LET'S SCIENCE!

4

Andrea Danani

WAVES AND US

What we know about
electromagnetic waves

IBSA FOUNDATION for scientific research

LET'S SCIENCE!

Andrea Danani

WAVES AND US

What we know about electromagnetic waves

IBSA FOUNDATION for scientific research

Repubblica e Cantone Ticino
Dipartimento dell'educazione, della cultura e dello sport

Original edition: *Le onde e noi... Cosa sappiamo sulle onde elettromagnetiche* (Carocci, 2019)

Graphic project by Ulderico Iorillo and Valentina Pochesci

CONTENTS

PREFACE

How familiar are we with the repercussions of scientific research and medical practice for our daily lives? What are the “passions” and motivations that drive researchers and healthcare professionals? What do we know about their professions?

Society strives to make science and its implications known to ordinary people in many different ways. Just think, for example, of the variety of leaflets promoting the importance of a healthy lifestyle and well-being in general. Of course, school does its part as well, introducing the principles of scientific literacy and raising awareness of a series of issues that help foster scientific thinking among young people.

These considerations are in fact the starting point for the *Let’s Science!* project, carried out by the IBSA Foundation for Scientific Research in collaboration with the Department of Education, Culture, and Sport of the Canton of Ticino (DECS). The partnership has made it possible to identify interesting topics that have been addressed by the project, getting scientists working in the canton involved. Two different worlds that are often far apart – scientific research and school – have thus been brought together, promoting dialogue between professionals and students through themed workshops, in order to develop awareness of both the topic itself and how to communicate it.

But what was the range of topics the project would address and what considerations led to certain strategic decisions? Science and research are advancing rapidly, especially in biomedicine and related disciplines, and the continuous expansion of fields of investigation requires a constant effort to stay up to date, in order to both maintain a historical perspective and accommodate the numerous innovations. Access to scientifically accurate information, conveyed in accessible language, opens up the opportunity for children to get to know and become passionate about topics that are generally considered “difficult”.

And that’s the idea behind the *Let’s Science!* series, which aims to broaden the range of scientific topics that can be explored at school. The topics, which are interdisciplinary and directly related to individual health and well-being, are presented in an innovative way: the scientific text is in fact accompanied by a story that draws on the experience of cantonal middle school classes, who, under the guidance of their teachers, developed original scripts, which were then translated into comics by professionals in the industry.

The only thing left for us to do is invite young readers to explore the fascinating fields of research presented by *Let's Science!*, which in turn open up opportunities for further questions and insights. Who knows, one of these readers might in turn one day become the one taking important steps forward in understanding the complexity of life and the delicate balance that allows us to be healthy and happy. Enjoy reading!

SILVIA MISITI
Director of the IBSA Foundation for Scientific Research

NICOLÒ OSTERWALDER
Educational consultant for science at the Department of Education (DECS)

PART ONE

Waves and us

INTRODUCTION

In the modern world, means of communication such as radio, television, telephone, and the internet enable us to receive or transmit information with great ease and speed. We have gotten so used to it that we get annoyed as soon as there is even a minor transmission problem.

But how does this transmission of information that has become so important to us actually happen? The answer lies in the title of this booklet: it's a matter of waves.

Let's see with an example how a message could be sent in the past, without relying on modern means of communication. In 1742, to convey the news of the coronation of Empress Elizabeth in Moscow to St. Petersburg, a chain of soldiers with flags was arranged along the route between the two cities. At the moment of the coronation, the first soldier waved a flag, then the second soldier, and so on. The news thus reached St. Petersburg, where a cannon was fired when the final flag was waved. This is an example of wave transmission.

The term **wave** is a common word with a very ancient history dating back long before it became a scientific term. While the origins of the English term are Germanic, in other European languages such as Italian (*onda*), it comes from the Latin word *unda*, referring to the ripples on the surface of water, and this root can also be seen in English words such as "undulate". But the connection with water is much deeper than that. The Latin term actually comes from the Greek root *hyd-*, which appears in the word *hydor*, which, in fact, means "water", and is found in English in all words beginning with "hydr-", such as hydraulic, hydropower etc. The root, however, is even older, and dates back to Indo-European, that is, to a time when almost all European languages (and some Asian languages) were a single language. The Indo-European root *vud-* or *vad-* is recognizable in many languages and refers to water or closely related concepts. Although the waves in water are actually, as we will see, only one particular type of wave, a much larger and more important physical concept is connected to this ancestral word.

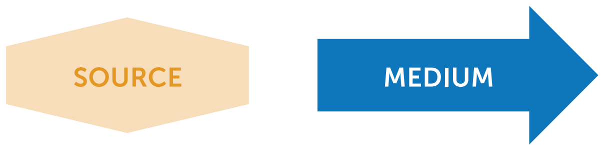
In general, we can say that if we want to transmit information, we have to transport energy. This transportation takes place from a source to a receiver. To communicate with someone, we can speak to them directly, call them on the phone, send a letter, or write an email, for example. Or use a horn to warn them of a danger.

In all these examples, there is a **source** (vocal cords, telephone, letter, computer, horn), a **transmission medium** (air, telephone cable, postal services, optical fiber) and a **receiver** (ears, telephone, eyes, computer) [**figure 1**]. When energy is transported without matter also being transported or exchanged, this is what we call propagation in wave form.

Without being fully aware of it, we live in a world full of waves: **natural** ones, such as the aforementioned waves in water or earthquakes, as well as light, radio waves, and infrared radiation that the Earth's atmosphere lets through; but also **artificial** waves generated by human beings (telecommunications, wi-fi, X-rays, microwave ovens, etc.). We essentially perceive the world through our sense organs, which gather stimuli and send them to the brain, which re-processes them; various types of waves (which become signals to all intents and purposes) are processed in this way.

The aim of this booklet is to explain the concept of waves and to illustrate the relationship between living beings – humans and animals – and some very important wave phenomena. Starting from the sense organs and the type of wave, several examples of interaction will be discussed, in terms of both the source and the receiver. In addition, we will look at some examples of technological applications of waves, where humans have managed to domesticate and exploit certain types of waves in a controlled manner.

Figure 1 Diagram of transmission



WHAT IS A WAVE?

What is the scientific definition of a wave?

In physics, a wave is defined as a **disturbance** that propagates in space and can carry energy from one point to another. For this to happen, the presence of a medium that deforms via a local vibration as the wave moves through it is necessary. The particles of the medium therefore do not travel along with the wave; it is only the disturbance these particles undergo that travels. This is what happens in what we call mechanical waves. This concept of the medium of propagation was considered valid until the beginning of the twentieth century, when it was shown that electromagnetic waves have the extraordinary property of being able to propagate in a vacuum, meaning in the absence of matter. In this case, what "vibrates" is an immaterial and somewhat mysterious entity called an **electromagnetic field**, which nonetheless produces a multiplicity of real and well-known effects on matter, as we will see later.

Waves always originate with a series of oscillating pulses. Vocal cords and the membranes of speakers vibrate, while electrons in a radio antenna or light bulb oscillate.

Waves can be divided into two broad categories: mechanical waves and electromagnetic waves.

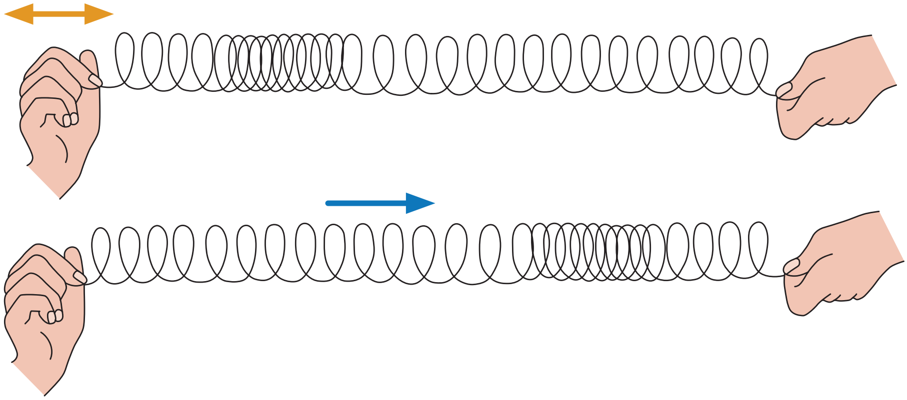
Three elements are necessary for energy to propagate in mechanical waves:

- a source of the disturbance;
- a medium that undergoes the disturbance;
- an elastic connection that connects the disturbed matter to the adjacent matter.

In turn, there are three types of mechanical waves, depending on how the propagation medium vibrates locally: longitudinal, transverse, and mixed.

In **longitudinal** waves, the particles of the medium in which the wave propagates oscillate along the direction of propagation. Sound, a spring pulled back

Figure 2 Longitudinal wave



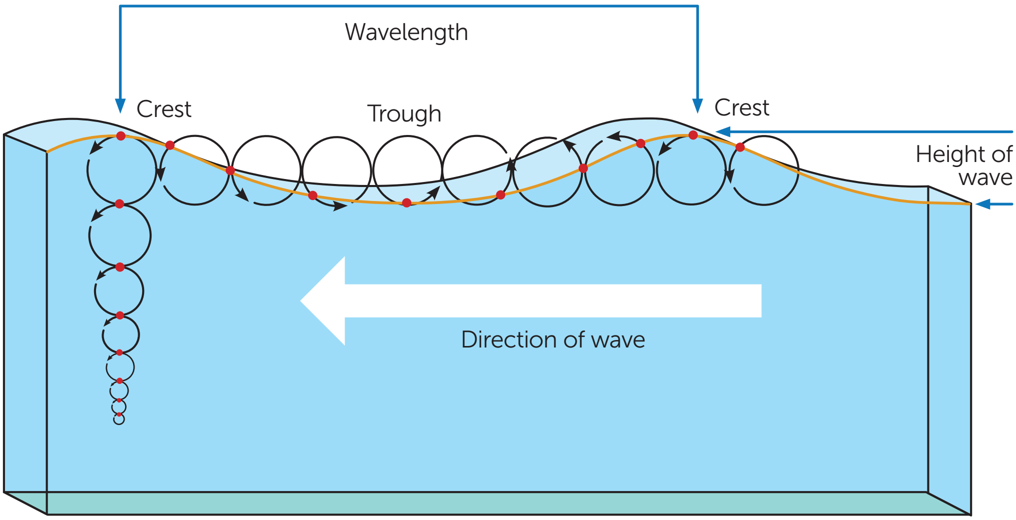
and forth, or a steel bar struck by a hammer, are all examples of a longitudinal wave propagating [**figure 2**].

In **transverse** waves, the particles of the medium oscillate perpendicular to the direction of propagation. A transverse wave propagates in a spring pulled up and down or the string of an instrument. The famous Mexican wave done in stadiums is a macroscopic example of transverse wave, as spectators stand up and sit back down in their seats [**figure 3**].

Figure 3 Transverse wave

In **mixed** waves, the two movements overlap. The best-known example is that of waves propagating in a liquid. If you look closely at a buoy on the surface of the water, you will notice that it not only moves up and down, but also back and forth, causing the water particles to rotate around a point. This is due to the fact that water, which is not in fact a true elastic medium, cannot be compressed, and this makes analyzing the wave motion inside it complicated [**figure 4**].

Figure 4 Mixed wave



As we will see later, in electromagnetic waves, what propagates by oscillating is the intensity of an electromagnetic field, which is made up of the combination of an electric field and a magnetic field. It is generated by a distribution of stationary or moving charges and it can also propagate in a vacuum.

Waves are involved in virtually every aspect of modern science. Over the coming pages, we will investigate our ability to perceive the world around us through waves. We will look at various types of waves and the very close **relationship** between these waves and **our sensory abilities**.

SOUND WAVES: HAVING A GOOD EAR!

Sound is an example of a mechanical wave. In fact, it is a wave whose source is a vibrating body, like the strings of a guitar, vocal cords, or a sheet of metal. The propagation medium is normally a gas, often air [**figure 5**].

For example, the vibration of a sheet creates zones of compression and rarefaction of the air that propagate: the property that oscillates in this case is the air pressure (or density).

The resulting sound is a longitudinal wave formed by successive compressions and rarefactions of the medium, and this is why it is called a **pressure wave** or density wave. We hear sound because the sound wave makes our eardrums vibrate [**figure 6**].

Let's now take a closer look at the structure of the human ear and, in particular, its three substructures: the outer, middle, and inner ear [**figure 7**].

- **Outer ear** (the auricle or pinna and the auditory canal): the auditory canal, also known as the ear canal (l ~ 25 mm), acts as a resonator at the frequency of about 3,500 Hz.
- **Middle ear** (eardrum, ossicles, and oval window): the ossicle system (a type I or first class lever) transmits the vibrations of the eardrum to the inner ear through the oval window.
- **Inner ear** (cochlea and acoustic or cochlear nerve/semicircular canals): this is a complex hydrodynamic system (the cochlea), containing a fluid

Figure 5 Sound waves

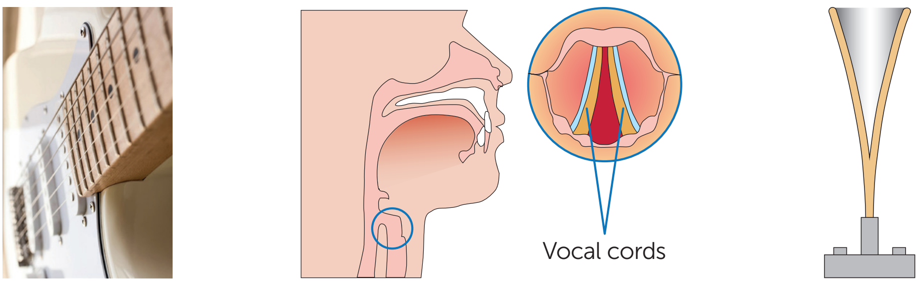


Figure 6 The perception of sound

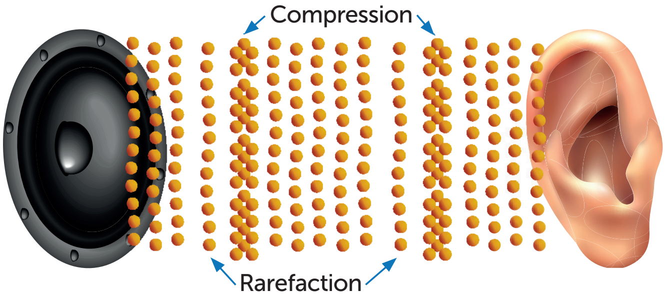
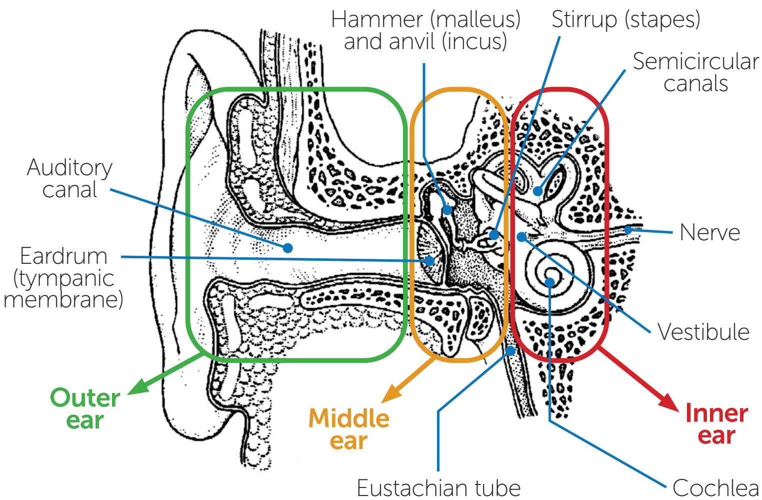


Figure 7 Structure of the human ear



(perilymph) and nerve receptors (hair cells). This is where the mechanical impulses are converted into nerve signals.

PROPERTIES OF SOUND

- **Pitch**: distinguishes a high-pitched (shrill) sound from a low-pitched (deep) one and depends on the fundamental frequency of the vibration. The higher the frequency, the higher pitched the sound; the lower the frequency, the lower pitched the sound.

- **Intensity**: distinguishes a high-volume sound from a low-volume one and depends on the amplitude of the oscillation, i.e., the energy of the disturbance; a greater amplitude is equivalent to a louder sound and a lower amplitude to a quieter sound.
- **Timbre**: depends on the particular periodic law with which the sound wave oscillates. It is a characteristic property of every sound source. The higher the frequencies, the shriller the sound [**figure 8**].

The frequency of sound is measured in Hertz (Hz), named after the German physicist Heinrich Rudolf Hertz. One Hertz is equivalent to one complete oscillation in a period of one second; if a sound is 500 Hz, it means that the body that produces it vibrates 500 times per second. In nature, sounds range from a minimum of 1 Hz to a maximum of about 1,000,000 Hz.

Can we hear ultrasound?

The human ear can perceive sounds between 20 Hz and 20,000 Hz. Sounds with a frequency <20 Hz are called **infrasound**; those >20,000 Hz are called **ultrasound**. Many animals are able to hear these types of sounds because they have hearing with a wider frequency range than humans [**figure 9**].

Figure 8 Properties of sound

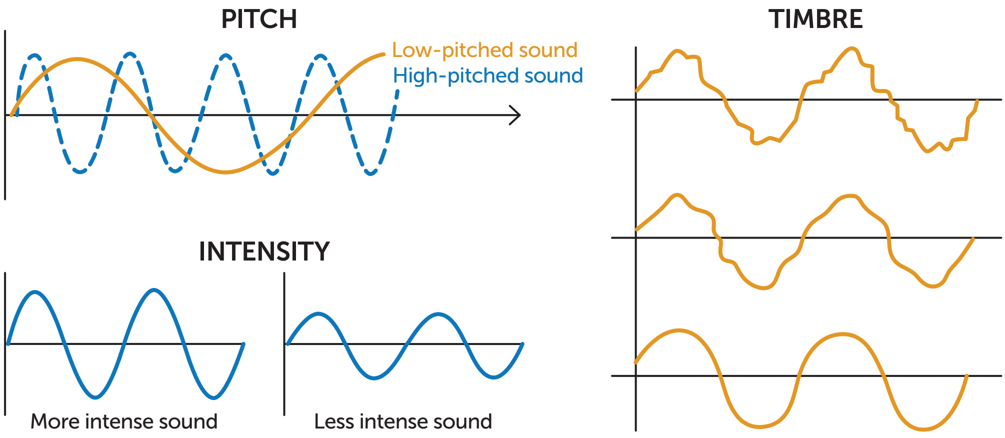
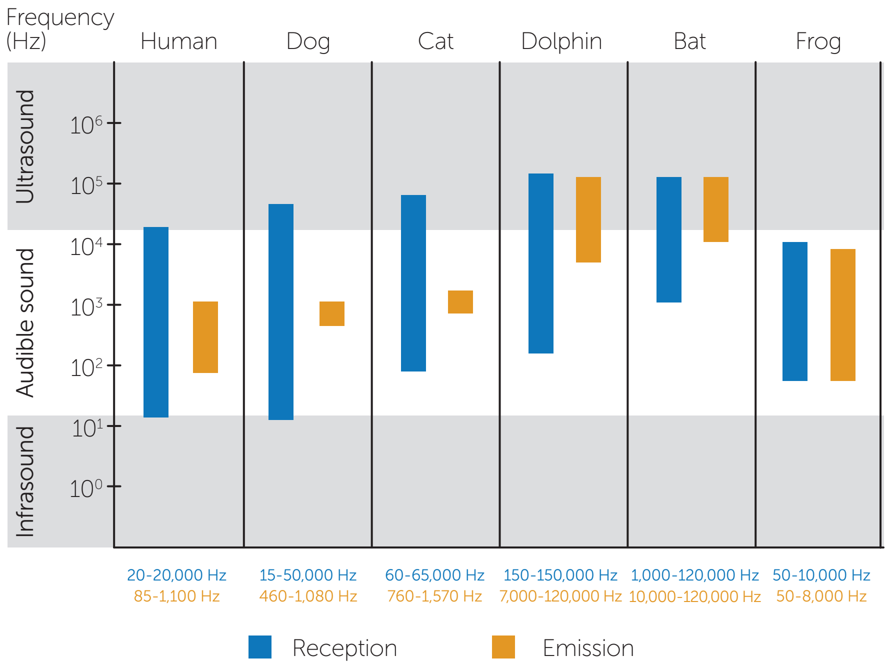


Figure 9 Frequency of sound

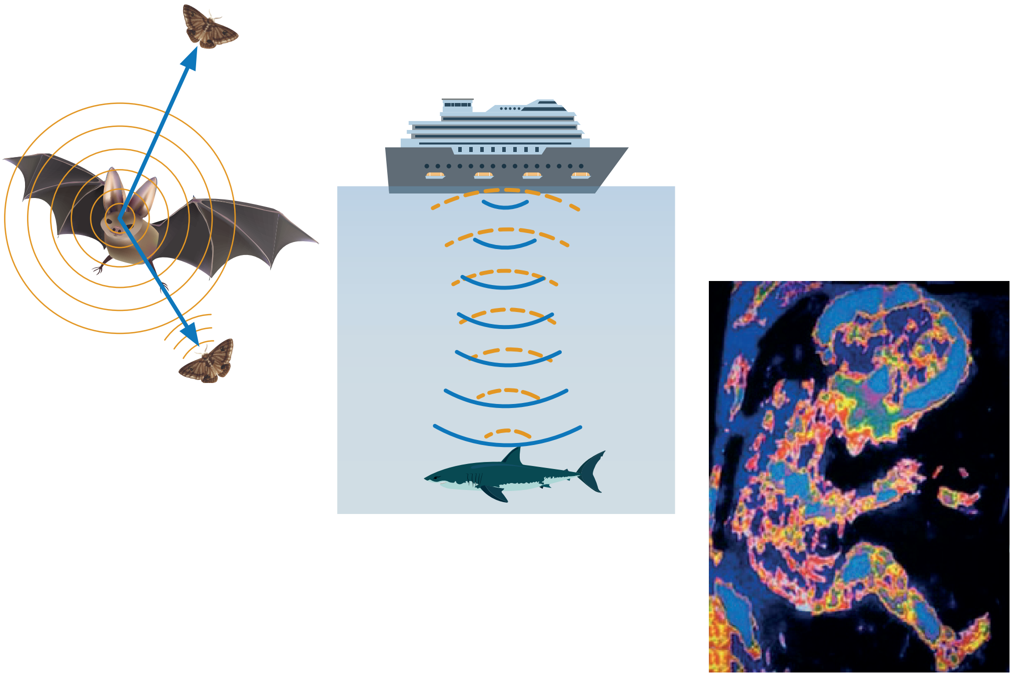


The properties of ultrasound are exploited in many fields [**figure 10**]. **Bats**, for example, can perceive the environment around them and find their way around in the dark thanks to a sophisticated system called **echolocation** (bio sonar): by emitting short bursts of ultrasound into the environment and listening to the echo that comes back, they can locate even small objects and estimate how far away they are.

Sonar is a device used in the naval sector that enables us to measure the depth of the sea and the distance of objects below its surface by measuring the time between when ultrasound signals are emitted and bounced back to the receiver.

In medicine, the best-known application of ultrasound is the **sonogram**. By measuring how long it takes for the ultrasound signals it generates to be reflected back, this diagnostic tool can produce, for example, an image of the fetus in the mother's womb.

Figure 10 Examples of the use of ultrasound

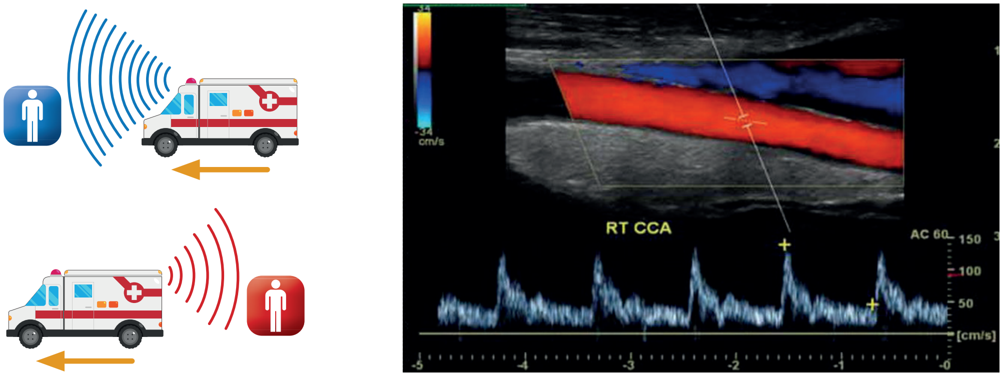


THE DOPPLER EFFECT: SENSORS AND ANGIOGRAMS

The frequency of a periodic wave detected by a receiver that is moving with respect to the source is different from that of a wave detected by a receiver that is stationary with respect to the source. When we hear the siren of an ambulance approaching us and then moving away, we initially hear a more high-pitched sound and then a lower pitched one. The same goes for Formula 1 cars as they race around the track.

Many motion sensors take advantage of this phenomenon, called the **Doppler effect**: the reflected wave has a lower or higher frequency depending on whether the moving object is moving further away or closer. In medicine, the Doppler effect of ultrasound is also used to measure the speed of blood in the veins and arteries [**figure 11**].

Figure 11 The Doppler effect



ELECTROMAGNETIC WAVES

Electromagnetic waves are the combination of electric and magnetic fields that propagate perpendicular to each other in space with wave properties [**figure 12**]. Their propagation speed is indicated by the letter "c" and corresponds to about 300,000 km/s.

What makes electromagnetic waves special is that, unlike mechanical waves, they do not need a transmission medium but can propagate even in a vacuum. In other words, we cannot see them directly, but we know that they exist, that they are practically everywhere around us, and we can measure their indirect effects. The range of electromagnetic waves constitutes what we call the **electromagnetic spectrum**. Within the spectrum, electromagnetic waves are classified according to their wavelength and frequency [**figure 13**].

A **transmitting antenna** is a device capable of radiating electromagnetic waves by converting an electrical signal. Conversely, if the antenna receives waves, transforming them into an electrical signal, it is called a **receiving antenna**.

The effects of electromagnetic waves on matter, on humans, and on biological systems in general depends on their frequency and the amount of energy they carry.

Figure 12 Electromagnetic waves

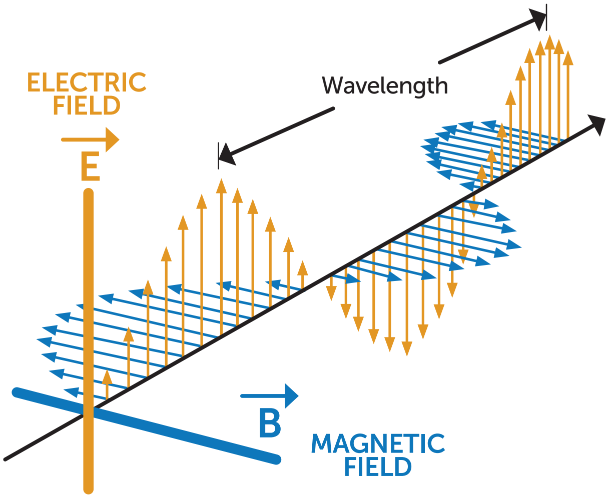
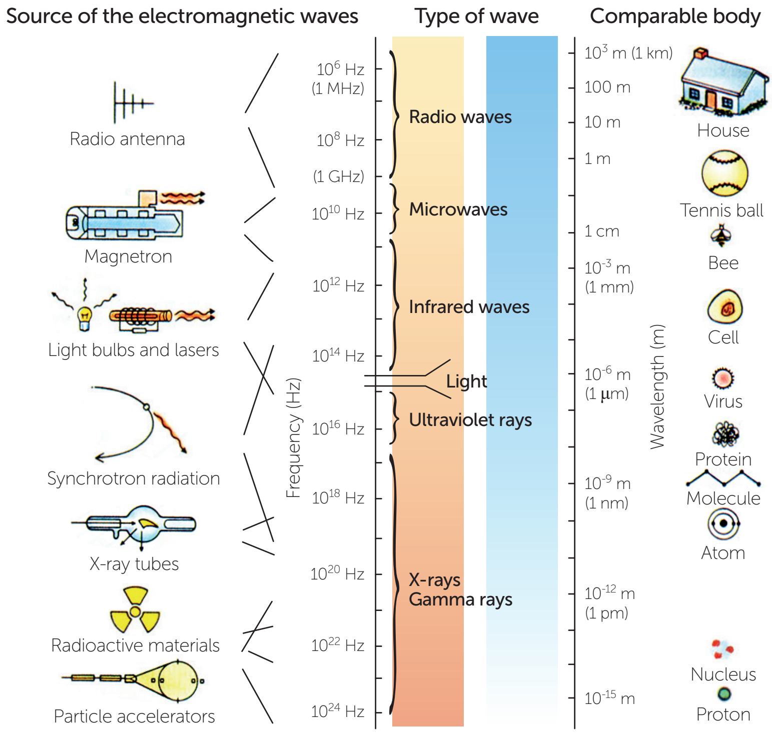


Figure 13 The electromagnetic spectrum



The atmosphere only lets in visible radiation, radio waves, and some infrared radiation. To observe the gamma, X-, and ultraviolet rays emitted by stars, we need to go into space.

Waves enable us to study phenomena that are far away in both space and time: astronomy and astrophysics base their observations on studying the spectrum of electromagnetic radiation emitted by celestial bodies, interstellar matter, and deep space. The radiation studied occupies the entire spectrum of electromagnetic waves and comes from such distances that its origin can be traced back to remote times, even to the first moments of life of the universe.

Radio waves occupy the low-frequency part of the spectrum, with wavelengths ranging from 10 km to 10 cm. Television signals, for example, travel on waves with a wavelength of about 1 meter [**figure 14**].

The wavelength of **microwaves** is between a few dozen centimeters and a millimeter. They are used in radar and telephone communications and in applications such as microwave ovens, which we will discuss in more detail later.

Visible radiation is made up of electromagnetic waves that we perceive in the form of **light**. This part of the electromagnetic spectrum is between the wavelength of 7×10^{-7} m (red) and 4×10^{-7} m (violet) [**figure 15**].

Why do we see colors?

Figure 14 Radio waves

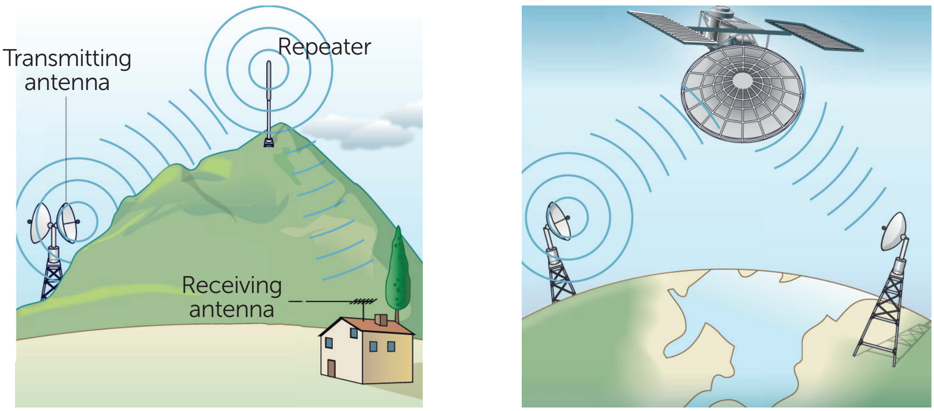
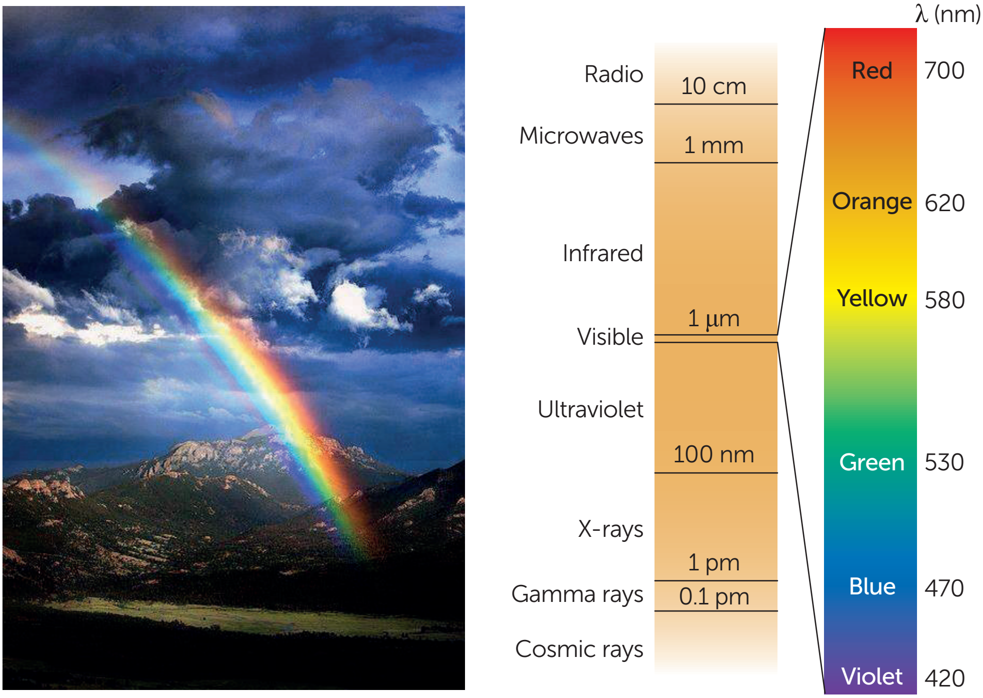


Figure 15 Visible radiation

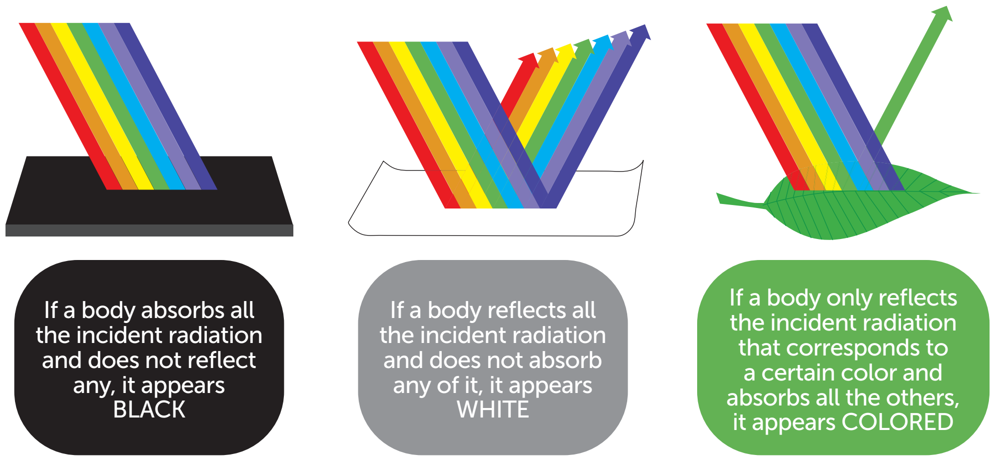


Color is a sensation that arises in our visual system when it is stimulated by waves of a particular length and most of the colors we see are due to the way illuminated bodies react to light from light sources. The light emitted by a light source that covers the entire visible spectrum is composed of all colors [figure 16].

Our eyes enable us to convert light into information that reaches the brain in the form of electrical impulses. Human beings process about 70% of the information from their external environment through vision.

When we look at an object, the light coming from it enters our eyes and passes through a series of natural lenses, called the dioptric apparatus – in order, the **cornea**, the **crystalline lens**, and the **vitreous body** – which correspond to the lenses of a camera. The light then strikes the retina, which we can think of as like the film or digital sensor in photography. The **retina**, stimulated by the

Figure 16 Color



light that hits it, transmits information to the brain by sending electrical impulses through a biological cable: the **optic nerve** [**figure 17**]. The brain processes and uses visual information to determine the behavior and reactions of the entire organism.

At wavelengths greater than $7x10^{-7}$ m and up to 1 mm is what we call **infrared radiation**, also known as thermal radiation because our body perceives it in the form of heat [**figure 18**]. This radiation makes it possible for us to observe "cold" celestial bodies, which are otherwise invisible.

Figure 19 shows how the **greenhouse effect** works, a phenomenon of natural temperature regulation caused by the presence of certain gases (in particular, methane, carbon dioxide, and nitrous oxide) in the atmosphere. Although until now the greenhouse effect has created the ideal climate for the presence and development of life on our planet, the excessive increase in these gases in recent decades is leading to global warming, a cause of great concern.

Ultraviolet radiation is found at wavelengths of less than $4x10^{-7}$ m and down to 10^{-8} m. Ultraviolet rays have the property of facilitating various chemical reactions, such as the production of melatonin in the skin, although excessive exposure can cause serious damage to the skin and eyes [**figure 20**].

Figure 17 The eye

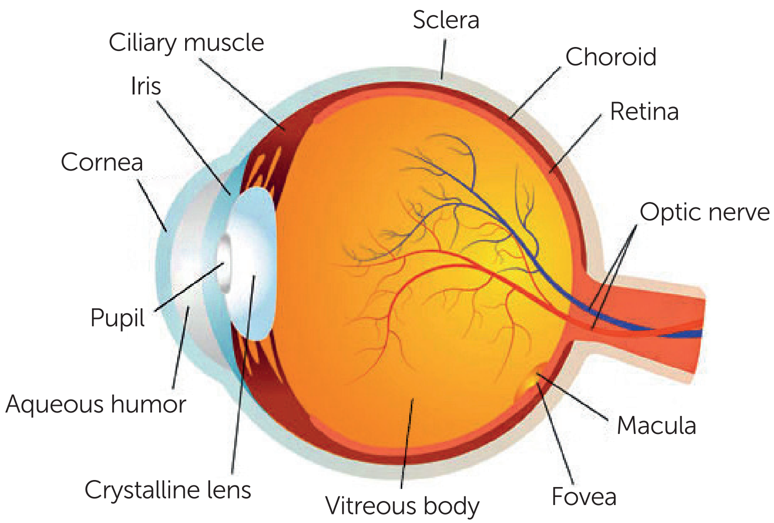
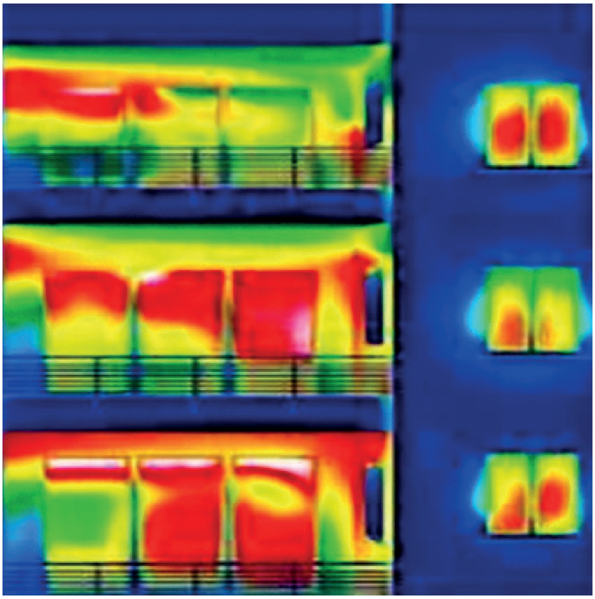


Figure 18 Infrared radiation



Infrared radiation makes it possible for us to observe "cold" celestial bodies, which are otherwise invisible.

Figure 19 The greenhouse effect

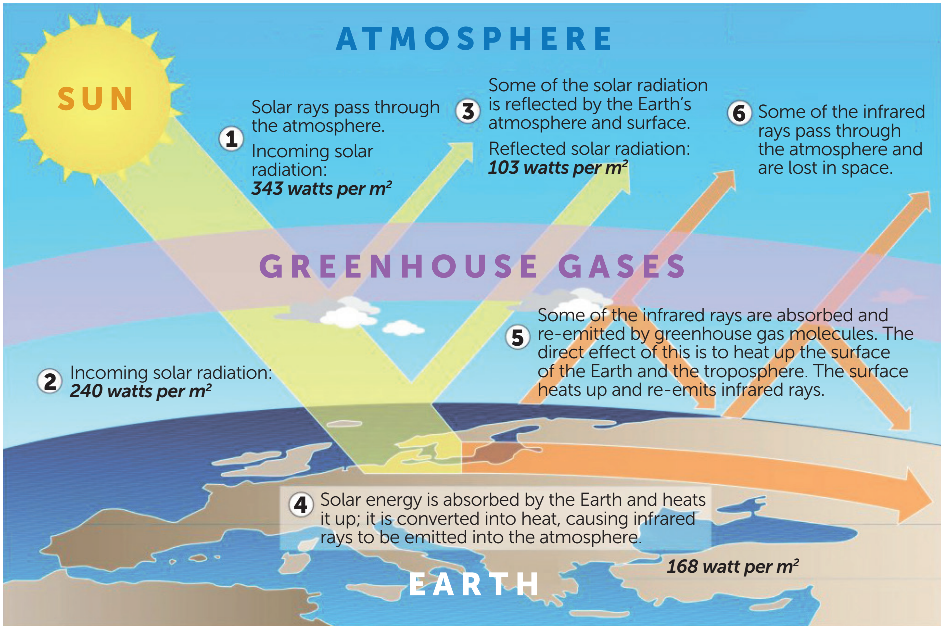
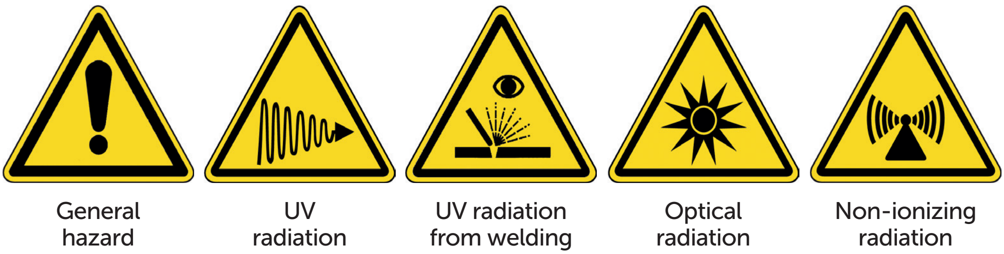


Figure 20 Hazard signs



X-rays have wavelengths between 10^{-8} m and 10^{-11} m. The most familiar applications of X-rays are without a doubt radiography and computed tomography (CT) or computerized axial tomography (CAT).

The X-rays produced by the radiological equipment pass through the patient's body, losing intensity in a differentiated way depending on the components of the body (such as water and bones), and form an image of the segment being examined on a photosensitive system (similar to a photographic system). The image obtained is processed, interpreted (radiological report), archived, and delivered to the patient on CD or DVD.

Gamma rays are found at wavelengths of less than 10^{-11} m and are naturally transmitted by nuclei during radioactive transformations and nuclear reactions. Gamma rays have a high capacity to ionize atoms and can be dangerous to living things. In medicine, they are used in cancer treatments.

EXAMPLES IN EVERYDAY LIFE: MICROWAVE OVENS AND WI-FI

THE MICROWAVE OVEN

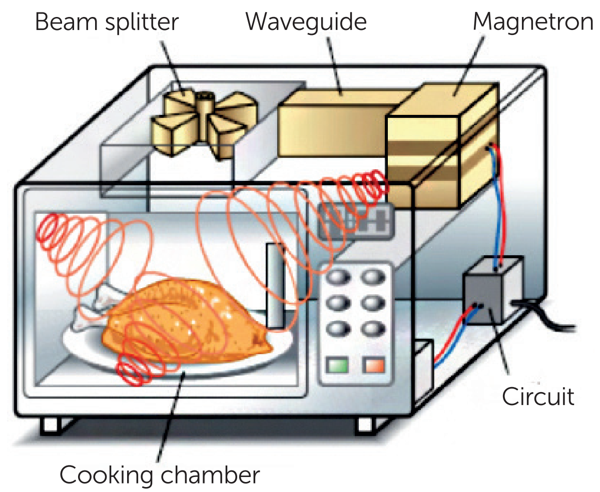
This is a very widespread kitchen appliance that cooks food through the heating effect caused by the interaction between electromagnetic fields emitted in the microwave spectrum and the food [**figure 21**].

> How does a microwave oven work?

The microwaves react with certain components of the food, such as water and fat. In water molecules, which are composed of two hydrogen atoms and one oxygen atom, the oxygen attracts electrons more than the hydrogen. This means that there is a non-neutral charge distribution that creates something called an electric dipole, which naturally tends to align with the electric field of the microwave. Since the microwave oven emits waves with an oscillation frequency of 2.45 GHz, 4.9 billion dipole direction changes occur per second! Due to this field effect, agitated water molecules tend to collide with nearby molecules, heating them up. The longer the microwaves last, the more heat will be released by the molecules and the hotter our food will be.

The microwaves are produced by a special device called a **magnetron**, which converts the electrical current into microwaves, with a power ranging from

Figure 21 The microwave oven



400 to 1,000 W. The waveguide then directs the microwaves produced by the magnetron to a beam splitter, which splits the waves evenly throughout the cooking chamber. The turntable helps further spread the microwaves across the food. The first microwave model (Radarange) was released in 1946, but it was 1.8 meters tall and weighed 340 kg!

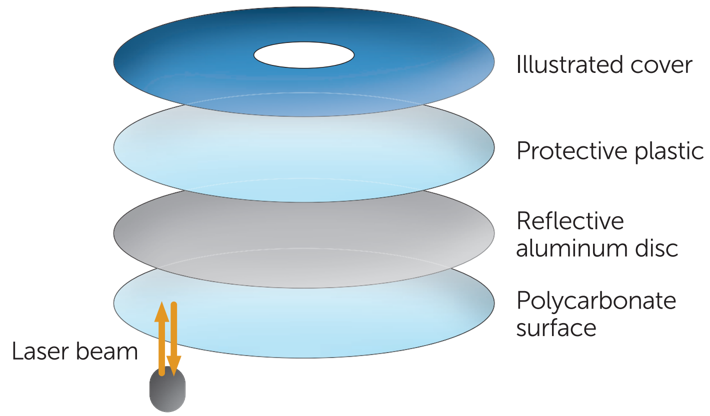
OPTICAL MEMORIES (CD, DVD, BLU-RAY)

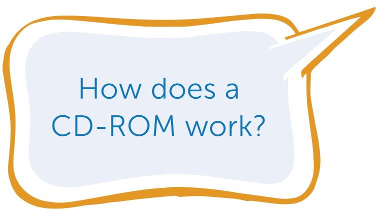
Optical memories are a type of mass memory device (also called secondary memory); they are digital and can store a large amount of data. They are called optical memories precisely because the information is read and written using laser beams on a medium called an optical disk.

The first optical memory was the compact disc (CD), which contained music and was released by Philips and Sony in 1982. A few years later, the CD-ROM (Read Only Memory) appeared, which enabled other forms of data to be recorded, such as videos [figure 22]. You can encode an impressive amount of information on CDs with a simple series of holes.

The CD-ROM is a plastic disc 12 centimeters in diameter and about a millimeter thick, composed of four layers.

Figure 22 The CD-ROM

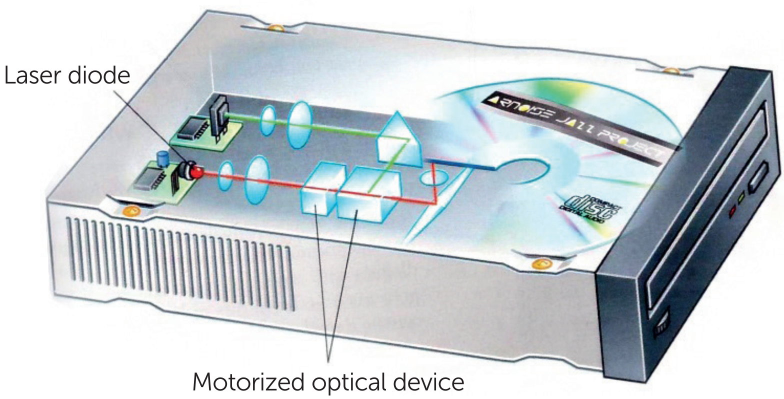




Data is stored on a CD by making tiny holes (bumps or pits) on a polycarbonate surface along a single track that spirals out from the center to the edge of the disc. The individual bits of each byte are written like this, with the flat surface (land) representing 0 and the bump representing 1. Once the plastic disc has been etched with millions of bumps, a thin layer of reflective aluminum is printed to cover and protect them. An acrylic layer and finally the label complete the whole thing. One aspect to emphasize is the size of the spiral: it is about half a micron wide and the distance between one circle and another is about 1.6 microns. The bumps etched in the track are also half a micron wide, 0.83 microns long, and 125 nanometers high (1 nanometer = 1 billionth of a meter). If you could remove the spiral from the CD and stretch it out, you would get a line 0.5 micron wide and about 5 km long!

To be able to read data printed in such a miniaturized format requires a very precise reading mechanism, the **CD player**, which is based on the laws of reflection and refraction, which are the basis of optics. A CD player is made up of three fundamental components: the laser diode, the photodiode, and an optical system [**figure 23**].

Figure 23 The CD player



The **laser diode** emits an infrared laser beam and is paired with a motorized optical device that directs the beam emitted by the diode towards the CD and allows the laser to be pointed along the entire spiral track from the center to the edge. As it passes through the plastic layer, the laser beam reflects off the aluminum layer and the reflected light is redirected towards the photodiode, which measures the intensity of the reflected beam, emitting an electrical signal proportional to the amount of light received. This sensitivity of the photodiode to light changes enables it to detect the presence of bumps and flat areas, which have a different reflected intensity, and to reconstruct the original binary code that had been digitized on the disk.

The most delicate part is keeping the laser centered on the spiral. This task is carried out by the tracking system, which controls the movement of the laser towards the edge and thus regulates the rotation speed of the disc. In fact, it is important to note how the number of bumps is related to the spiral: at the beginning of the spiral (where the radius is the smallest), a lot fewer bumps can be stored than at the end (where the radius is the largest), so it is only by synchronizing the rotation with the movement of the laser that it is possible to read the data at a constant speed.

In addition to the CD-ROM, there are also other types of compact discs such as the CD-R and CD-RW. The R in **CD-R** stands for "Recordable".

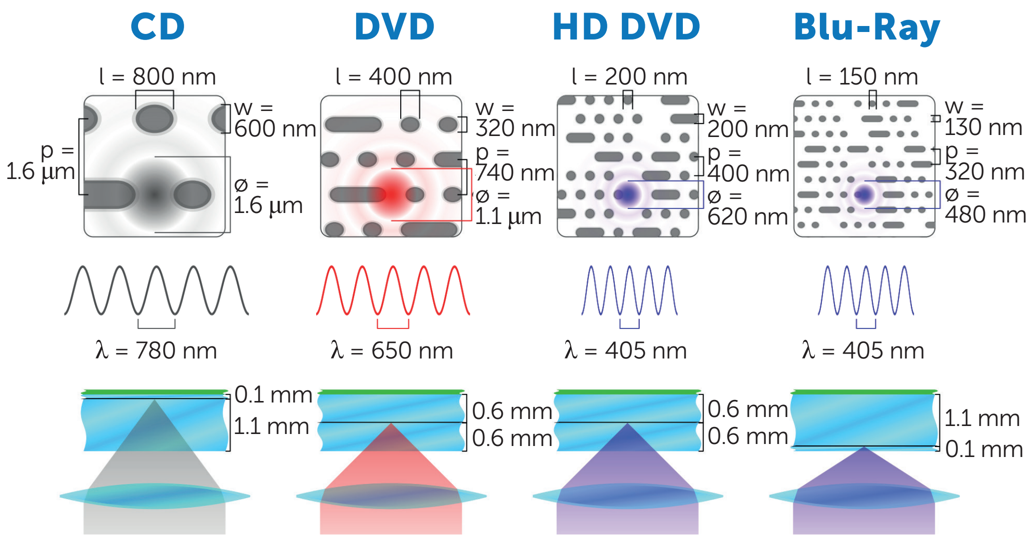
It is also called a virgin CD and has a different structure than a CD-ROM. In fact, it does not have any pits or land, but a layer of organic dye (that is, carbon-based molecules) trapped between a layer of plastic and a metal layer. As in the CD-ROM, the metal layer is protected by an acrylic layer coated by the label.

The expression "burning a CD" helps us understand how information is recorded on this structureless CD. During the recording process, the laser burns the organic dye, which reacts to light, a bit like skin tanning in the sun. This means that during the reading phase, the burned organic layer absorbs the laser light that is not reflected by the metal layer, while the unburned dye reflects most of the laser light. The dye used (there are generally three different types) and the metals used (gold or silver) determine the different colors that CD-Rs can be. The need to erase data and repeat the recording process at will gave rise to the CD-RW (which stands for "ReWritable"). Without going into detail, the dye layer on the CD-R is replaced by three layers of a material that changes some of its optical properties depending on the intensity of the laser. The process is based on the material transitioning from an amorphous phase to an ordered crystalline phase due to the application of a laser beam of variable intensity. This intensity modulation is not present in a normal CD player.

The DVD is the natural evolution of the CD: it is very similar in size and works in a very similar way. The main differences are the distance between the tracks, which drops to 0.74 microns, and the length of the pits, which is reduced to about 400 nanometers (i.e., 250 times smaller than the diameter of a hair). This makes it possible to store a much larger amount of data: in fact, a DVD can contain up to 20 times the data stored on a CD. Unlike CDs, which have a single layer of data and a capacity of about 800 MB, DVDs can have one or two layers on one or both sides, which obviously gives them a much greater capacity of between 4.38 and 15.9 GB.

Continuous improvements in the technique of printing on the metal of CDs and DVDs have made it possible to create tracks even closer together than those on DVDs, around 0.3 microns. To read these tracks, it is necessary to decrease the wavelength of the laser by 405 nanometers, which makes it

Figure 24 CD, DVD, HD DVD, Blu-Ray



blue. This is why these discs are called Blu-Ray Discs; they were launched in 2004 and make it possible to store between 25 and 128 GB of data per layer, the amount necessary to record high-definition films. As of 2015, there is now also the Ultra HD Blu-Ray standard, which supports 4K technology [**figure 24**].

◎ WI-FI

The need to always stay connected on the move has required new technologies that make it possible to connect to the network without the use of electrical conductors, i.e., **wirelessly**.

Wireless typically uses low-power radio waves; however, the definition also extends to less common devices that harness infrared radiation or lasers. In the 1990s, the spread of the internet pushed the development of technology towards data transfer without the use of a fixed network, favoring the development of both technologies such as WAP or GPRS, which enabled the creation of long-range data networks, and medium- and short-range wireless standards, leading to the creation of WLANs [**table 1**] in 1997.

Table 1 Acronyms

GPRS	*General Packet Radio Service*
GSM	*Global System for Mobile Communications*
LAN	*Local Area Network*
UMTS	*Universal Mobile Telecommunications System*
WAP	*Wireless Application Protocol*
WLAN	*Wireless Local Area Network*

The main benefits of wireless networks, in addition to being the architecture of choice in situations where wiring is difficult, can be summarized in the following points:

- *Mobility*: users can move around while continuing to use their own terminal and connect in public areas (hotspots).
- *Short-term connectivity*: it is possible to create ad hoc networks, for example for a particular meeting or event.
- *Quality/price ratio*: a wireless network can be installed quickly without the need for masonry work and has practically zero maintenance costs.

There are two families of wireless networks:

- *mobile radio networks*, where users can move around the region without losing connectivity with the network;
- *wireless LAN*, wireless networks that provide the coverage and services typical of a LAN.

One of the characteristics of mobile telephony is the possibility of keeping communication active while moving freely around the region. This may involve frequent changes in the transmission cells or channels for optimal transmission quality. This switching is called a handover.

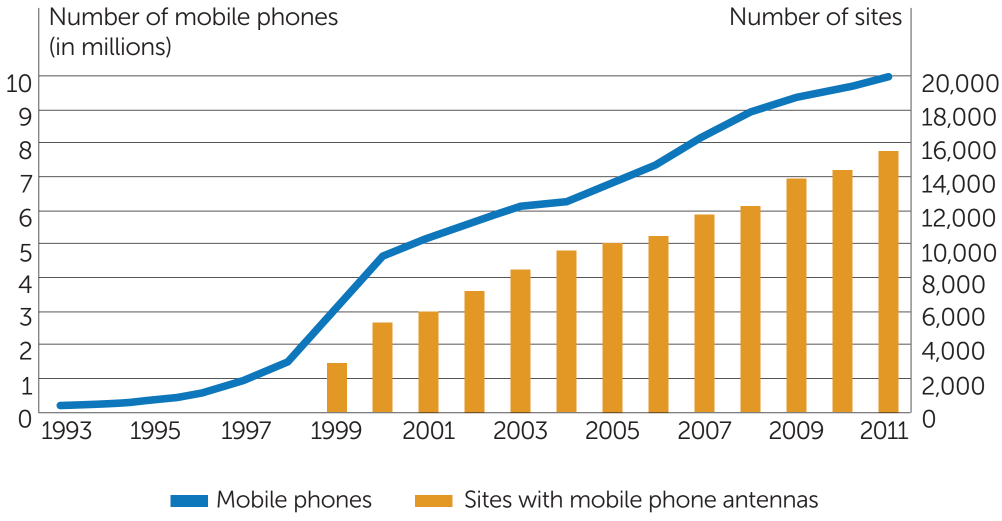
Wireless networks can also be classified on the basis of the geographical distance of the "coverage area":

- BAN (up to 2 meters);
- PAN (up to 10 meters);
- WAN (up to 100 meters);
- WWAN (up to a few dozen kilometers).

In 2007, the number of mobile phone subscriptions in Switzerland exceeded the number of inhabitants. At the end of 2010, there were 124 mobile phone subscriptions registered per 100 inhabitants and almost 14,500 sites with mobile phone antennas were registered [**figure 25**].

The absorption of electromagnetic waves by the human body is measured by a value called the **SAR** (Specific Absorption Rate). It is calculated in units

Figure 25 Subscriptions and sites with antennas in Switzerland

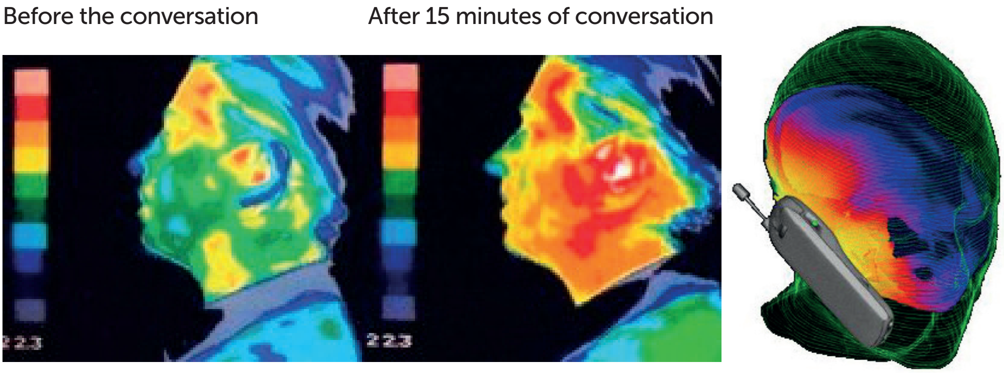


Source: Swiss Federal Office of Communications.

of power per mass and the permitted limit in Europe is 2 watts per kilogram (2 W/kg) in a sample of 10 grams of tissue, while in the United States the value must be less than or equal to 1.6 W/kg.

Figure 26 shows the heat generated by a mobile phone on the face after 15 minutes of conversation due to the electromagnetic radiation emitted.

Figure 26 Thermographic images during a conversation on a mobile phone

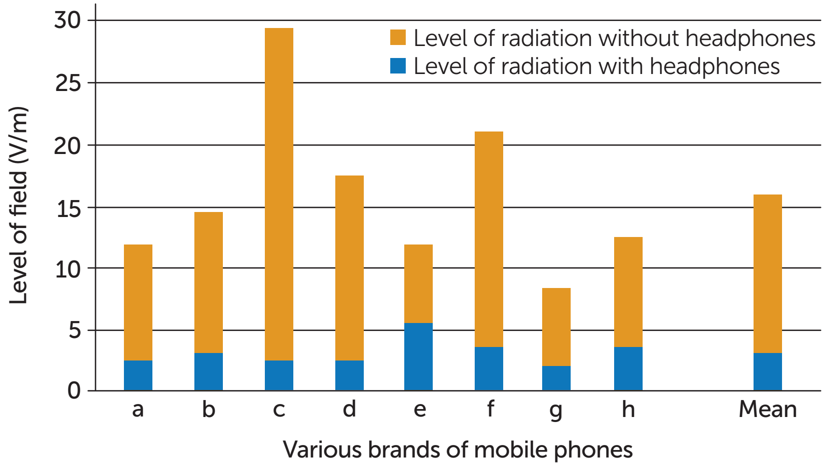


SAR values can vary greatly by brand, so you should check the official SAR value before buying a model.

With this in mind, it is definitely advisable to use headphones, which greatly reduce the absorption of the radiation to which you are exposed. In Switzerland, the Federal Office of Public Health (FOPH), for example, examined a number of Bluetooth headphones, finding that SAR levels dropped to 0.01 W/kg. A WWF study showed that headphone use reduces exposure to non-ionizing radiation by about 70% to 90% [**figure 27**].

Mobile phones, however, are not the only source of electromagnetic fields in the world all around us. In the home, for example, there are often devices such as a wi-fi router (2.4 GHz; 100 mW), a cordless phone (1,900 MHz; 150-250 mW), and a wireless repeater (2.4 GHz and 433 MHz; 10 mW).

Figure 27 Level of exposure to the magnetic field of mobile phones with and without headphones



Source: WWF.

◎ OTHER APPLICATIONS

Using the same principle that underlies many modern diagnostic techniques in medicine, such as the aforementioned X-rays in radiography and ultrasound in sonograms, most of the properties of matter at the molecular or atomic level are measured by irradiating a sample with waves (typically, electromagnetic waves such as visible light, ultraviolet, X-rays, and gamma rays, but also electron or neutron beams), and observing the reaction of the sample.

The science of conserving and restoring works of art, for example, uses techniques based on the use of appropriate spectroscopy: fluorescence, absorption, transmission in the optical band, infrared, ultraviolet, and X-rays.

Thanks to certain well-known TV series, everyone is now familiar with scientific investigative techniques that are a fundamental tool for law enforcement nowadays. Based on a set of physical, chemical, and biological investigative techniques known as forensics, it is possible to obtain elements to reconstruct a crime scene that are often decisive for the purposes of investigations. For example, police forensic departments use similar methods to highlight otherwise invisible organic traces at the scene of a crime.

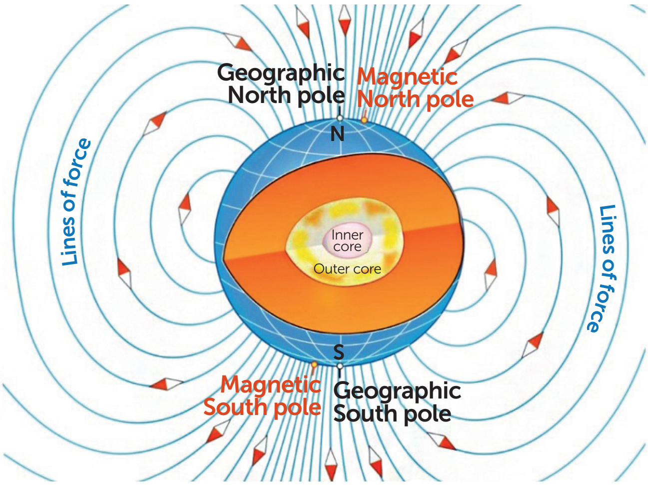
THE EARTH'S MAGNETIC FIELD: MAGNETORECEPTION

The discovery of the Earth's magnetic field and thus of the compass is attributed to the Chinese, who at first, however, only used it as an attraction trick: they would throw magnetized needles like dice and, to the amazement of the spectators present, they always ended up pointing north. It was only around the 11th century that they began to use it for navigation. The compass was then introduced to Europe in the 12th century through the Arabs and Amalfitans: the first reference to the use of the compass in navigation in Western Europe is the *De nominibus utensilium* by Alexander Neckam (1180-1187) [**figure 28**].

Magnetoreception is a sort of internal biological compass that enables animals to sense the Earth's magnetic field and is characteristic of many species [**figure 29**]. Below are the dates of the most important discoveries about some migratory animals made by researchers.

- 1850: Alexander Theodor Middendorf deduces that migratory birds follow fluxes to the magnetic north.

Figure 28 The Earth's magnetic field



- 1947: Henry Lincoln Yeagley demonstrates that the routes of homing pigeons change if a magnet is attached to them.
- 1965: Wolfgang Wiltschko shows that the behavior of robins is influenced by the magnetic field.
- 1976: the spouses Fred and Norah Urquhart identified the migratory movements of monarch butterflies, discovering that from southern Canada and the central and eastern United States, these butterflies reach a small valley located in Mexico at 3,000 m above sea level, where more than 14 million butterflies are concentrated in an area measuring one and a half hectares during the winter. In the following spring, after mating, individuals of both sexes begin the return journey, during which some females stop to lay eggs; in some cases, it is the next generation that completes the journey, recolonizing the northernmost regions. The migrations north to Canada take place over three generations, while the return to Mexico takes place in a single generation. This is a rare case of migration across multiple generations.

Over the past few decades, further experiments have confirmed that migratory birds are indeed able to detect the Earth's magnetic field and use it to navigate.

Many other animal species have now been hypothesized to possess magnetoreception, such as lobsters, turtles, manta rays, sharks, dolphins, bees, and microorganisms, which all exhibit behaviors that are influenced by the Earth's magnetic field.

Figure 29 Migratory animals

Monarch butterfly | Robin (*Erithacus rubecula*) | Sea turtle (*Caretta caretta*) | Homing pigeon

How does magnetoreception work?

But what physiological processes are involved in this phenomenon? How can a fairly weak magnetic field like the one generated by the Earth translate into a nerve signal capable of changing the behavior of an animal? Numerous experts in biophysics have started to take an interest in this question and have set out in search of magnetoreceptors.

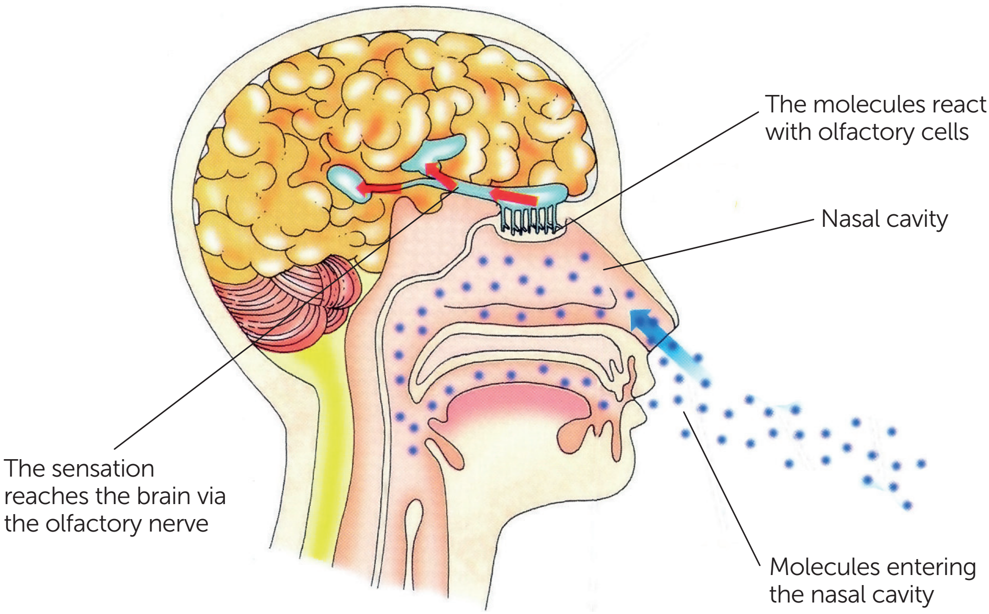
At the moment, there are two ideas. According to the first, when light hits the bird's eyes, the Earth's magnetic field triggers chemical reactions in a particular type of protein present in the retina, the **cryptochromes**. The second idea, on the other hand, suggests that there are cells in the body that contain small "compasses" made up of magnetite molecules that can *open* or *close* neural circuits when they move. It has not been possible to obtain irrefutable scientific evidence for either hypothesis so far, not least because the experiments are difficult to replicate due to magnetic interference.

Recently, experiments have been carried out by an international research team led by academics from the California Institute of Technology (Caltech) and the University of Tokyo, which suggested that Homo Sapiens also has the ability to perceive the Earth's magnetic field. Their tests showed that the frequency of alpha waves in the brains of some participants collapsed as soon as the scientists started a magnetic stimulation that reproduced the Earth's magnetic field, and then immediately returned to their original state. But, as you can tell from these considerations, there is still a lot of work to be done on the phenomenon of magnetoreceptivity!

SMELL: A MATTER OF WAVES AS WELL?

The nose has no role other than to channel air. Smell and taste, which are closely connected, receive information directly from contact with the detected object (molecule) through olfactory receptors, of which there are a few hundred. The measuring instruments used for other senses, such as sound (frequency, pitch, chromaticism, timbre, key), do not exist for odorous molecules [**figure 30**].

Figure 30 Smell



Questions about smell have always intrigued human beings, since ancient times. Democritus was the first to theorize the atomic nature of scents and today we know that molecules are composed of atoms. For him, smell was the instrument responsible for feelings, desires, and impulses. Later, Plato, while recognizing the aesthetic contribution of smell, denounced carnal deviations as "a symbol of decadence and sexual perversion". It is interesting to note that the link between body odors and sexuality is now a scientific reality, especially after the discovery of pheromones, substances that have an effect on individuals of the same species, causing certain behaviors. For example, dogs bite because they detect the scent of fear.

Later Aristotle, who had described the characteristics of odorous substances, elaborated his theory on the basic smells from which all the others could be derived, which remained in vogue for centuries. For him, there were six basic odor categories: sweet, sharp, acidic, greasy, bitter, and foul. The Pompeian Lucretius, likewise an atomist, believed instead that the world of scents played an important role in the lives of human beings and, driven by the desire for knowledge, he came up with the lock and key concept, according to which smells were captured by receptors. This theory was then further developed by the Austrian chemist Hermann Emil Fischer in 1894, who speculated on the specific interaction between the enzyme and the substrate. He thought that when they became volatile, odorous substances "produce atoms of all the same shape and size, which give rise to the perception of odor when they reach the pores inside the nose; these pores have different shapes and the nature of the smell depends on the type of pore that the atoms fit into".

Subsequently, many other scholars who studied the subject have tried to classify odors to establish if the enormous variety of scents could be produced starting from a limited number of "basic" smells. In 1756, the famous botanist Linnaeus, following the Aristotelian doctrine, proposed a classification of seven basic smells: ambrosial, aromatic, fragrant, alliaceous, hircine, repulsive, and nauseating. Other attempts have also been made to apply basic color theory to odors, but without success. Just consider that with three basic colors, you can describe the entire chromatic universe, while in the case of smell, there are millions of nerve fibers that work separately, making describing the olfactory universe practically impossible.

There are currently two theories:

- key and lock: the odorous molecules fit complementarily into the corresponding receptors. So molecules with a similar shape have a similar smell;
- vibration theory (Dyson and Turin): it is the frequency at which certain molecular bonds between the atoms of the molecule vibrate that determines the smell.

The latter thesis is supported by the fact that replacing some atoms with heavier isotopes does not change the structure of the molecule in question, but it does change the vibration frequency of some bonds. And, in fact, the way the smell is perceived also changes.

At the moment, however, there is no scientific certainty that enables us to say that one of the two theories is valid. It cannot be ruled out that the two effects may ultimately work in conjunction.

CONCLUSIONS

We have come to the end of our journey through the world of waves, during the course of which we have investigated the principles behind many natural phenomena involving the way living beings perceive the world around them.

At the same time, we have also seen how human ingenuity has enabled mankind to exploit the knowledge of the vibrations of matter to our advantage, to develop a whole series of technologies that exploit waves and are useful to us today: from data transmission to diagnostics, and even in the kitchen.

We therefore live immersed in a reality populated by waves both natural and manmade, waves that propagate in a transmission medium and that carry energy, waves that are able to generate effects on matter ranging from minor to major. The nature of the effects depends on the energy carried by the wave and the size of the target with which it interacts, as well as other properties of flux intensity. Knowing the nature of these waves can ultimately be useful for us to be able to lead better lives, allowing us to make the best rational choices.

The next time find ourselves discussing smells, having to comment on the effects of an earthquake, or talking about telephone antennas, we will have a new way of thinking that will give us a better understanding of the problems and enable us to come up with the best solutions.

Wave upon wave...

PART TWO

TEXTS

By the students of class 3A of the Caslano Middle School:

Filippo Bassi
Luana Berbasconi
Maura Berbasconi
Andrea Carulli
Tommaso Colaciuri
Maya Corradina
Gabriele Della Ca'
Shania Donnicola
Eleonora Fattorini
Elena Grassi
Enea Maina
Lia Maina
Andrea Martilotta
Marika Masciale
Moe Pasquali
Alissa Pellizzari
Edoardo Ratti
Eleonora Roscia
Nicolò Sürder
Alan Tobler
Leonardo Zaccarelli

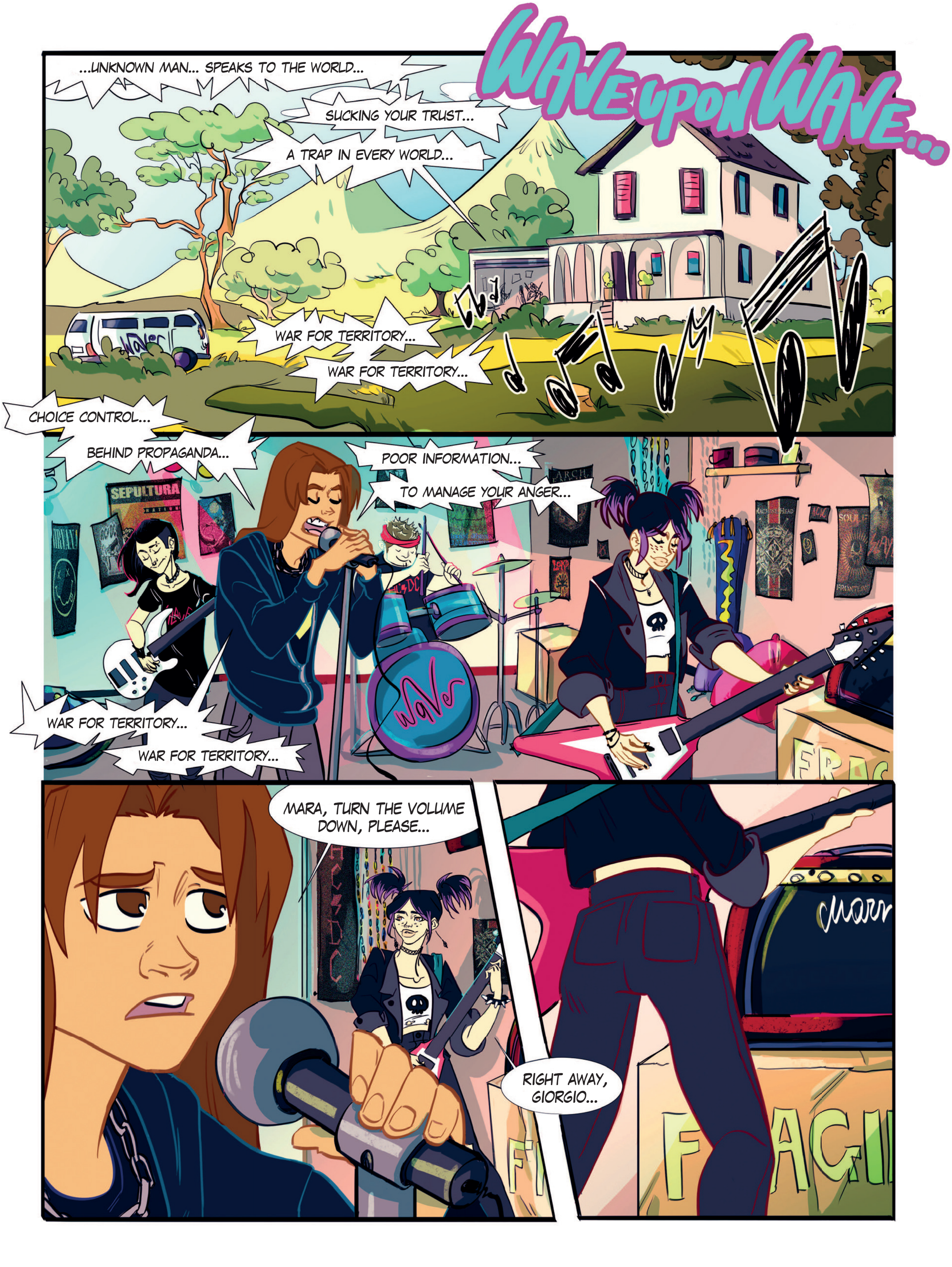
Under the coordination of the teachers:

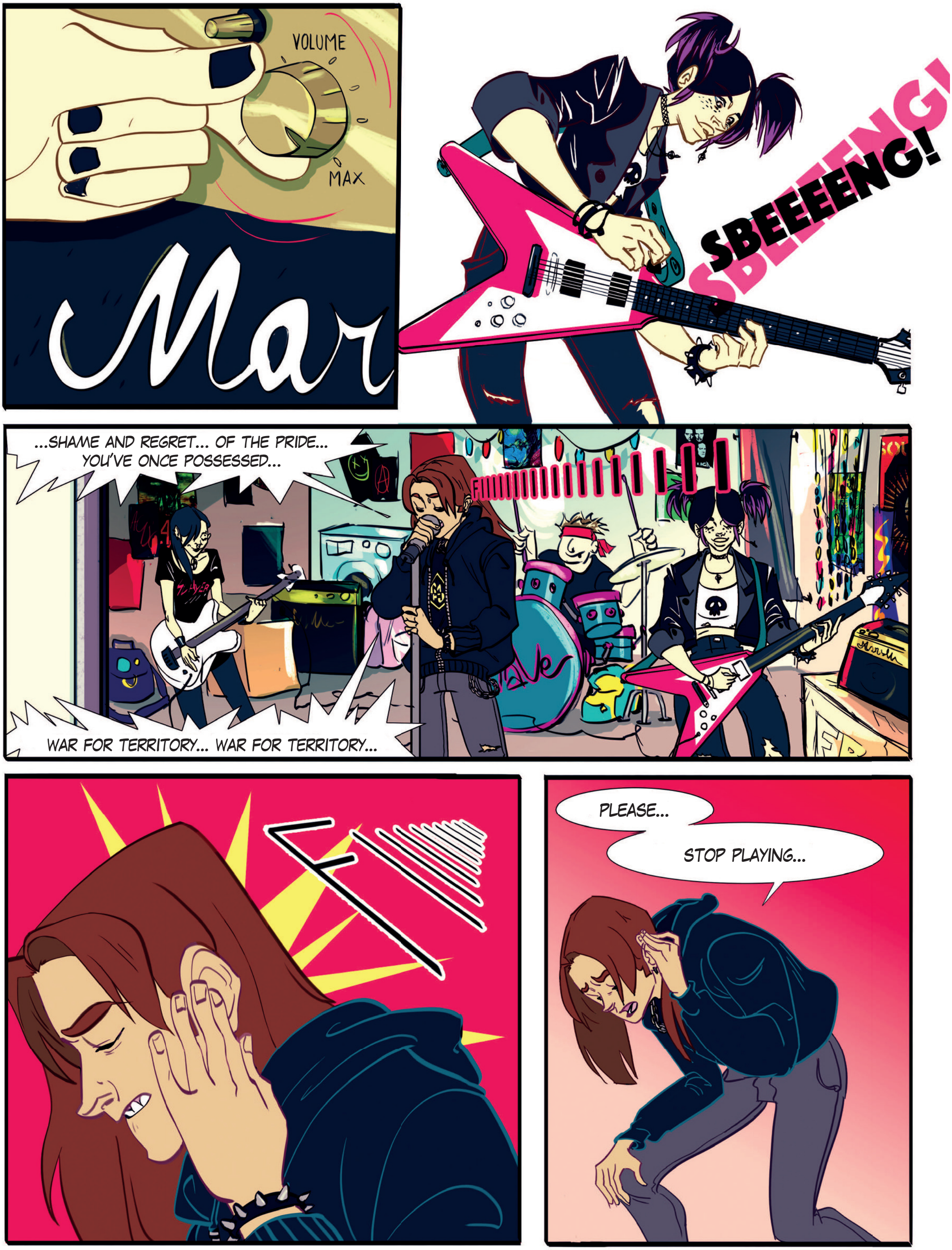
Erika Longhi Gygax (science and mathematics teacher)
Lavinia Anzalone (Italian teacher)
Luca Montanaro (visual education teacher)

Caslano Middle School
27 Via Industria - 6987 Caslano
Ticino - Switzerland
www.smcaslano.ti.ch
decs-sm.caslano@edu.ti.ch
Head teacher: Lara Pfyffer Gianocca

ILLUSTRATIONS

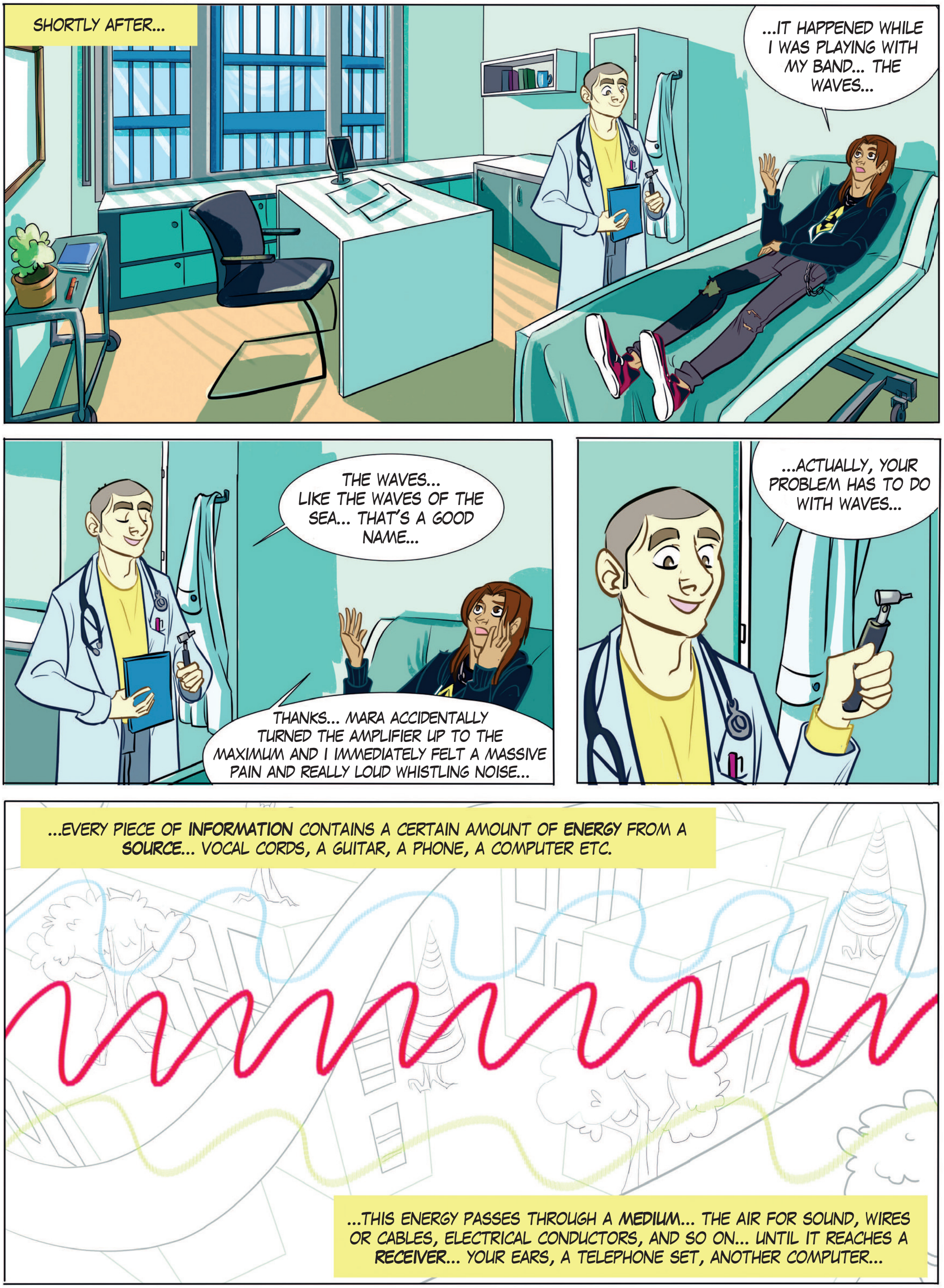
By Angela Piacentini for the Scuola Romana dei Fumetti.


WAVE UPON WAVE...
...UNKNOWN MAN... SPEAKS TO THE WORLD...
SUCKING YOUR TRUST...
A TRAP IN EVERY WORLD...
WAR FOR TERRITORY...
WAR FOR TERRITORY...
CHOICE CONTROL...
BEHIND PROPAGANDA...
POOR INFORMATION...
TO MANAGE YOUR ANGER...
WAR FOR TERRITORY...
WAR FOR TERRITORY...
MARA, TURN THE VOLUME DOWN, PLEASE...
RIGHT AWAY, GIORGIO...

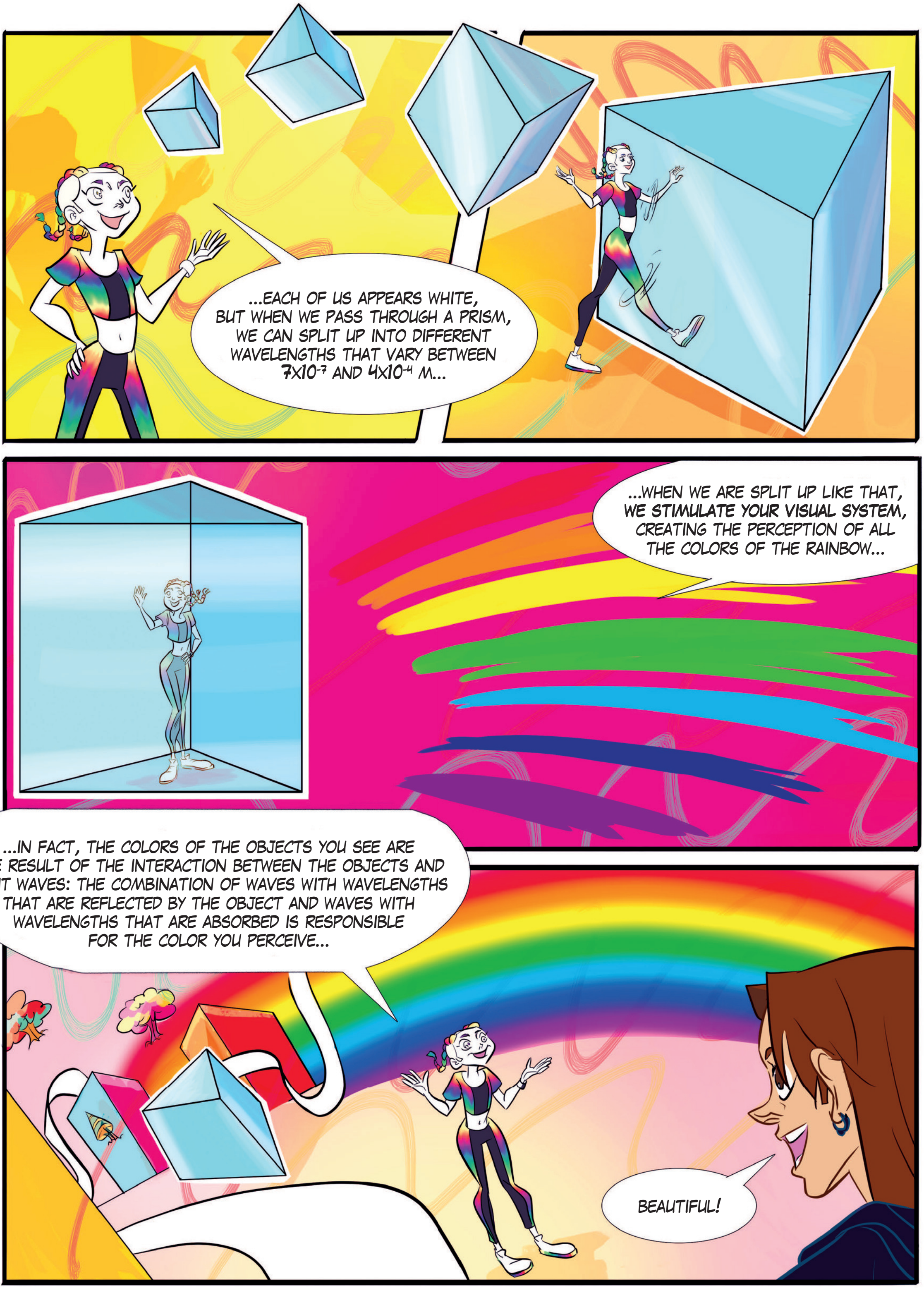

VOLUME
MAX
Mar
SBEEEENG!
SBEEEENG!
...SHAME AND REGRET... OF THE PRIDE... YOU'VE ONCE POSSESSED...
FIIIIIIIIIIIIIII
WAR FOR TERRITORY... WAR FOR TERRITORY...
FIIIIII
PLEASE...
STOP PLAYING...


BUT WE'VE ALREADY STOPPED, GIORGIO...
THEN WHY CAN I STILL HEAR THE SCREECH OF THE GUITAR LIKE A REALLY LOUD WHISTLE?
...IT'S UNBEARABLY PAINFUL!
LET'S SEE WHAT IT SAYS ONLINE...
Google
severe pain in the ea...
...in the ear
IT SAYS HERE THAT A SUDDEN LOUD NOISE CAN ALSO CAUSE PERFORATION OF THE EARDRUM...
MAYBE THE BEST THING TO DO IS GET HIM TO THE HOSPITAL RIGHT AWAY... THE DOCTORS WILL KNOW WHAT'S WRONG BETTER THAN THE INTERNET!
RIGHT! LET'S TAKE THE VAN...


VROOOM
LET'S HOPE IT'S NOTHING SERIOUS... WE'VE GOT THE CONCERT IN A FEW WEEKS...
IT WON'T BE, YOU'LL SEE...
P
A&E
TI·12345
A & E
THE DOCTOR WILL SEE YOU RIGHT AWAY... YOUR FRIENDS CAN WAIT FOR YOU HERE...

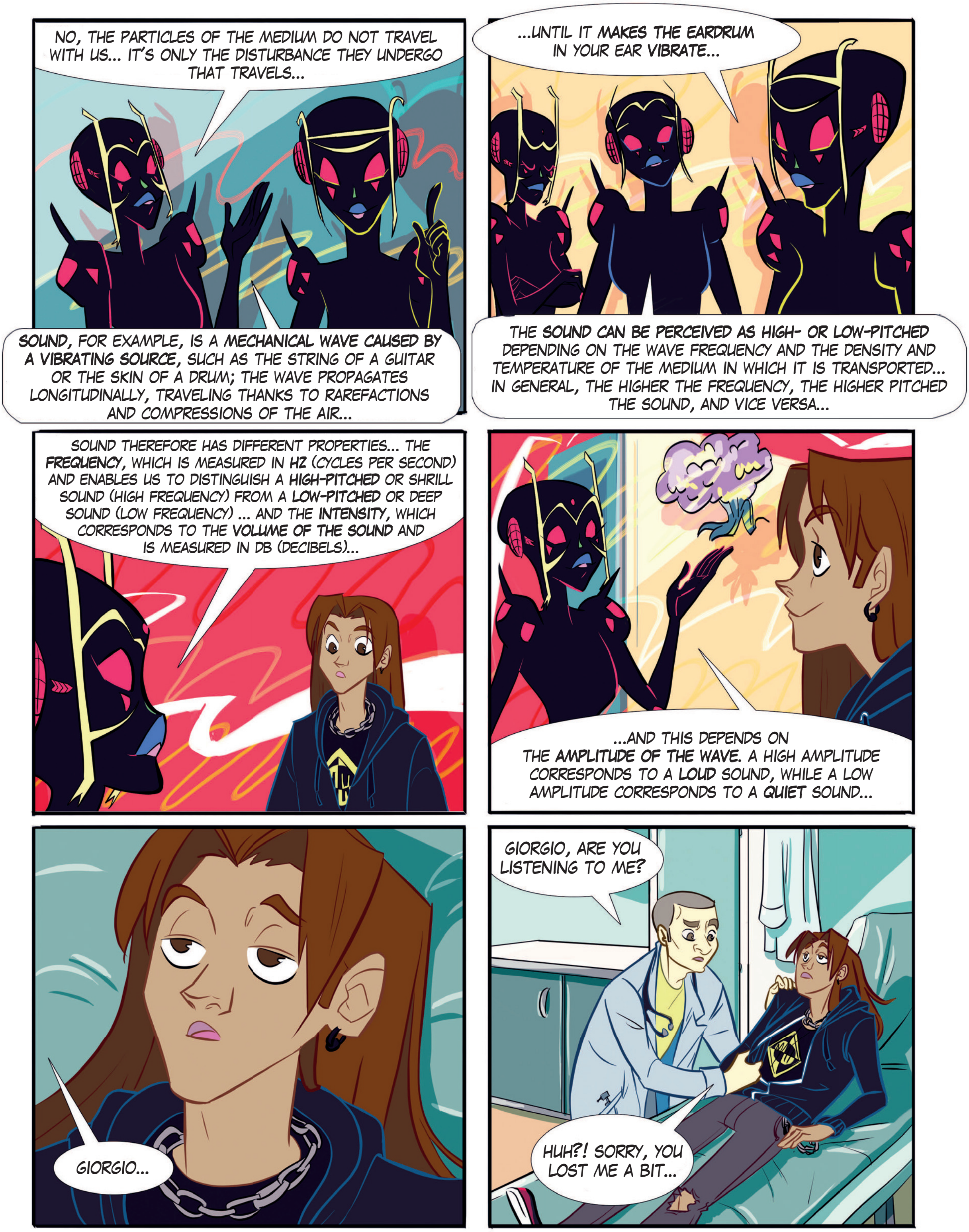

SHORTLY AFTER...
...IT HAPPENED WHILE I WAS PLAYING WITH MY BAND... THE WAVES...
THE WAVES... LIKE THE WAVES OF THE SEA... THAT'S A GOOD NAME...
THANKS... MARA ACCIDENTALLY TURNED THE AMPLIFIER UP TO THE MAXIMUM AND I IMMEDIATELY FELT A MASSIVE PAIN AND REALLY LOUD WHISTLING NOISE...
...ACTUALLY, YOUR PROBLEM HAS TO DO WITH WAVES...
...EVERY PIECE OF **INFORMATION** CONTAINS A CERTAIN AMOUNT OF **ENERGY** FROM A **SOURCE**... VOCAL CORDS, A GUITAR, A PHONE, A COMPUTER ETC.
...THIS ENERGY PASSES THROUGH A **MEDIUM**... THE AIR FOR SOUND, WIRES OR CABLES, ELECTRICAL CONDUCTORS, AND SO ON... UNTIL IT REACHES A **RECEIVER**... YOUR EARS, A TELEPHONE SET, ANOTHER COMPUTER...

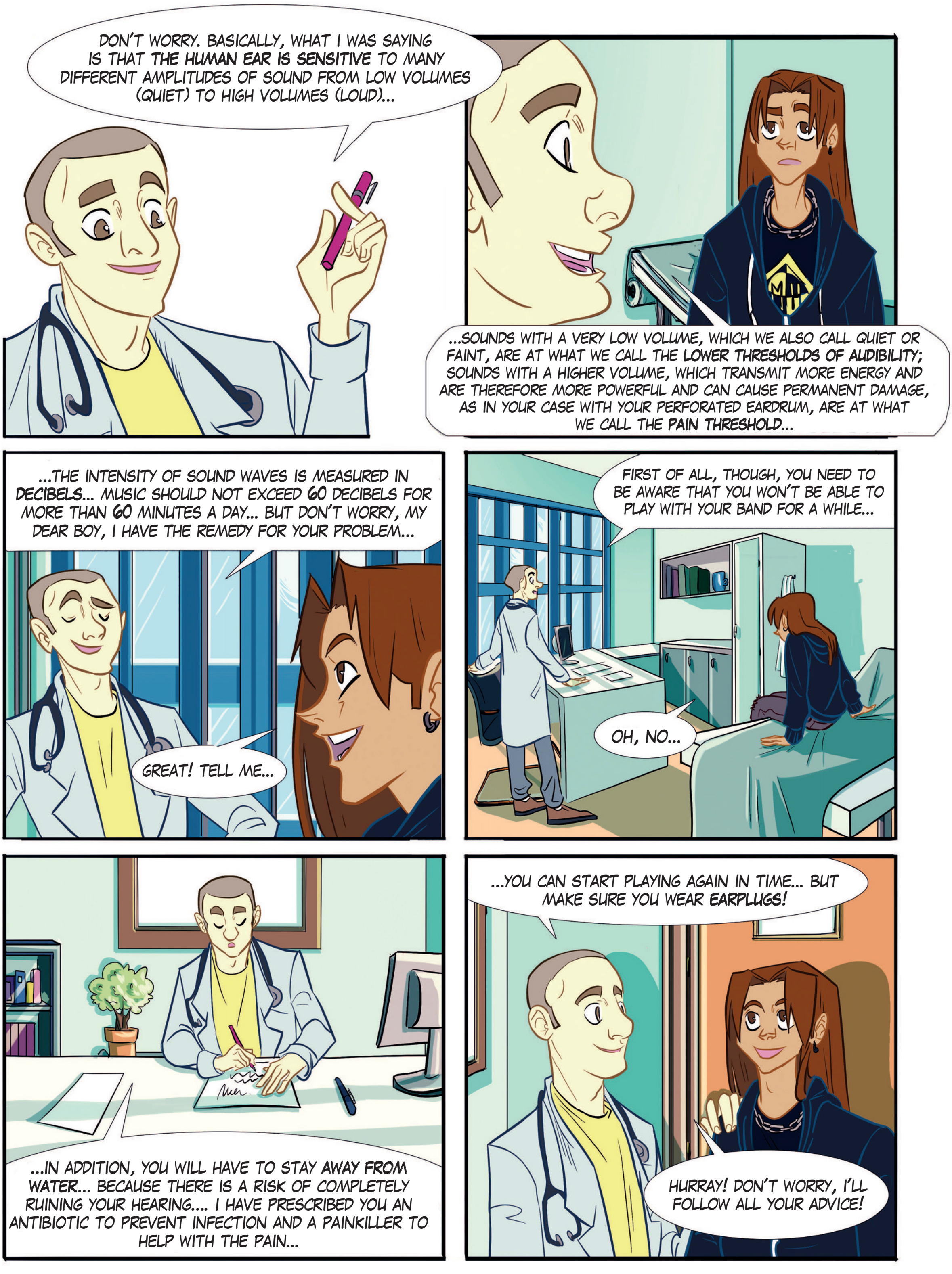

...IF THE ENERGY IS CARRIED ALONG WITH MATTER, THIS IS CALLED MECHANICAL TRANSMISSION, WHILE IF NO MATTER IS TRANSPORTED, IT'S CALLED TRANSMISSION BY ELECTROMAGNETIC WAVES...
HI... I'M A LIGHT WAVE...
...AND I'M THE COMBINATION OF AN ELECTRIC FIELD AND A MAGNETIC FIELD PROPAGATING PERPENDICULAR TO EACH OTHER IN SPACE...
...I'M A DEFORMATION OF SPACE... I'M ENERGY AND WHEN I MOVE, I DON'T NEED MATTER, SO I CAN ALSO MOVE THROUGH A VACUUM, TRAVELING AT A SPEED OF 300,000 KM/S...
YOU SCARE ME...
US LIGHT WAVES ARE NOT HARMFUL; IN FACT, IT'S THANKS TO US THAT YOU CAN SEE THE COLOR OF OBJECTS...
OHHH...

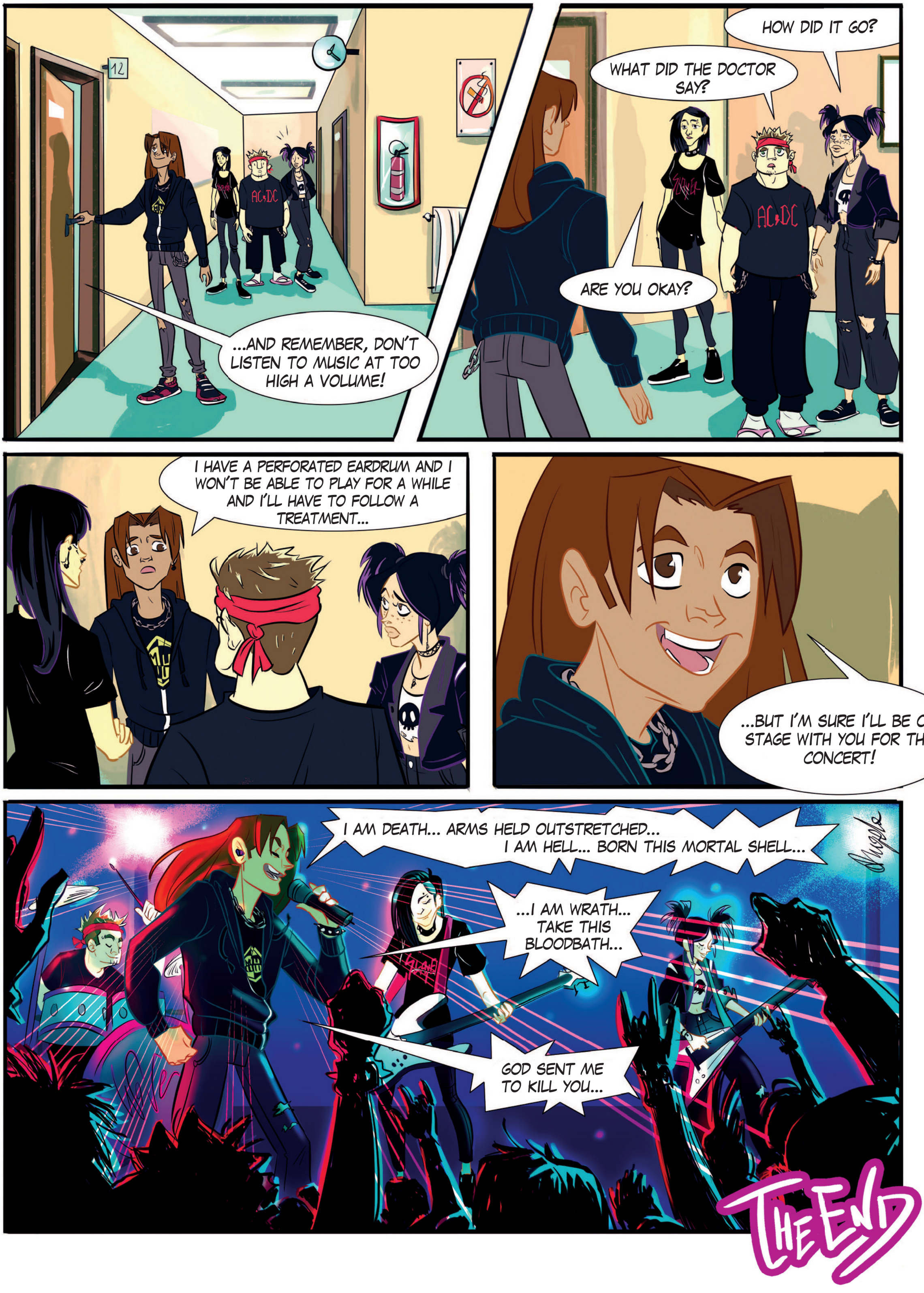

...EACH OF US APPEARS WHITE, BUT WHEN WE PASS THROUGH A PRISM, WE CAN SPLIT UP INTO DIFFERENT WAVELENGTHS THAT VARY BETWEEN 7×10^{-7} AND 4×10^{-4} M...
...WHEN WE ARE SPLIT UP LIKE THAT, WE **STIMULATE YOUR VISUAL SYSTEM**, CREATING THE PERCEPTION OF ALL THE COLORS OF THE RAINBOW...
...IN FACT, THE COLORS OF THE OBJECTS YOU SEE ARE THE RESULT OF THE INTERACTION BETWEEN THE OBJECTS AND LIGHT WAVES: THE COMBINATION OF WAVES WITH WAVELENGTHS THAT ARE REFLECTED BY THE OBJECT AND WAVES WITH WAVELENGTHS THAT ARE ABSORBED IS RESPONSIBLE FOR THE COLOR YOU PERCEIVE...
BEAUTIFUL!


...THE WAVELENGTHS NEXT DOOR TO US ARE **ULTRAVIOLET** WAVES...
HI... REMEMBER - WITHOUT US, YOU COULDN'T GET A TAN AND YOU'D BE WHITE AS A SHEET...
HA! HA! HA! GOOD THING YOU'RE HERE THEN!
YES, BUT IF YOU ARE EXPOSED TO US FOR TOO LONG, YOU RISK GETTING SKIN CANCER, SO I ADVISE YOU TO WEAR **SUNSCREEN** OR NOT TO EXPOSE YOURSELF TO DIRECT SUN FOR TOO LONG...
BUT WHY ARE YOU SO HARMFUL?
BECAUSE WE HAVE A **SHORTER WAVELENGTH** THAN OTHERS... BETWEEN 4×10^{-7} M AND 10^{-8} M... SO WE CAN PENETRATE RIGHT INTO THE DNA OF YOUR SKIN CELLS...
NOW THAT I KNOW, I'LL BE MORE CAREFUL...
...AND THEN THERE ARE THE **INFRARED** WAVES...


HELLO! I'M AN INFRARED WAVE... WE ARE **THOSE WAVES THAT DEPEND ON THE HEAT EMITTED BY BODIES** AND WE HAVE A WAVELENGTH FROM **7×10^{-7}** M UP TO **1** MM...
NICE TO MEET YOU...
WE ARE RESPONSIBLE FOR THE **GREENHOUSE EFFECT**, WHICH GUARANTEES LIFE ON EARTH... WE ARE FAINTLY VISIBLE TO YOU HUMANS AND, AS YOU CAN SEE, WE'RE RED...
...TO SEE US BETTER, YOU CAN USE AN **INFRARED CAMERA**, WHICH LETS YOU DETECT US TO SEE WHICH OBJECTS ARE HOTTER THAN OTHERS...
WE'LL SAY GOODBYE NOW...
THE **MECHANICAL WAVES** HAVE JUST GOT HERE...
HI! WE ARE THE MECHANICAL WAVES... AND WE MOVE THROUGH MATTER, WHICH TRANSMITS US BY DEFORMING LOCALLY...
NICE TO MEET YOU! BUT SHOULDN'T YOU HAVE A TRANSPORT MEDIUM?


NO, THE PARTICLES OF THE MEDIUM DO NOT TRAVEL WITH US... IT'S ONLY THE DISTURBANCE THEY UNDERGO THAT TRAVELS...
SOUND, FOR EXAMPLE, IS A MECHANICAL WAVE CAUSED BY A VIBRATING SOURCE, SUCH AS THE STRING OF A GUITAR OR THE SKIN OF A DRUM; THE WAVE PROPAGATES LONGITUDINALLY, TRAVELING THANKS TO RAREFACTIONS AND COMPRESSIONS OF THE AIR...
...UNTIL IT MAKES THE EARDRUM IN YOUR EAR VIBRATE...
THE SOUND CAN BE PERCEIVED AS HIGH- OR LOW-PITCHED DEPENDING ON THE WAVE FREQUENCY AND THE DENSITY AND TEMPERATURE OF THE MEDIUM IN WHICH IT IS TRANSPORTED... IN GENERAL, THE HIGHER THE FREQUENCY, THE HIGHER PITCHED THE SOUND, AND VICE VERSA...
SOUND THEREFORE HAS DIFFERENT PROPERTIES... THE FREQUENCY, WHICH IS MEASURED IN HZ (CYCLES PER SECOND) AND ENABLES US TO DISTINGUISH A HIGH-PITCHED OR SHRILL SOUND (HIGH FREQUENCY) FROM A LOW-PITCHED OR DEEP SOUND (LOW FREQUENCY) ... AND THE INTENSITY, WHICH CORRESPONDS TO THE VOLUME OF THE SOUND AND IS MEASURED IN DB (DECIBELS)...
...AND THIS DEPENDS ON THE AMPLITUDE OF THE WAVE. A HIGH AMPLITUDE CORRESPONDS TO A LOUD SOUND, WHILE A LOW AMPLITUDE CORRESPONDS TO A QUIET SOUND...
GIORGIO...
GIORGIO, ARE YOU LISTENING TO ME?
HUH?! SORRY, YOU LOST ME A BIT...


DON'T WORRY. BASICALLY, WHAT I WAS SAYING IS THAT **THE HUMAN EAR IS SENSITIVE** TO MANY DIFFERENT AMPLITUDES OF SOUND FROM LOW VOLUMES (QUIET) TO HIGH VOLUMES (LOUD)...
...SOUNDS WITH A VERY LOW VOLUME, WHICH WE ALSO CALL QUIET OR FAINT, ARE AT WHAT WE CALL THE **LOWER THRESHOLDS OF AUDIBILITY**; SOUNDS WITH A HIGHER VOLUME, WHICH TRANSMIT MORE ENERGY AND ARE THEREFORE MORE POWERFUL AND CAN CAUSE PERMANENT DAMAGE, AS IN YOUR CASE WITH YOUR PERFORATED EARDRUM, ARE AT WHAT WE CALL THE **PAIN THRESHOLD**...
...THE INTENSITY OF SOUND WAVES IS MEASURED IN **DECIBELS**... MUSIC SHOULD NOT EXCEED **60** DECIBELS FOR MORE THAN **60** MINUTES A DAY... BUT DON'T WORRY, MY DEAR BOY, I HAVE THE REMEDY FOR YOUR PROBLEM...
GREAT! TELL ME...
FIRST OF ALL, THOUGH, YOU NEED TO BE AWARE THAT YOU WON'T BE ABLE TO PLAY WITH YOUR BAND FOR A WHILE...
OH, NO...
...IN ADDITION, YOU WILL HAVE TO STAY **AWAY FROM WATER**... BECAUSE THERE IS A RISK OF COMPLETELY RUINING YOUR HEARING.... I HAVE PRESCRIBED YOU AN ANTIBIOTIC TO PREVENT INFECTION AND A PAINKILLER TO HELP WITH THE PAIN...
...YOU CAN START PLAYING AGAIN IN TIME... BUT MAKE SURE YOU WEAR **EARPLUGS**!
HURRAY! DON'T WORRY, I'LL FOLLOW ALL YOUR ADVICE!


...AND REMEMBER, DON'T LISTEN TO MUSIC AT TOO HIGH A VOLUME!
HOW DID IT GO?
WHAT DID THE DOCTOR SAY?
ARE YOU OKAY?
I HAVE A PERFORATED EARDRUM AND I WON'T BE ABLE TO PLAY FOR A WHILE AND I'LL HAVE TO FOLLOW A TREATMENT...
...BUT I'M SURE I'LL BE ON STAGE WITH YOU FOR THE CONCERT!
I AM DEATH... ARMS HELD OUTSTRETCHED... I AM HELL... BORN THIS MORTAL SHELL...
...I AM WRATH... TAKE THIS BLOODBATH...
GOD SENT ME TO KILL YOU...
THE END

GLOSSARY

Antenna An electrical device that makes it possible to transmit and/or receive electromagnetic waves; they are called transmitter and/or receiver antennas respectively. It is a device that makes telecommunications i.e., long-distance communications without cables, possible.

Cryptochrome Cryptochromes are proteins found in animals, plants, and bacteria that act as receptors for blue and ultraviolet light. They are involved in regulating various bodily functions related to photoreception.

Doppler effect An apparent change in the frequency or wavelength of a wave perceived by an observer who is moving relative to the source of the waves.

Earth's magnetic field The Earth's magnetic field is generated by a magnetic dipole located at the center of the Earth and is also known as the geomagnetic field. The Earth's geomagnetic field plays a primary role as an electromagnetic shield that is crucially important for life on Earth, because it protects living organisms from the most high-energy and dangerous solar rays.

Echolocation Echolocation, also called bio sonar, is the ability of some animals (in particular odontocetes, or toothed whales, such as dolphins, and some bats) to map out the surrounding environment by emitting sound waves. When these waves bounce back off objects, this echo provides useful information to the animal.

Electromagnetic field A combination of an electric field and a magnetic field. An electric field and a magnetic field are defined as a property or disturbance of space produced by the presence of electric charges and the motion of an electric charge respectively.

Electromagnetic spectrum The electromagnetic spectrum is the entire range of frequencies of electromagnetic waves, which are divided into different types of radiation according to the frequency and wavelength.

Electromagnetic wave Electromagnetic waves are waves that can propagate both in elastic media and in empty space, since what oscillates is not a material medium, but the electric and magnetic fields, which vary in space and time and are produced by electric charges in motion.

Frequency In a periodic phenomenon, the frequency corresponds to the number of events that repeat in a given unit of time.

Gamma radiation Gamma rays are electromagnetic radiation with extremely small wavelengths, ranging from 10^{-10} to 10^{-14} meters. The corresponding frequencies are therefore very high, above 300 billion GHz! Gamma rays are essentially produced by nuclear or subatomic transitions.

Greenhouse effect A natural phenomenon that heats up the Earth and makes life on our planet possible. It is due to the presence of certain gases in the Earth's atmosphere, such as carbon dioxide, methane, and water vapor. The overheating caused by the emission of greenhouse gases of human origin is one of the main current environmental problems.

Infrared radiation Electromagnetic radiation in the frequency band lower than that of visible light, but higher than that of radio waves, i.e. with a wavelength between 700 nm and 1 mm. It is often associated with the concepts of heat or thermal radiation, since each object spontaneously emits radiation in this band.

Intensity The acoustic or sound intensity is a physical quantity equivalent to the energy that crosses a unit of the surface positioned perpendicular to the direction of propagation of the sound within a unit of time.

Laser diode Laser diodes are optoelectronic devices capable of emitting a very intense, coherent beam of light from the active region of the semiconductor that the device is made from. They are the basis of many important applications in the field of electronics.

Longitudinal wave A longitudinal wave is characterized by an oscillation of the propagation medium in the same direction of propagation as the wave itself.

Magneto-reception This is a sense that enables an organism to detect a magnetic field in order to determine its own direction, altitude, or position. A number of animals use this sense for orientation and navigation.

Magnetron A device that enables microwaves to be generated by causing electrons to move in a particular way inside a vacuum tube.

Mechanical wave A mechanical wave is energy being carried through the propagation of a disturbance in a gaseous, liquid, or solid medium.

Microwave In physics, microwaves are electromagnetic radiation with wavelengths between the upper ranges of radio waves and infrared radiation. The microwave spectrum is usually defined as the frequency range of 1 GHz to 1,000 GHz.

Mixed wave A mixed wave is the superposition of a transverse wave and a longitudinal wave. The best-known example is a water wave.

Photodiode Photodiodes are light sensors that generate a current or voltage when the junction in the semiconductor inside the diode is illuminated by light.

Pitch The pitch of a sound depends on the frequency of the sound wave that generated it and enables you to distinguish whether the sound is high- or low-pitched (shrill or deep). The higher the frequency, the more high-pitched the sound, while the lower the frequency, the more low-pitched the sound.

Pressure wave A type of longitudinal wave that propagates in a gas and is characterized by local variation in gas pressure, such as in sound waves.

Radio wave Radio waves are electromagnetic radiation in the frequency band between 0 and 300 GHz, i.e., with a wavelength greater than 1 mm.

Sonar An acronym that stands for "Sound Navigation and Ranging", sonar is a technique that uses the propagation of sound underwater for navigation, communication, or detecting the presence and position of boats.

Sound Sound refers to all vibrations propagated in a medium. Vibrations can be excited in the medium (solid, liquid, or gas) or transmitted to it by the vibrations of a body, which represents the source of the sound.

Timbre A property that makes it possible to distinguish sounds emitted from different sources, even if they have the same frequency and intensity. For example, each musical instrument has a different timbre even when playing the same note and is thus perceived differently by the ear.

Transverse wave A transverse wave is characterized by an oscillation of the propagation medium in the direction perpendicular to the propagation of the wave itself.

Ultrasound Ultrasounds are mechanical sound waves. Ultrasound is characterized by frequencies higher than those that can typically be heard by the human ear and lie in a range between 20 kHz and one GHz; above this, it is referred to as hypersound.

Ultrasound/ sonogram	A non-invasive diagnostic technique that uses ultrasound emitted by special probes resting on the patient's skin to create an image of organs, subcutaneous structures, muscle structures, and tendons in numerous parts of the body.
Ultraviolet radiation	Also called UV, it is a range of electromagnetic radiation with a wavelength immediately lower than the light visible to the human eye and immediately higher than that of X-rays, i.e., between 100 and 400 nm.
Wi-fi	An acronym for Wireless Fidelity, wi-fi includes all technology that is used to connect an electronic device (notebook, personal computer, tablet, etc.) to a public or private network.
Wireless	In computing and telecommunications, the term wireless refers to communication between electronic devices that does not use wires or cables. By extension, the respective communication systems or devices implementing such a communication mode are also referred to as "wireless". Wireless generally uses low-power radio waves.
X-rays	X-rays (or Röntgen rays) are electromagnetic radiation with a wavelength between approximately 10 nanometers and 1/1,000 of a nanometer (i.e., a picometer). X-rays are mainly used for medical purposes (radiography), in chemical analysis, and for analyzing the structure of materials.

Our whole reality is populated by waves, both natural and man-made. Waves that propagate through a transmission medium carrying energy and waves capable of producing effects on matter ranging from minor to major.

The author takes us on a fascinating journey through the world of waves, revealing natural and artificial wave phenomena and showing us how humans have managed to exploit some types of waves in a controlled manner, such as in telecommunications, wi-fi, X-rays, and microwave ovens.

Andrea Danani, Dalle Molle Institute for Artificial Intelligence Research (IDSIA); University of Applied Sciences and Arts of Southern Switzerland (SUPSI); University of Italian-speaking Switzerland (USI), Lugano.

Inside the comic:

Wave upon wave…

Texts by the students of class 3A of the Caslano Middle School, Ticino, Switzerland.

Illustrations by Angela Piacentini for the Scuola Romana dei Fumetti.

Repubblica e Cantone Ticino
Dipartimento dell'educazione, della cultura e dello sport