能源及環境學院
SCHOOL OF ENERGY AND ENVIRONMENT

CityU

# SEE 1003
# Introduction to Sustainable Energy and Environmental Engineering

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**School of Energy and Environment**

**Module 3 –** Noise Pollution in Urban Environment

Feb 21, 2022

# SEE 1003 class overview

| Week | Topics | Assignment issued | Key dates |
|---|---|---|---|
| **Week 1** | Course introduction; Climate Change and the Engineering approach | | **Quiz 1** |
| **Week 2** | **MODULE I**<br>Introduction to Sustainability<br>Energy, Natural Resources and pollution,<br>Electromagnetic energy; Electrical energy – Lighting,<br>Light pollution, Policy | **Semester-long Project** | |
| **Week 3** | | **Project deliverable 1.1** | |
| **Week 4** | **MODULE II**<br>Energy and Environmental Implications– Transportation<br>Human-Environment Impacts | | |
| **Week 5** | | **Project deliverable 1.2** | **Project deliverable 1.1** |
| **Week 6** | **MODULE III**<br>Noise Pollution in Urban Environment | **Project deliverable 1.3** | **Quiz2** |
| **Week 7** | **MODULE IV**<br>Urban Sustainability; Water and Energy Nexus | | **Project deliverable 1.2** |
| **Week 8** | **MODULE V**<br>Tools: Systems Analysis for Sustainability<br>Cost-Benefit Analysis, Material Flow Analysis, Life Cycle Assessment | | |
| **Week 9** | | | |
| **Week 10** | **MODULE VI**<br>Advances in Environmental and Energy Engineering | **Project deliverable 1.4** | **Project deliverable 1.3; Quiz3** |
| **Week 11** | **MODULE VII**<br>Waste management and Waste-to-Energy | | |
| **Week 12** | **MODULE VIII**<br>Economics and Policy of Energy and Environment | **Project deliverable 1.5** | **Quiz4**<br>**Project deliverable 1.4** |
| **Week 13** | **Individual Presentations (5-mins)** | | **Final Project Report** |

# Class Schedule

**January 2022**

| | S | M | T | W | T | F | S |
|---|---|---|---|---|---|---|---|
| | | | | | | | 1 |
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| WK 1 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| WK 2 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| WK 3 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| | 30 | 31 | | | | | |

**February 2022**

| | S | M | T | W | T | F | S |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 |
| WK 4 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| WK 5 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| WK 6 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| WK 7 | 27 | 28 | | | | | |

**March 2022**

| | S | M | T | W | T | F | S |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 |
| WK 8 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| WK 9 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| WK 10 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| WK 11 | 27 | 28 | 29 | 30 | 31 | | |

**April 2022**

| | S | M | T | W | T | F | S |
|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 |
| WK 12 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| WK 13 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| | 24 | 25 | 26 | 27 | 28 | 29 | 30 |

**May 2022**

| | S | M | T | W | T | F | S |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| | 29 | 30 | 31 | | | | |

Final class on Apr 11th

Exam period

**13 weeks of classes**

Chinese New Year break
Holiday on 31st Jan, 2022

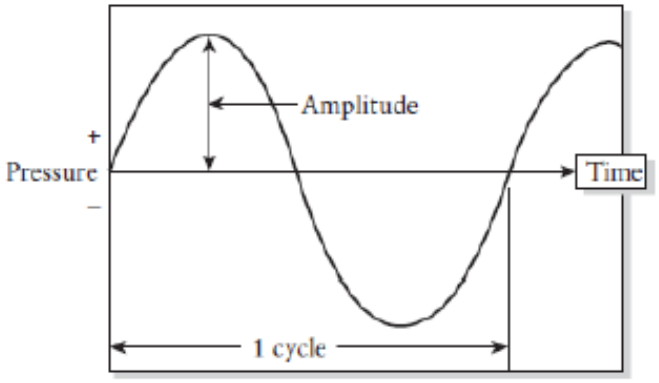
# Recap

- Energy Consumption in Hong Kong
- Transportation sector and its Energy Dependence
- Environmental Impacts associated with Transportation
- Impact Assessment for Sustainable Development
  - IPAT equation
  - Rebound Effect
- System Thinking is key for Understanding the Overall Impacts
  - Feedback loops

# Noise Pollution: Outline

# Sound

- Pure sound is described by pressure waves traveling through the medium.
- The pure sound wave can be described as a sinusoidal curve, having positive and negative pressures within one cycle.
- The number of cycles per unit time is called frequency (Hz).
- Typical sounds that healthy ears hear range from about 15 Hz to 20,000 Hz.
- The wide frequency spectrum is significantly reduced by age and environmental exposure to loud noise.




- The loudness of a noise is expressed by its amplitude.

# Sound Pressure Level

# Sound Pressure Level

- With respect to sound, it is necessary to consider energy level of the sound. The ration of two sound energies is

$$\log_{10}\left(\frac{W}{W_{ref}}\right)$$

where the $W$ represent the energy in watts (W) of the sound wave and $W_{ref} = 10^{-12}W$, respectively.

- Because the energy is proportional to the pressure squared, this ratio can also be expressed as

$$\log_{10}\left(\frac{P^2}{P_{ref}^2}\right)$$

where $P$ is the sound pressure $(N/m^2)$ and $P_{ref} = 2 \times 10^{-5} N/m^2$ is some reference pressure $(N/m^2)$ or (Pa).

- The unit of Pressure

$$1\ Pa = 1\ N/m^2$$

$$1\ atm = 1.01325 \times 10^5\ Pa$$

$$\Rightarrow 1\ Pa = 9.8692 \times 10^{-6} atm$$

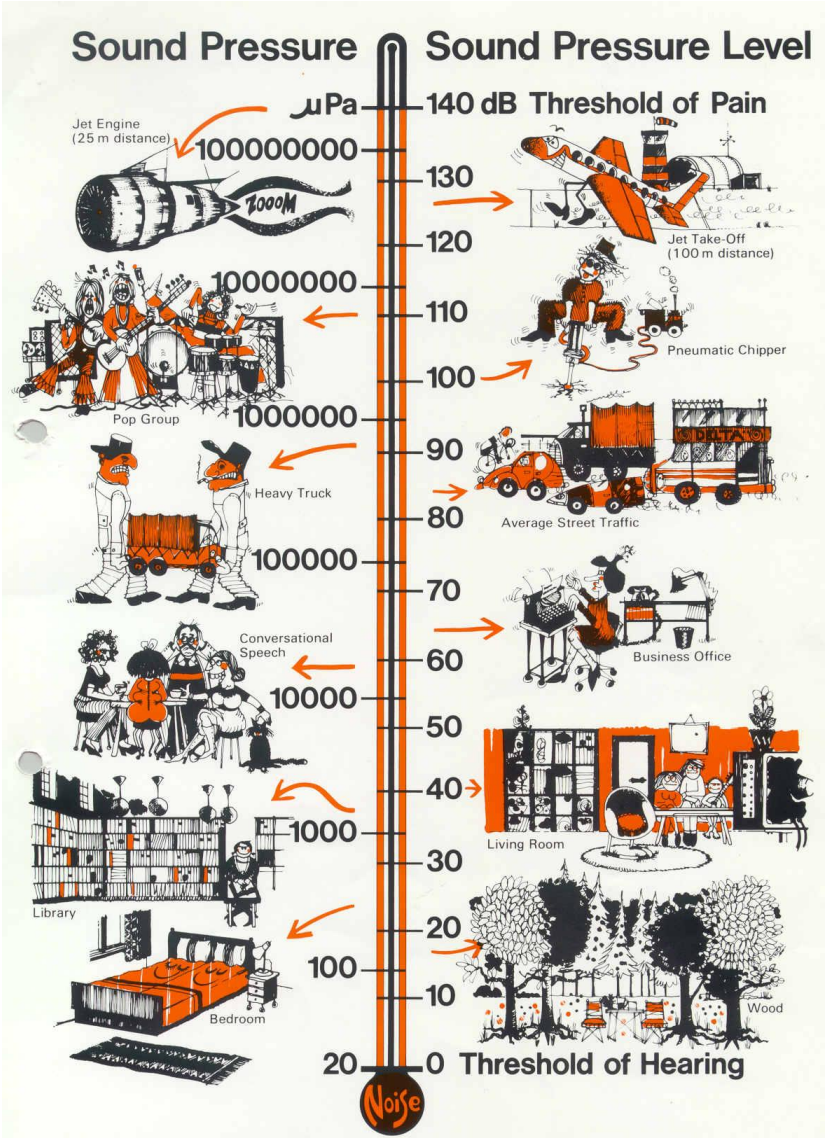
# Sound Pressure Level

- By convension, this expression has unit the bel. Dividing this unit into 10 makes it easier to use and avoids fractions and known as the decibel (dB).
- The $P_{ref}$ appears that the minium pressure a human ear is able to detect.
- The sound pressure level (SPL) is then defined as

$$SPL = 10 \log_{10} \left( \frac{W}{W_{ref}} \right) = 10 \log_{10} \left( \frac{P^2}{P_{ref}^2} \right) = 20 \log_{10} \left( \frac{P}{P_{ref}} \right)$$

the unit of $SPL$ is dB.

# Sound Pressure Level



# Sound Pressure Level

**Example**

**Problem** Determine the sound pressure corresponding to a sound pressure level of 90dB and compare the pressure to atmospheric pressure

**Solution**

$$SPL = 10 \log_{10}\left(\frac{P^2}{P_{ref}^2}\right) = 20 \log_{10}\left(\frac{P}{P_{ref}}\right)$$

# Sound Pressure Level

- If there are more than one sound source

$$SPL_{Total} = 10 \log_{10} \left( \Sigma 10^{SPL_i/10} \right)$$

- If two equal sounds are added, they result in approximately a 3 dB increase in overall sound level.
- If the difference between two sound is greater than 10 dB, the lesser of the two does not contribute much to the overall level of sound.
- Sound in the atmosphere travels uniformly in all directions, radiating out from its source (homogenity).
- SPL fufill inverse square law

$$SPL \propto 1/r^2$$

where $r$ is the radial distance from the source.

- 

$$SPL_r \cong SPL_0 - 10 \log r^2$$

where $SPL_r$ is sound pressure level at distance $r$, $SPL_0$ is sound pressure level at the source.

## Example

**Problem** Two identical machines produce a combined sound pressure level of 90 dB. If one machine is turned off, what will be the sound pressure level?

**Solution** let SPL be the sound pressure which are emitted by individual machine.

$$SPL_{Total} = 10 \log_{10} \left[ \sum 10^{SPL_i/10} \right]$$

## Example

**Problem** A straight road with uniform density of cars may be regarded as a line source of noise. If cars produce an average acoustic energy of 0.01W and there is an average of 1 car every 100 m on a highway. What is the sound pressure level at a distance of 100m from the road?

**Solution** let $SPL_r$ is sound pressure level at distance $r$, $SPL_0$ is sound pressure level at the source.

$$SPL_0 = 10 \log_{10} \left( \frac{W}{W_{ref}} \right)$$

## Example

**Problem** If a car produces 0.01 W of sound power and the tunnel is 8 m in diameter (assume circular cross-section), calculate the sound pressure level on the wall of the tunnel.

**Solution**

$$SPL_r \cong SPL_0 - 10 \log r^2$$

## Example

**Problem** According to the question above, what will be the sound pressure level if there are 10 cars in the tunnel on the wall?

**Solution**

$$SPL_r = SPL_{Total} = 10 \log_{10} \left[ \sum 10^{SPL_i/10} \right]$$

## Example

**Problem** You are standing 10 m from 3 jet aircrafts on the ground to test their engines. Each of their sound pressure level is 140 dB, which is the threshold of pain. You want to move further away from the aircraft so that the sound pressure level is a more reasonable 100 dB. How far from the aircraft do you need to be?

**Solution**

$$SPL_{Total} = 10 \log_{10} \left[ \sum 10^{SPL_i/10} \right]$$

# Outline

# Average Sound Pressure Level

- Average sound pressure level

$$SPL_{avg} = 10 \log \left( \frac{1}{N} \right) \sum_{j=1}^{N} 10^{SPL_j/10}$$

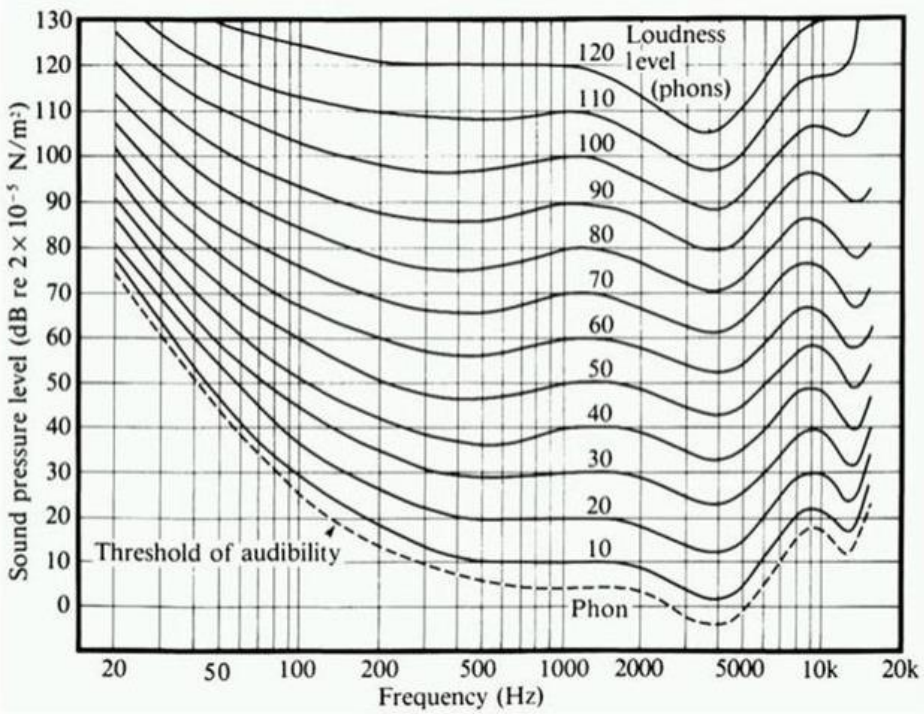
where $N$ is the number of measurements taken and $SPL_j$ are the $j$ $(1 \leq j \leq N)$ th sound pressure level.

- The picture of sounds in the environment can be obtained by a frequency analysis.

# Outline

# Loudness

- Loudness is defined as the subjective intensity of sound. It depends on both intensity and frequency.
- Although an increase of 3 dB represents a doubling of the pressure, an increase of about 10 dB is required before a sound subjectively appears to be twice as loud.
- The contours obtained by conducting tests on a large numbers of people in a free field room (i.e. anechoic chamber).




Curves of equal loudness

# Outline

# Loudness Level

- Loudness level = subjective comparison of the loudness of a sound compared to that of a 1000Hz pure tone
- Unit: Loudness: sone; Loudness level: phon
- The phon is numerically equal to the sound pressure level, in dB, of a 1000Hz tone.

**Example**

According to the curves of equal loudness, an 80 Hz tone of 70 dB has the same loudness as a 1000 Hz tone of 60 dB. Therefore, the loudness level of an 80 Hz tone at 70 dB is 60 phons.

**Examples**

According to the curves of equal loudness, an 40 Hz tone of 90 dB has the same loudness as a 1000 Hz tone of 70 dB. Therefore, the loudness level of an 40 Hz tone at 90 dB is 70 phons.

# Loudness Level

- Doubling of loudness = an increase of 10 phons.
- The sone is defined as the loudness of a pure tone of 1000 Hz with a sound pressure level of 40 dB.
- 2 sones is a sound which is twice as loud as 1 sone. 3 sones is 3 times as loud etc.
-

$$1\ sone = 40\ phons$$
$$2\ sones = 50\ phons$$
$$4\ sones = 60\ phons$$
$$8\ sones = 70\ phons$$

- Mathematically we may write:

$$S = 2^{(L_L - 40)/10}$$
$$L_L = 33.3 \log_{10} S + 40$$

where $S = loudness$ (sones) and $L_L = loudness\ level$ (phons)

# Loudness Level

**Example**

**Problem** How many times louder would a pure tone at 50 Hz and 100 dB be compared to a pure tone of 50 dB at 6 kHz?

# Outline

# Measure of Sound

- Sound is measured with an instrument that converts the energy in the pressure waves to an electrical signal.
- Sound level meters, which measure sound pressure, are the most widely used instrument.
- Sound analyzers, more expensive equipment, are able to measure the frequency content of sound
- Sound intensity meters, recent developed instruments are able to measure sound intensity.
- A typical sound level meter consists of a microphone, amplifier, frequency weighting networks and display.
- Microphones are the most important component of a sound meter and usually determines the frequency response of the whole instrument. It is sound sensitive to sound pressure. A good micriphone will cost HK$10,000.

# Measure of Sound

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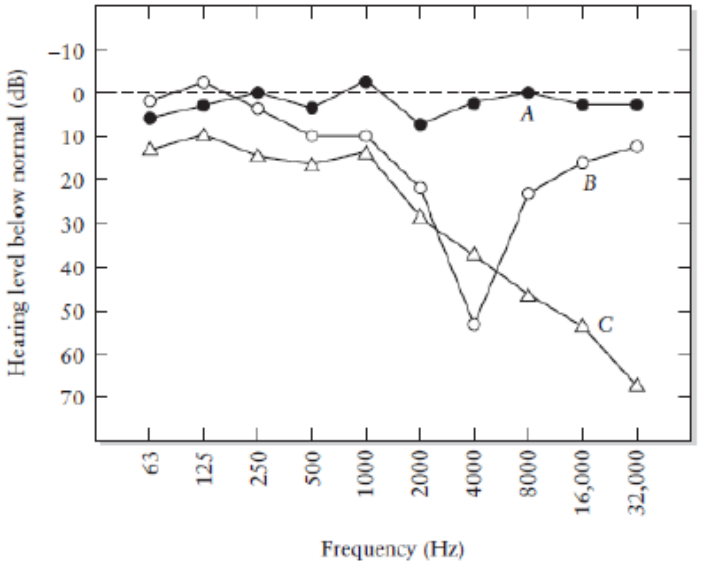
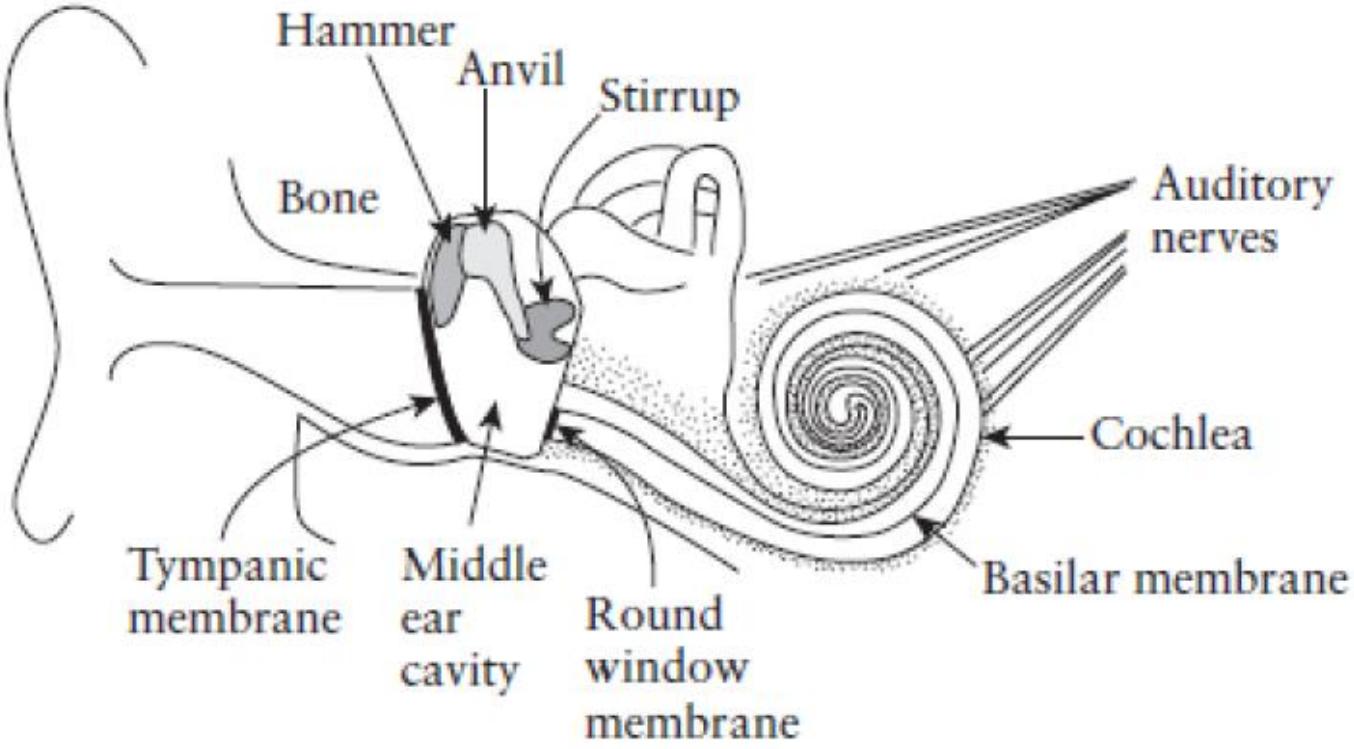
(A) Typical sound level meter; and (B) frequency analyser.

# Measure of Sound

- Using the hearing ability of an average young ear as the standard, an *audiometer* measures the hearing ability at various frequencies, producing an *audiogram*. Such audiograms are then used to identify the frequencies at which hearing aids must be able to boost the signal.
- An example of audiogram: Person A has excellent hearing with a basically flat response. Person B has lost hearing at a specific frequency range, in this case around 4000 Hz. Person C shows a typical audiogram for either an older person who has lost much of the higher-frequency range or young person who has sustained severe damage to his/her ears.

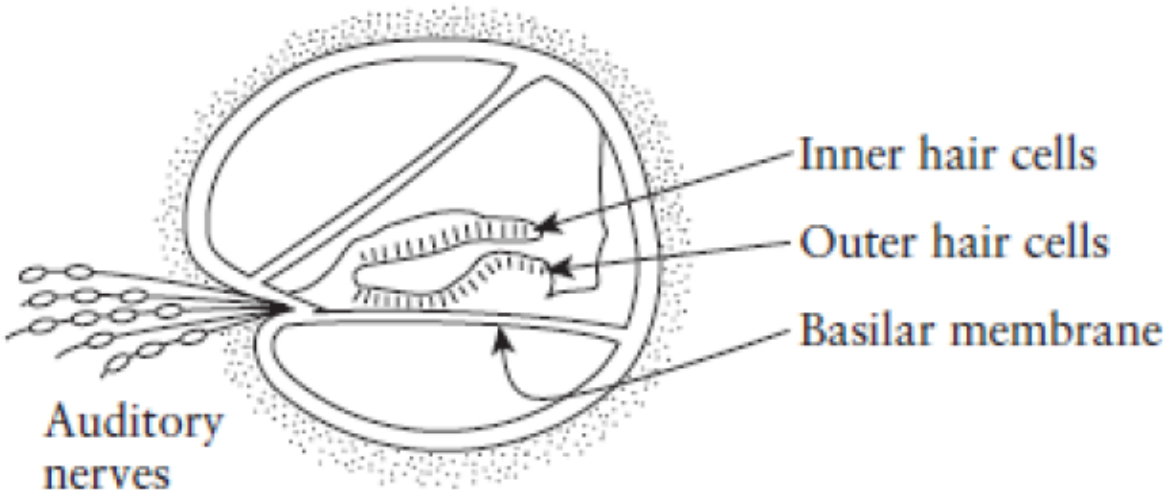


# Outline


Hammer
Anvil
Stirrup
Bone
Auditory nerves
Cochlea
Basilar membrane
Tympanic membrane
Middle ear cavity
Round window membrane

# Effect of Noise on Human Health

- The air pressure waves first hit the ear drum (tympanic membrane), causing it to vibrate.
- The cavity leading to the tympanic membrane and the membrane itself are often called the outer ear.
- The tympanic membrane is attached physically to three small bones in the middle ear that start to move when the membrane vibrates.
- The purpose of these bones, called colloquially the hammer, anvil, and stirrup due to their shapes, is to amplify the physical signal (to achieve some gain in audio terms).
- This air-filled cavity is called the middle ear.
- The amplified signal is then sent to the inner ear by first vibrating another membrane called the round window membrane, which is attached to a snail-shaped cavity called the cochlea.




- Within this fluid-filled cochlea, a cross section is another membrane, the basilar membrane, which is attached to the round window membrane.
- Attached to the basilar membrane are two sets of tiny hair cells, pointing in opposite directions.

# Effect of Noise on Human Health

- As the round window membrane vibrates, the fluid in the inner ear is set in motion, and the thousands of hair cells in the cochlea shear past each other, setting up electrical impulses that are then sent to the brain through the auditory nerves.
- The frequency of the sound determines which of the hair cells will move. The hair cells close to the round window membrane are sensitive to high frequencies, and those in the far end of the cochlea respond to low frequencies.
- Damage to the human ear can occur in several ways.

1. Very loud impulse noise can burst the ear drum, causing mostly temporary loss of hearing, although frequently torn eardrums heal poorly and can result in permanent damage.
2. The bones in the middle ear are not usually damaged by loud sounds, although they can be hurt by infections. Because our sense of balance depends very much on the middle ear, a middle ear infection can be debilitating.

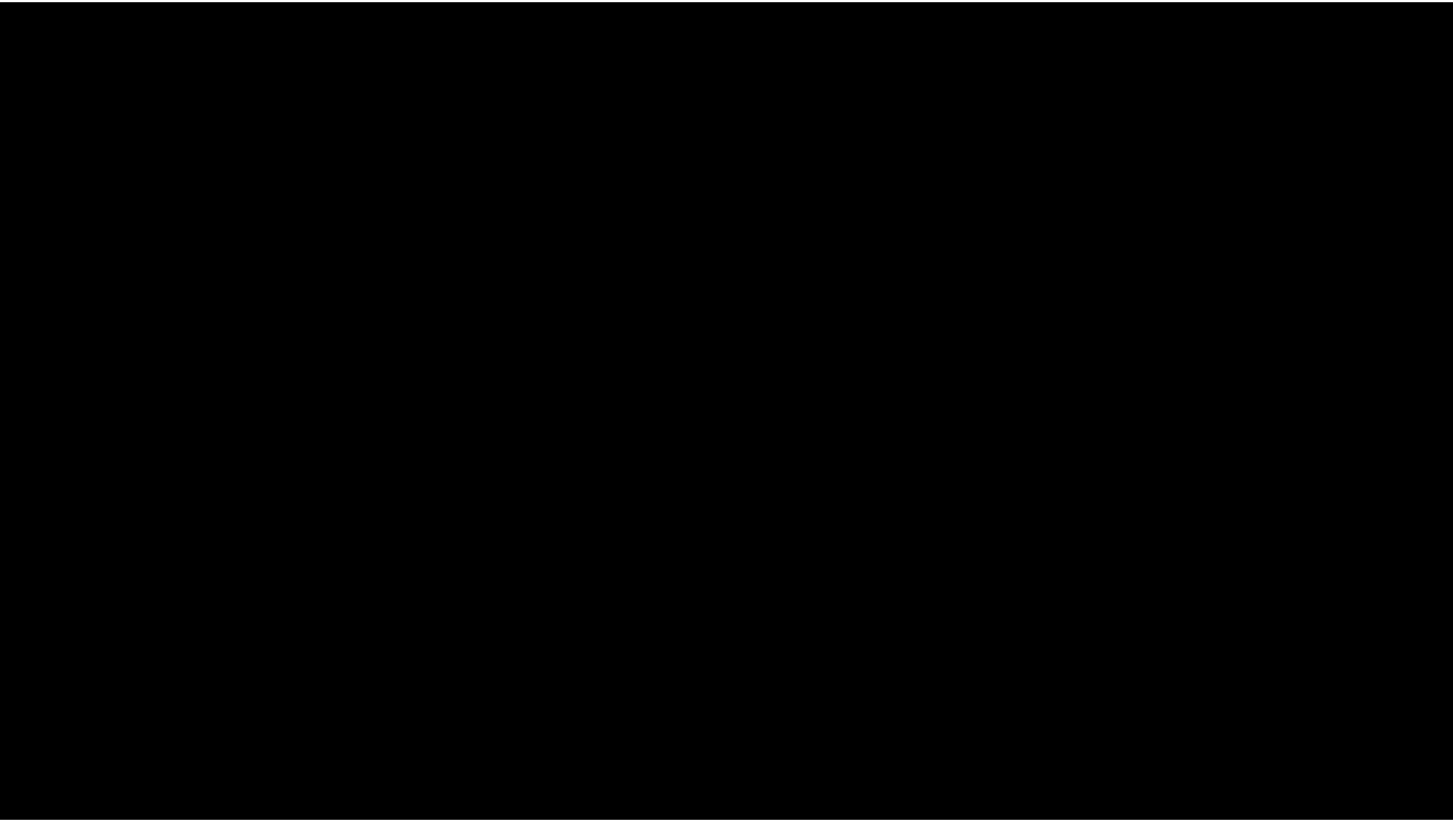
# How does sound reach the brain?

- The most important and most permanent damage can occur to the hair cells in the inner ear. Very loud sounds will stun these hair cells and cause them to cease functioning. Most of the time this is a temporary condition, and time will heal the damage. Unfortunately, if the insult to the inner ear is prolonged, the damage can be permanent. This damage cannot be repaired by an operation or corrected by hearing aids. It is this permanent damage to young people, inflicted by loud music, that is the most frequent and insidious - and the saddest.
- Is it really worth it to spend your time in front of huge loudspeakers in concerts or to turn up the volume of the iPod when the result will be that you will not be able to hear any music by the time you are 40 years old?
- People who live and work in noisy environments have measurably greater general health problems, are grouchy and ill-tempered, and have trouble concentrating. Noise that deprives a person of sleep carries with it an additional array of health problems.

- The level of noise can be reduced by using one of three strategies: protect the recipient, reduce the noise at the source, or control the path of sound.
- Protecting the recipient usually involves the use of earplugs or other ear protectors. Small earplugs, although easy and cheap, are not very effective for many frequencies of noise. The ear can detect sound not only coming through the ear canal but also from the vibration of the bones surrounding the ear. Thus, small earplugs are only partially effective. Far better are ear muffs that cover the entire ear and protect the wearer from most of the surrounding noise.
- Reducing the source of the noise is, of course, often the most effective means of noise control. The redesign of commercial airplanes has already been mentioned as an example of the effectiveness of this control strategy. Changing the type of motors used in and around the home also often effectively reduces noise.

1. Sound
   - sound
   - Sound pressure level
   - Average sound pressure level
   - Loudness
   - Loudness level
2. Measurement of sound
   - Measurement of sound
3. Effect of noise on human health
   - Effect of noise in human health
4. Noise control
   - Noise control
   - Control Path of Noise
   - Legislation in Hong Kong

- Changing the path of the noise is a third alternative. The most visible evidence of this tactic is the growth of noise walls, or barriers, along our highways.
- A variety of materials and designs have been used for noise barriers.
- While earth berms are the cheapest noise barrier to construct, they, of course, require large areas of land, something that is typically lacking in urban areas.
- Noise walls provide maximum noise reduction to only the first row of receivers (e.g., houses). The reduction is half as much for the second row and negligible for others.
- If a barrier is installed on only one side of a road, the receivers on the opposite side of the road actually receive more noise. These effects are due to the properties of sound and noise walls.
- Noise walls create a shadow zone, in which the maximum noise reduction occurs. Unfortunately, noise is not like light. A noise shadow is not perfect, and noise can bend and bounce off the barrier and even off the air, depending on atmospheric conditions. Sometimes noises miles away can be heard as the pressure waves bounce off inversion layers.



# Like other large cities in the world, Hong Kong has its share of noise problems.

- Hong Kong's economy has grown in recent decades
  - Compact, densely populated city

- Noise can cause damage
  - lead to mental stress and hearing loss
  - interfere with daily activities such as doing homework, watching television, talking on the telephone and sleeping

- Government has made sure that major forms of environmental noise are under statutory control
  - restricting noise from construction activities, commercial and industrial activities, newly registered vehicles and air transport

# Policies for Countering Noise Pollution

Minimize the number of people who are exposed to unnecessary noise

- planning and policy making in consultation with the public

# Environmental Noise in Hong Kong

| Type of Environmental Noise Source | Examples |
|---|---|
| Transportation | aircrafts, trains, road vehicles, vessels |
| Industrial buildings | factories - machineries, air-conditioning systems |
| Commercial buildings | office buildings - air-conditioning systems<br>restaurants - air-conditioning systems, kitchen ventilating systems |
| Construction sites | site formation (e.g. excavation), piling, road work, demolition, renovation |
| Domestic buildings | mahjong playing, hi-fi, musical instruments |
| Public places | open markets, streets, parks |
| Products | intruder alarms of buildings and motor vehicles |

# Construction Noise

- Construction noise in a compact city like Hong Kong can be a significant problem
  - commercial and residential premises are mixed together

- Environmental Protection Department (EPD) has worked to reduce this problem by carefully managing construction noise
  - **Goal: strike a balance between the needs of the construction industry and social harmony**
  - Noise Control Ordinance was created

***Before NCO***

- Pile-drivers operated 12 hours a day in urban areas

***After NCO***

- Piling is limited to three to five hours a day in built-up areas
- Quieter piling equipment must be used

# Construction Noise

- **Noise Control Ordinance** came into effect in 1989 and included controls on construction noise that have been progressively tightened
- **Two categories:**
  - general construction work
  - percussive piling (for example, piling by means of a hydraulic hammer or a drop hammer)
- Rules under NCO
  - general construction work using powered mechanical equipment between 7 p.m. and 7 a.m. or at any time on a general holiday (including Sunday), is prohibited under the Ordinance unless a valid Construction Noise Permit is in force
  - use of specified powered mechanical equipment (for example, hand-held breakers and dump truck) and/or the carrying out of the prescribed construction activities (for example, erection or dismantling of formwork and hammering) requires a permit
  - percussive piling during the daytime may only be carried out in accordance with a Construction Noise Permit

# **Acceptable Noise Levels (ANLs)** in dB(A)

"Any Noise Sensitive Receiver (NSR) shall be assigned an Area Sensitivity Rating (ASR) of C if it is within 100 m of a zone designated as Industrial or Industrial Estate on a statutory Outline Zoning Plan, or an ASR of B if it is between 100 m and 250 m from such a zone, except in cases where the above table indicates an ASR of C"

| Time Period \ ASR | A | B | C |
|---|---|---|---|
| **Day** (0700 to 1900 hours) | 60 dB(A) | 65 dB(A) | 70 dB(A) |
| **Evening** (1900 to 2300 hours) | | | |
| **Night** (2300 to 0700 hours) | 50 dB(A) | 55 dB(A) | 60 dB(A) |

C rating is most stringent and A is least stringent

**Environmental Protection Department (EPD): Environmental Noise**
https://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m2/types_5.html

# Steps to Reduce Construction Noise

- A Construction Noise Permit, with appropriate conditions, is issued if the Authority is satisfied that the noise which will be generated will comply with the requirements

- Noise Control Ordinance also provides for the control of noise from hand-held percussive breakers and air compressors
  - Breakers that weigh more than 10 kilograms must be fitted with noise emission labels when being used for construction work

- The Environmental Protection Department also published a Code of Practice to encourage the reduction of noise and implementation of good management practices within the construction industry

# About 960,000 are affected by excess traffic noise alone, making it the biggest noise problem in the SAR.

# Traffic Noise

- The EPD is addressing two sources of traffic noise
  - One is from new roads
  - Other from existing roads
- EPD's strategy:
  - Preventing traffic noise on new roads through careful planning
  - Noise abatement on existing roads.
  - Control of noise emissions from individual vehicles.
  - Other environmentally friendly measures.


*E.g.*
Tung Chung New Town was designed with EPD involvement so residents would not be exposed to excessive aircraft or road noise

- **New Roads**
  - More than 105 kilometres of barriers and screens have been erected along new roads since 1990, benefiting some 350,000 people
  - Low-noise surfaces are also commonly used in design of new roads and buildings to reduce noise

- **Existing Roads**
  - Retrofitting noise barriers and resurfacing roads with low-noise materials has been implemented
  - Around 90 roads have been identified for resurfacing with low-noise materials, which will benefit about 60,000 dwellings on completion
  - In1999, the Government completed a $658 million programme to insulate more than 10,000 classrooms for 500,000 students

- **Individual Vehicles**
  - only the motor vehicle complying with the noise emission standards shall be allowed for first registration in Hong Kong

# Aircraft Noise

- With a daily average of over 1,000 flight movements at the Hong Kong International Airport, aircraft noise is a particular environmental concern
  - The preferential use of runways and flight paths at night to avoid overflying densely populated areas as much as possible
  - Noise abatement departure and approach procedures
  - The prohibition of noisy aircraft from operating at the Airport
  - Aircraft noise and flight tracks are monitored around the clock by the Aircraft Noise and Flight Track Monitoring System, which comprises 16 noise monitoring terminals installed at various areas under or near landing and take-off flight paths

# Neighbourhood Noise and Noise from Commercial and Industrial Premises

- **Neighbourhood Noise**
  - Neighbourhood noise from domestic premises and public places is restricted under the Noise Control Ordinance.
  - Reported to the police for immediate assistance.

- **Noise from Commercial and Industrial Premises**
  - Noise from commercial and industrial premises is restricted under the Noise Control Ordinance through a Noise Abatement Notice system
  - Environmental Protection Department conducts investigations and assessments based on a set of statutory noise limits.

# Project Deliverable 2 due Next Week

**SEE1003**
**Introduction to Sustainable Energy and Environmental Engineering**

**Project Deliverable 2**

Due: 28 Feb, 2022 by 9 am on Canvas
Total Points 35

**Note**: You can do your research from Google Scholar, ScienceDirect, or Scopus to provide data and evidence in support of your arguments, but you need to give the source (full url, photos, etc.) of where you find the information.

Go to: https://libguides.library.cityu.edu.hk/citing for more information. Learn how to use Endnote to make citation management easy.

**Note**: for "calculate", please show your steps

1. Semester-long Project: Comparison of Primary Energy Sources (20 points)

   In order to compare the four types of car technologies: 1) Biofuel-based cars, 2) Electric Cars, 3) Hybrid Cars and 4) Hydrogen Cars, we must evaluate the associated environmental impacts.

   **Research the underlying technology of all four types of car.** (10 Points)
   a. What is the underlying technology (for e.g. internal combustion engine for gasoline based cars)?
   b. What is the performance of this technology?

   **Answer the following questions about the environmental impacts (i.e., air pollution, water pollution, biodiversity loss, etc.) associated with the different car technologies.** (10 Points)

   c. What are the *Upstream environmental impacts* (associated with the production of the product) related each of the car technologies?
   d. What are the *Downstream environmental impacts* (includes everything after the product has left the factory) associated with each of the car technologies?


   Please provide data to support your claims, along with the references where you got the information.
   *Total word count for question 1: min. 500 and max. 1500.*

2. Take the following data as referring to 2000 (they come from UNDP (2001), population size (P) and per capita activity or affluence (A) are for 1999 and emissions per unit production (T) uses CO2 data for 1997), and the world as being the sum of these three groups of nations. (15 points)

| | Population *(millions)* | Activity per capita *(PPP US$)* | Technology *(tonnes of $CO_2$ per US$)* |
|---|---|---|---|
| Rich OECD | 848 | 26 050 | 0.0004837 |
| EE and CIS | 398 | 6 290 | 0.0011924 |
| Developing | 4610 | 3 530 | 0.0005382 |

   2.a Calculate total world $CO_2$ emissions in 2000. (3 points)

   2.b Work out the share of total population and $CO_2$ emissions for the three different groups in 2000. (2 points)

   2.c Assume population growth at 0.5% per year in Rich OECD and EE and CIS and at 1.5% per year in Developing, out to 2050. Assume per capita income growth at 1.5% per year in Rich OECD, at 2.5% per year in EE and CIS, and at 3.0% in Developing, out to 2050.

   Work out total world emissions and share of emissions for each group in 2050, and the total world population and share of population for each group in 2050. (5 points)

   2.d For the same population growth and per capita income growth assumptions as given in the previous sub-question, by how much would T have to fall in Rich OECD for that group's 2050 emissions to be the same as in 2000? With this new T for Rich OECD in 2050, assume that T for EE and CIS in 2050 achieve same level of T for Rich OECD in 2000 and work out what total world CO2 emissions would then be. (5 points)