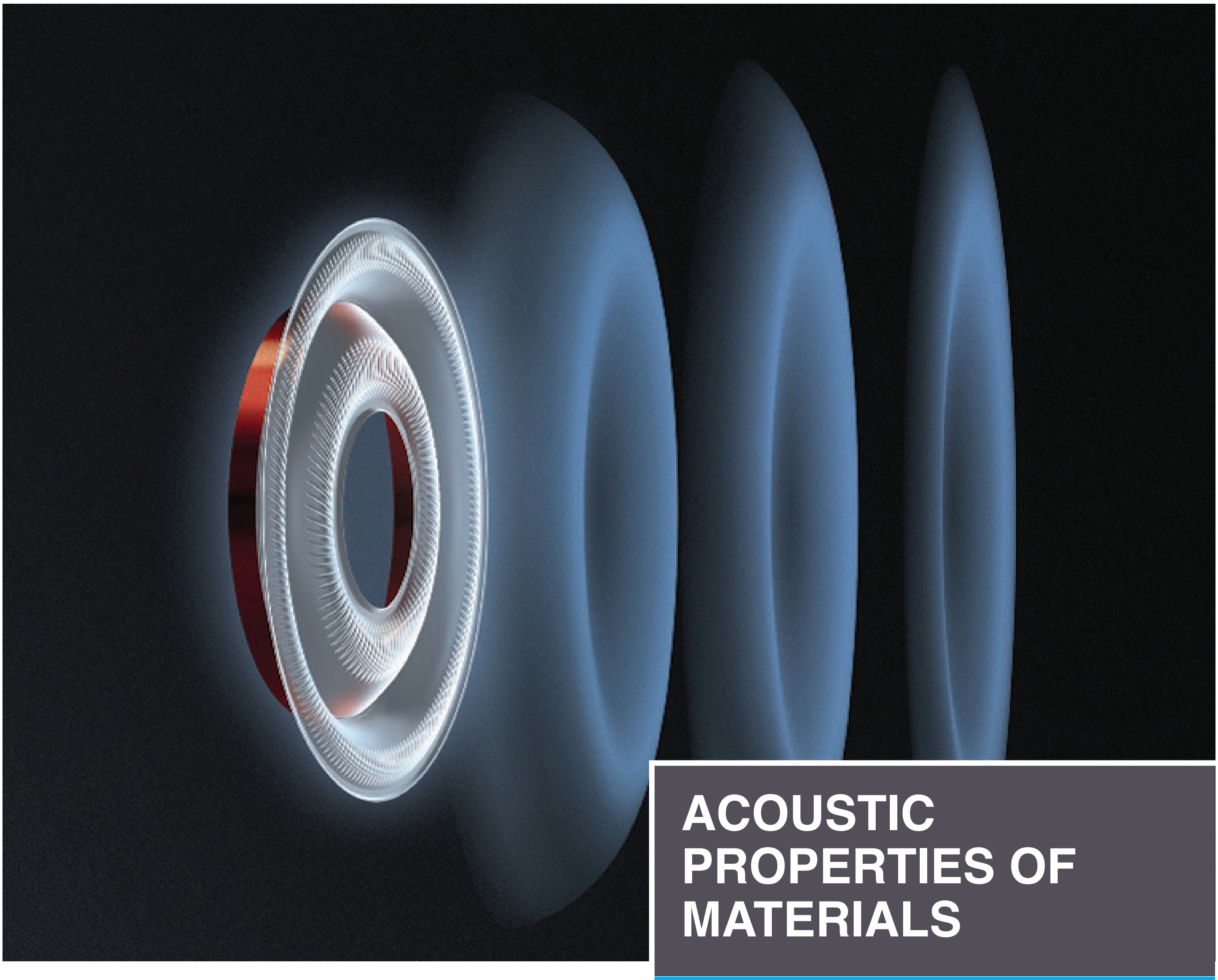

ACOUSTIC PROPERTIES OF MATERIALS

TEACHING AND LEARNING ACTIVITIES

ADAPTED VERSION

MATERIALS SCIENCE PROJECT

UNIVERSITY-SCHOOL PARTNERSHIPS FOR THE DESIGN AND IMPLEMENTATION OF RESEARCH-BASED ICT-ENHANCED MODULES ON MATERIAL PROPERTIES

SPECIFIC SUPPORT ACTIONS

FP6: SCIENCE AND SOCIETY: SCIENCE AND EDUCATION

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CONTENTS

Why is it important to learn about "Acoustical properties of materials"?

Do you know how long it has been since people have considered sound as an interesting area of study? The architects of ancient Greece were already interested in controlling the sonority in the theatres that they designed in that period.

Since then, many scientists have studied what sound is, how it originates, how it propagates, how to control its qualities, how to record it or how to avoid it... The study of sound and sound phenomena has led to a scientific discipline called Acoustics. Other disciplines, such as Architecture or Engineering, take into account the theories elaborated in the field of Acoustics when designing buildings, cities or infrastructures. In addition, Acoustics has led to technological innovations such as ultrasound scanning in medicine, sonar sensing for navigation, audio recording, digital treatment of music, etc.

Acoustics, like any other science, also strives to produce knowledge in order to contribute to the solution of social problems. Nowadays, sound pollution is already acute in some places. Many devices that are useful for human activity, such as various types of machines and motors, create this problem. Sound pollution can lead to hearing loss or cardiovascular and nervous system disorders, especially where the sounds are of high intensity and the exposure to them is continuous. For this reason, various authorities have developed regulations for the protection of citizens from sound pollution.

This module deals with these problems, focusing on the particular case of a disco that is situated near a residential area. The aim of the module is to acquaint you with the necessary scientific and technological tools so that you can develop an understanding of the problem of sound pollution and be able to propose solutions.

Different rooms have different acoustical conditions. Watch the videos in the folder “Acoustics” on your computer and describe, in writing, the differences in what you hear.

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0.1. MAKING SOUNDS WHILE SPEAKING. SPEAKING ABOUT SOUND.

In this module you will hear several sounds but you will also have to speak about questions related with the nature of sound. This first activity will help you to begin to think about sounds.

a) **Produce a sound with your voice or with another object or instrument. One of your partners will have to describe the emitted sound. Then switch roles.**

   Write your description in as much detail as possible.

b) **Now, think about two different sounds that you could produce with your voice for example, and describe how they would be.**

c) **Exchange with another partner the descriptions that you have written so that both you and s/he can attempt to produce the sounds that have been described.**

   Does the sound produced by your partner coincide with your description?
   Why is it so difficult to describe sounds?

In the former activity you may have realized how important it is to have a specific vocabulary to be able to understand and communicate effectively about sound.

Next, read the following dialogs:

Conversation between two neighbours

N1: I could not sleep all night long with so *much noise* in the street!

N2: For me the music of the cars with that so *loud volume* is also very annoying. However, I imagine that you will hear it more because your window looks out onto the main street.

N1: In spite of having windows of double glass, we don't achieve to *avoid hearing so much noise*; especially that deep noise caused by some motorbikes without a muffler.

Conversation between the owner of the flan and an expert at acoustics

E: You suffer a serious problem with *noise pollution*! The measurements of the *sound intensity* level in your street and inside your flat at various hours are very *high*.

O: And what do you recommend us? Because we changed the windows for double glass ones but despite of that, the problem persists...

E: We will have to use certain materials to *attenuate the sounds* that arrive, especially the sounds with *low* frequencies.

0.2. Match the corresponding words in *italic* of the conversation between the two neighbours and the words (also in *italic*) used by the expert of the second conversation.

so much noise	attenuate the sounds
loud volume	noise pollution
avoid hearing so much noise	low frequencies
deep noise	high sound intensity level

WHAT DOES SCIENCE TELL US?

Scientific language is characteristically more precise than everyday language. This is partly achieved by avoiding multiple meanings for the same term or concept.

For this reason, it is important that you remember from the beginning some scientific terms related with the topic of sound, since you will use them all along the module.

We say that a sound is **high-pitched** when its **frequency** is **high**. Also we speak about **low-pitched** sounds when their **frequency** is **low**. Therefore, we can relate frequency to the characteristic that musicians call **pitch**.

In the same way, we say that a sound is **loud** or has a **high volume** when it has a **high intensity**. We say that a sound is weak when its **intensity level** is **low**. Again, a measurable physical quantity (intensity) is associated with a characteristic of the sound that we can perceive through our senses (**volume**).

0.3. GENERATING SOUND

Watch the simulation at http://phet.colorado.edu/simulations/sims.php?sim=Sound
Press "Run" in order to start the simulation.

How is the sound produced in this case?

What happens when you change the frequency?
How is the movement of the speaker changing?

What happens when you change the amplitude?
How is the movement of the speaker changing?

Sound is produced when one object vibrates. This **vibration** pushes air (or other medium) particles and these particles oscillate from side to the other. In oscillating, each particle collides with the one which is near and this one collides with the nearby, and so on and so forth. In this way, the initial vibration propagates.

0.4. PROPAGATION OF SOUND

Use the slinky coil to produce waves.

How are these waves travelling?

Is the material that makes up the coil travelling from one end to the other?

Can you use the propagation of the wave through the coil to describe how sound propagates in air?

Predict the necessary conditions for sound to propagate.

Place a mobile phone (or other sound generating object) into the glass chamber and set the pump running. Call the phone.

What do you observe as air is removed from the chamber?

We say that sound is transmitted in the form of **waves**. Therefore, sound is a process of **energy transfer** from the initial object which started vibrating. This transfer does not require transport of matter, since the particles of the medium do not travel but they oscillate around a point.

Sound **intensity** is the characteristic that indicates the quantity of **energy** that sound waves transfer in unit time. Therefore, a more intense sound implies a sound wave with greater amplitude.

UNIT 1: SOUND WAVE – MATERIAL INTERACTION

1.1 ACOUSTIC PROBLEMS OF A DISCO

The owner of a new disco is worried about the noise. The neighbours have already complained about the first sound tests before the inauguration and the owner is confident that, if he does not find a solution, neighbours will report to the police.

The acoustic treatment of the disco has been a problem from the beginning. At the beginning, there were a lot of mixed sounds and eco, but the problem disappeared after the installation of the furniture and the decoration.

In fact, the music sounded very well inside; because it seemed that the sound was distributed uniformly around the space. Even though, behind the loudspeakers! This fact had always surprised him: why does music arrive everywhere? The problem is that music also arrives at the neighbours in spite of the walls in the middle. To find a solution, he decided to hire the services of an expert.

DSR enterprise has a wide experience in acoustic conditioning of discos; their technicians develop projects according to the structural conditions of the setting up. The design of discos has lots of possibilities, but they always have to keep in mind the variability of tax occupation. The different spaces of a disco can be wide or smaller, they can have high or lower ceilings, hard walls, and decoration made of mirrors or fitted carpets.

Next, you can see the specific distribution of that disco. DSR Enterprise divides the disco in different spaces in order to analyze precisely the variables that take part on the acoustics of the disco.

Sectors of the disco

- **Entrance and cloakroom:**

  ..\..\..\Desktop\photos_disco\vestibule.bmp

- **Dance floor:**

  ..\..\..\Desktop\photos_disco\Dancefloor.jpg

  Bar:

  ..\..\..\Desktop\photos_disco\little_dance_floor_2.jpg

- **VIP lounge:**

  ..\..\..\Desktop\photos_disco\VIP_lounge_6.jpg

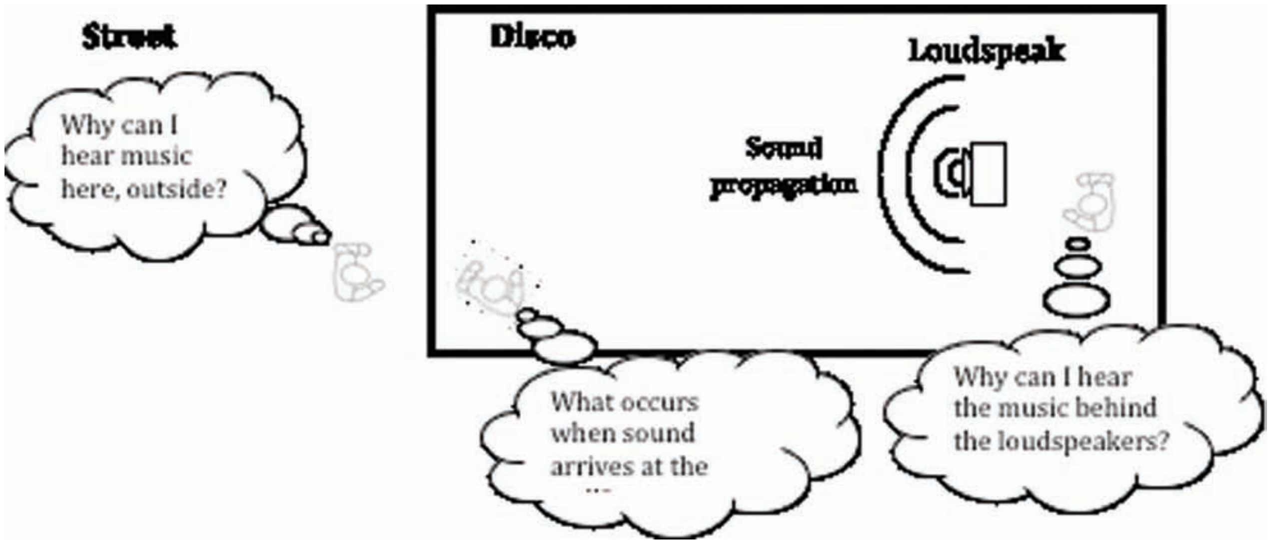
From the virtual tour of each sector and the map of the disco, it is possible to identify different elements (e. g., columns, loudspeakers, etc.).

1.1.1. Which characteristics do you think that each of the aforementioned sectors of the disco should have according to the sound intensity that should arrive there?

The technicians are working in three basic questions related to the acoustics of the disco:

- ***In which parts of the disco should be convenient to hear the sound with more intensity? What are the variables that affect the fact that we hear sound more or less intense?***
- ***What occurs when sound arrives at an obstacle? Where the loudspeakers should be situated?***
- ***Which conditions avoid hearing sound outsider of the disco?***

Next, you have a simplified representation of the dance floor of the disco:



1.1.2. Discuss with your partners which answers you would give to the questions that the technicians wonder. Argue your answer:

a) What happens to the sound that is emitted by the loudspeaker when it arrives at the walls of the disco? Why can I hear the music if I stand behind the loudspeaker?

b) If I am in the street in front of the disco, and the doors are closed, I can hear the music even though with less volume that inside. Why can I hear it?

1.2 WHY CAN SOUND ARRIVE AT THE WHOLE DANCE FLOOR?

One of the acoustic engineers of DSR enterprise comments to the disco owner that one of the phenomena to take into account is what occurs when sound arrives at an obstacle big enough (e.g., a wall). It seems that sound “rebounds”. The owner needs more information about that “rebound” to take decisions. For instance, he wants to know where he should put the loudspeakers to allow sound to “rebound” in order to be heard in the whole space and he also wants to know what he could do to avoid the “rebound” when it is not appropriate. So, he needs to predict the direction of the sound propagation after the “rebounds” and also how to avoid or reduce them.

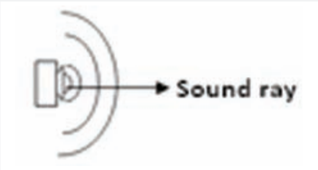
The acoustic engineer has used an everyday language. However, the scientific term to express the fact that sound “rebounds” is different.

How do you think this fact could be called?

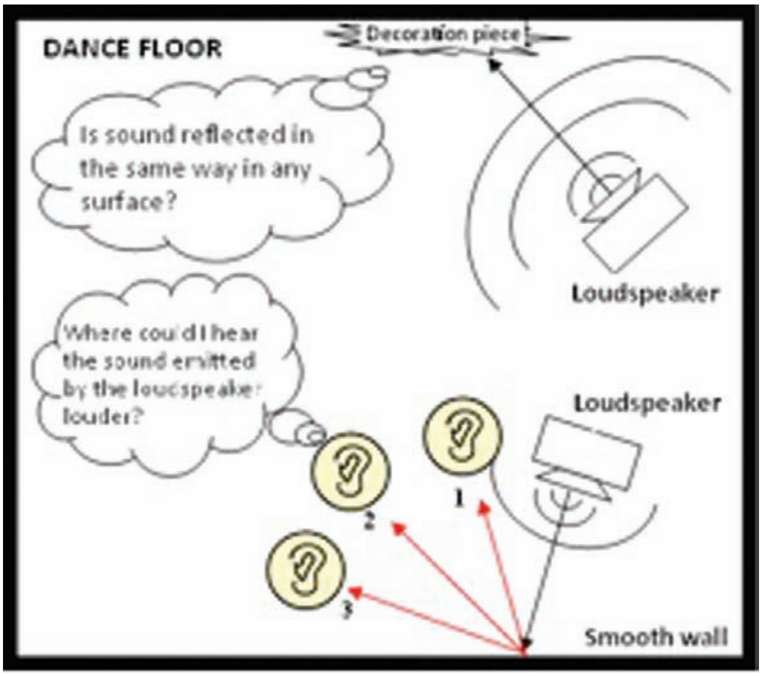
WHAT DOES SCIENCE TELL US?

It is not usual to say that sound waves rebound when they arrive at the surface of a material. We say that sound waves are reflected. We call reflection to the phenomenon in which waves change their direction of propagation when they arrive at an object, but they continue propagating through the same medium.

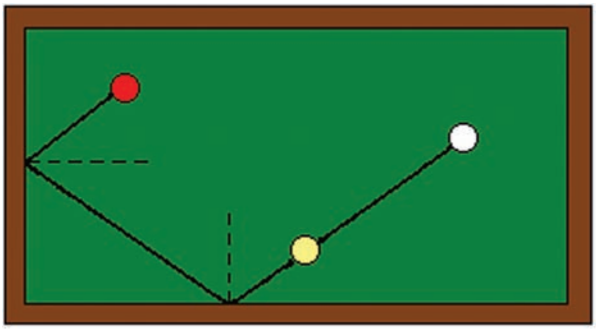
Sound waves are considered spherical waves because they propagate in all directions from the sound source. In order to represent them, is commonly used a group of curve lines which do not intersect and have a radius greater as they move away from the source. The representation of the “sound ray” is also used to indicate the direction of propagation of sound waves in which the most of the energy is transmitted, that is, in which sound intensity level is the maximum.

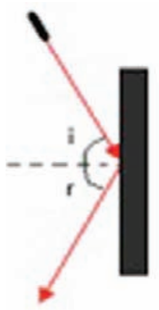


1.2.1. **Observe the following picture and try to answer the posed questions:**



IN WHICH DIRECTION IS SOUND REFLECTED?



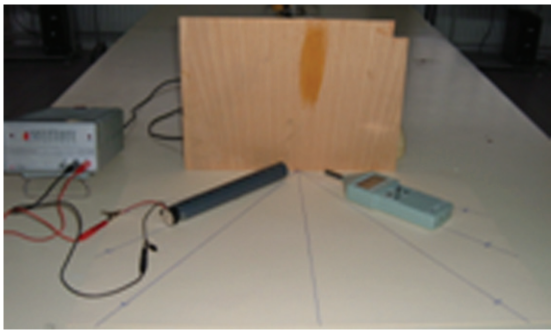


Analyze how some objects rebound (e.g., billiard balls), or how other waves are reflected (e.g., laser beam), off smooth surfaces (polished wood and mirrors, respectively). Notice the directions of propagation of the balls and the laser beam.

We call **angle of incidence** to that formed by the direction of propagation of the incident sound ray with the perpendicular line to the interface between two mediums (broken line in the picture). The **angle of reflection** is that formed by the direction of propagation of the reflected sound ray with the normal line.

1.2.2. **Which kind of relationship do you think that exists between both angles?**

TO KNOW MORE: LET'S MEASURE THE ANGLE OF REFLECTION



We can measure the angle of reflection of the sound with an experimental setting like that in the picture:

- On the left, there is a sound source, which is called buzzer and is emitting inside a pipe made of PVC.
- Aim the pipe at a smooth surface (in the picture wood veneer was used) in a way that the angle of incidence is 45º.
- Measure the sound intensity level placing a sound level meter in different directions.
- In order to know the directions where you are measuring, draw in a piece of card lines which form 30º, 45º and 60º with the perpendicular to the surface.

Sound intensity level is measured in **decibels (dB)**. The scale of decibels is adjusted to the audition range of the human hearing since it goes from 0 dB, which corresponds to the minimum intensity which we can hear, to 120 dB, which is considered the pain threshold for the human being, and beyond.

EVERYDAY SOUND	SOUND INTENSITY LEVEL (dB)
Audition threshold	0
Perfect silence. Exceptional level in natural environments	20
Calm. Quiet street	40
Little noisy environment. Ordinary conversation	60
Quite noisy environment. Inside a vehicle	80
Dangerous level for hearing. 1m away from a mixer	100
Pain threshold. Inside a disco 1m away from a loudspeaker	120
Very dangerous level. 50m away from a plane taking off	140

Sound intensity level can be measured with a special instrument which called **sound level meter**. Sound level meters use a microphone which gathers sound. They have to point at the direction of the sound source. The microphone is connected to a set of devices which produce a measurement of the sound intensity level in decibels (dB) and show the value in a screen.

Prediction

Having established the setting up shown in the picture above, in which direction do you expect to measure greater sound intensity level?

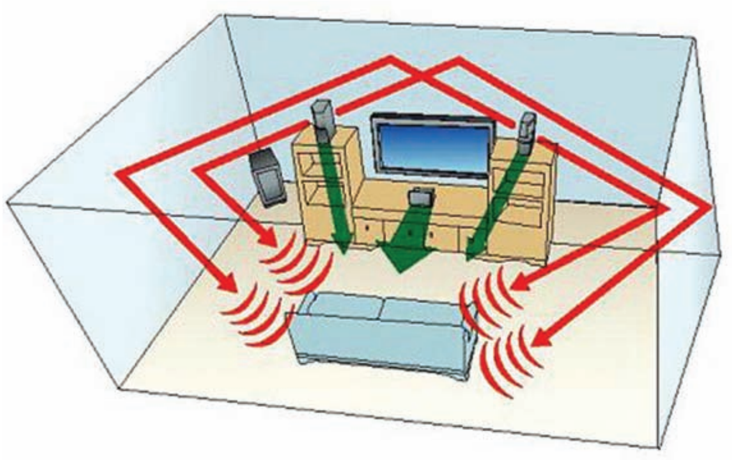
What really happens?

Switch on the buzzer and explain what happens while you are aiming sound level meter at different directions (try to maintain the sound level meter always aimed at the wood and at the same distance from it!).

- Why do you hear the sound from the buzzer in any point of your classroom, independently where you are placed?

- Explain the results of this experiment, using what you have learned about reflection.

The fact that the angle of incidence is the same as the angle of reflection can be tested experimentally.



Some surround sound systems take advantage of the property of sound reflection in certain directions to amplify the sound the listener hears. Part of the sound will directly reach the listener and another part will reach him after being reflected on the walls.

1.2.3. In conclusion:

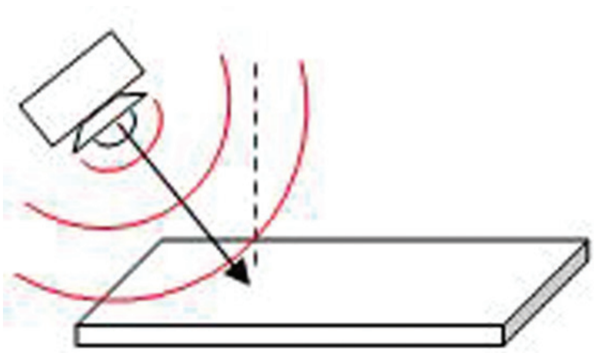
a) **Complete the sentence: When sound propagates in a certain direction and encounters an obstacle (its surface), is reflected, that is...**

....

b) **Complete the sentence: The direction of propagation of the reflected sound ray is...**

....

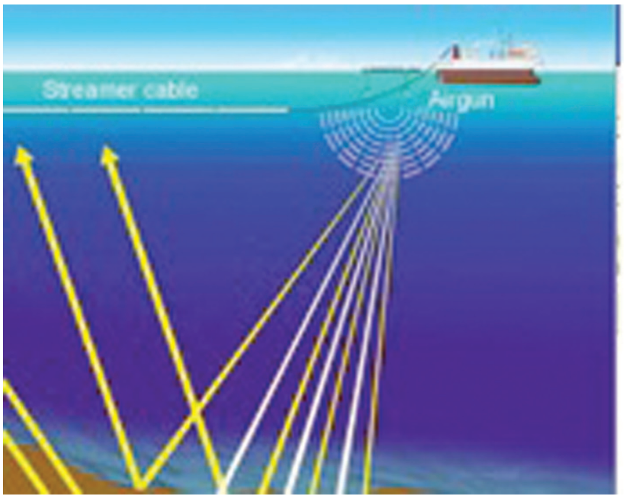
c) **Draw the reflected sound ray using an arrow and represent the propagation of the reflected waves using semi-circumferences. Mark the angles of incidence and refection.**



AN APPLICATION OF THE REFLECTION OF SOUND WAVES: THE SONAR

The sonar is a device which emits and detects sounds which have very high frequency (ultrasounds) and our ear is not able to detect and, therefore, we can not hear.

These ultrasounds, like all sound waves, can also be reflected. Sonar is used by ships to locate objects (such as shoals or fishes or the sea bottom) because the reflections are given in certain directions.

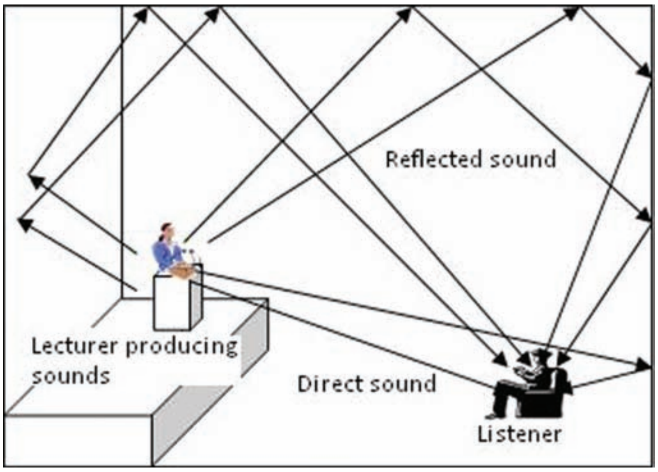


1.2.4. **Invent an explanation about how is it possible to measure the distance to a distant object using sonar:**

WHICH PATH DOES THE SOUND FOLLOW FROM THE LECTURER TO THE LISTENER IN AN AUDITORIUM?

In very big rooms with high and smooth ceilings (as it is the case of the picture), notice the path that sound follows from the lecturer (sound source) to the listener.

Part of the sound is reflected on the ceiling or the walls. Another part is not reflected (direct sound).



1.2.5. a) Looking at the picture above, could you say which part of sound (direct or reflected) will arrive later at the listener?

Why?

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b) If different parts of sound follow different paths and, therefore, some of this parts arrive later than others at the listener, do you think that the listener would hear sound as if it had more duration or would hear different sounds?

Explain your answer.

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WHAT DOES SCIENCE TELL US?

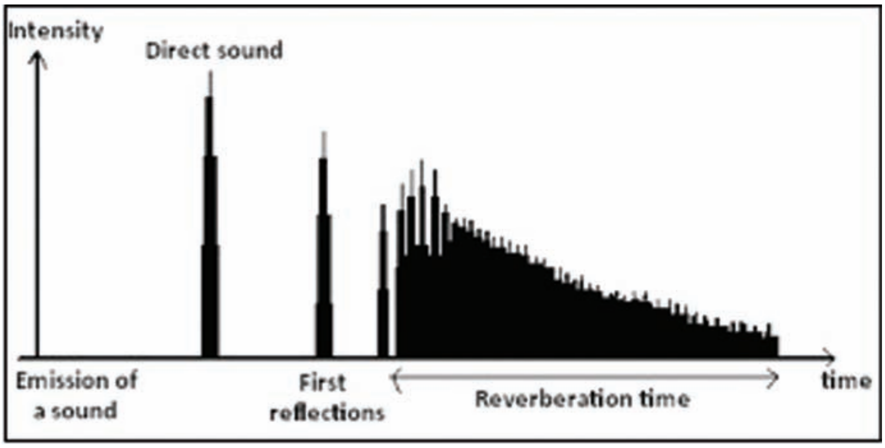
In wide precincts, such as theatres or lecture rooms, it is usual that we hear that sounds last more than usually. This phenomenon is called **reverberation** and is due to sound reflection. The reflected waves are delayed in respect of the direct sound for a time small enough in order human ear is not able to distinguish two different sounds. Human ear can only appreciate a sound with greater duration. If this delay is very big, the phenomenon is called echo.

The reverberation in a precinct is characterized by the **reverberation time**. That is the time that pass in a certain precinct since a sound is produced until its intensity diminishes enough not to be heard.

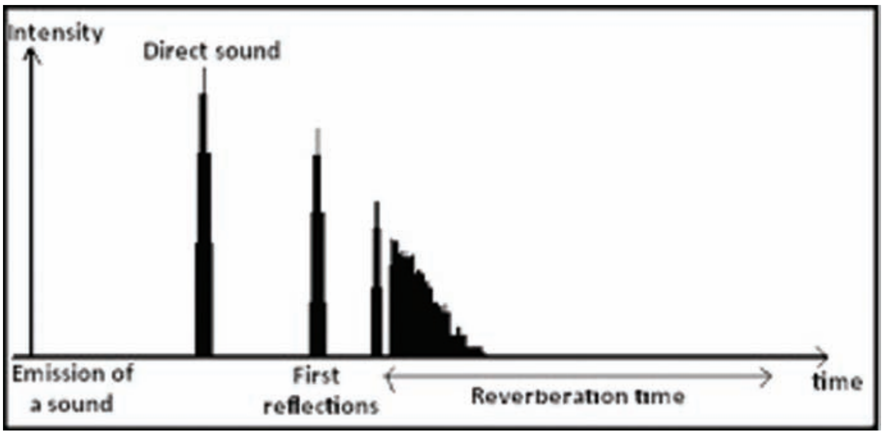
REVERBERATION TIME

The time that a sound remains being heard after having been emitted, also called reverberation time, has been measured in a room which has high and smooth ceilings.

This graph is obtained by measuring the time that a prompt sound (e.g., a word said by a lecturer) continues being heard in the big room.



After this measurement, objects with irregular surfaces have been placed on the ceiling of the room in order sound can be reflected in diverse directions, and the walls have been lined with materials that reflect sound very little. When the room has been acoustically conditioned, the same kind of measurement has provided the following graph:



1.2.6. a) Which differences do you observe between both graphs?

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b) When would you understand better the lecturer, before or after conditioning acoustically the room?

Why?

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Each precinct has an ideal reverberation time according to the function that it has. A room allocated to make lectures or plays needs a short time of reverberation so that sounds that arrive at the audience are very clean and intelligible. However, in a room allocated to listen to music, largest reverberation time are needed to improve the acoustic sensation, avoiding musical sounds finish in an abrupt way and attenuating them slowly.

USE OF THE ROOM	IDEAL REVERBERATION TIME (s)
Theatre and lectures	0,4 – 1
Chamber music	1 – 1,4
Orchestral music	1,5
Opera	1,6 – 1,8
Choral and sacred music	Up to 2,3

Some people think that the Palau de la *Música Catalana* is a room which turns out "excessively muffled" for the orchestral music. An expert at acoustics architecture measured the average reverberation time of this room and obtained an approximate value of 1,2s.

Do you think that this measurement corroborates the listeners' opinion? Explain your answer.

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REFLECTION AND AUDITORIUMS CEILINGS

1.2.7. Remember the picture in the first activity of this unit:

a) **Is the sound reflected in the same way on a smooth wall and on a decoration piece which has an uneven surface?**

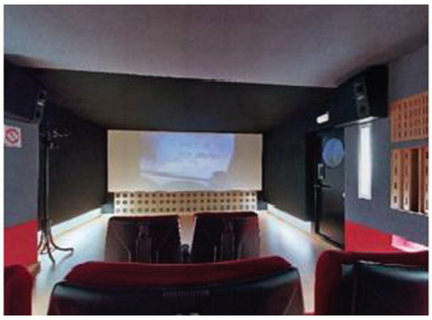
b) **Is the sound reflected in the same way on a smooth wall and on a wall which is lined with cork or felt?**

In some rooms, ceilings are modified to avoid too much reflection towards the spectators. With this purpose, materials or objects with uneven surfaces are used. These materials reflect sound in different directions, that is, sound is diffused. This kind of materials is called **sound diffusers**.

1.2.8. The following pictures show three rooms allocated to different uses.

Which of them do you think that have used sound diffusers?
How is that related with the use of each room?


A

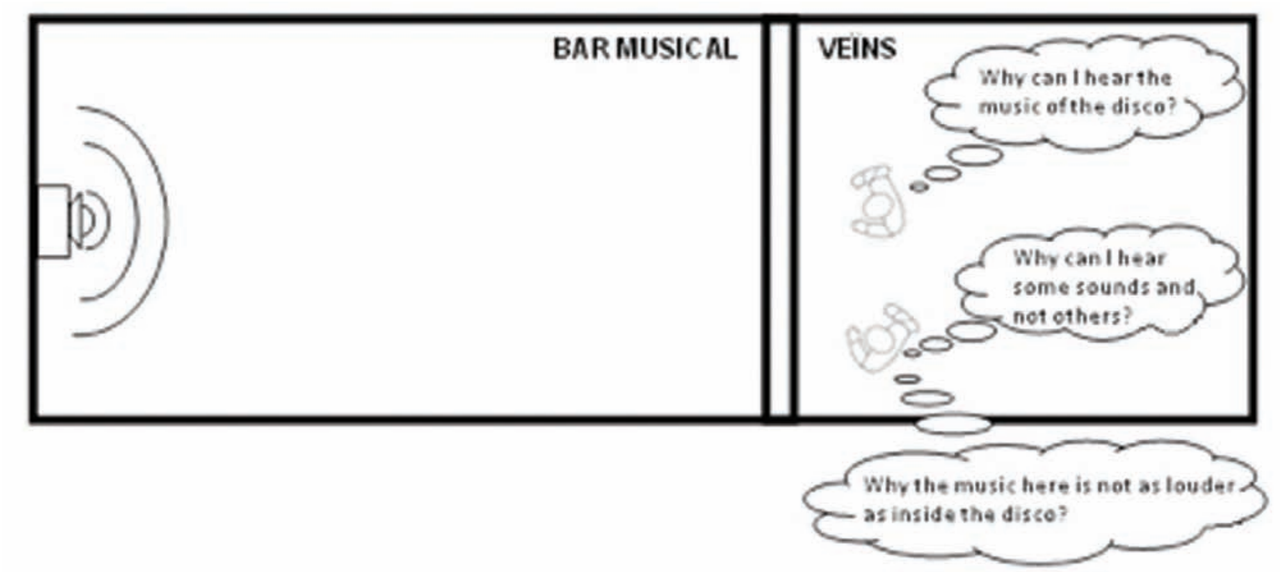

B


C

1.3 HOW CAN WE MANAGE TO AVOID HEARING SOUND OUTSIDE THE DISCO?

The owner of the disco is in better spirit since some problems of acoustic conditioning seem to begin to be solved. He is looking forward to starting it up and even he has already decided the music that he will be the deejay in the disco personally. Even so he does not want to neglect his duty with the neighbours, who are very anxious since they have been informed about the kind of business he will set up. He thinks that his music is quite pleasant, but there is no accounting for tastes.

Below here you can see a simplified representation of the disco and one of the adjacent houses which are separated from the disco only by a wall:



1.3.1. a) How would you explain the fact that neighbours can hear the music coming from the disco?

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b) Do you think that the neighbours would hear less the music if sound reflection inside the disco was increased?

Explain.

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In order to propose a solution for attenuating the sound coming outside the disco, both in the street and in the flats situated on the top and the sides, firstly the engineer has to measure the intensity level of sound produced inside the disco and sound that arrives at different points outside the disco.

1.3.2. How can we measure the variations of sound intensity level?

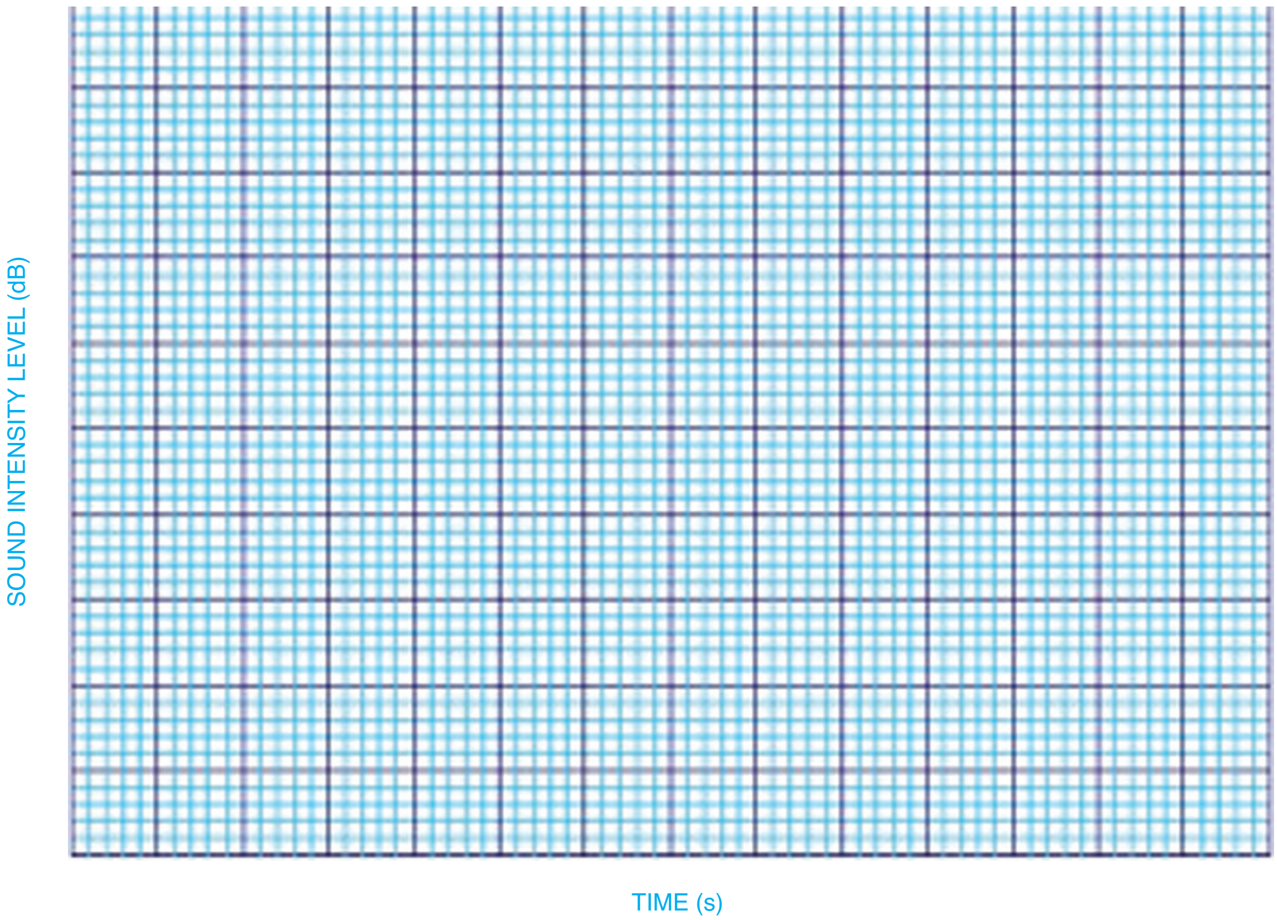
The engineer uses a sound level meter that measures the sound intensity level that arrives at him in dB. The more decibels it indicates, the more intense the measured sound is. Now you will learn to use this device for measuring the intensity level.

Unlike the engineer, we will use it connected to the computer, using the appropriate software, as it is shown in the picture. This equipment will allow you to observe the graph of the variations of the sound intensity level throughout time, in the screen of the computer.

IN ORDER TO MEASURE USING THIS EQUIPMENT, IT NEEDS TO BE CONFIGURED. FOLLOW THE CONFIGURATION GUIDELINES.

a) **Produce sounds with different intensities (whistling, or speaking loudly and quietly, or keeping silent, or with a buzzer*, etc.) in front of the microphone of the sound level meter. Observe in the computer screen how different produced sounds are represented graphically.**

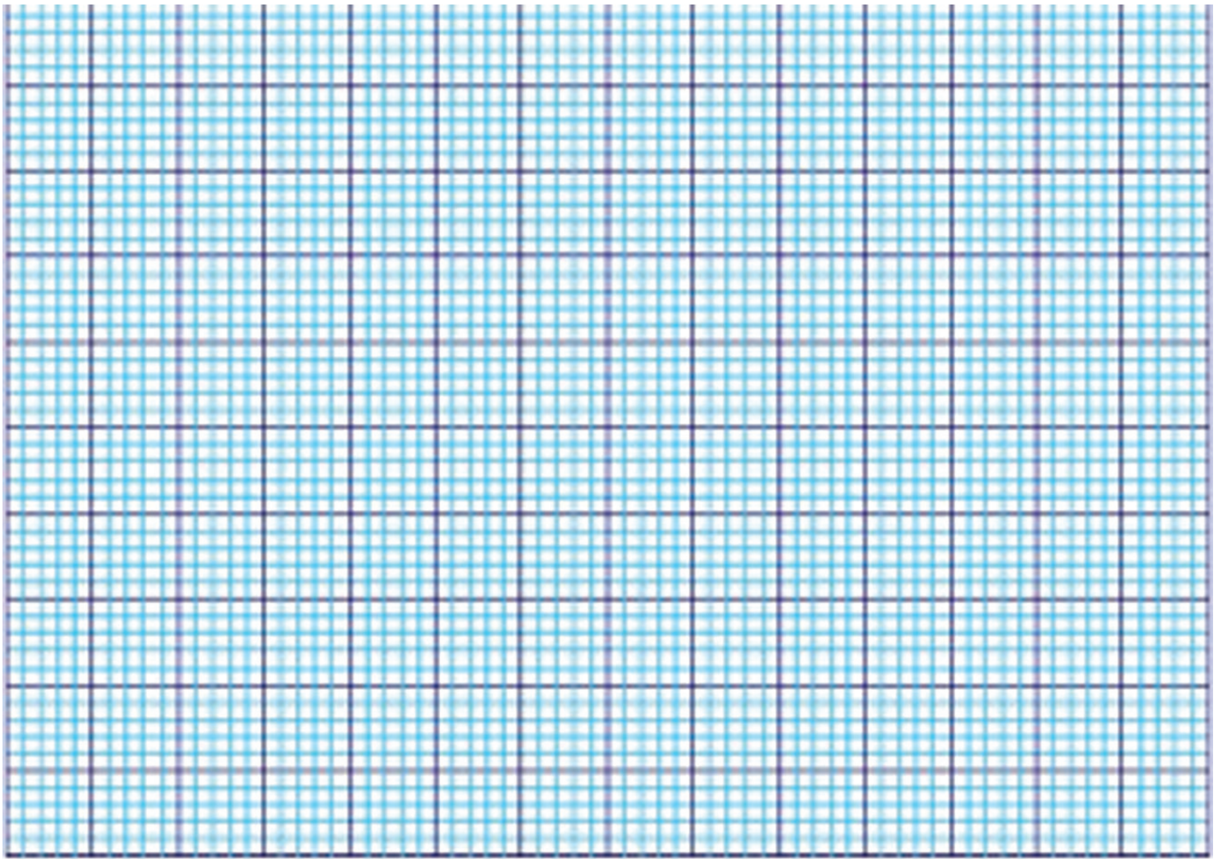
b) Draw in the following axis the obtained graph for the sounds you have emitted. Identify in the graph which kind of sound you were producing in each time interval. Mark in the graph the moments in which the sound intensity level was high.



1.3.3. How does the sound level meter – buzzer distance affect the measurements of sound intensity level?

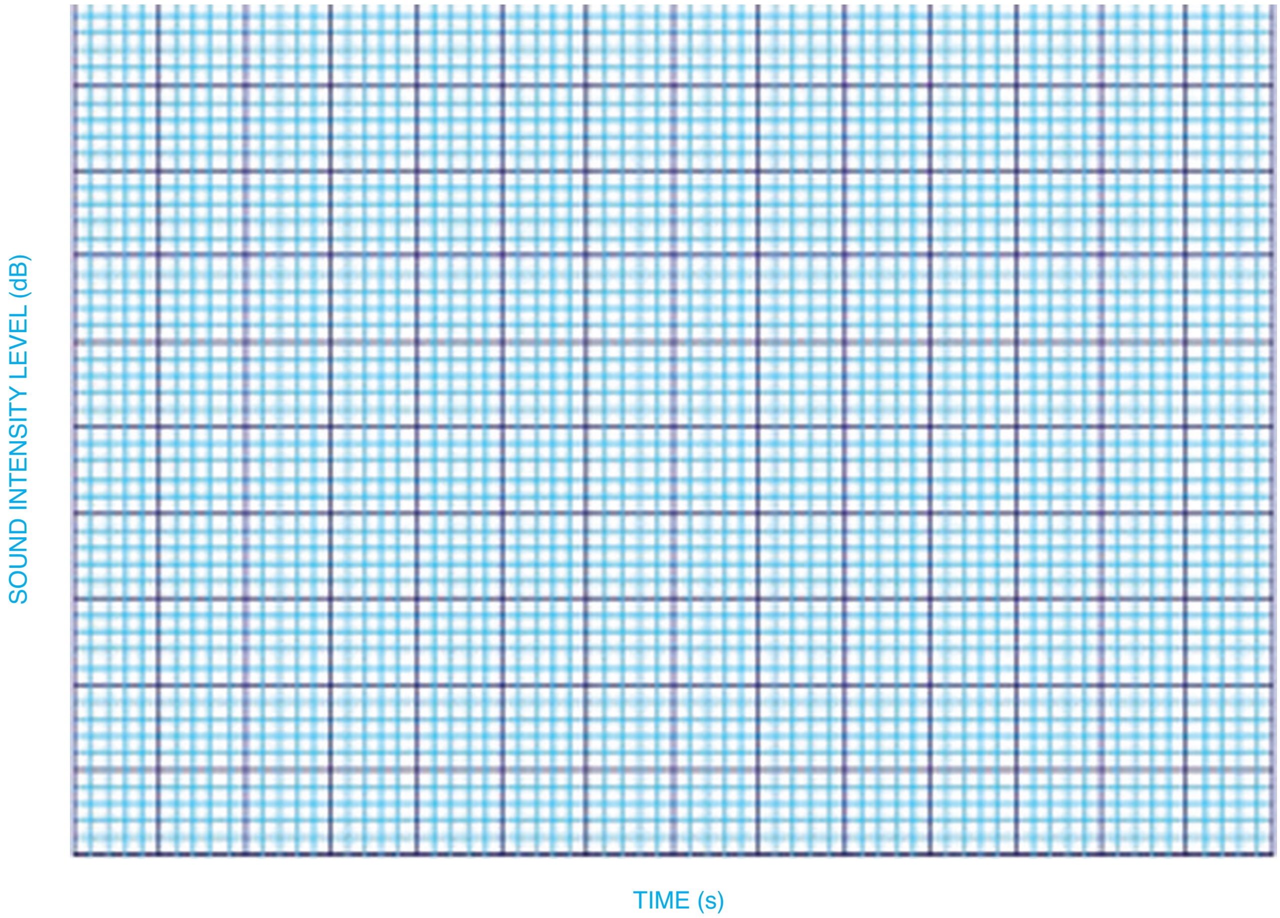
a) **Before analyzing the influence of the distance on the measurements, you should think about how it can affect and draw your prediction in the following axis. Represent the graph that you think you could observe in the computer screen when you move the sound level meter away from the sound source.**

SOUND INTENSITY LEVEL (dB)



TIME (s)

b) **Now proceed to measure this variation of the sound intensity level. Move steadily the sound level meter away from the buzzer. Draw the obtained graph in the following axis:**



c) **Discuss briefly the similarities and differences between your prediction and the obtained graph.**

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Conclusions:

From the obtained graph, explain how the sound level meter – buzzer distance affects the measured values of sound intensity.

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If you place the sound level meter at a certain distance, will you always measure the same sound intensity from the same sound source?
Explain your answer.

Which results would you have obtained if there was not any background noise?

WHAT DOES SCIENCE TELL US?

When sound propagates through a medium, **its intensity diminishes with the distance**. This phenomenon is due to the fact that sound waves propagate in all directions, and therefore its energy per unit of area is reduced by the spreading of the wave.

1.3.4. Comparing sound intensities. How much sound is transmitted through the walls?

The technician places inside the disco a loudspeaker and adjusts it to emit a sound with 500 Hz at 100dB. In the following table, you can observe the measurements taken in the neighbour's house at night, which correspond to the values of sound intensity there if the disco is only separated from the houses by everyday building elements (concrete walls, bricks):

FREQUENCY (Hz)	EMITTED SOUND (dB)	TRANSMITTED SOUND (dB)
500	100	58

a) Compare the emitted and transmitted sound intensity level.

Which is your conclusion?

b) *Which sound intensity level has not arrived at the other side of the wall?*

What do you think has happened to the part of sound that has not been transmitted?

WHAT DOES SCIENCE TELL US?

The sound decrease produced when a part of the sound is not transmitted through a material is called **attenuation**.

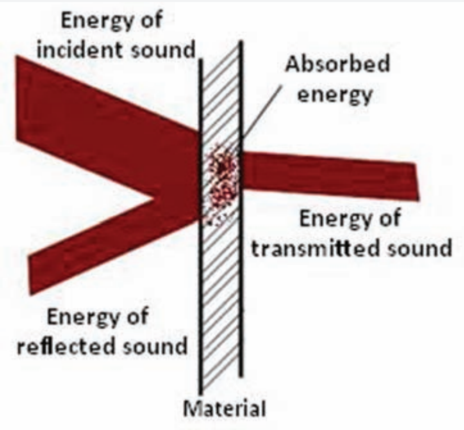
When the sound arrives at a disco's wall, a part of its energy is reflected (reflected sound) and another part penetrates into the wall. From this latter part, part remains in (or it is transferred to) the wall (absorbed sound) and another part is transmitted again through the wall and it arrives at the neighbours' flat (transmitted sound). As sound has an associated energy, we can say that the energy of the incident wave which hasn't been transmitted at the other side of the wall corresponds to the energy that has been attenuated.

$$E_{\text{attenuated sound}} = E_{\text{incident sound}} - E_{\text{transmitted sound}}$$

As sound intensity is related to the energy that it brings associated, we can calculate attenuation as the subtraction between the emitted and the transmitted sound intensity level.

$$I_{\text{attenuated sound}} = I_{\text{incident sound}} - I_{\text{transmitted sound}}$$

Therefore, sound attenuation is due to both **reflection** and **absorption**.



When the engineer finishes his measurements, she tells the owner of the disco that his business doesn't fulfil the regulations because it is required a transmitted sound lower than 30 dBA.

To solve the problem, the engineer explains to the owner that sound has to be attenuated. Her proposal in order to achieve that is using sound reflecting materials or sound absorbing materials. In fact, she suggests a solution combining both kinds of materials.

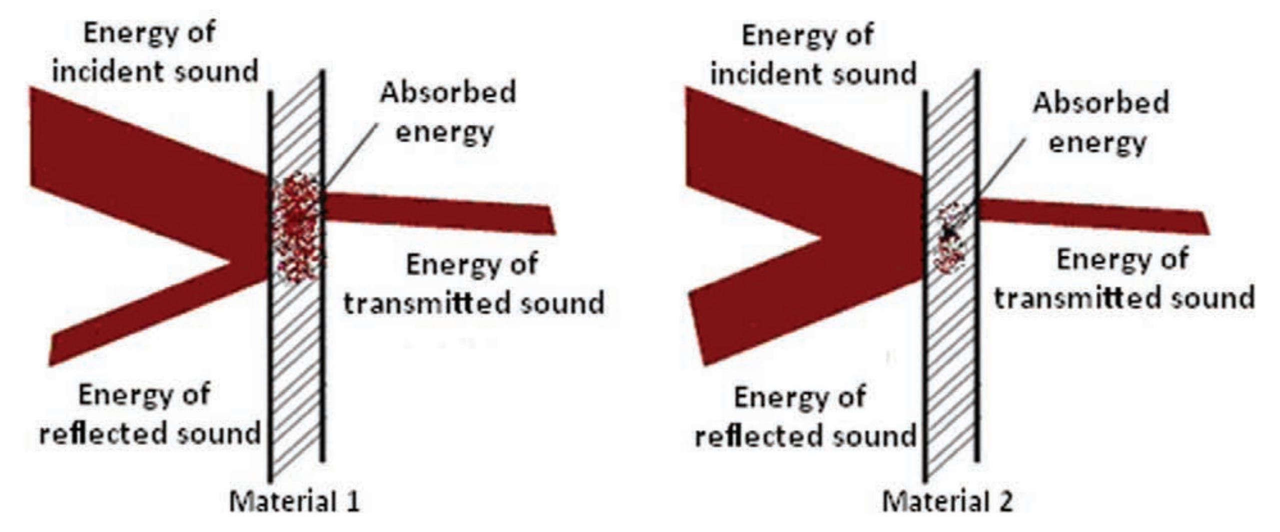
WHAT DOES SCIENCE TELL US?

The material called **sound reflector** is the one which reflects the most of the sound that arrives at its surface.

The material called **sound absorber** is the one which absorbs the most of the sound which has penetrated on it.

All materials reflect, absorb and transmit (a lot or a little) the sound which arrives at them. However, we say that a material is a **sound insulator** when it attenuates sound a lot, that is, when it transmits a little of the energy of sound and, therefore, it reduces the intensity level of a sound a lot. As sound attenuation is due to reflection and absorption, **any good sound reflector or sound absorber or any combination of both materials is considered a sound insulator.**

The following diagrams represent the process of energy transfer when airborne sound waves reach an object.



a) Which diagram represents a sound reflector and which one represents a sound absorber?

....

....

....

b) Explain your answer.

1.3.5. Are all the sounds attenuated equally?

In order to recommend the best solution for the alterations to the owner of the disco, the engineer measures the intensity level for sounds with different frequencies. The owner doesn't understand why it is necessary to measure sounds with different frequencies. Then the engineer suggests wondering why the neighbours can't hear all the sounds in their flats.

The measurements carried out with sounds with different frequencies are presented in the following table:

FREQUENCY (Hz)	EMITTED SOUND (dB)	TRANSMITTED SOUND (dB)
125	100	63
250	100	62
500	100	58
1000	100	53
2000	100	49
4000	100	44

From the previous table, could you answer which sounds will be heard louder in the neighbours' houses, the low-pitched or the high-pitched ones?

Analyzing all the obtained data, the engineer makes some recommendations to the owner of the disco about the best constructive solutions in order to attenuate enough the sound that arrives at the neighbours' house. After a few weeks from the last visit, the engineer goes back to the disco, where the alterations have already been carried out, to check out whether her recommendations have been followed. First of all, she observes that in the surface of the walls there is not exactly the material that she advised. She fears the worst, but she does not want to draw conclusions. She carries out measurements again using sounds with different frequencies and she obtains the following results:

FREQUENCY (Hz)	EMITTED SOUND (dB)	TRANSMITTED SOUND (dB)
125	100	48,5
250	100	39
500	100	36
1000	100	31,7
2000	100	24,8
4000	100	24,6

To what extent will the constructive solution used in the alterations solve the problem?

1.3.6. Let's organize our ideas!

Elaborate a conceptual map trying to relate the following concepts that you have studied throughout these units:

Sound, reflection, reverberation, diffraction, energy, intensity, absorption, transmission, attenuation, materials, sound absorbers, sound reflectors, and sound insulators.

REMEMBER THAT IN A CONCEPTUAL MAP YOU NEED TO RELATE OR CONNECT THE AFOREMENTIONED WORDS, WHICH ARE THE **CONCEPTS**, USING THE TERMS CALLED **CONNECTORS**, WHICH ARE VERBS WHICH INDICATE THE KIND OF RELATION THAT YOU CONSIDER BETWEEN THE CONCEPTS YOU HAVE RELATED.

IT DOES NOT MATTER IF YOU DO NOT USE ALL THE PREVIOUS CONCEPTS. YOU CAN ADD SOME OTHER CONCEPT WHICH YOU CONSIDER IMPORTANT TO ELABORATE YOUR MAP.

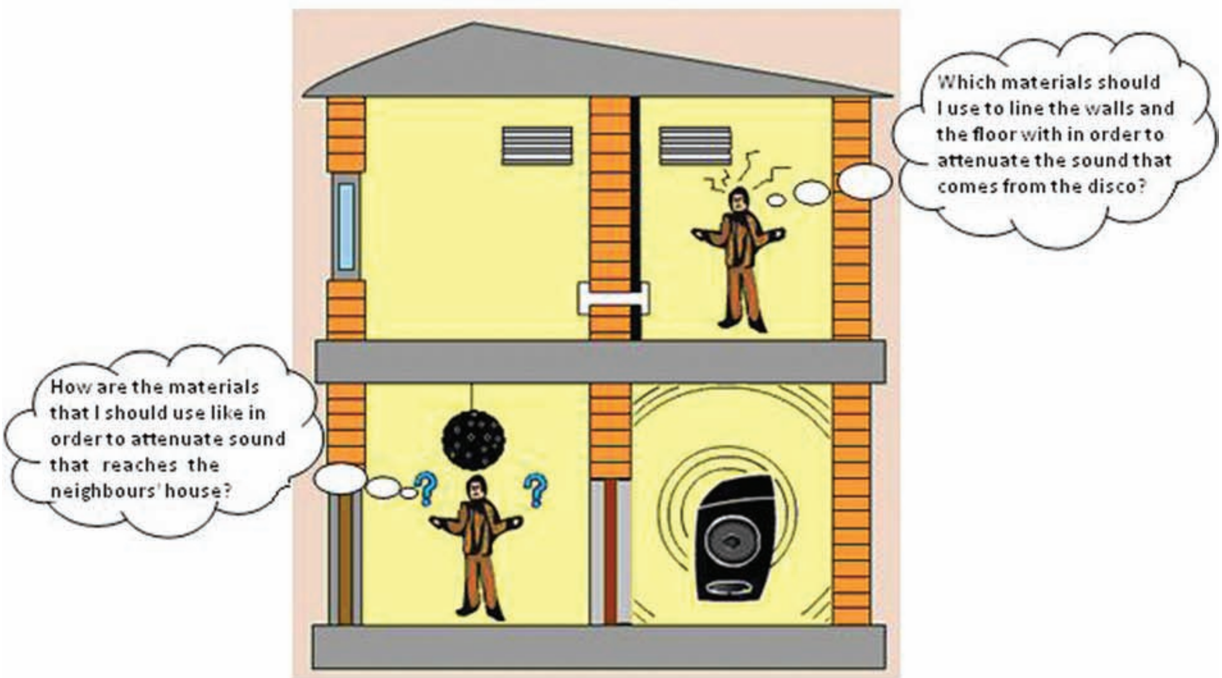
THE MAIN OBJECTIVE OF DOING THIS ACTIVITY IS REORGANIZING YOUR IDEAS EXPLAINING SCHEMATICALLY WHAT YOU HAVE LEARNT UNTIL NOW ABOUT *WHAT HAPPENS TO SOUND WHEN IT ARRIVES AT AN OBJECT OR SOME SPECIFIC MATERIAL.*

UNIT 2: PROPERTIES AND INTERNAL STRUCTURE OF SOUND REFLECTORS AND SOUND ABSORBERS

2.1 WHICH CHARACTERISTICS DOES A GOOD SOUND REFLECTOR HAVE? AND A GOOD SOUND ABSORBER?

The sound that arrives at the houses from the disco can annoy the neighbours. Some of them are thinking ways to attenuate the noise that arrive at them; meanwhile others are considering that it is the owner who has to take decisions. That's why the owner asked a solution to the engineer from DSR company since he was already aware of the problem and considered that he had to find ways to attenuate the sound which goes out of his bar. A constructive solution that seemed to solve the problem was proposed from the engineer of DSR. However, the technical recommendations were not completely followed and the solution failed. The money that the owner of the disco wanted to spare, now it will have to be spent to cover all the walls and roof of the disco, using laminated plates made with different materials.

These materials should have special characteristics in order they can attenuate the sound that arrives at the neighbours, that is, in order to reduce the sound intensity level to acceptable values.



2.1.1. As you could see in the previous section, sound reflectors and absorbers behave differently: the first reflect the sound in their surface while the others attenuate the sound that is propagating inside them, absorbing part of the energy of the sound.

a) Think about which characteristics these materials should have in order to attenuate sound which comes from the disco. Discuss the characteristics with your partners and write them.

....

....

....

b) Do you consider that both kinds of materials have the same characteristics? Why?

....

....

....

c) **Discuss with your partners which characteristics a material should have to be considered sound reflector or absorber respectively.**

Explain why you think that these characteristics make a material good sound reflector or absorber.

Fill the squares below with the characteristics that you have agreed during the idea-sharing.

CHARACTERISTICS OF SOUND REFLECTORS

CHARACTERISTICS OF SOUND ABSORBERS

2.1.2. Will be certain materials good sound absorbers or reflectors?

Now that you have already discuss which characteristics of sound absorbers and sound reflectors are relevant, we provide you with some material samples so that you can observe them and predict if these materials will be good sound absorbers or reflectors.

Explain your answer.

MATERIAL	GOOD SOUND REFLECTOR OR ABSORBER? WHY?
Aluminium sheet	
Felt	
Expanded polystyrene	
Chipboard	
Formica	
Glass wool	

2.1.3. How can we test empirically if a material attenuates sound a lot or a little?

The owner of the disco does not know yet which materials he should use to line the walls of the disco in order to attenuate the sound which arrives at the neighbours. In order to answer to this doubt, it would be advisable to design an experiment in order to test if certain materials or objects are good at attenuating sound. Can you help him to design an experiment?

Next, **draw a diagram** of the experiment you would carry out in the classroom or in the laboratory to test if a material attenuates sound a lot, that is, if reduces a lot the intensity level of transmitted sound:

Explain why this is an appropriate set-up for the experiment

Prepare a list with the materials you need to carry out the experiment

....

....

....

Share your proposal with the rest of your partners to decide together which experiment you will carry out to measure if a material or object attenuates sound a lot or a little.

When you come to a consensus on the experiment you will perform, change in your previous diagram what it is necessary, highlighting with a different colour what you need to change from your original experimental design or drawing a new diagram in one side.

Perform the designed experiment. Fill the table with the obtained values:

! BEFORE YOU CARRY OUT YOUR EXPERIMENT, YOU HAVE TO CONSIDER THAT THE SOUND INTENSITY LEVEL IS AFFECTED BY THE DISTANCE BETWEEN THE SOUND METER AND THE SOURCE.

In order to keep stable this distance, measure it and note it down:

d = ___________ m

You also need to know the intensity of the sound that reaches the meter without any material between so you have this value as reference:

Intensity of incident sound: $I_{incident}$ = ___________ (dB)

Carry out the experiment you have designed. Note down your measurements at the following table and calculate the attenuation for each material:

Remember that: $I_{attenuated} = I_{incident} - I_{transmitted}$

MATERIAL	INTENSITY OF TRANSMITTED SOUND (dB)	ATTENUATION (dB)
Aluminium		
Felt		
Expanded polystyrene		
Chipboard with Formica		
Glass wool		

WHAT DOES SCIENCE TELL US?

Sound-insulator is a material that does not allow sound to be transmitted through it. That is, the transmitted sound is significantly lower than the incident.

2.1.4. How can we test empirically if a material is a good sound absorber or a good sound reflector?

Thanks to the acoustic engineer, the owner of the disco has learnt that there are materials that attenuate sound and avoid it arrives at the neighbours. Some materials reflect sound meanwhile some others absorb great part of the energy of the sound. However, he needs to know how to identify whether a material is sound absorber or sound isolator in order to use one or the other in each space of the disco. In some areas sound should be amplified in order to hear loud music; in other spaces it is necessary to hear clear sounds in order two people can understand each other. In all the areas it is necessary to take into account that sound that arrives at the neighbours must be attenuated. For this reason, he would need to design an experiment in order to test if certain materials are good sound reflectors or absorbers.

a) Next, draw a diagram of the experiment you would carry out in the classroom or in the laboratory in order tot test if a material is:

I. A good sound insulator, that is, a material that does not allow sound to be transmitted through it.

II. A good sound absorber or a good sound reflector, that is, to distinguish whether it absorbs or reflects the incident sound.

b) Share your proposal with your partners, and if it is necessary, change the diagrams that you drew before in order to adapt these experiments to those you will perform in the classroom.

2.1.5. Testing how good sound absorbers or reflectors are certain materials

In the previous activity you have discussed how to test empirically if a material is a sound absorber or reflector. We propose you a specific experimental design using boxes covered inside with different materials (look at the figure). These boxes have a little hole in one side so that you can introduce the microphone of the sound level meter inside the box when you want to measure the sound intensity level inside.

As a sound source, you can use a buzzer. The buzzer can be put inside one of the boxes and the microphone of the sound level meter will be introduced inside the box through the hole it has.

I) The box can be covered inside with a sound absorber.
II) The box can be covered inside with a sound reflector.

a) **Predictions**

Do you think that the value of the sound intensity which will measure the sound level meter **inside the box** will be higher, lower or the same as the obtained when measuring with the buzzer without being covered with any box in each case (I, II)?

Discuss your answer with your partners.

b) Measure the sound intensity level inside each box in order to distinguish between good sound reflectors or good sound absorbers.

First of all, you will need to know the intensity level of the sound emitted by the buzzer (without being covered with any box) which arrives at the sound level meter. This value has to be compared with the one you have obtained when the buzzer is covered by a box to know if the sound inside the box has been attenuated or amplified. Having done this comparison, you will know if the box is lined with a sound absorber or sound reflector, respectively.

Remember to keep a fixed distance.

Write down the value of the sound level meter – buzzer distance at which you will measure:

d = __________ cm

Fill the following tables with your measurements:

INTENSITY LEVEL OF THE INCIDENT SOUND (WITHOUT COVERING THE BUZZER)

MATERIAL	SOUND INTENSITY LEVEL OUTSIDE THE BOX (dB) $I_{transmitted}$	SOUND INTENSITY LEVEL INSIDE THE BOX (dB) $I_{incident\ sound} + I_{reflected\ sound} - I_{absorbed\ sound}$
Aluminium		
Felt		
Expanded polystyrene		
Chipboard with Formica		
Glass wool		

c) From the obtained values, answer which of these materials are good sound insulators and whether they behave as sound reflectors or sound absorbers.

MATERIAL	BEHAVES AS GOOD SOUND INSULATOR	BEHAVES AS SOUND ABSORBER/REFLECTOR
Aluminium		
Felt		
Expanded polystyrene		
Chipboard with Formica		
Glass wool		

2.1.6. How are these materials? Which properties do they have?

In the previous experimental activity you have classified empirically some materials depending on whether they are good or bad sound reflectors or absorbers. Now you will observe these materials in order to test which properties they have that make them good sound reflectors or absorbers.

For instance, are they dense or not?
Are they easily distorted?
Do they have porous?

a) Fill the following table with the relative intonations:

MATERIAL	BEHAVES AS SOUND ABSORBER OR REFLECTOR	PROPERTIES RELATED WITH ITS BEHAVIOUR
Aluminium		
Felt		
Expanded polystyrene		
Chipboard with Formica		
Glass wool		

b) Which properties have in common all sound reflectors you have used?
Which properties have in common all sound absorbers?
Share your answer with your partners.

Sound reflectors:

Sound absorbers:

How could you measure the aforementioned properties more accurately?

2.1.7. Working with more precise data of the properties

Knowing the properties of a material is very important in order to predict its acoustic behaviour (if it is sound reflector or absorber), before testing it experimentally. Now you will work with some data about the materials that you have obtained in the laboratory in order to test if sound reflectors and sound absorbers have the properties that you imagined at the beginning.

DENSITY

Remember that density is defined as: $d = \frac{m}{V}$

We say that a material is very dense when it has a lot of mass per each unit of volume.
From the values obtained experimentally, answer if these materials are sound reflectors or sound absorbers.

MATERIAL	DENSITY (g/cm³)	REFLECTOR / ABSORBER
Aluminium	2,70	
Felt	0,33	
Expanded polystyrene	0,02	
Chipboard with Formica	0,70	
Glass wool	0,02	

From these data of density and your empirical knowledge for these materials (as sound absorbers or reflectors):

What do you suggest for the density of sound reflectors?

....

....

....

What do you suggest for the density of sound absorbers?

....

....

....

RIGIDITY

We say that a material is rigid when it is very difficult to deform it, that is, when it is necessary to apply great force in order to deform it a little. Flexible materials deform very easily when a little force is applied to them. So, the rigidity is the resistance that a material puts up to be deformed under the action of an applied force.

Testing with your hands the various materials, say if they are rigid or not.

MATERIAL	RELATIVELY RIGID	RELATIVELY FLEXIBLE	REFLECTOR / ABSORBER
Aluminium			
Felt			
Expanded polystyrene			
Chipboard with Formica			
Glass wool			

Compare the rigidity of each material with its acoustic behaviour.

What could you conclude about the rigidity of sound reflectors?

What could you conclude about the rigidity of sound absorbers?

POROSITY

Porosity is defined as the quantity of empty spaces (full of air) in the total volume of a material. We can test that a material is porous putting it into water. If it does not absorb water, it will mean that its cells are closed, therefore, we do not consider it porous. If it is porous, it slowly will absorb water because its pores are interconnected.

Observe carefully samples of the materials:

- With naked eye: Describe the surface and structure you are seeing (smooth, flat, transparent, homogenous, there are porous, cavities or small spheres etc.)
- With an optical microscope (magnification 40x): Describe the internal structure you are seeing. If you don't have a microscope, use the provided pictures.

Fill the following table with your observations.

MATERIAL	REFLECTOR / ABSORBER	OBSERVATION WITH NAKED EYE	OBSERVATION WITH AN OPTICAL MICROSCOPE
Aluminium			
Felt			
Expanded polystyrene			
Chipboard with Formica			
Glass wool			

What do you conclude from your observations, about the sound reflecting ability of materials of high porosity?

....

....

....

What do you conclude from your observations, about the sound absorbing ability of materials of high porosity?

....

....

....

2.1.8. Final conclusions

Use the data from the previous table to draw conclusions on the properties of sound reflectors and sound absorbers. Fill the following table with your conclusions about which properties sound reflectors and sound absorbers have:

PROPERTIES	SOUND REFLECTORS	SOUND ABSORBERS
Density		
Rigidity		
Porosity		

Compare your conclusions with your previous perceptions:

2.1.9. To know more

One hot summer night, the girl who lives in the first floor of the building tried to sleep, having the window open. She had to get up early but the noise that arrived from the disco avoided her falling asleep. Meanwhile, her father was sleeping peacefully; he did not hear the noise because he had lost hearing in his job.

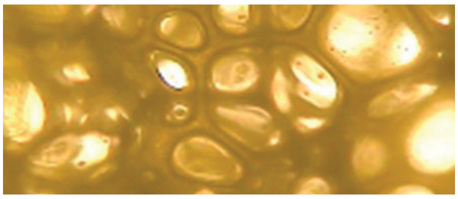
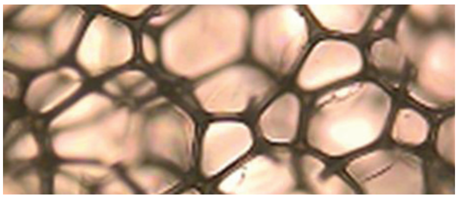
Although the night was very hot, she closed the window, which was made of aluminium with a double-layer of glass, and spread out the thick curtains of cotton and polyester. The noise became softer but it was still unbearable; it seemed as if the noise was going through the walls of the building, made of bricks, and the floor, made of cement. The noise even went through the fitted carpet, made of fibre of hemp.

Suddenly, she remembered that her mother had some earplugs for emergency situations. She found them. They seemed as made of foam. Following the instructions from the package, she compressed the earplugs doing a little ball and put them inside each ear. Although both earplugs fitted well, she still heard a faint noise that seemed that arrived from far away. Finally, the girl fell asleep. She was looping forward to the soundproofing of the disco!!

Different objects and materials, which have properties that make them good sound insulators, have been mentioned in the text: cement, fabric made of cotton, walls made of bricks, earplugs, fabric made of polyester, fibre of hemp, etc.

Which of them do you consider denser?
Which of them do you think that are more rigid?
Which of them do you consider more porous?

Examine the following photos:

	DESCRIBE THEIR DENSITY, RIGIDITY AND POROSITY
Earplugs 	
Synthetic foam 	

	DESCRIBE THEIR DENSITY, RIGIDITY AND POROSITY
Fabric of cotton 	
Fibre of hemp 	
Fibre of polyester 	
Cement 	
Wall of bricks 	
Choose other common material	

Which of them do you consider sound reflectors?

Explain.

Which of them do you consider sound absorbers?

Explain.

2.2 HOW COULD WE EXPLAIN SOUND ATTENUATION IN A MATERIAL IN TERMS OF ITS INTERNAL STRUCTURE?

In the previous activities, we have related the sound attenuation capacity of different materials with certain properties: rigidity, density and porosity. The fact that these materials present these properties depends on their internal structure.

We have empirically tested that the most dense and rigid materials reflect sound a lot and, on the other hand, porous materials absorb sound a lot. The following activity will help us to establish a model to interpret how a material behaves in front of sound in terms of its internal structure.

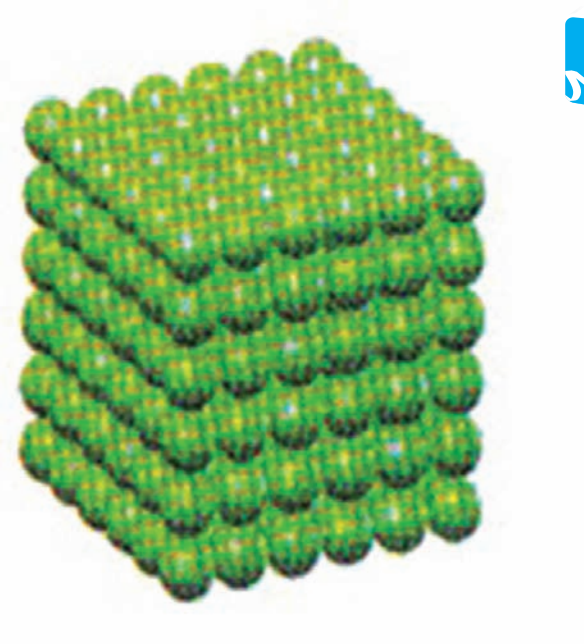
2.2.1. Attenuation: what are sound insulators like inside?

VERY OR LITTLE DENSE MATERIALS

When a material is very **dense** (it has more mass per unit of volume) presents much inertia, that is, much resistance to be moved.

At the picture below the structure of the molecules of a high dense material is presented.

How would you present the structure of a low dense material?



MODEL OF THE STRUCTURE OF A HIGH DENSE MATERIAL (MOLECULES ARE DEPICTED AS SPHERES)

MODEL OF THE STRUCTURE OF A LOW DENSE MATERIAL

Using the model of the structure of a material, explain with your own words, how do you think that density affects the ability of a material to reflect the incident sound.

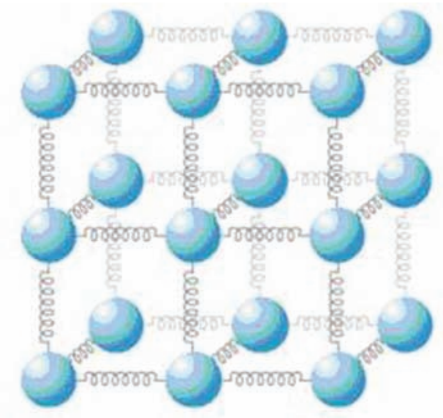
(Take into consideration the nature of sound and how is transmitted from one material to an other.)

Using the model of the structure of a material, explain with your own words, how do you think that density affects the ability of a material to absorb the incident sound.

VERY OR LITTLE RIGID MATERIALS

Rigid materials are very difficult to deform.

In order to understand how the rigidity affects the fact that a material reflects sound a lot or a little, you could use the following **ball and spring model**. This model represents a solid object as a lattice of particles (balls) linked by means of some kind of bond (springs). Depending on these bonds, the connection between particles will be more or less strong and, therefore, will be more or less difficult to deform the object.



THE BALL AND SPRING MODEL OF A SOLID
(MOLECULES ARE REPRESENTED AS BALLS AND BONDS BETWEEN THEM AS SPRINGS)

HOW WOULD YOU REPRESENT A MATERIAL OF HIGH RIGIDITY THAT IS DIFFICULT TO DISTORT?

HOW WOULD YOU REPRESENT A MATERIAL OF LOW RIGIDITY THAT IS EASY TO DISTORT?

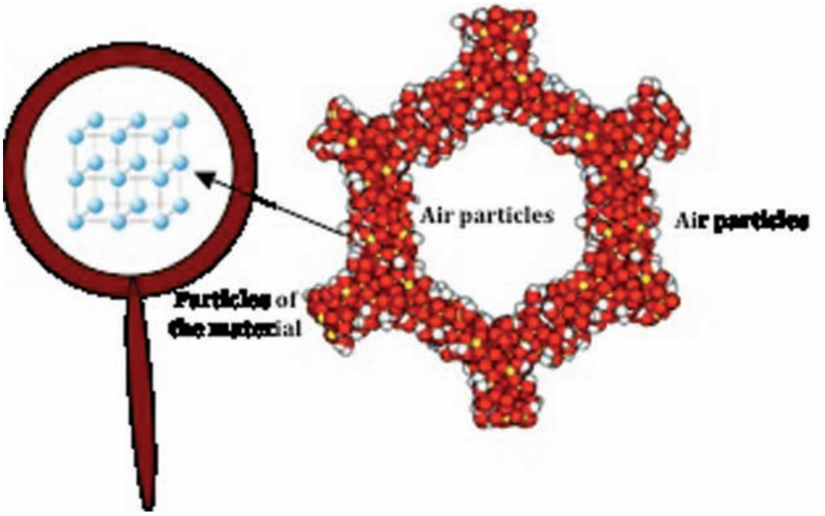
Using the model of the structure of a material, explain with your own words, how you think that rigidity affects the ability of a material to reflect the incident sound.

Using the model of the structure of a material, explain with your own words, how you think that rigidity affects the ability of a material to absorb the incident sound.

Attenuation by absorption: what are sound absorbers like inside?

VERY OR LITTLE POROUS MATERIALS

A porous material has a solid structure (skeleton or fibres), which is generally dense and rigid, and numerous holes or spaces (called pores) in which there are air particles, which are interconnected between them if the pores are open. The following image shows the representation of a pore of a porous material. The rigid part is constituted by linked particles as in any other solid and the pores are spaces full of air particles.



MODEL OF THE PORE OF A POROUS MATERIAL

HOW WOULD YOU REPRESENT A MATERIAL WITH LOW POROSITY IN MICROSCOPIC LEVEL?

HOW WOULD YOU REPRESENT A MATERIAL WITH LOW POROSITY IN MICROSCOPIC LEVEL?

LOW POROSITY MATERIAL

HIGH POROSITY MATERIAL

*Draw more than one porous.

Using the microscopic model of a porous material, explain in your own words how you think the porosity affects the ability of the material to absorb sound.

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2.2.2. The scientific model for the attenuation of sound

In the previous activity, you have suggested some explanations based on microscopic models, in order to explain how density, rigidity and porosity affect the ability of materials to reflect or absorb the sound.

Let's see how science explains these:

	HOW ENGINEERS AND SCIENTISTS OF MATERIALS SCIENCE EXPLAIN THAT?
DENSITY	• **High density.** In a high density material is difficult to move molecules away from their equilibrium position, because in little volume there a lot of molecules. For the transmission of sound, molecules have to vibrate. Because of the difficulty to move molecules away from their equilibrium position, these materials prevent the penetration of a large amount of sound energy. Thus, only a small part of the sound energy penetrates and the most of the energy is reflected. • **Low density.** Molecules can vibrate easily and that makes penetration of sound energy easier. Moreover, while sound is transmitted through them, part of the energy is spread in all directions, because of the movement of the molecules: they are able to move easily and a lot of energy is consumed and transformed to heat at the end. **So, a good sound reflector has to be of high density, while a good sound absorber has to be of low density.**

<table>
<tr><th colspan="2">HOW ENGINEERS AND SCIENTISTS OF MATERIALS SCIENCE EXPLAIN THAT?</th></tr>
<tr><td>RIGIDITY</td><td>

- **High rigidity.** At rigid materials, molecules are connected between them with strong bonds (like we represented with springs) and is difficult to move from their equilibrium position. So, when sound arrives, they hardly vibrate, preventing the penetration of sound energy into the material. Like in high density materials, only a small part of the incident energy penetrates and the rest is reflected.

- **Low rigidity.** Since the material is flexible, molecules move easily, making possible the easy penetration of sound. While sound is transmitted through the material, energy is spread in all directions, because of the movement of the molecules: again they are able to move easily and a lot of energy is consumed and transformed to heat at the end.

So, a good sound reflector has to be rigid, while a good sound absorber has to be flexible.

</td></tr>
<tr><td>POROSITY</td><td>

- **Explanation based on the model of particles**
  In a porous material, sound is transmitted both through the solid material and the air that is contained into the porous. The air particles that vibrate when sound arrives in the porous, lose part of their energy because of friction with the solid material around porous (material is slightly heated).

  We consider energy that is spread in the material as absorbed. Thus, a porous material is a good sound absorber.

- **Explanation based on reflection**
  Sound is transmitted through air into the porous and is reflected every time it collides on solid material. In every reflection a part of the energy is absorbed into the material and after multiple reflections a large part of the energy is absorbed.

</td></tr>
</table>

2.2.3. Let's associate structure and properties of materials

Comment on the following statements based on the model of the internal structure of a dense material, of a rigid material and a porous material:

1. Aluminum is good sound insulator because it is good sound reflector.

2. Porous materials like glass-wool are good sound absorbers.

3. Chipboard with Formica is both good sound absorber and reflector.

2.2.3. Let's organize our ideas!

Elaborate a conceptual map trying to relate the following concepts that you have studied throughout these units:

Sound absorbers, sound reflectors, sound insulators, sound attenuation, energy, reflection, absorption, properties, density, rigidity, porosity, particles, collisions, vibrations, sound propagation.

REMEMBER THAT IN A CONCEPTUAL MAP YOU NEED TO RELATE OR CONNECT THE AFOREMENTIONED WORDS, WHICH ARE THE **CONCEPTS**, USING THE TERMS CALLED CONNECTORS, WHICH ARE VERBS WHICH INDICATE THE KIND OF RELATION THAT YOU CONSIDER BETWEEN THE CONCEPTS YOU HAVE RELATED.

IT DOES NOT MATTER IF YOU DO NOT USE ALL THE PREVIOUS CONCEPTS. YOU CAN ADD SOME OTHER CONCEPT WHICH YOU CONSIDER IMPORTANT TO ELABORATE YOUR MAP.

THE MAIN OBJECTIVE OF DOING THIS ACTIVITY IS REORGANIZING YOUR IDEAS EXPLAINING SCHEMATICALLY WHAT YOU HAVE LEARNT UNTIL NOW ABOUT *HOW SOUND INSULATORS (REFLECTORS AND ABSORBENTS) BEHAVE IN FRONT OF SOUND DEPENDING ON THEIR PROPERTIES AND THEIR INTERNAL STRUCTURE.*

UNIT 3: ACOUSTIC CONDITIONING AND SOUNDPROOFING

3.1 HOW WOULD YOU CONDITION ACOUSTICALLY THE DISCO?

DSR enterprise suggests studying how to soundproof and condition acoustically the disco, dividing the space in three sectors which correspond to different environments:

- Stairs and cloakroom (Task A)
- Dance floor (Task B)
- VIP lounge (Task C)

Imagine your one of the engineers of DSR enterprise. Now it is your turn to find a solution in each case:

Form groups of three and, in order to relate all the things you have learnt during the module, share the tasks and try to provide a suitable solution for each environment.

The report should include the following points:

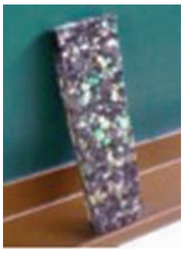
1. Acoustic characteristics of each sector.
2. Arrangement of the space and justification according to the characteristics of each sector.
3. Arrangement of the sound absorbing and/or reflecting materials and justification.
4. Advantages and disadvantages of your proposal.

Think also about the arrangement of the most appropriate pieces of furniture and the decoration to achieve the acoustic conditions that each sector requires.

When you find a solution, you will have to prepare a report that gathers all the information necessary to carry out the project of alterations and the explanation of your proposal.

You have to think about the more appropriate materials. Search in the Internet some materials that are commonly used with acoustic purposes and explain the materials that you consider more adequate in terms of their acoustic properties but also in terms of other characteristics of these materials that are relevant to choose a certain material (e.g., aesthetic reasons, thermal insulating properties, fireproofing, economical reasons, transport ease, etc).

On the following table there are some materials for which you could search for information:

MATERIAL	IMAGE	DESCRIPTION (DENSITY, RIGIDITY, POROSITY)	POSSIBLE USE OF THE MATERIAL
Felt			
Felt with rubber			
Cork			
Polyurethane			
Foam			
Stone wool			

TASK A: STAIRS AND CLOAKROOM

The entrance to the disco is the sector where it is necessary to avoid more the high levels of sound intensity towards the outside. This caution requires a certain complexity because, according to the sketch of the virtual visualization, the proposed decoration does not provides a good sound insulation of neither the interior nor the exterior sectors.

Which conditions should be provided?

According to the sketch you have, analyze if you find the arrangement and decoration appropriate.

Make a proposal with the most appropriate materials for furniture, walls, floor and ceiling, explaining your choice.

Finally, write a detailed report.

TASK B: DANCE FLOOR

As you can see in the sketch of the virtual visualization, this sector is a circular dance floor which contains the bars and a space to listen at the music. Therefore, this sector needs higher sound intensity level.

Which conditions should be provided?

According to the sketch you have, analyze if you find the arrangement and decoration appropriate.

Make a proposal with the most appropriate materials for furniture, walls, floor and ceiling, explaining your choice.

Finally, write a detailed report.

TASK C: VIP ZONE

The VIP lounge is situated in a corner and is intended as a sector with an environment that allows relaxed conversations. Therefore, the acoustic conditions should allow that people understand each other. As you can see in the sketch of the virtual visualization, the VIP lounge is situated in the area adjacent to the dance floor and the bar.

Which conditions should be provided?

According to the sketch you have, analyze if you find the arrangement and decoration appropriate.

Make a proposal with the most appropriate materials for furniture, walls, floor and ceiling, explaining your choice.

Finally, write a detailed report.

MATERIALS
SCIENCE PROJECT

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