Adult Basic Education

Science

Physics 2104C

Waves, Light and Sound

Study Guide

Prerequisite: Physics 2104 A

Credit Value: 1

Text: *Physics: Concepts and Connections*. Nowikow et al. Irwin, 2002

<u>Physics Concentration</u>

Physics 1104
Physics 2104A
Physics 2104B
Physics 2104C
Physics 3104A
Physics 3104B
Physics 3104C

Table of Contents

To the Student

I. <u>Introduction to Physics 2104C</u>

This course will introduce you to the nature of sound and light. One way that light appears to behave is as a wave. (The other way light can behave is as a particle and you will study this in Physics 3104C). The study of light waves and then sound waves will involve many applications of both light and sound.

In addition to your textbook, you will need your scientific calculator. This course, like the previous courses in Physics does require some understanding of trigonometry. If you have not studied any trigonometry, you will need to get some extra help on the problems that use trigonometry.

II. <u>Use of Science Study Guides</u>

Before beginning this course, ensure you have the text and any other resources needed *(see the information in the Introduction to this course for specifics)*.

As you work through the Study Guide, you will see that it is divided according to the Units listed in the Table of Contents. When you open a unit it will have the following components:

To the Student

Reading for this Unit:
Here you will find the chapters, sections and pages of the text you will use to cover the material for this unit. Skim the sections of the textbook, look at the titles of the sections, scan the figures and read any material in the margins. Once you have this overview of the unit, you are ready to begin. Do not be intimidated by the content. You will work through the text, section by section, gaining knowledge and understanding of the material as you go.

References and Notes	Work to Submit
This left hand column guides you through the material to read from the text. Read any highlighted notes that follow the reading instructions. The symbols ▶▶ direct you to the questions that you should complete when finished a reading assignment..	You come across three (3) headings in this right hand column. **Writing:** This section comprises your notes for the unit. Here you will find either written questions or references to specific questions or problems from your text. You may want to write out each question followed by the answer. This material should be checked by your instructor before moving on to the next unit. Mathematical problems should have their solutions checked as you go. **Laboratory:** This section indicates if there is a Lab that should be completed for the unit. Let the instructor know in advance that you will be ready for the lab. A lab report should be submitted for each Lab. Your instructor will provide guidelines as to how s/he wants the report written. **Assignment:** This section indicates if there is an assignment that should be completed for the Unit. The information in the "References and Notes" column will indicate how you obtain the assignment. These assignments frequently relate the science content to technology, society and the environment.

III. Recommended Evaluation

Written Notes	10%
Labs/Assignments	20%
Test(s)	20%
Final Exam *(entire course)*	50%
	100%

The overall pass mark for the course is 50%.

Unit 1 - Waves

To fulfill the objectives of this unit, students should complete the following:

Reading for this unit:	*Physics: Concepts and Connections:* Chapter 10: Section 10.1: pages 385-389 Section 10.2: pages 390-393

References and Notes	Work to Submit
A mechanical wave is a transfer of energy in the form of one or more disturbances through an elastic medium. Some terms that you met in Simple Harmonic Motion will apply to waves. A *mechanical wave's* *energy is proportional to the square of its amplitude in the same way as that of a simple harmonic oscillator (*$E = kA^2$*)*	**Writing:**
Read pages 385 to 389 of Section 10.1.▶▶	1.1 What is a mechanical wave? 1.2 Explain the difference between a transverse and a longitudinal wave using a Slinky as an example. 1.3 How are longitudinal and transverse waves created on a Slinky? 1.4 How does the particle motion compare to the direction of the wave's velocity for a (i) transverse wave and (ii) longitudinal wave? 1.5 What are the two (2) fields that comprise light? 1.6 In what direction do the fields that compose light move with respect to each other and to their vibrations?

Unit 1 - Waves

References and Notes	Work to Submit
	1.7 What are compressions and rarefactions? 1.8 How are longitudinal and transverse waves illustrated? 1.9 Explain what each of the following is and indicates its symbol: (a) period (b) frequency (c) wavelength (d) amplitude 1.10 Use a diagram to illustrate each of : (a) amplitude (b) crest (c) trough (d) wavelength 1.11 What mathematical expression relates frequency to period? 1.12 What does phase and phase shift mean for waves? 1.13 Sketch a diagram of a wave whose wavelength is 5 cm and whose amplitude is 2 cm. Now below this sketch a phase shift of $\lambda/4$ and $\lambda/2$ for this wave. 1.14 Complete Questions 1 to 3 on page 389. 1.15 Complete Questions 29 to 30 on page 435.

Unit 1 - Waves

References and Notes	Work to Submit
Read pages 390 to 393 of Section 10.2 ▶▶	1.16 What is the wave equation? Explain what each variable represents. 1.17 What is the electromagnetic spectrum? 1.18 List the seven (7) major regions of the electromagnetic spectrum. 1.19 What is ***c*** and what is its value and units? 1.20 Complete Problems 1 and 2 on page 393.

Unit 2 - Light Properties I

To fulfill the objectives of this unit, students should complete the following:

Reading for this unit:	*Physics: Concepts and Connections:*	
	Chapter 10:	Section 10.3: pages 394-395
		Section 10.4: pages 396-400
		Section 10.5: pages 400-402
		Section 10.6: pages 402-404
		Section 10.7: pages 405-406
		Lab 10.1: page 442.

References and Notes	Work to Submit
	Writing:
Read pages 390 to 393 of Section 10.3 ▶▶	2.1 What is meant by “rectilinear propagation of light”?
	2.2 For light define: (a) reflection (b) transmission (c) refraction
	2.3 In optics, what is (a) a ray, (b) the normal, (c) point of incidence and (d) incident ray.
	2.4 In optics, what is a beam?
	2.5 Explain the difference between regular (or specular) reflection and diffuse reflection.
Read pages 396 to 400 of Section 10.4 ▶▶	2.6 State the two Laws of Reflection for flat surfaces.
	2.7 What are virtual images?

Unit 2 - Light Properties I

References and Notes	Work to Submit
	2.8 Describe the five aspects of an image produced in a plane mirror.
	2.9 What is lateral inversion?
	2.10 Write out the rules for determining how the eye sees an image in a plane mirror (Figure 10.24).
	2.11 Complete Question 3 on page 400.
	2.12 Complete Problems 48 and 49 on page 437.
Read pages 400 to 402 of Section 10.5 ▶▶	2.13 Define refraction.
	2.14 What happens to a refracted ray when light travels from a less optically dense medium to a more optically dense medium? (Use a diagram to illustrate your answers).
	2.15 What happens to a refracted ray when light travels from a more optically dense medium to a less optically dense medium?
	2.16 Complete Question 3 on page 402.
	2.17 Complete Question 10(a) and (b) on page 434.
Read pages 402 to 403 of Section 10.6 ▶▶	2.18 Define index of refraction.

Unit 2 - Light Properties I

References and Notes	Work to Submit
	2.19 What is the mathematical expression for the index of refraction? Explain what each letter represents.
	2.20 Complete Problems 1 and 2 on page 404.
Read page 405 of Section 10.7 ▶▶	2.21 Express Snell's Law in (a) words and in (b) a mathematical expression.
Check to ensure your calculator is in degrees mode not radians. Try Example 9 to ensure you can use your calculator correctly.	2.22 Complete Problems 62 and 63 on page 438.
Study Example 10 on page 406 ▶▶	2.23 Complete Problem 1 and 2 on page 407.
	2.24 Complete Problem 2 on page 407.
Let your instructor know you are ready to do Lab 10.1.	**Laboratory:**
	Complete and submit Core Lab #1: Lab 10.1: Snell's Law on page 442.

Unit 3 - Light Properties II

To fulfill the objectives of this unit, students should complete the following:

Reading for this unit:	*Physics: Concepts and Connections:*	
	Chapter 10:	Section 10.8: pages 408-409
		Section 10.9: pages 411-413
		Section 10.10: pages 414-418
		Section 10.11: page 419
		Section 10.12: page 424-429
		Section 10.13: pages 429-430

References and Notes	Work to Submit
Read pages 411 to 413 of Section 10.9. ▶▶	**Writing:** 3.1 What is total internal reflection of light? 3.2 Explain why light is an efficient means of transferring information. 3.3 What is a critical angle? 3.4 Why does total internal reflection only occur for light travelling from a more dense medium to a less dense medium? 3.5 List 5 examples of the use of fibre optics for information transfer.

Unit 3 - Light Properties II

References and Notes	Work to Submit
Read "The Rainbow," on pages 414 to 415 in Section 10.10 ▶▶	3.6 Explain how the rainbow colors are produced.
Read pages 424 to 425 of Section 10.12 and Study Figures 10.70 and 10.71 on page 426. ▶▶	3.7 What is the principle of superposition?
	3.8 Explain (using a diagram) the difference between constructive and destructive interference.
	3.9 What is meant by phase shift?
	3.10 What are maxima?
	3.11 What are nodal lines?
You may want to use the process described in Figure 12.3 on page 487 to help you solve Problem 90.	3.12 Complete Problem 90 on page 440.

Unit 4 - Sound Properties I

To fulfill the objectives of this unit, students should complete the following:

Reading for this unit:	*Physics: Concepts and Connections:*	
	Chapter 11:	Section 11.1: pages 445-449
		Section 11.2: pages 450-453
		Section 11.3: pages 453-458
		Section 11.4: pages 458-461
		Section 11.5: page 463
		Section 11.6: pages 468-470
		Section 11.7: pages 471-473
		Lab 11.2: page 483
	Study Guide	Appendix B

References and Notes	**Work to Submit**
	Writing:
Read pages 445 to 448 of Section 11.1 ▶▶	4.1 What is simple harmonic motion?
	4.2 What type of wave are produced in strings of musical instruments?
	4.3 What type of waves are sound waves?
	4.4 Referring to Figure 11.4, explain why water waves are complex waves.
	4.5 What is the wave equation? Explain what each variable represents.
	4.6 Complete Problems 1 to 3 on page 449.
Read the information in Question 1 on page 449 ▶▶	4.7 Explain how animals use echolocation (sonar) to locate objects.

Unit 4 - Sound Properties I

References and Notes	Work to Submit
Read pages 450 to 452 of Section 11.2 ▶▶	4.8 Describe the three factors that affect the speed of sound.
You are not responsible for solving problems involving Mach Numbers.	4.9 Explain what the terms (a) compression and (b) rarefaction mean.
	4.10 Explain how sound is transmitted to another person.
	4.11 What is the mathematical expression for the effect of temperature on the speed of sound in air?
	4.12 Complete Questions 1 to 3 on page 453.
Read pages 453 to 457 of Section 11.3 ▶▶	4.13 What is a Mach Number?
	4.14 Explain what each of the following mean (a) subsonic, (b) supersonic (c) hypersonic.
	4.15 What is the sound barrier?
	4.16 Explain how a sonic shock originates.
You may want to use the glossary at the back of the text for definitions.	4.17 Define acoustic pressure.
	4.18 Explain why supersonic travel is prohibited over North America.
	4.19 What types of sound speeds are associated with a sonic boom?
	4.20 Complete Question 3 on page 458.

Unit 4 - Sound Properties I

References and Notes	Work to Submit
Inform your instructor you are ready to complete Core Lab #2. *Submit the completed lab report for evaluation.*	**Laboratory:** Complete and submit the report for Core Lab #2: Speed of Sound on page 483.
Read pages 458 and 459 of Section 11.4 to the end of Example 7 ▶▶	**Writing:** 4.21 Define intensity. 4.22 What is the mathematical expression for sound intensity. Explain what each variable represents.
Assume for problem 50 that "close proximity" means 1 m.	4.23 Complete Problems 49 and 50 on page 479.
Read from "Decibel System" on page 459 to end of page 461. ▶▶	4.24 What is the mathematical expression for the decibel unit of sound intensity? 4.25 Complete Problems 1 and 2 on page 462.
Read page 463 of Section 11.5 ▶▶	4.26 What is the Doppler effect? 4.27 Explain how the Doppler effect arises. 4.28 Complete Question 1 on page 467.
Read pages 468 to 470 of Section 11.6 <u>and</u> Appendix B. ▶▶	4.29 Explain the role of the outer, middle and inner ear in our ability to hear. 4.30 How do loud bursts of noise damage our hearing? 4.31 What frequency range can we hear?

Unit 4 - Sound Properties I

References and Notes	Work to Submit
	4.32 To what frequencies are our ears most sensitive?
	4.33 Are we more sensitive to high pitch or low pitch frequencies?
Read page 471 of Section 11.7 ▶▶	4.34 Define the terms infrasonic and ultrasonic.
	4.35 Explain how sonar functions.

Unit 5 - Sound Properties II

To fulfill the objectives of this unit, students should complete the following:

Reading for this unit:	*Physics: Concepts and Connections:*	
	Chapter 12:	Section 12.1: pages 486
		Section 12.2: pages 486-489
		Section 12.3: pages 489-491
		Section 12.4: pages 491-492
		Section 12.5: pages 494-496
		Section 12.7: pages 505-507
		Section 12.8: pages 508-510
	Study Guide	Appendix A - "The Physics of Guitars"

References and Notes	**Work to Submit**
Read pages 486 to 488 of Section 12.1 and 12.2 ►►	**Writing:** 5.1 Why are longitudinal sound waves illustrated as transverse waves? 5.2 Define interference. 5.3 What is the principle of superposition? 5.4 Use Figure 12.3 to write a summary of applying the principle of superposition. 5.5 Complete Problem 10 on page 515.

Unit 5 - Sound Properties II

References and Notes	**Work to Submit**
Read pages 489 to 491 of Section 12.3 ▶▶	5.6 Explain what is meant by the following as applied to sound waves: (a) absorption (b) transmission (c) reflection
	5.7 What happens to sound waves as they move from a slower to a faster medium?
Read pages 491 to 492 of Section 12.4 ▶▶	5.8 Define standing wave (see glossary).
	5.9 Explain what each of the following terms mean: (a) nodes (b) antinodes (c) internodal distance
	5.10 If there are five (5) nodes, how many internodal distances exist?
	5.11 Complete Question 1 on page 494.
Read pages 494 to 495 of Section 12.7 ▶▶	5.12 What is mechanical resonance?
	5.13 Describe how mechanical resonance resulted in the collapse of the Tacoma bridge.
Read pages 505 to 507 of Section 12.7 ▶▶	5.14 Explain what is meant by each of the following terms: (a) pitch (b) loudness (c) quality.

Unit 5 - Sound Properties II

References and Notes	Work to Submit
Read pages 508 to 510 of Section 12.8 ▶▶	5.15 Explain how interference causes interesting effects in the case of: (a) side by side speakers and (b) beat frequency.
Loud speaker interference occurs in space - that is if you have two loud speakers parallel to each other, there will be places where the sound is very loud (constructive interference) and other places with destructive interference where the sound is very low or there is no sound at all.	
Beats involve interference in time. Sound level rises (constructive interference) and falls (destructive interference). The regularly spaced intensity changes are called beats.	**Assignment:**
Read Appendix A ▶▶	Complete and submit the Questions 1 to 4.

Appendix A

The Physics of Guitars

Outcomes:

1. To describe and evaluate the design of technological solutions and the way they function, using scientific principles.
2. To analyze natural and technological systems to interpret and explain their structure.
3. To analyze and describe examples where technological solutions were developed based on scientific understanding.
4. To analyze society's influence on scientific and technological endeavors.
5. To analyze why and how a particular technology was developed and improved over time.
6. To analyze and describe examples where scientific understanding was enhanced as a result of the invention of a technological device.
7. To describe what is meant by a vibration, and give examples from technology.
8. To explain how standing waves are produced on a stretched string.
9. Given the fundamental frequency and fundamental wavelength of a vibrating string, produce diagrams of various overtones labelled to show wavelength and frequency of each.
10. Describe how sound as a form of energy is produced and transmitted.

Introduction

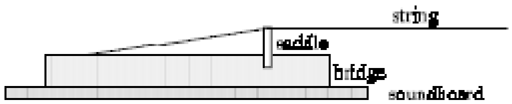
Chris Griffiths of St. John's, Newfoundland has had a lifelong interest in music, beginning guitar lessons at the age of twelve. He began building guitars at the age of seventeen. Since then he has turned his interest into the successful guitar making business known as Griffith's Guitar Works - a 20 000 square foot, multimillion dollar high tech acoustic guitar factory. Though Griffiths may not have chosen physics as a career, a knowledge of physics was certainly important in producing great sounding guitars like his latest creation - the Garrison. The Garrison guitar line includes a full range of acoustic guitars, beginning with the G-10 and following through to the top of the line G-50. Through innovative construction techniques, these guitars offer "superb playability and clarity of tone" that is setting a new standard for acoustic guitars (Garrison Guitars).

Construction

There are many different types of acoustic guitars, producing varying qualities of sound. However they all share some basic construction features. The three main parts of any guitar are the hollow body, the neck and the head.

Body

The guitar body includes the soundboard, a wooden piece mounted on the front of the guitar. The soundboard should be made so that it can vibrate up and down relatively easily. It is usually made of spruce or another light springy wood. Griffith's Garrison guitars are constructed from all solid wood including East Indian rosewood, sapele, englemann spruce, sitka spruce, Canadian birch and western red cedar. There is a large hole in the soundboard called the sound hole. Also attached to the soundboard is the bridge. The bridge anchors one end of the six strings. On the bridge is a saddle which the strings rest against.



When the strings are plucked they vibrate. The vibrations travel through the saddle and bridge to the soundboard. The hollow body of the guitar then amplifies the vibrations of the soundboard. These vibrations then disturb the air producing a sound wave reaching our ears. Without the amplification of sound produced by the hollow body, these vibrations would be barely audible. Bracing refers to the internal reinforcement of a guitar that must add strength where necessary but still allow the top to vibrate as freely as possible. Garrison guitars boast a single-unit brace that allows the resonant sound to travel uninterrupted through the guitar no matter where the vibration is created.

Neck

The neck of the guitar joins the body to the head. On the face of the neck (called the fingerboard) are metal pieces called frets that are cut at specific intervals. When a string is pressed onto a fret, the length of the string is changed. Changing the length changes the sound that is produced. The frequency of sound produced is inversely proportional to length (f % $^{1}/_{L}$). As length decreases frequency increases. The six strings on guitars also have different weights which affect the sound produced. The first string is as fine as a thread while the sixth is wound much heavier and thicker. More massive strings vibrate more slowly. The frequency of sound produced is inversely proportional to the square root of the density of the string $f \propto 1/\sqrt{P}$. As the density decreases the frequency increases. The frequency is also inversely proportional to the diameter of the string $f \propto 1/d$. This means that as the diameter decreases, the frequency increases.

The strings themselves do not make much noise when plucked since they do not cause a large disturbance to the air around them. It is the vibrations of the bridge and body that produce such pleasing sounds.

Head

Joining the neck to the head is a piece called the nut. The nut has grooves to hold the strings. From the nut the strings are connected to the tuning pegs on the head. Turning these pegs allows the tension in the strings to be increased or decreased. These pegs are used to tune the guitar. The tighter the string the higher the pitch and frequency of sound produced. In fact, frequency varies directly as the square root of the tension $f \propto \sqrt{T}$.

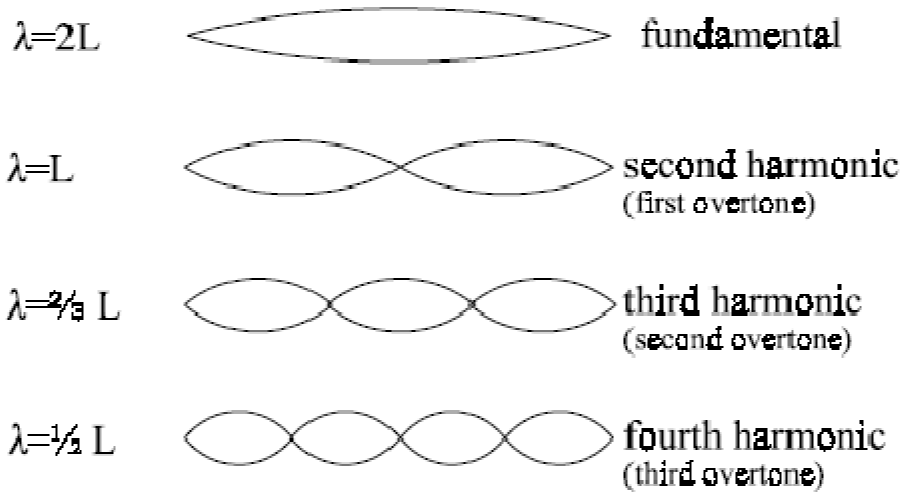
Electric Guitars

The major difference between electric guitars and acoustic guitars is in the body. Electric guitars have a solid body with no sound hole. A string plucked on an electric guitar makes almost no sound if not connected to an amplifier. This is because without a hollow body there is nothing to amplify the sound. Electric guitars therefore rely on amplifiers and speakers to produce sound. Vibrations are sensed electronically and then sent to the amplifier and speaker.

Theory

Standing Waves

Guitar strings are fixed on both ends by the saddle and the nut. The body of the guitar will resonate when standing waves are set up on the strings. A string will resonate when its length is equivalent to ½λ, ,λ,3/2λ, 2λ, etc. This is the same pattern of resonant lengths that exist in an open air column. The standing waves in the strings are illustrated in the following diagrams.



Note that since the string is fixed at both ends, any vibration of the string will have nodes at each end. This limits the possible vibrations that can be achieved on a given length of string. We can see that for each of the diagrams, the wavelengths are 2L, L, $^2/_3$L and ½ L. In general this is written as $\lambda = \frac{2L}{n}$ where n is the harmonic number. Thus for each standing wave pattern, the frequencies are as follows (where v is the speed of sound):

Fundamental: $f = \frac{v}{\lambda} = \frac{v}{2L} = f_1$

Second Harmonic: $f = \frac{v}{\lambda} = \frac{v}{L} = 2f_1$

Third Harmonic: $f = \frac{v}{\lambda} = \frac{v}{2L} = \frac{3v}{2L} = 3f_1$

Fourth Harmonic: $f = \frac{v}{\lambda} = \frac{v}{L/2} = \frac{2v}{L} = 4f_1$

Harmonic:

Since all waves in the same string travel with the same speed, then waves with these different wavelengths must have different frequencies. The frequencies f_1, $2f_1$, $3f_1$, $4f_1$, etc. are referred to as the harmonic series. It is the rich variety of harmonics that make a guitar or any stringed instrument interesting to hear.

Conclusion

Guitar construction is really a combination of art and science. Physics principles dictate the kind of sound produced in terms of frequency and wavelength. However it is the craftsman's artistry in constructing the shape of the body and soundboard that give each guitar its distinctive sound. For Griffiths there has been a "brilliant blend of technology, art and craftsmanship" which has set a new standard for acoustic guitars worldwide.

Questions

1. A guitar string of length 0.60 m has a frequency of 395 Hz. If the string is shortened to 0.30 m, what is it's new frequency?

2. A standing wave is set up on a guitar string of length 0.60 m. If the string vibrates in the third harmonic, what is the wavelength of the sound produced?

3. What is the main function of the body of the guitar in producing the music we hear?

4. A guitar string has an original tension of 146 N. How would the tension have to change to have the string vibrate with a frequency of 292 Hz?

5. Research: How has Griffith's guitars upped the

standard for worldwide acoustic guitar construction?

References

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News Release. (2001). Available: http://www.gov.nf.ca/releases/2001/indrural/0926n02.htm

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The Guitar. Available: http://www.bsharp.org/physics/stuff/guitar.html

Activity

Activity:

Purpose: To experimentally determine whether the soundboard really amplifies sound.

Materials: large bowl C tape
C plastic wrap C rubber band

Procedure:

1. Tightly seal a large bowl with plastic wrap (you may need to use tape to wrap the plastic tightly to the sides).

2. Tape a rubber band to the center of the taut plastic wrap and twang the rubber band.

3. Compare the sound heard to the twang of an identical rubber band not taped to the plastic wrap. You should notice a big difference. The plastic wrap greatly increases the amount of surface area that is vibrating, so the sound is much louder. (This activity is taken from the web site "How stuff works" http://www.howstuffworks.com/guitar1.htm)

4. Demonstrate how to produce standing waves for students. A very effective way to do this is to attach one end of a string to an electric drill, and the other securely to some immovable object. When the drill is turned on at varying speeds, students can clearly see standing waves at the fundamental frequency and various overtones.

5. Refer to the activity at the following web site for an activity on making standing wave patterns on a

Appendix B

Hearing Loss

Some people lose their hearing ability in their 30s and 40s. One out of 5 adults and more than half of all people over the age of 80 have hearing loss. Age related hearing loss is called **presbyacusis**. Presbyacusis generally involves the loss of ability to hear high frequency sounds first. This involves difficulty to hear speech sounds with consonants such as s, t, k, p and f.

This hearing loss generally occurs due to problems with the inner ear, usually due to damage to the tiny hair cells in the cochlea. Once damaged these hair cells cannot be repaired or replaced. As people age they gradually lose these hair cells, resulting in a gradual hearing loss.

Hair cells however can also be damaged by excessive noise. When ears are exposed to high intensity noise due to either a work environment or to listening to loud music, hearing impairment can results. For this reason, ear protection devices should be worn in working environments where there is loud noise. Young people in particular should be careful as to how loud is music they listen to.

Other reasons for hearing loss involves having been exposed to diseases such as mumps, meningitis, multiple sclerosis or to certain drugs such as quinine, or some antibiotics such as streptomycin and gentamicin. Hearing loss can occur in an infant if the mother is exposed to German measles (rubella) while she is pregnant. It can also occur due to head or ear injuries. Sometimes hearing impairment can be inherited.

Some people can use technology to overcome hearing loss. Hearing aids work for some people and for others surgery can be used to treat the problem.