due to overlapPing of syllables. Number 4: The reverberation, which is persistence of audible sound in the room after the source is stopped, should be quite proper neither too large nor too small.

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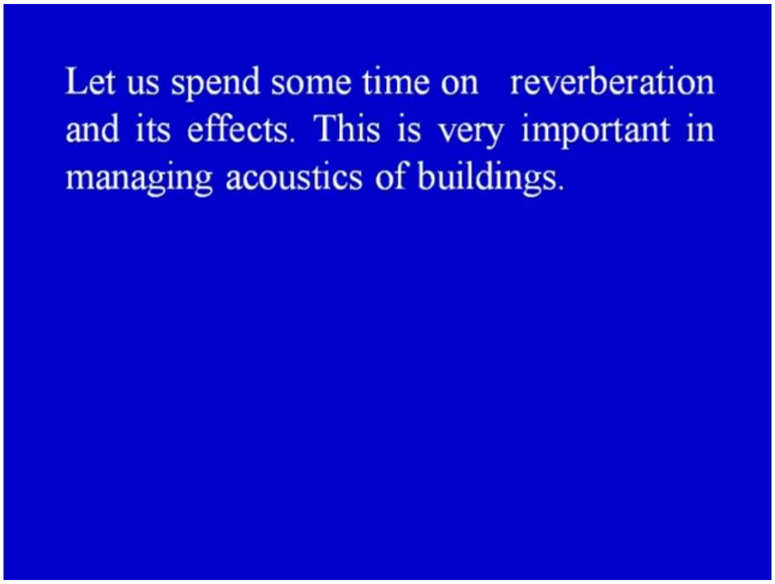
Let us spend some time on reverberation and its effects. This is very important in managing acoustics of buildings.

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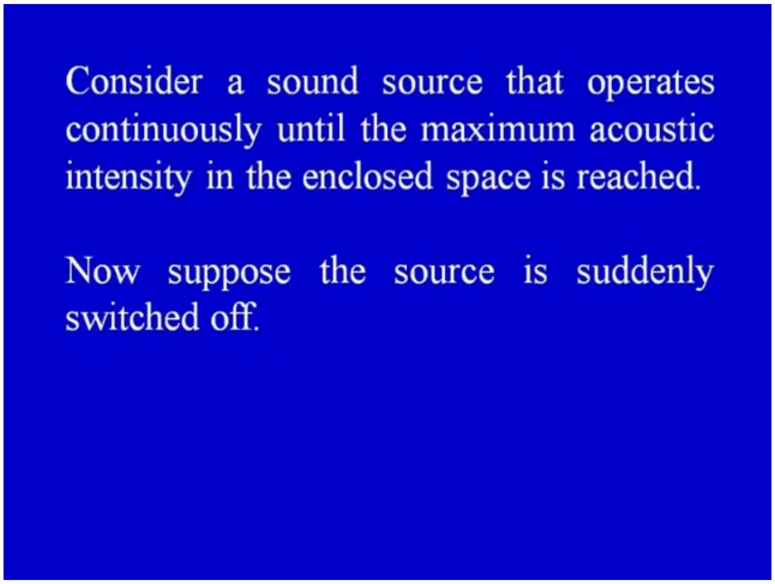

Consider a sound source that operates continuously until the maximum acoustic intensity in the enclosed space is reached.

Now suppose the source is suddenly switched off.

Consider sound source that operates continuously until the maximum acoustic energy in the enclosed space is reached. Now suppose the sources suddenly switched off.

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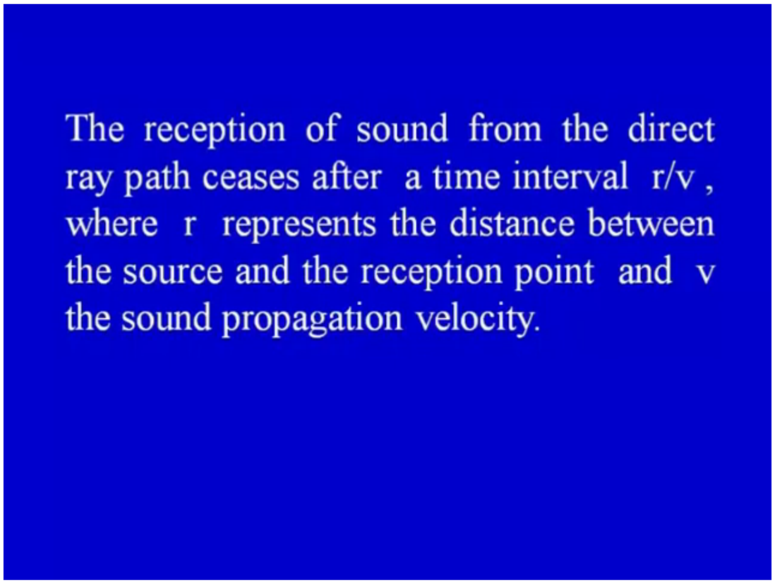

The reception of sound from the direct ray path ceases after a time interval r/v , where r represents the distance between the source and the reception point and v the sound propagation velocity.

The reception of sound from the direct ray path ceases after a time interval r by v where r represents the distance between the source and the reception point and v the sound propagation velocity.

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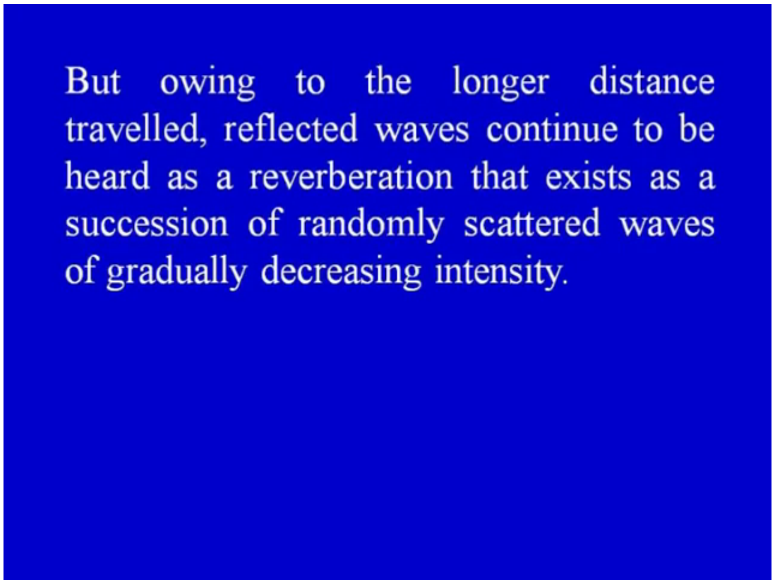

But owing to the longer distance travelled, reflected waves continue to be heard as a reverberation that exists as a succession of randomly scattered waves of gradually decreasing intensity.

But owing to the longer distance travelled, reflected waves continue to be heard as a reverberation that exists as a succession of randomly scattered waves of gradually decreasing intensity.

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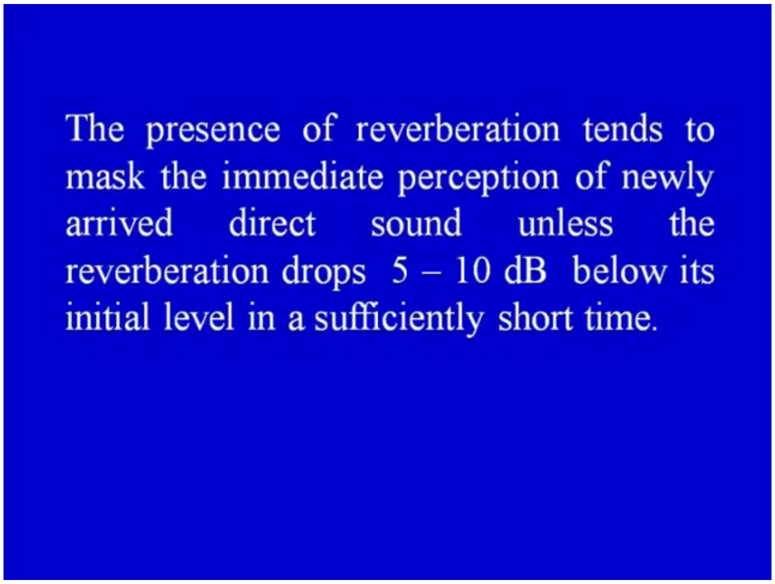

The presence of reverberation tends to mask the immediate perception of newly arrived direct sound unless the reverberation drops 5 – 10 dB below its initial level in a sufficiently short time.

The presence of reverberation tends to mask the immediate perception of newly arrived direct sound unless the reverberation drops 5 to 10 decibels below its initial level in a sufficiently short time.

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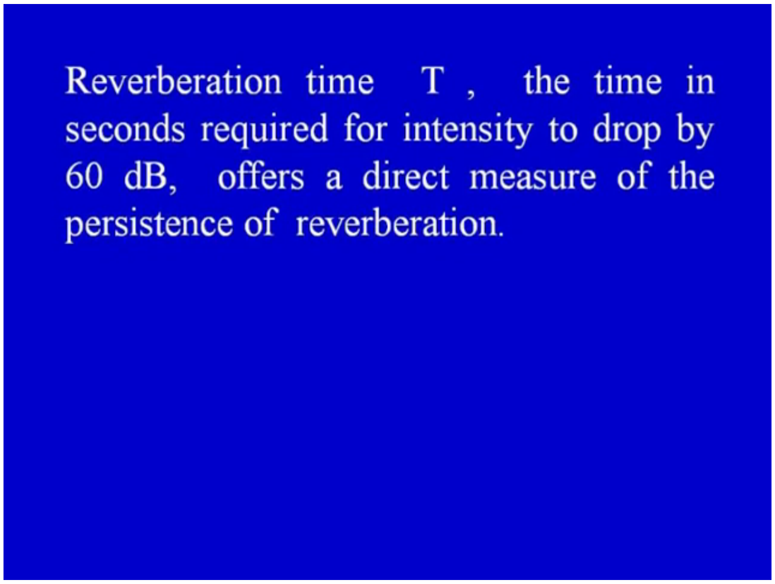

Reverberation time T , the time in seconds required for intensity to drop by 60 dB, offers a direct measure of the persistence of reverberation.

Reverberation time T the time in seconds required for the intensity to drop by 60 decibels offers a direct measure of the persistence of reverberation.

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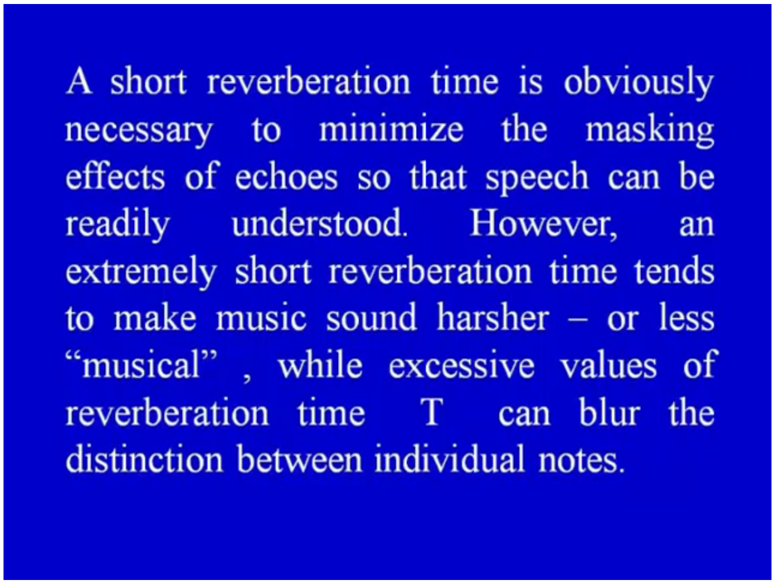

A short reverberation time is obviously necessary to minimize the masking effects of echoes so that speech can be readily understood. However, an extremely short reverberation time tends to make music sound harsher – or less "musical" , while excessive values of reverberation time T can blur the distinction between individual notes.

A short reverberation time is obviously necessary to minimize the masking effects of echoes so that the speech can be readily understood. However, an extremely short reverberation time tends to make music sound harsher or less musical while excessive values of the reverberation time T can blur the distinction between individual notes.

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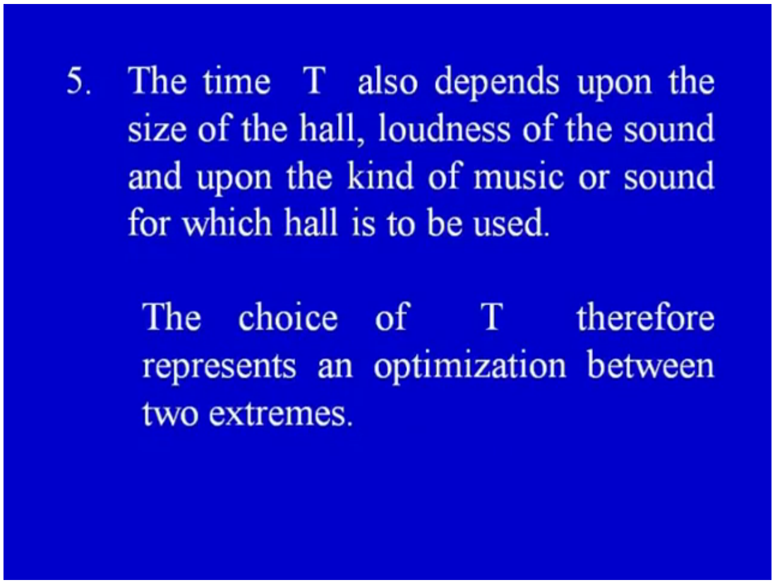

5. The time T also depends upon the size of the hall, loudness of the sound and upon the kind of music or sound for which hall is to be used.

The choice of T therefore represents an optimization between two extremes.

Number 5: The time T reverberation time also depends upon the size of the hall, loudness of the sound and upon the kind of musical sound for which the hall is to be used. The choice of T therefore represents an optimization between two extremes.

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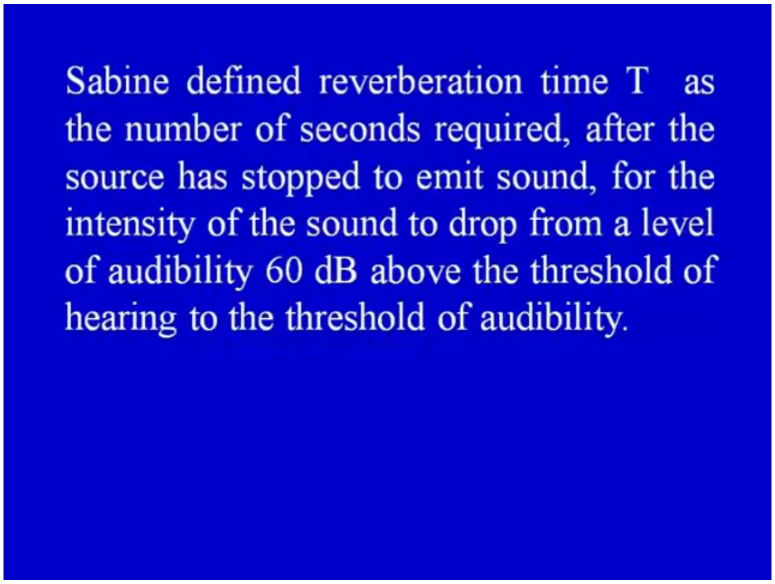

Sabine defined reverberation time T as the number of seconds required, after the source has stopped to emit sound, for the intensity of the sound to drop from a level of audibility 60 dB above the threshold of hearing to the threshold of audibility.

Sabine defined reverberation time T as the number of seconds required after the source has stopped to emit sound, for the intensity of the sound to drop from a label of audibility 60 decibels above the threshold of hearing to the threshold of audibility.

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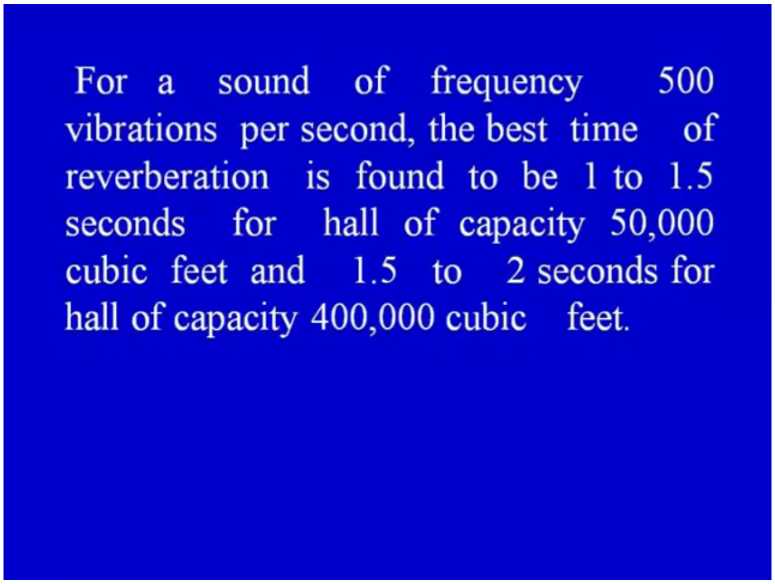

For a sound of frequency 500 vibrations per second, the best time of reverberation is found to be 1 to 1.5 seconds for hall of capacity 50,000 cubic feet and 1.5 to 2 seconds for hall of capacity 400,000 cubic feet.

For a sound of frequency, 500 vibrations per second the best time reverberation is found to be about 1 to 1.5 seconds for hall of capacity 50,000 cubic feet and 1.5 to 2 seconds for hall of capacity 400,000 cubic feet.

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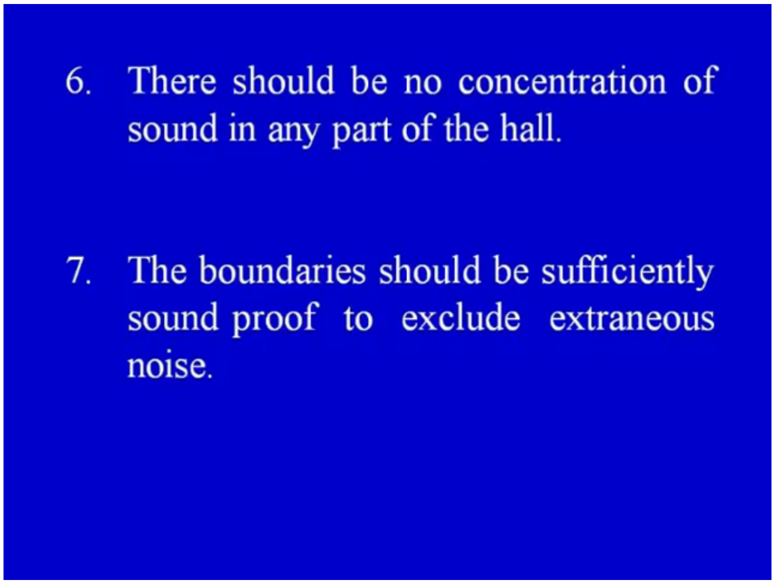

6. There should be no concentration of sound in any part of the hall.
7. The boundaries should be sufficiently sound proof to exclude extraneous noise.

Number 6: There should be no concentration of sound in any part of the hall. This means focusing should be avoided. Number 7: The boundaries should be sufficiently soundproof to exclude extraneous noise. That is the sound coming from, unwanted sound coming from outside.

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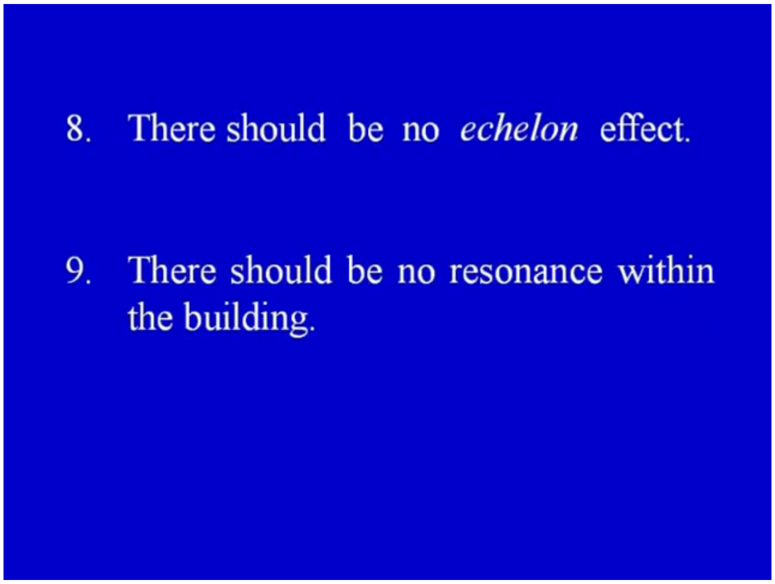

8. There should be no *echelon* effect.

9. There should be no resonance within the building.

Number 8: There should be no Echleon effect. We shall come to this later on. There should be no resonance within the building. Now, these are all the points which Sabine made.

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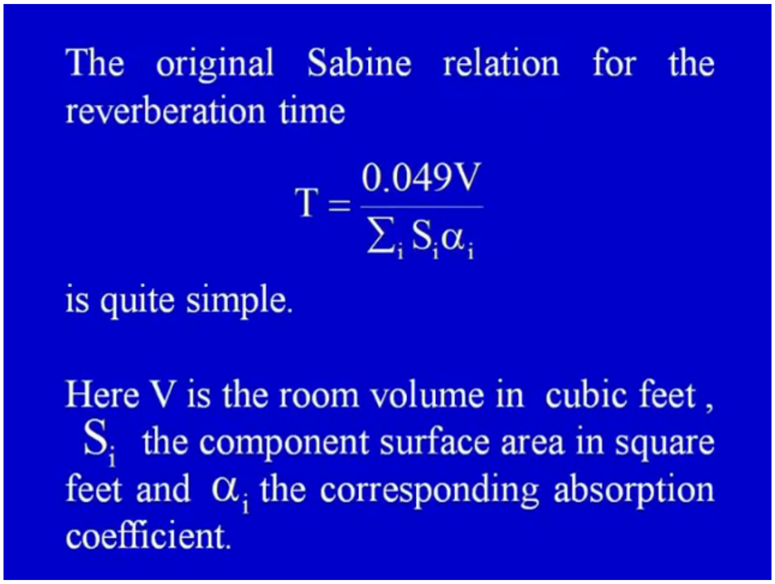

The original Sabine relation for the reverberation time

$$T = \frac{0.049V}{\sum_i S_i \alpha_i}$$

is quite simple.

Here V is the room volume in cubic feet, S_i the component surface area in square feet and α_i the corresponding absorption coefficient.

The original Sabine relation made for reverberation time is T is = 0.049V upon summation over Si alpha i. This is, relation is quite simple. Here V is the room volume in cubic feet, Si, the component surface area in square feet and alpha, the corresponding absorption coefficient.

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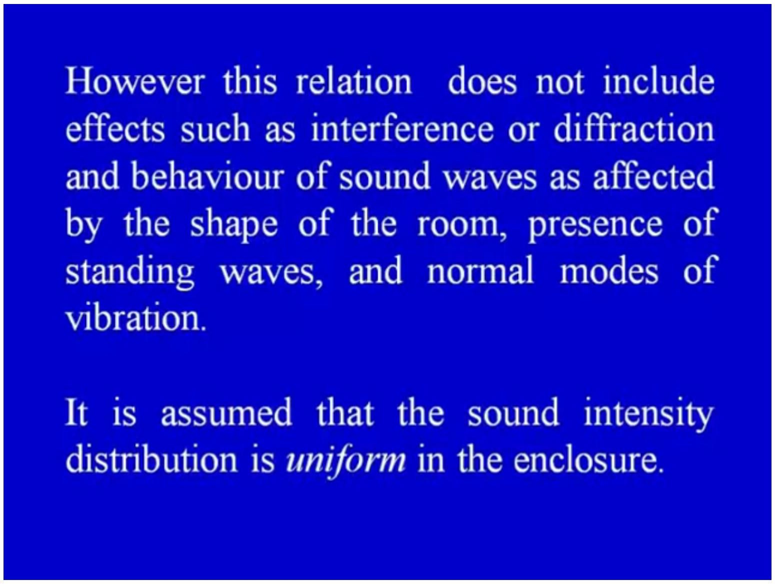

However this relation does not include effects such as interference or diffraction and behaviour of sound waves as affected by the shape of the room, presence of standing waves, and normal modes of vibration.

It is assumed that the sound intensity distribution is *uniform* in the enclosure.

However, this relation is a simple relation. This does not include effects such as interference at diffraction or behavior of sound waves as affected by the shape of the room, presence of a standing waves and normal modes of vibration. And it is assumed that the sound intensity distribution in the room is uniform.

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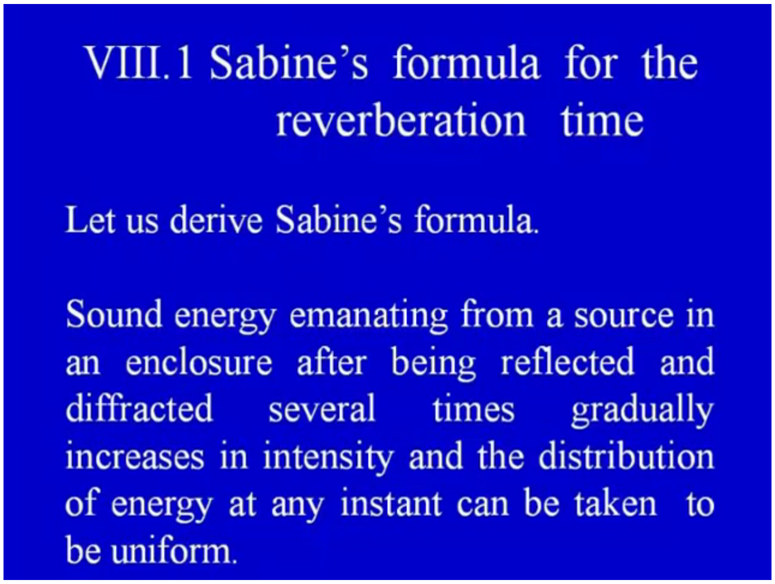

VIII.1 Sabine's formula for the reverberation time

Let us derive Sabine's formula.

Sound energy emanating from a source in an enclosure after being reflected and diffracted several times gradually increases in intensity and the distribution of energy at any instant can be taken to be uniform.

Let us derive Sabine's formula. Sound energy emanating from a source in an enclosure after being reflected an diffracted several times gradually increase in intensity and the distribution of energy at any instant can be taken to be uniform.

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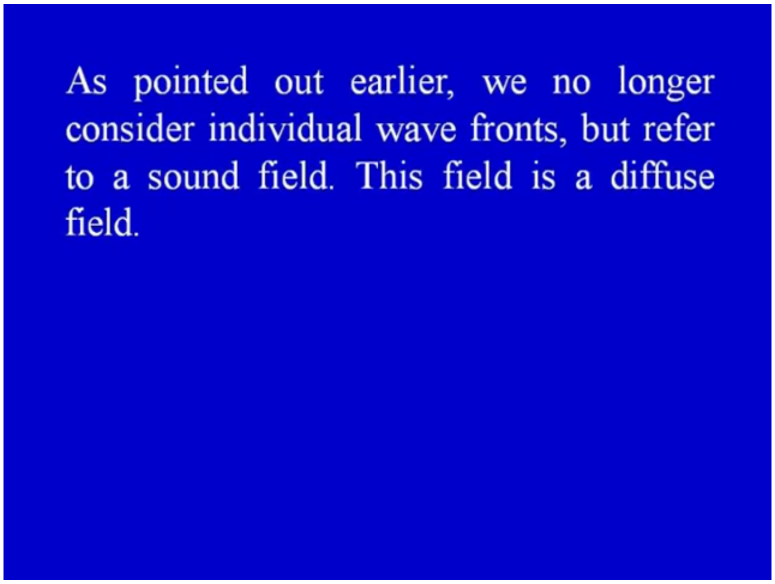

As pointed out earlier, we no longer consider individual wave fronts, but refer to a sound field. This field is a diffuse field.

As pointed out earlier, we no longer consider individual wave fronts but refer to a sound field. This sound field is a diffuse field.

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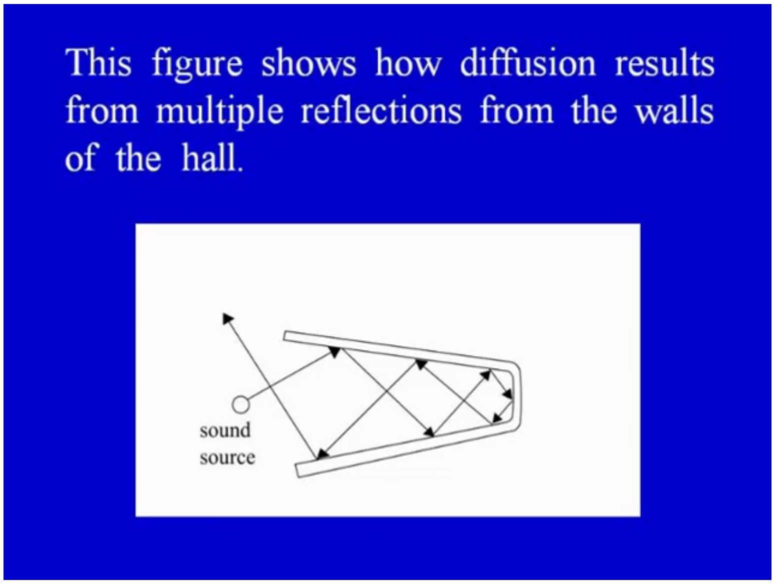

This figure shows how diffusion results from multiple reflections from the walls of the hall.

The figure shows how diffusion results from multiple reflections from the walls of the hall.

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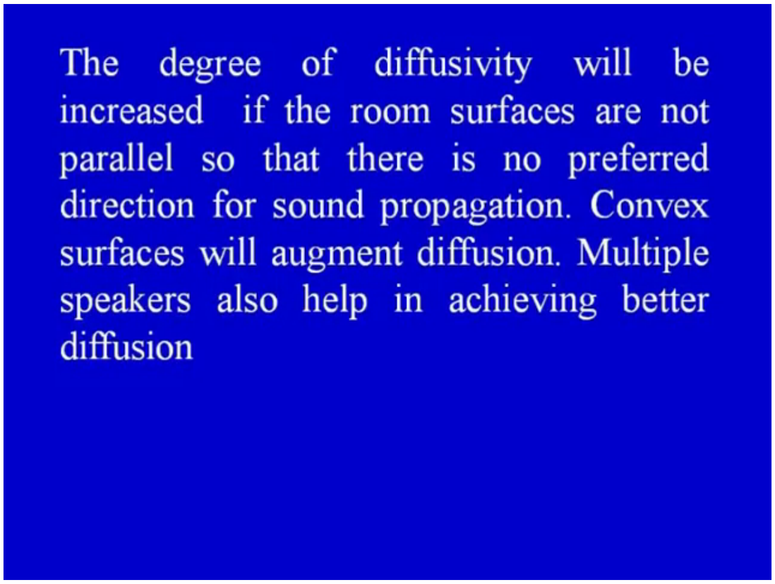

The degree of diffusivity will be increased if the room surfaces are not parallel so that there is no preferred direction for sound propagation. Convex surfaces will augment diffusion. Multiple speakers also help in achieving better diffusion

The degree of diffusivity will be increased in the room surfaces are not parallel so that there is no preferred direction for sound propagation. Convex surfaces will augment diffusion. Multiple speakers also help in achieving better diffusion.

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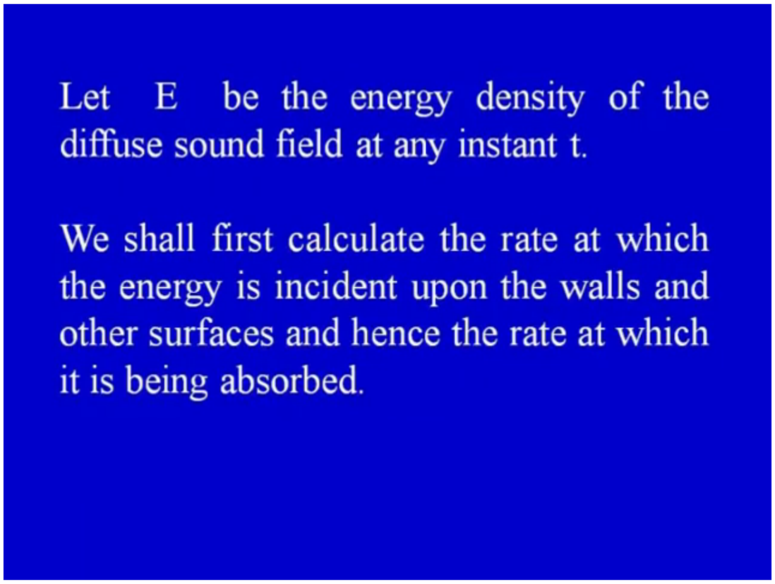

Let E be the energy density of the diffuse sound field at any instant t.

We shall first calculate the rate at which the energy is incident upon the walls and other surfaces and hence the rate at which it is being absorbed.

Now let E be the energy density of the diffused sound field at any instant t. We shall first calculate the rate at which the energy is incident upon the walls and other surfaces and hence the rate at which it is being absorbed.

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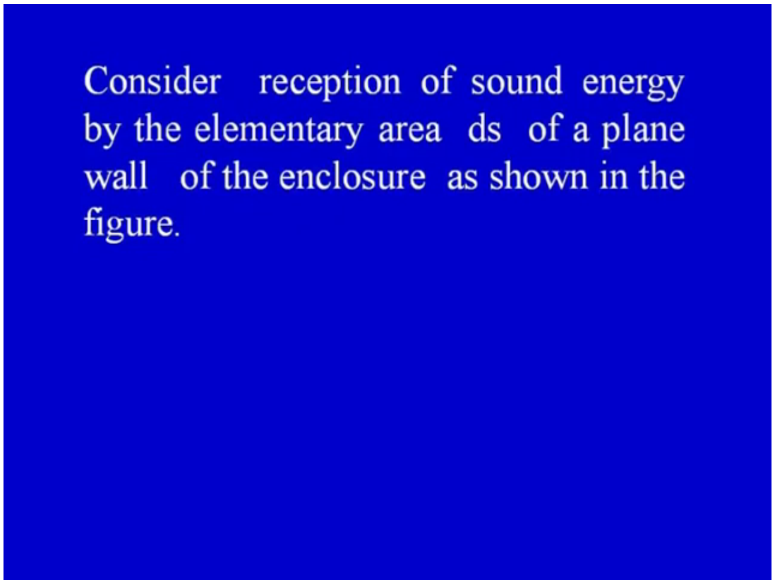

Consider reception of sound energy by the elementary area ds of a plane wall of the enclosure as shown in the figure.

Consider reception of sound energy by the elementary area ds of a plane wall of the enclosure as shown in the figure.

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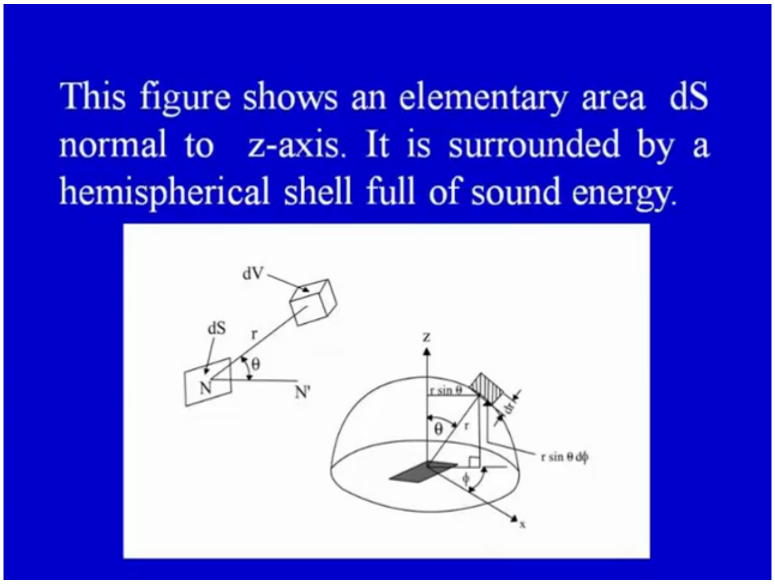

This figure shows an elementary area dS normal to z-axis. It is surrounded by a hemispherical shell full of sound energy.

This figure shows elementary area dS normal to z axis. It is surrounded by a hemispherical shell full of sound energy, diffuse sound energy.

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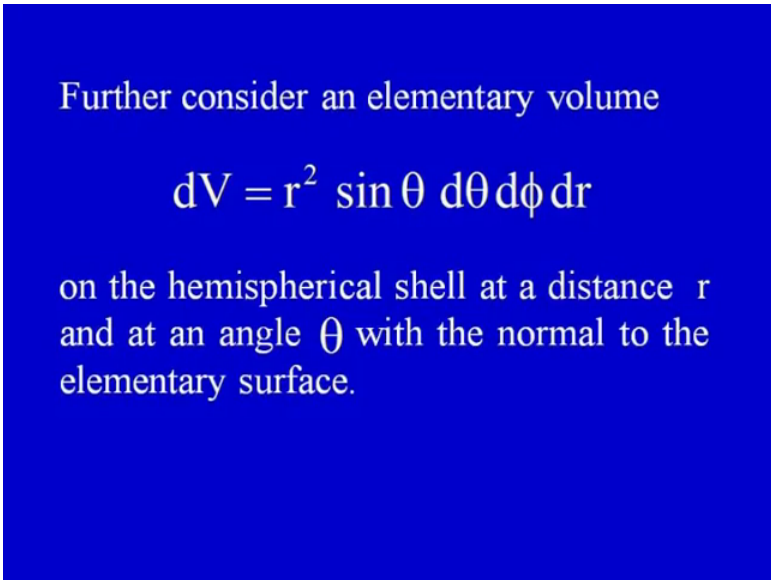

Further consider an elementary volume

$$dV = r^2 \sin\theta \, d\theta \, d\phi \, dr$$

on the hemispherical shell at a distance r and at an angle θ with the normal to the elementary surface.

Further consider an elementary volume dV, we are using spherical polar coordinates the dV is = r square sine theta d theta d Phi d r on the hemispherical shell at a distance r. r is the radius of the shell at an angle theta with the normal to the elementary surface.

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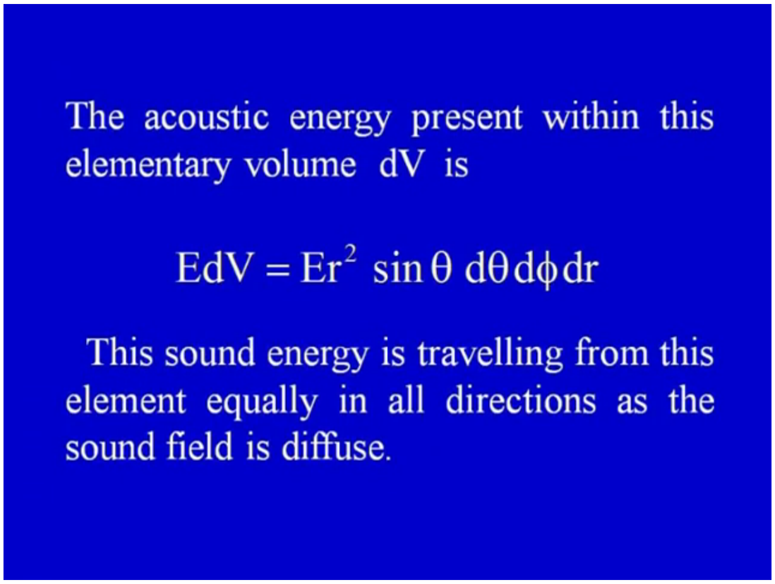

The acoustic energy present within this elementary volume dV is

$$EdV = Er^2 \sin\theta \, d\theta \, d\phi \, dr$$

This sound energy is travelling from this element equally in all directions as the sound field is diffuse.

The acoustic energy present within this elementary volume dV is E into dV which is = E into r square sine theta d theta d Phi d r. This sound energy is travelling from this element equally in all directions as the sound field is diffuse.

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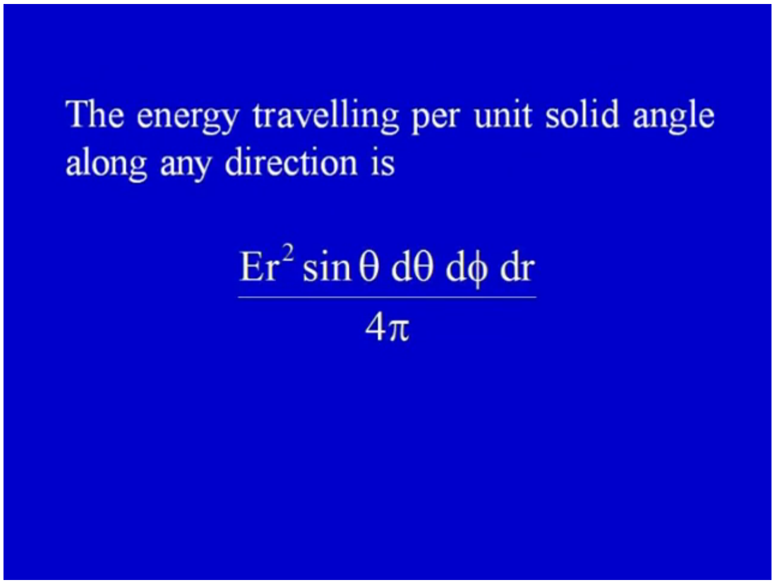

The energy travelling per unit solid angle along any direction is

$$\frac{Er^2 \sin\theta \, d\theta \, d\phi \, dr}{4\pi}$$

The energy travelling per unit solid angle along any direction is E r square sine theta d theta d Phi dr divided by 4Pi, which is the solid angle surrounding a point.

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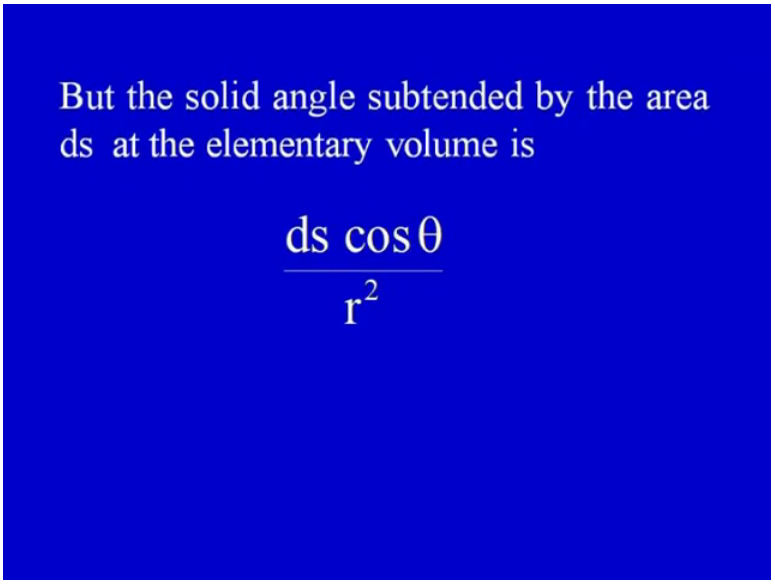

But the solid angle subtended by the area ds at the elementary volume is

$$\frac{ds \cos\theta}{r^2}$$

But the solid angle subtended by the area ds at this elementary volume is ds cos theta upon r square.

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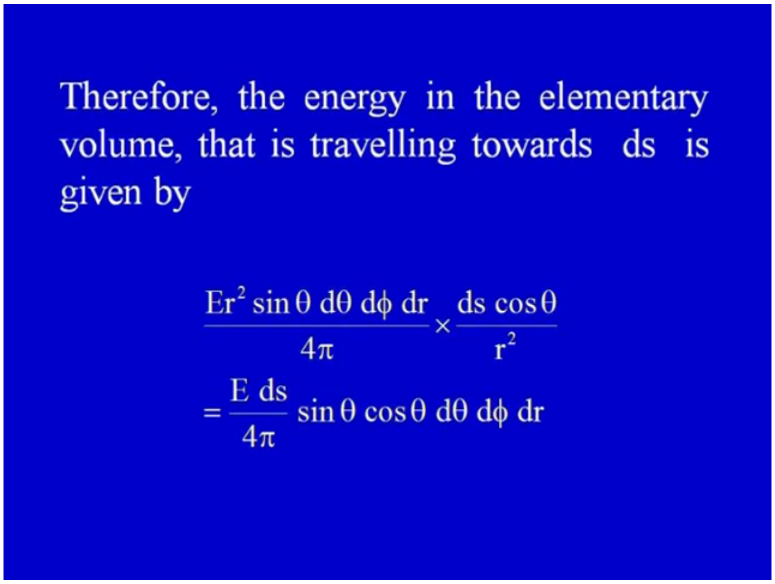


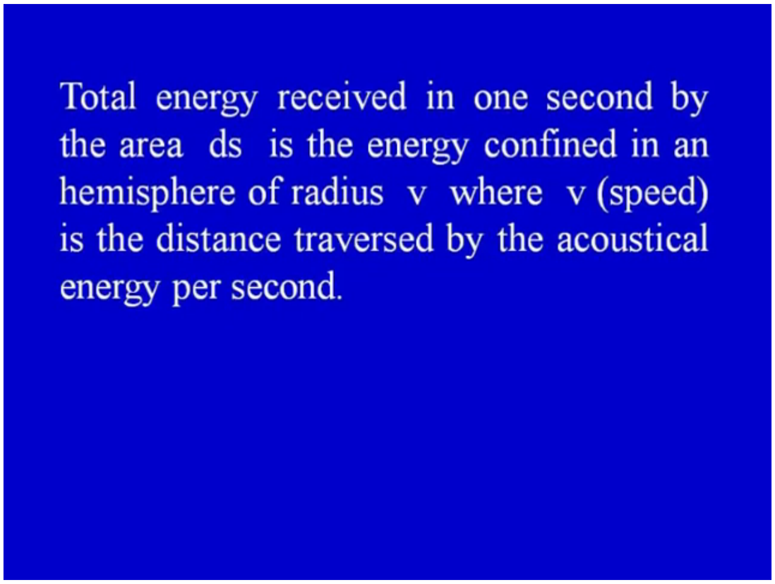
Therefore, the energy in the elementary volume, that is travelling towards ds is given by

$$\frac{Er^2 \sin\theta \, d\theta \, d\phi \, dr}{4\pi} \times \frac{ds \cos\theta}{r^2}$$

$$= \frac{E \, ds}{4\pi} \sin\theta \cos\theta \, d\theta \, d\phi \, dr$$

And therefore energy in the elementary volume that is traveling towards ds is given by E r squared sine theta d theta d Phi upon d Phi dr upon 4 Pi multiplied by ds cos theta upon r square. r square cancels out; so this is = E ds upon 4 Pi times sine theta cos theta d theta d Phi dr.

(Refer Slide Time: 17:33)



Total energy received in one second by the area ds is the energy confined in an hemisphere of radius v where v (speed) is the distance traversed by the acoustical energy per second.

Now, the total energy received in one second by the area ds in the energy confined in an hemisphere of radius V which is the speed distance travelled by the wave per second.

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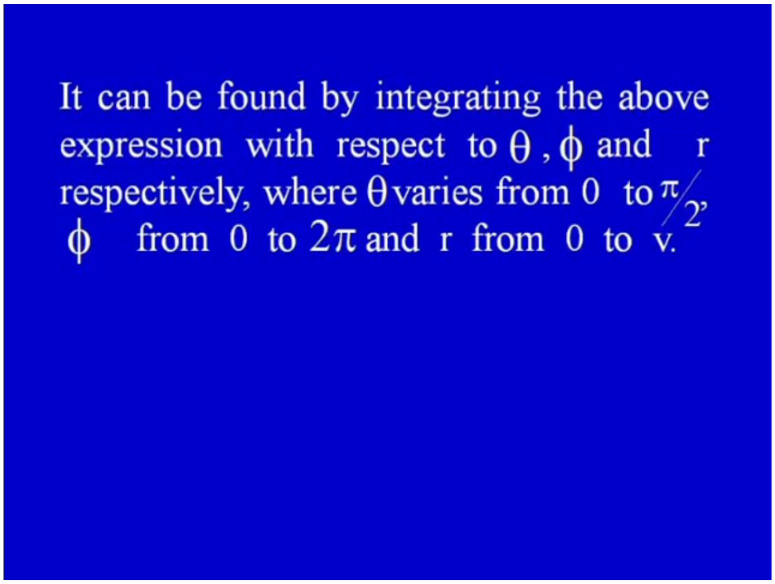

It can be found by integrating the above expression with respect to θ , ϕ and r respectively, where θ varies from 0 to $\pi/2$, ϕ from 0 to 2π and r from 0 to v.

It can be found by integrating the above expression with respect to theta, phi and r respectively, where theta varies from 0 to Pi by 2. Phi varies from 0 to 2Pi and r from 0 to V.

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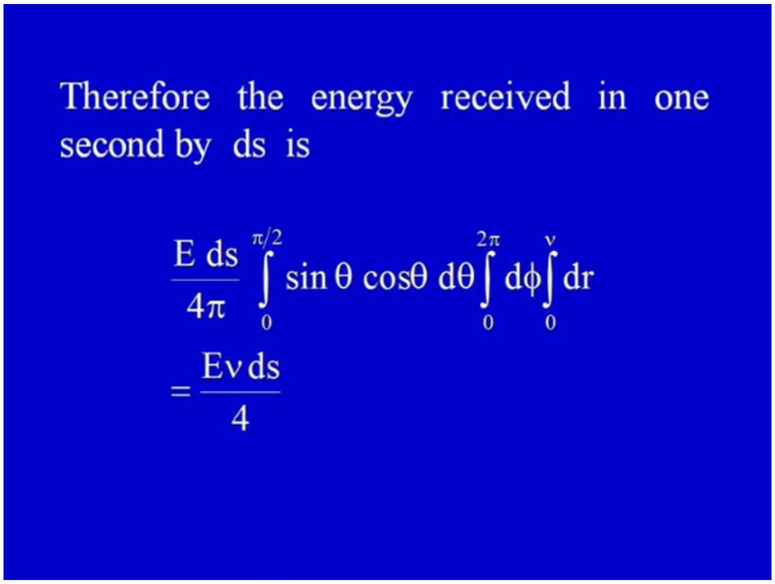

Therefore the energy received in one second by ds is

$$\frac{E\,ds}{4\pi}\int_0^{\pi/2}\sin\theta\cos\theta\,d\theta\int_0^{2\pi}d\phi\int_0^{v}dr$$

$$=\frac{E v\,ds}{4}$$

Therefore the energy received in one second by the area ds is E ds upon 4Pi integral from 0 to Pi by 2 sine theta cos theta d theta integral 0 to 2 Pi of d Phi integral 0 to V of d r. And this gives E v ds upon 4.

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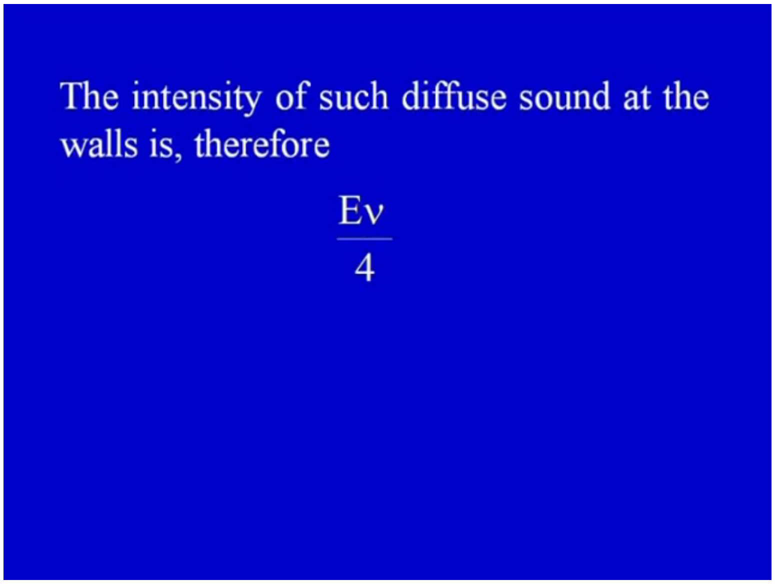

The intensity of such diffuse sound at the walls is, therefore

$$\frac{E\nu}{4}$$

The intensity of such diffused sound at the walls is, therefore Ev upon 4.

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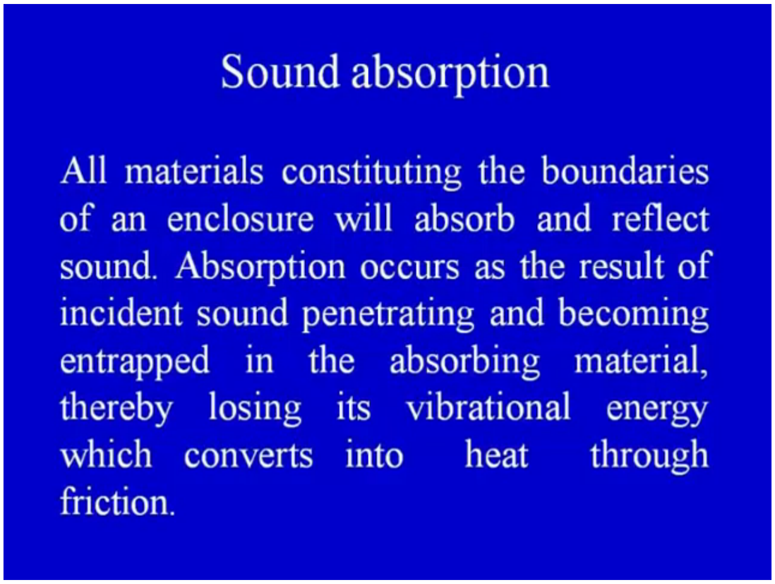

Sound absorption

All materials constituting the boundaries of an enclosure will absorb and reflect sound. Absorption occurs as the result of incident sound penetrating and becoming entrapped in the absorbing material, thereby losing its vibrational energy which converts into heat through friction.

Now, all materials constituting the boundaries of an enclosure will absorb sound and reflect sound. Absorption occurs as a result of incident sound penetrating and becoming entrapped in the absorbing material, thereby losing its vibrational energy which converts into heat through friction.

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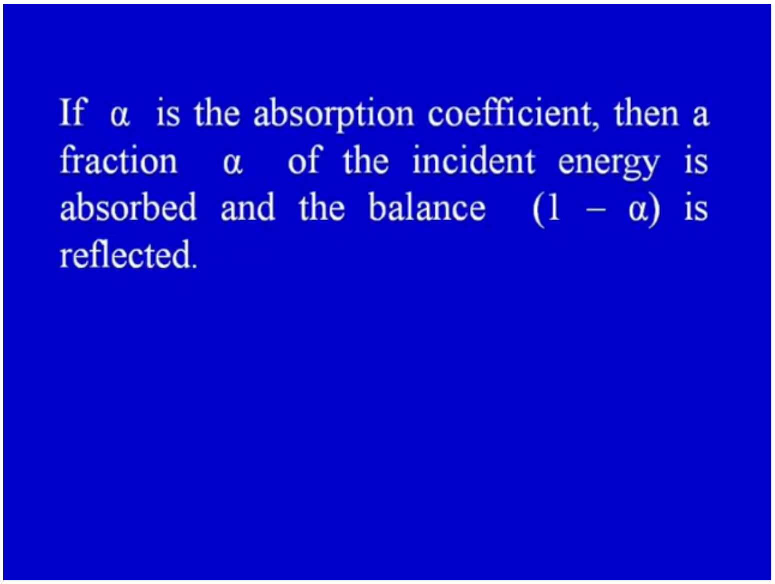

If α is the absorption coefficient, then a fraction α of the incident energy is absorbed and the balance $(1 - \alpha)$ is reflected.

If alpha is the absorption coefficient, the reflection alpha the incident energy absorbed and the balance 1 - alpha is reflected.

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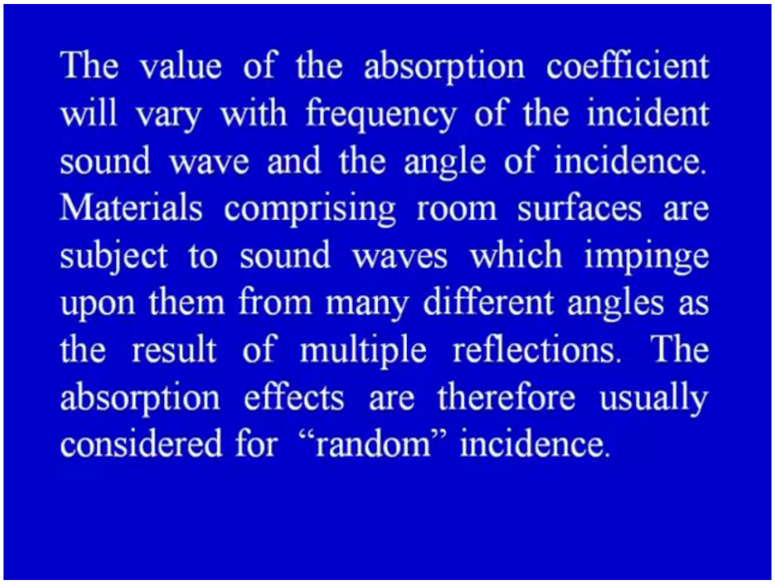

The value of the absorption coefficient will vary with frequency of the incident sound wave and the angle of incidence. Materials comprising room surfaces are subject to sound waves which impinge upon them from many different angles as the result of multiple reflections. The absorption effects are therefore usually considered for "random" incidence.

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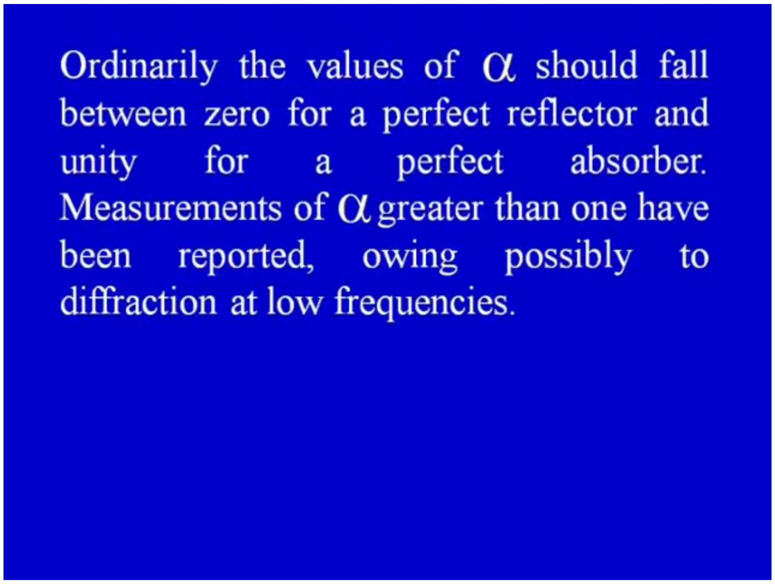

Ordinarily the values of α should fall between zero for a perfect reflector and unity for a perfect absorber. Measurements of α greater than one have been reported, owing possibly to diffraction at low frequencies.

Ordinarily, the values of alpha should fall between 0 are perfect reflection and unity for a perfect absorber. Measurements of alpha greater than 1 have also been reported, owing possibly to diffraction at low frequencies.

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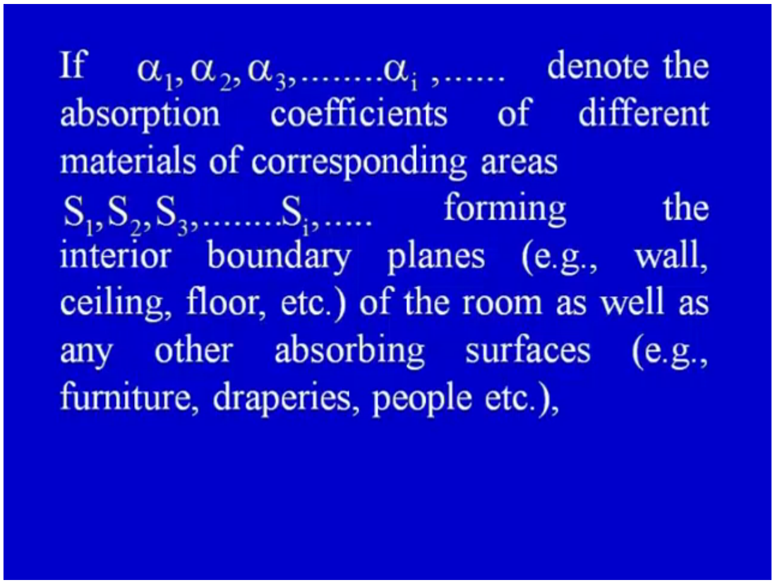

If $\alpha_1, \alpha_2, \alpha_3, \ldots\ldots\alpha_i, \ldots\ldots$ denote the absorption coefficients of different materials of corresponding areas $S_1, S_2, S_3, \ldots\ldots S_i, \ldots..$ forming the interior boundary planes (e.g., wall, ceiling, floor, etc.) of the room as well as any other absorbing surfaces (e.g., furniture, draperies, people etc.),

Now, if alpha 1, alpha 2, alpha 3, etcetera denote the absorption coefficients of different materials of corresponding areas S1, S2, S3,S like this, forming the interior boundary planes walls, ceiling, floors, etcetera as well as any other absorbing surfaces furniture, draperies, audience.

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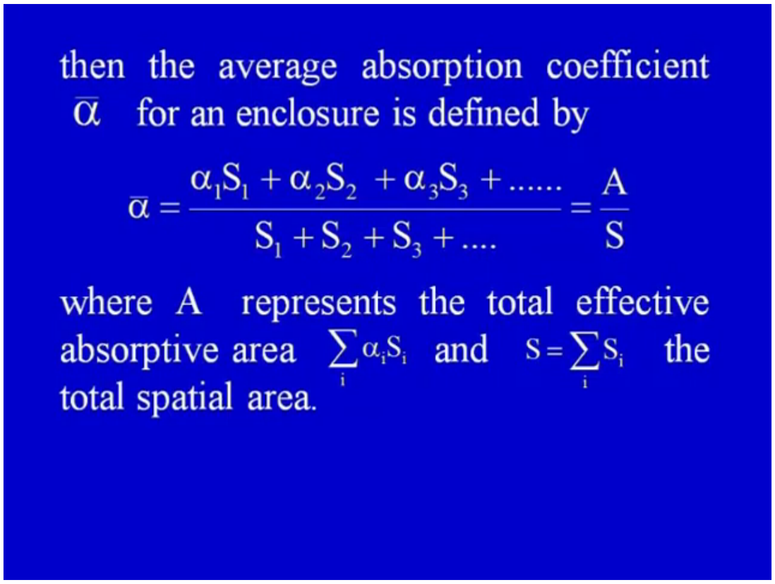

then the average absorption coefficient $\bar{\alpha}$ for an enclosure is defined by

$$\bar{\alpha} = \frac{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots\ldots}{S_1 + S_2 + S_3 + \ldots.} = \frac{A}{S}$$

where A represents the total effective absorptive area $\sum_i \alpha_i S_i$ and $S = \sum_i S_i$ the total spatial area.

Then, the average absorption coefficient alpha bar for an enclosure is defined by alpha bar is = in the numerator centrifugal contribution alpha 1 into S1 + alpha 2 into S2 + alpha 3 into S 3, like this; divided by the total area S1 + S2 + S3. So, this is = A. A is the total effective absorption area divided by S which is the total spatial area. Alpha bar is A by S.

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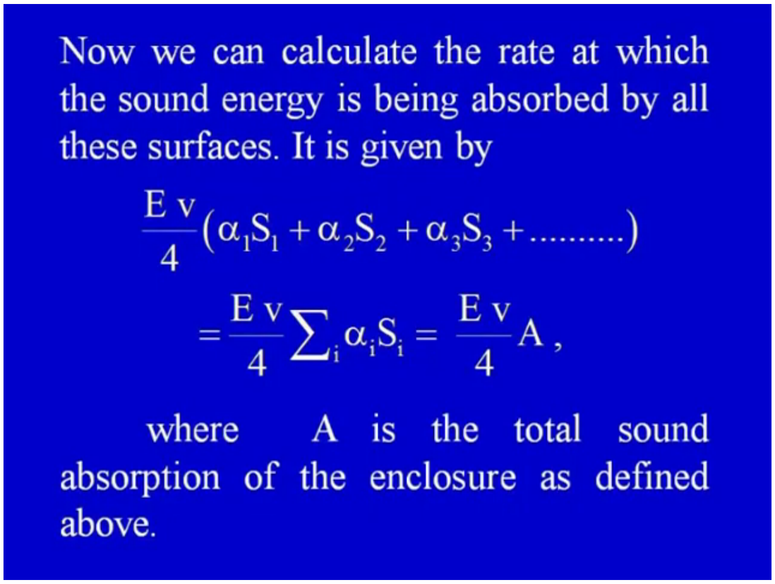

Now we can calculate the rate at which the sound energy is being absorbed by all these surfaces. It is given by

$$\frac{E\,v}{4}(\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots\ldots\ldots)$$

$$= \frac{E\,v}{4}\sum_i \alpha_i S_i = \frac{E\,v}{4} A,$$

where A is the total sound absorption of the enclosure as defined above.

Now, we can calculate the rate at which the sound energy is being absorbed by all these surfaces. It is given by Ev by 4 which was the intensity of the sound incident on the wall on the absorbers multiplied by all this contribution. The result therefore is this is = Ev by 4 times A. A is the total sound absorption of the enclosure as defined above.

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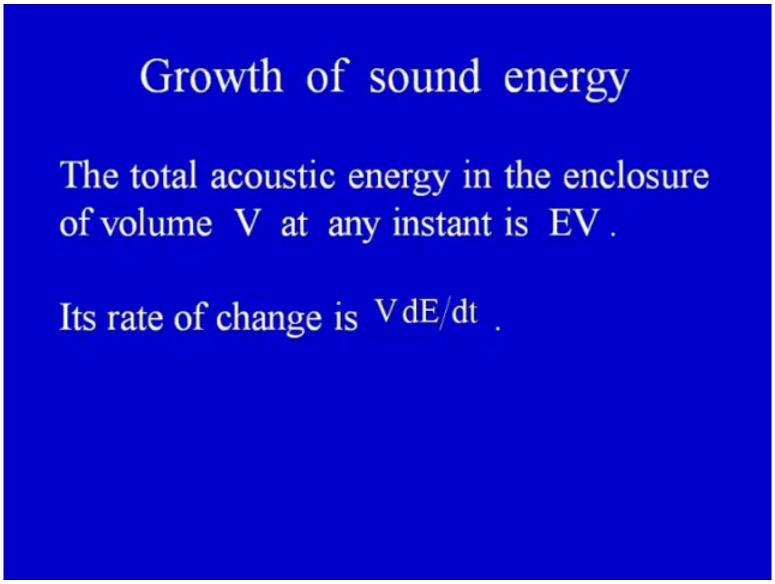

Growth of sound energy

The total acoustic energy in the enclosure of volume V at any instant is EV .

Its rate of change is $V\,dE/dt$.

Now, we can consider the growth of sound energy. The total acoustic energy in the enclosure of volume v at any instant is EV. E is the energy per unit volume multiplied by the volume V. Its rate of change naturally V times d E by dt.

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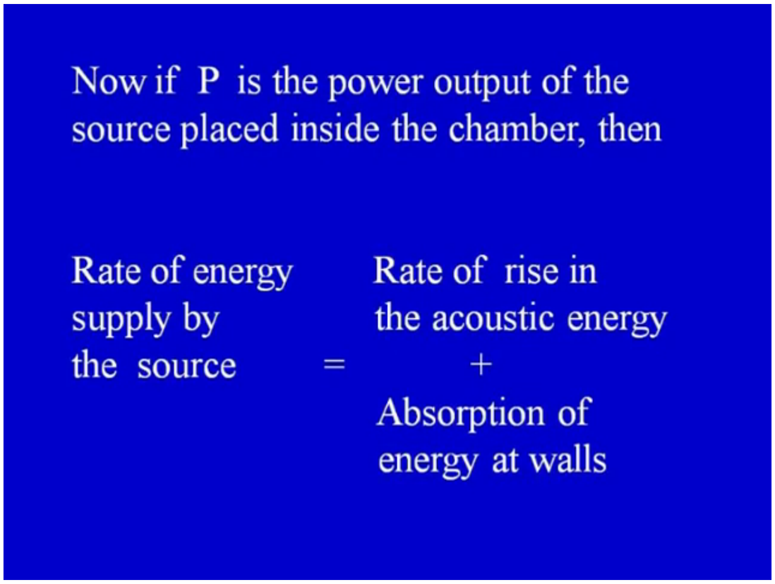

Now if P is the power output of the source placed inside the chamber, then

Rate of energy supply by the source = Rate of rise in the acoustic energy + Absorption of energy at walls

Now, if P is the power output of the source placed inside the chamber, then the rate of energy supplied by the source naturally in equilibrium; this will be = the rate of rise in the acoustic energy + absorption of energy at the walls.

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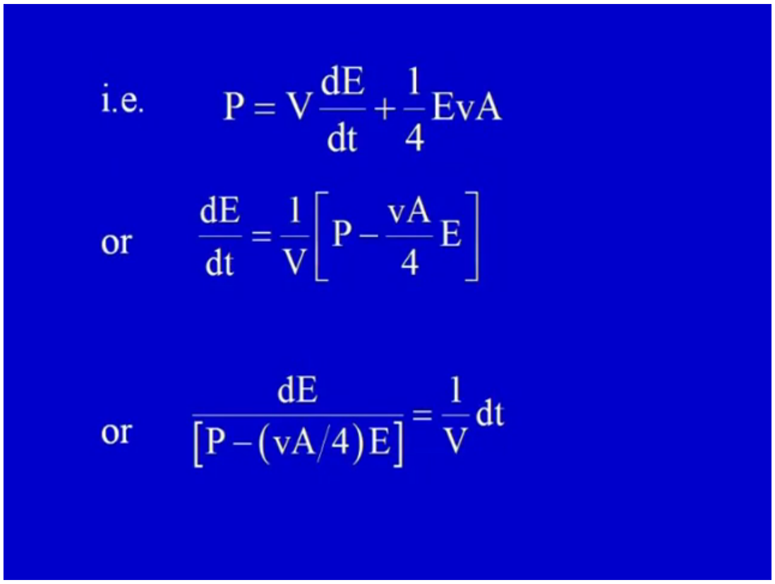

i.e. $$P = V\frac{dE}{dt} + \frac{1}{4}EvA$$

or $$\frac{dE}{dt} = \frac{1}{V}\left[P - \frac{vA}{4}E\right]$$

or $$\frac{dE}{[P-(vA/4)E]} = \frac{1}{V}dt$$

That is P is = V times dE by dt + E v by 4 times A. So, we solve it for dE by dt which is = 1 by V times P - vA upon 4 times E. That is we can, so now, we want to actually integrate this expression. So we write it like this: dE upon P - vA by 4 times E and this is = dt by capital V.

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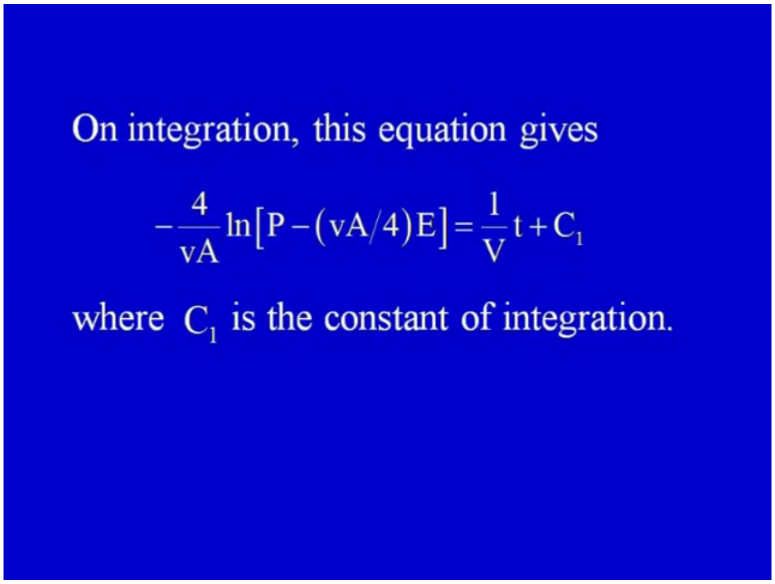

On integration, this equation gives

$$-\frac{4}{vA}\ln[P-(vA/4)E] = \frac{1}{V}t + C_1$$

where C_1 is the constant of integration.

On integration this equation gives - 4 upon vA times log of P - vA by 4 times E and this is = t by v + the integration constant C1.

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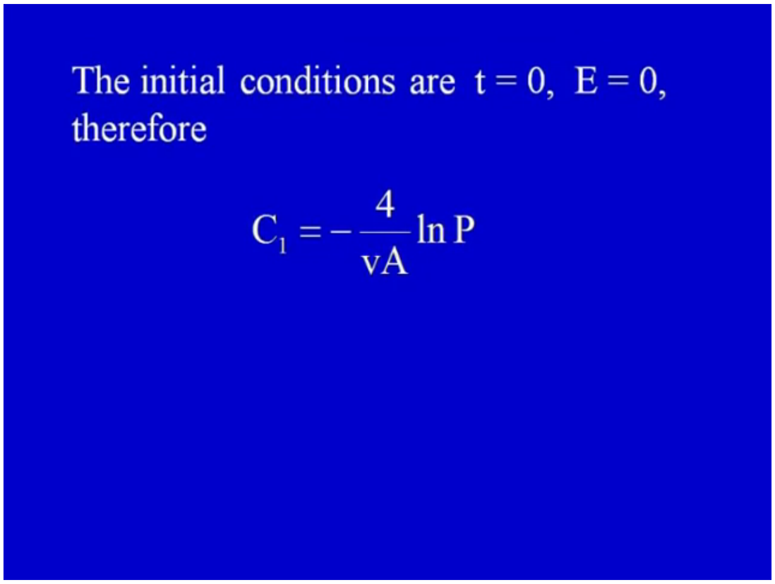

The initial conditions are $t = 0,\ E = 0$, therefore

$$C_1 = -\frac{4}{vA}\ln P$$

The initial conditions are initially t is = 0, no sound so E is also = 0 initially. And that gives C1 is = - 4 upon vA times log of P.

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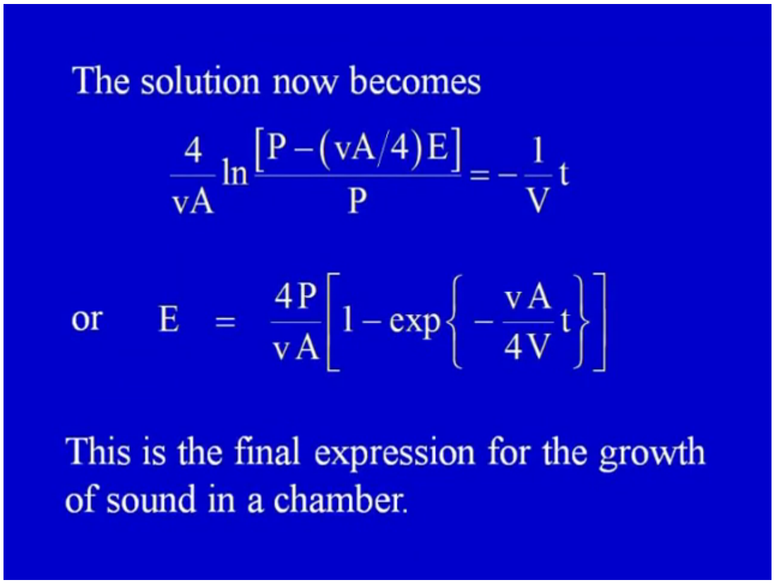

The solution now becomes

$$\frac{4}{vA}\ln\frac{[P-(vA/4)E]}{P} = -\frac{1}{V}t$$

$$\text{or} \quad E = \frac{4P}{vA}\left[1-\exp\left\{-\frac{vA}{4V}t\right\}\right]$$

This is the final expression for the growth of sound in a chamber.

If you use this value now, rearrange the terms and the result E is = 4P upon vA times 1 - exponential of - vA upon 4 v times t. This is the final expression for the growth of sound in a chamber.

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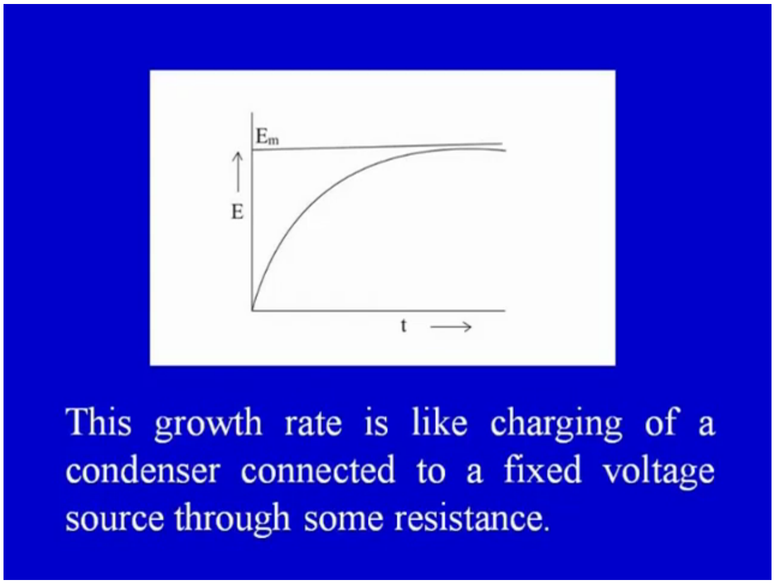

This growth rate is like charging of a condenser connected to a fixed voltage source through some resistance.

This figure shows the growth. It is like charging of a condenser connected to a fixed voltage source through some resistance. Let us now consider a decay of sound energy,

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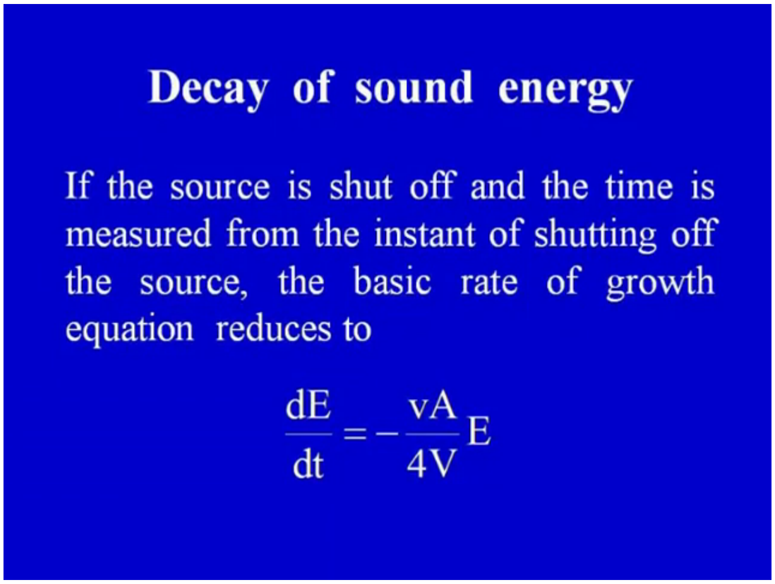

Decay of sound energy

If the source is shut off and the time is measured from the instant of shutting off the source, the basic rate of growth equation reduces to

$$\frac{dE}{dt} = -\frac{vA}{4V}E$$

The sounds of this shut off and the time is measured from the instant of shutting of the source, the basic rate of growth equation now, reduces to d E by dt is = - vA upon 4 capital V. Remember, small v, the speed capital which the volume time 3.

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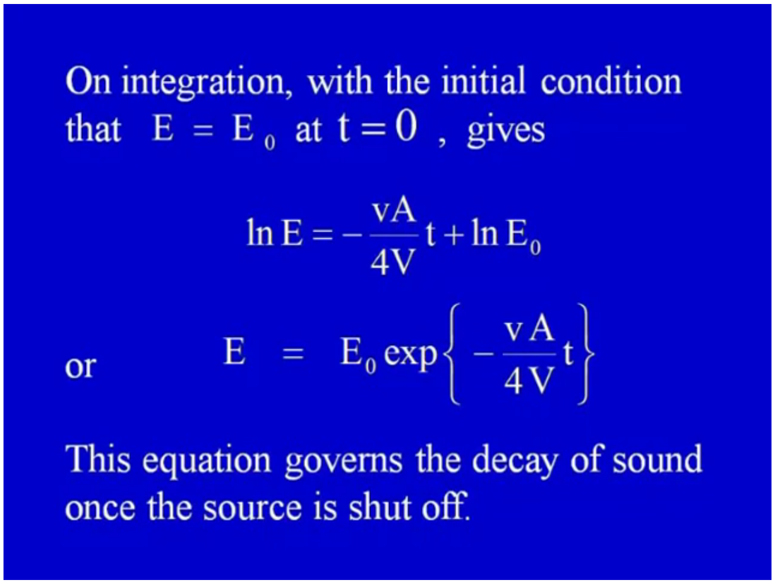

On integration, with the initial condition that $E = E_0$ at $t = 0$, gives

$$\ln E = -\frac{vA}{4V}t + \ln E_0$$

or

$$E = E_0 \exp\left\{-\frac{vA}{4V}t\right\}$$

This equation governs the decay of sound once the source is shut off.

On integration, with the initial conditions that E is = 0 initially, that is that t is = t0 or t is = 0 and this gives log of E is = - vA upon 4V times t + log of E0 which on integration leads to E is = E naught exponential of - vA upon 4V times T. This equation governs the decay of sound once the sources shut off.

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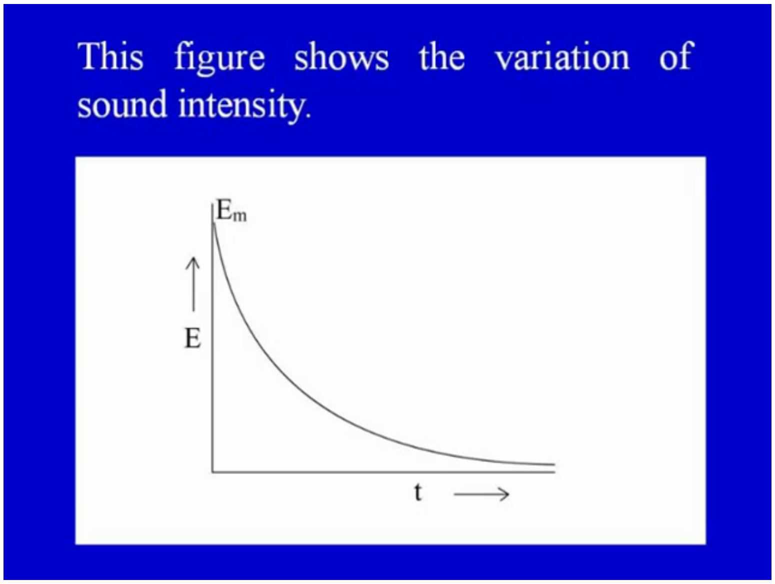

This figure shows the variation of sound intensity.

This figure shows the variation of sound intensity with time.

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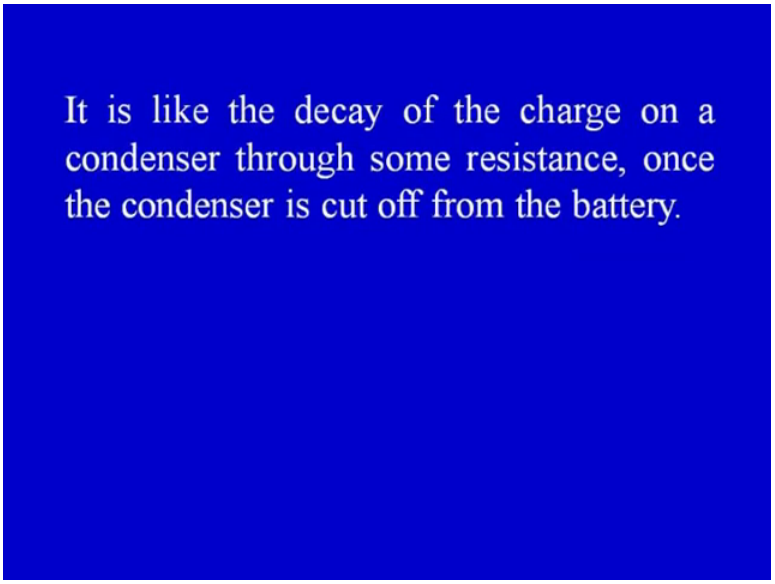

It is like the decay of the charge on a condenser through some resistance, once the condenser is cut off from the battery.

It is like the decay of the charge on a condenser through some resistance once the condenser is cut off from the battery.

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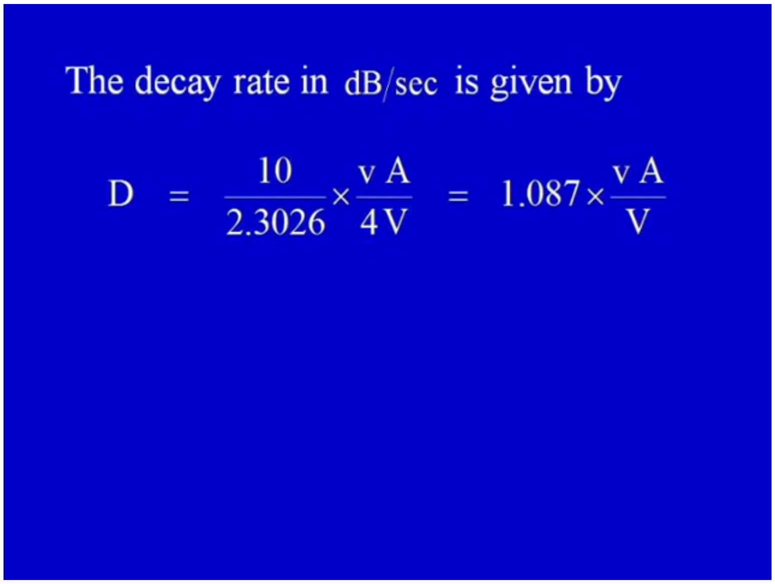

The decay rate in dB/sec is given by

$$D = \frac{10}{2.3026} \times \frac{v\,A}{4\,V} = 1.087 \times \frac{v\,A}{V}$$

Now, the decay rate in decibels per second is given by D is = 10 upon 2.3026 times vA upon 4V which is = 1.087 times vA upon capital V.

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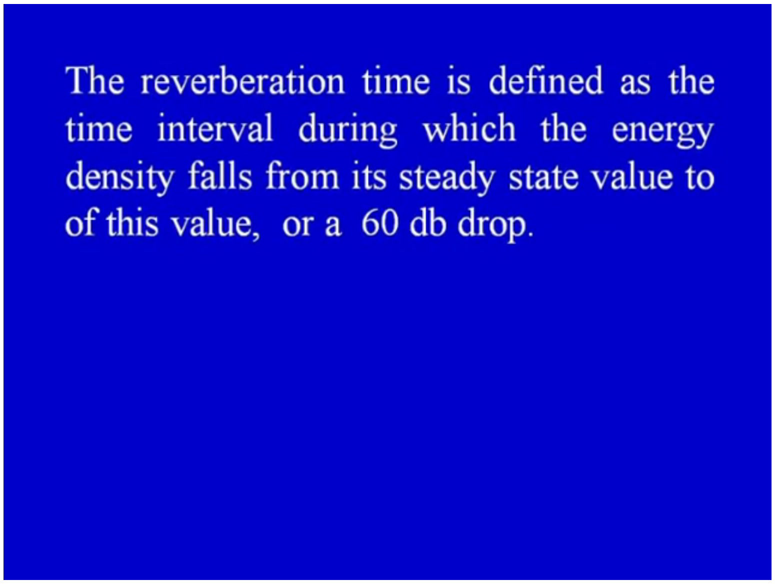

The reverberation time is defined as the time interval during which the energy density falls from its steady state value to of this value, or a 60 db drop.

The reverberation time by definition, this is defined as the time interval during which the energy density falls from a steady state value to this value or a 60 decibel drop.

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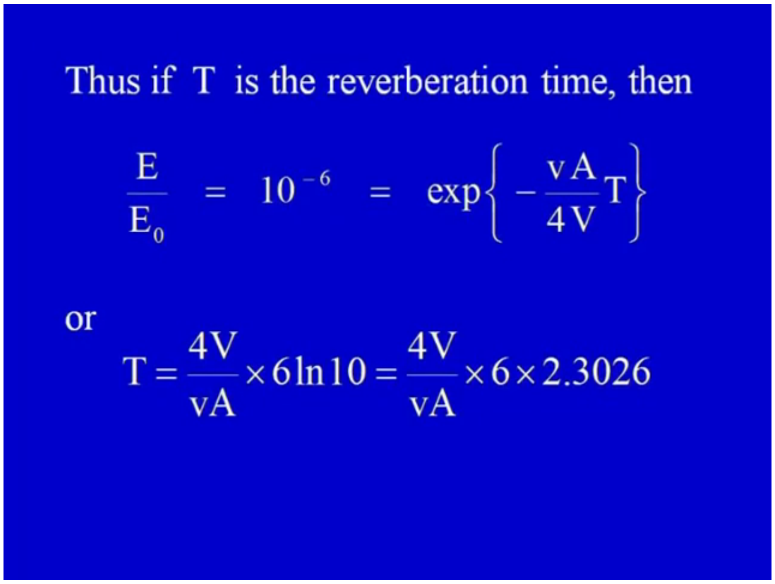

Thus if T is the reverberation time, then

$$\frac{E}{E_0} = 10^{-6} = \exp\left\{ -\frac{vA}{4V} T \right\}$$

or

$$T = \frac{4V}{vA} \times 6 \ln 10 = \frac{4V}{vA} \times 6 \times 2.3026$$

Thus if T the reverberation time then, E upon E naught is = 10 raised to the power -6 which is the value of the exponential - vA upon 4V times capital T. So, this can be solved for T and result is that T is = 4V upon v A into 6 into 2.3026.

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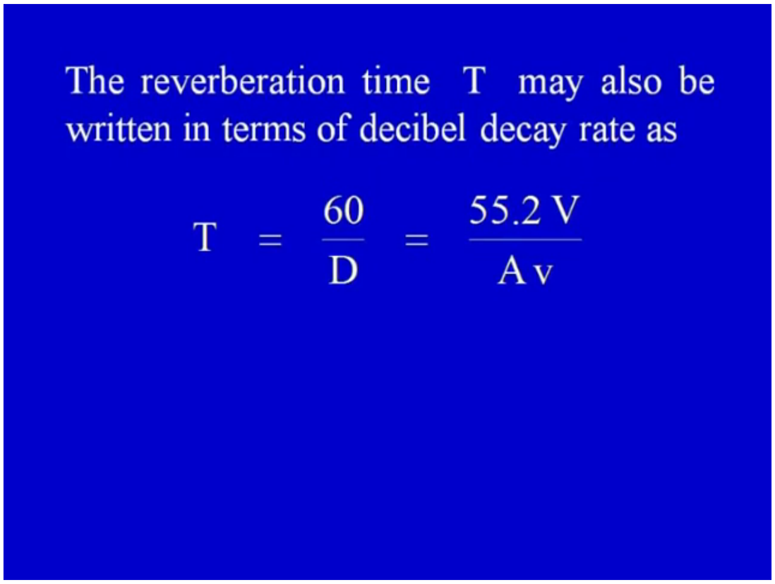

The reverberation time T may also be written in terms of decibel decay rate as

$$T = \frac{60}{D} = \frac{55.2\,V}{A\,v}$$

The reverberation time, this time T may also be written in terms of decibel decay rate D. In that case this T is given by 60 by D which is = 55. 2 V upon A times v. Remember again, capital v in the volume is small v is the speak is the total absorption in the enclosure.

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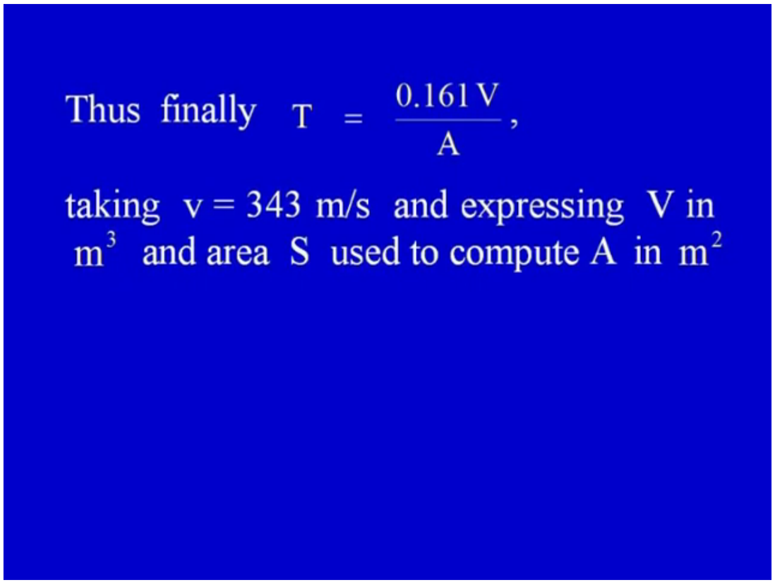

Thus finally $T = \frac{0.161\,V}{A}$,

taking $v = 343$ m/s and expressing V in m^3 and area S used to compute A in m^2

Thus finally, T is = 0.161 V upon A taking the speed as 343 meter per second and expressing V in cubic meters and area S in meters square.

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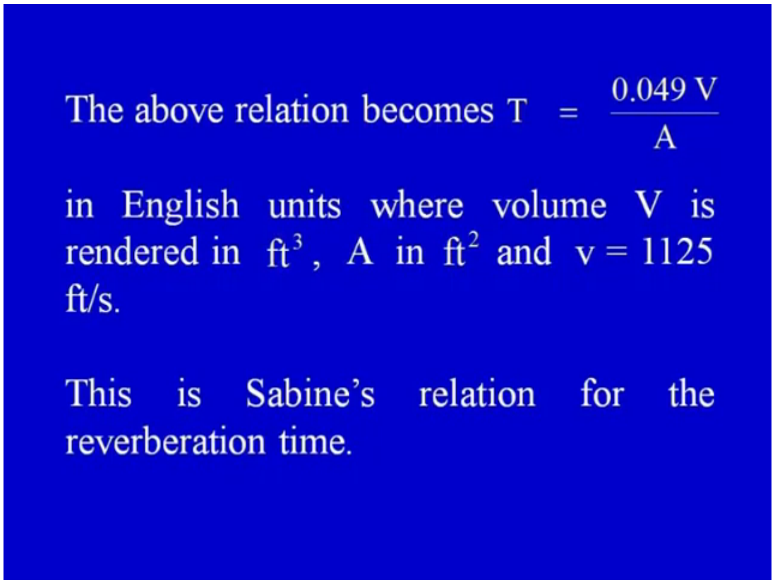

The above relation becomes $T = \frac{0.049\,V}{A}$

in English units where volume V is rendered in ft^3, A in ft^2 and $v = 1125$ ft/s.

This is Sabine's relation for the reverberation time.

The above relation becomes T is = 0.049 V over A in English units where V is now is in cubic feet, A is in square feet and the speed of sound is 1125 feet per second. This is the Sabine's relation for the reverberation time. And this, we have come to the end of this lecture. I hope you enjoyed it. Thanks