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LIGHT and MATTER INTERACTION

The International Year of Light

and Light-based Technologies

2015

LIGHT and MATTER
INTERACTION:
chemical aspects

Before to face this topic a short introduction on chemistry is needed

What is Chemistry?

Chemistry is inside and around us

All the processes that sustain life are based on chemical reactions, and most things we use in everyday life are natural (*e.g.*, water, wheat, oil, wood) or artificial (plastics, glass, medicines, pesticides) molecules

For these reasons Chemistry is a central science

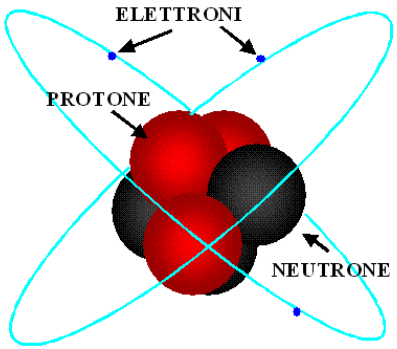
Chemistry is important

It explains how the world is made and how it works.
It explains how man is made and how he functions.

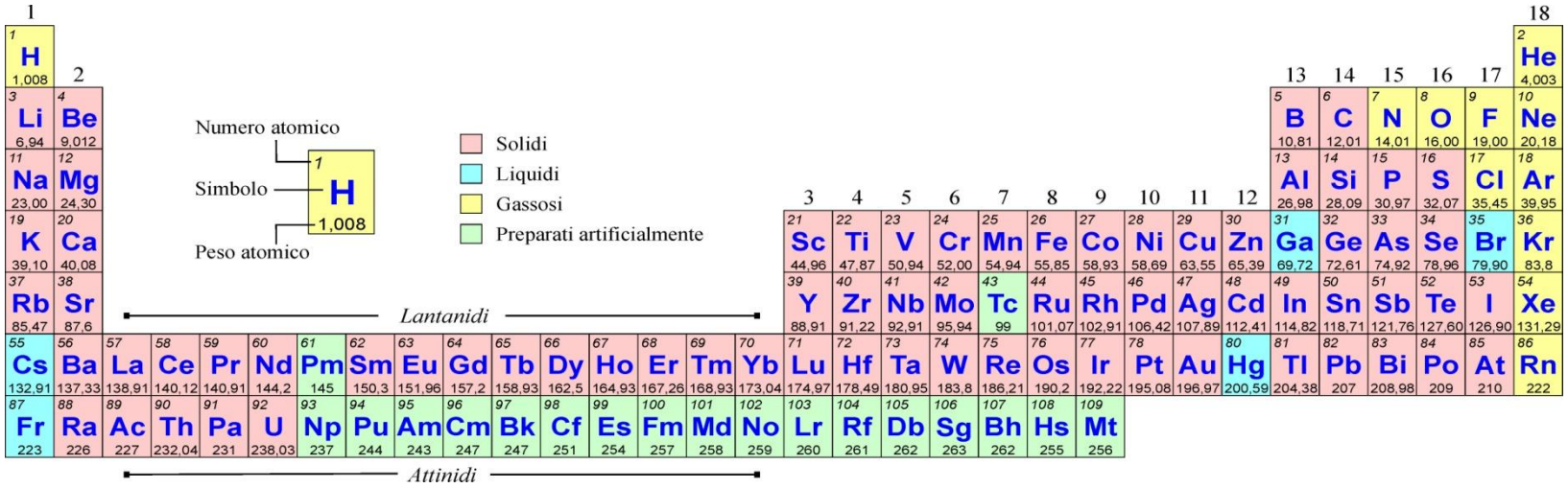
It uses its language made of atoms and molecules

Atom

- Atom is the smallest particle of matter (although we know that it has an inner structure)



- In nature there are approximately 100 different atomic species called elements (H, C, O, Fe, …)



Periodic Table o Periodic System

Dmitrji Mendeleev and his Periodic Table (1869)

Periodic Table is one of the most brilliant coups de force of the last ten centuries

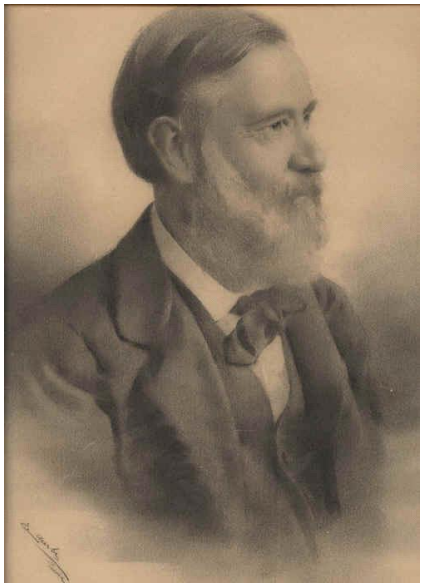
The most interesting characteristic of atoms

Their tendency to combine with other atoms to give rise to molecules that are atom aggregates

Molecule

The concept of a molecule has had a difficult time asserting itself in the history of science. It has emerged only in 1860 thanks to two great Italian chemists, Avogadro and Cannizzaro

Avogadro (1776–1856)



Cannizzaro (1826–1910)

Molecule

Today this concept plays a fundamental role in science so as we can define our age as the "age of the molecule"

With the hundreds of atomic species available and the various modes with which atoms can bond to each other, a huge number of molecules can be obtained

Many types of molecules are present in nature

Chemist, great explorer of nature, discovered up to now tens of millions of natural molecules

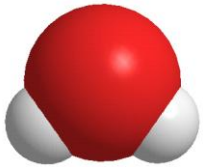
Chemists have learned to distinguish very well molecules

Each molecule is identified by a **name,** schematically represented by a **formula,** and also characterized by a specific **shape**

To visualize the molecule shapes **three dimensional models** are used; they are constructed by means of a method that resembles the famous game *Lego*

The Lego game of molecules

H_2O water

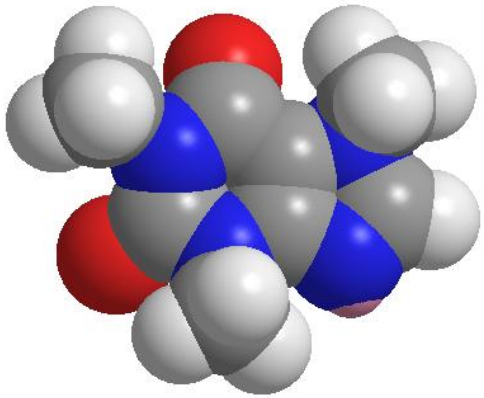


CH_4 methane

C_2H_5OH ethyl alcohol

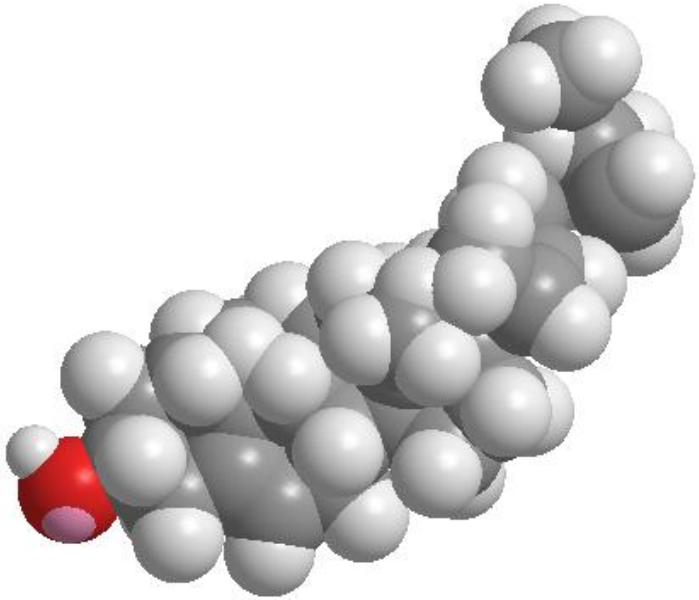
Caffeine

$C_8H_{10}O_2N_4$

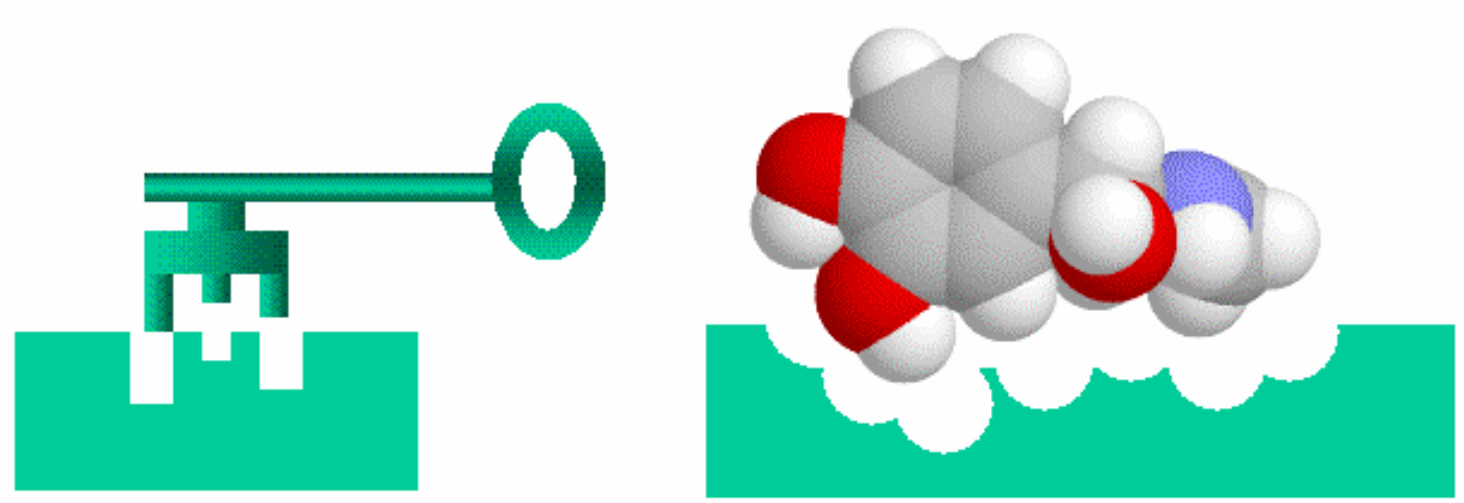


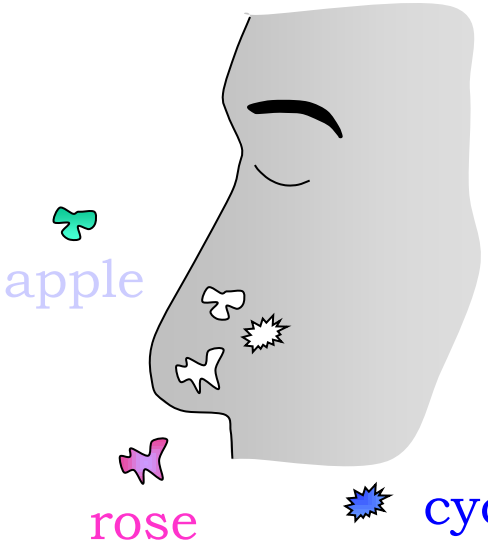
Cholesterol

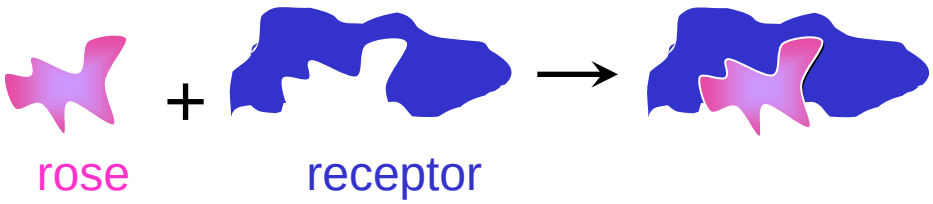
$C_{27}H_{46}O$



The shape of a molecule is very important to understant many biological processes (e.g., the action of drugs)




apple
rose
cyclamen


rose
receptor

Molecule world is really wonderful!

Molecules, however, have a big disadvantage: they are "objects" very small

Actually they are the smallest objects in the world to have a specific shape

The dimensions of molecules

The suitable unit of measure to express the dimensions of molecules is the **nanometer** that is a billionth of a meter

$1\ nm = 10^{-9}\ m$

Just to make an example: the thickness of a hair is equal to 1,000,000 nm

Molecules are really very small

Water molecules contained in 18 g of water

are 6×10^{23}

(10 times all the stars in the Universe!)

Obviously, objects of such small dimensions, taken singularly, can neither be seen, nor weighted, nor measured

For this reason, chemists work "in the dark", that is, work without seeing the objects they handle

The chemist's job

"… we (chemists) are like blind people with sensitive fingers. I say blind because, actually, the things we handle are too small to be seen, even with the most powerful of microscopes"

Primo Levi
The Monkey's Wrench

Chemists have never given up on their quest to see the molecules, even though past authoritative people did not share such aspirations

Goethe, for example, maintained that science should stick to human dimensions and was opposed to the use of microscopes when he asserted:

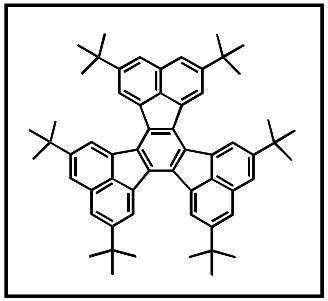
"That which is invisible to the human eye must not be sought, because evidently it is hidden from us for a very good reason"

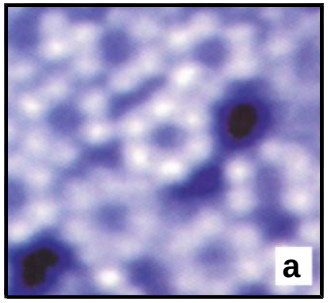
This assertion is in contrast to the logic of science and indeed today

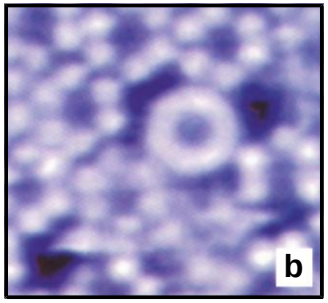
the technological progress

enabled to

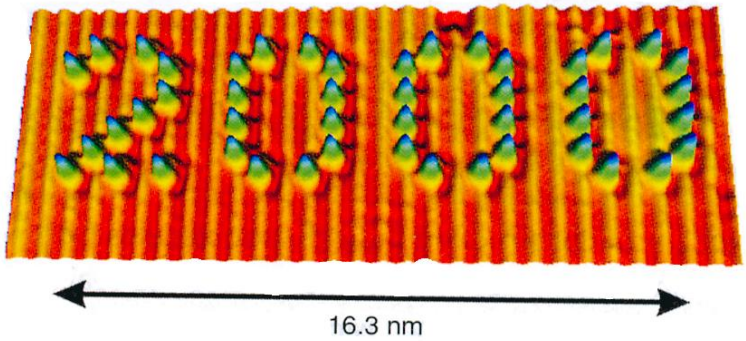
"see", "touch" and "handle" the individual molecules







Science, **1998**, *281*, 531



Picture of the celebrated date of the new millennium obtained positioning 47 molecules of carbon monoxide, CO, on a copper surface, taken with a very sophisticated technique known as probe microscopy

ChemPhysChem, **2**, 2001, pag. 362

Chemist:
from explorer to inventor

In the last few years chemists began to synthesize molecules in the laboratory that do not exist in nature

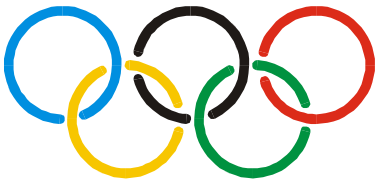
Artificial molecules

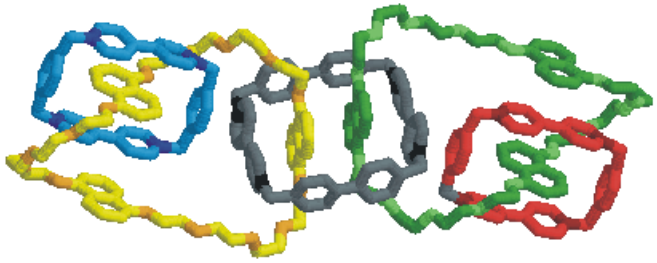
Chemistry is a a book not only to be read (natural substances and processes), but also to be written (artificial substances and processes); if the part not yet read is immense, then the part yet to be written is practically infinite

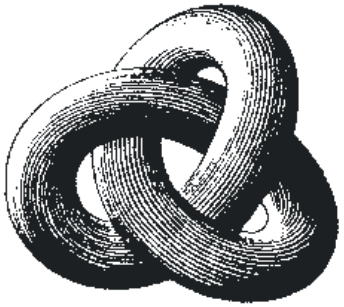
The big progress in organic synthesis

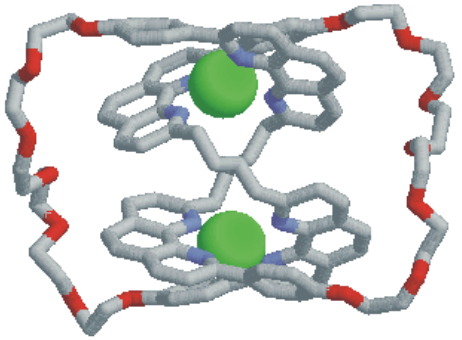
Today chemists are able to prepare molecules of whatever shape and dimension one wishes

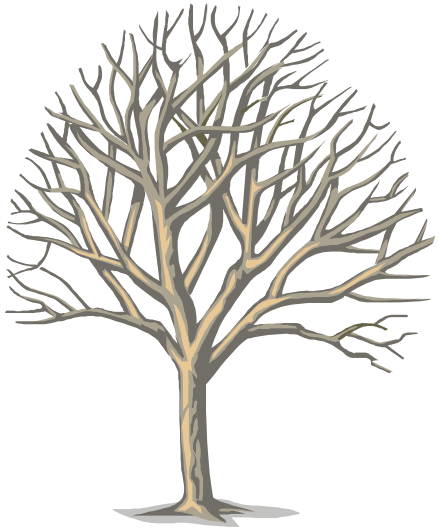
Beautiful molecules

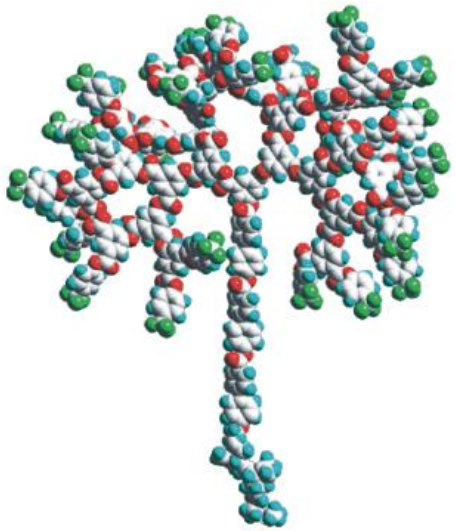


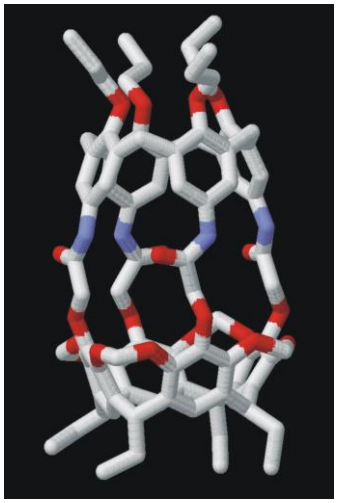


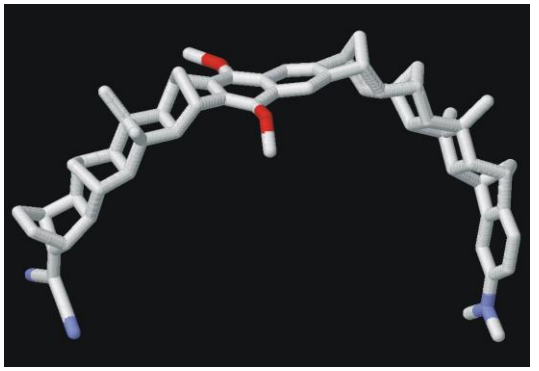






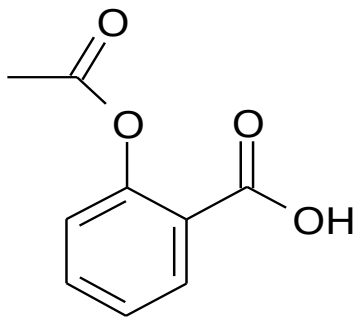


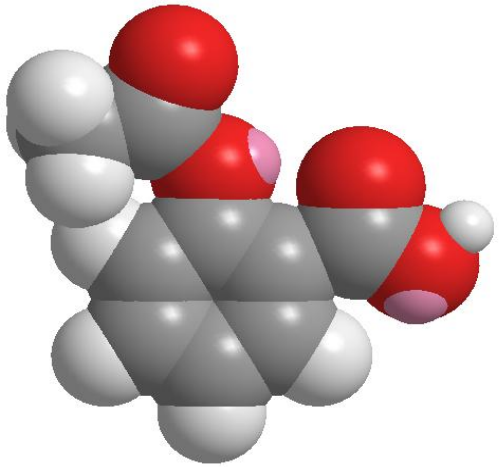




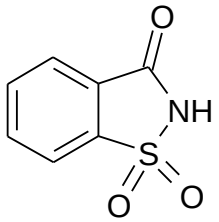
Beautiful molecules, but also useful molecules

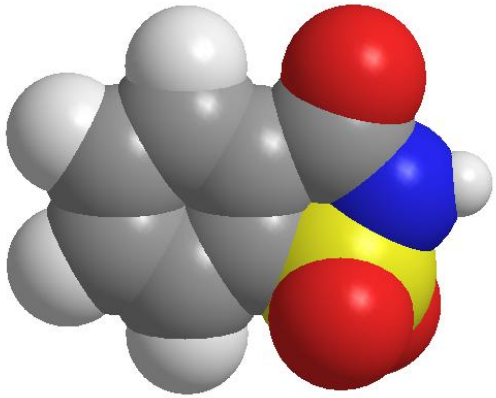
Acetylsalicylic acid (Aspirin) $C_9H_8O_4$





Saccharin $C_7H_5O_3NS$





Examples of useful artificial molecules

Chemistry is our everyday life

In fact, chemistry is at the base of all the benefits that, in some inconscious way, we enjoy daily

Chemistry is at the basis of the technological development

Chemistry is deeply involved in the development of nanotechnology

A new technology that deals with "objects" of nanometric dimensions

Molecules have the right dimensions!

Nanotechnology

The marriage of the synthetic talent of chemists with a "device driven" ingenuity

Roald Hoffmann

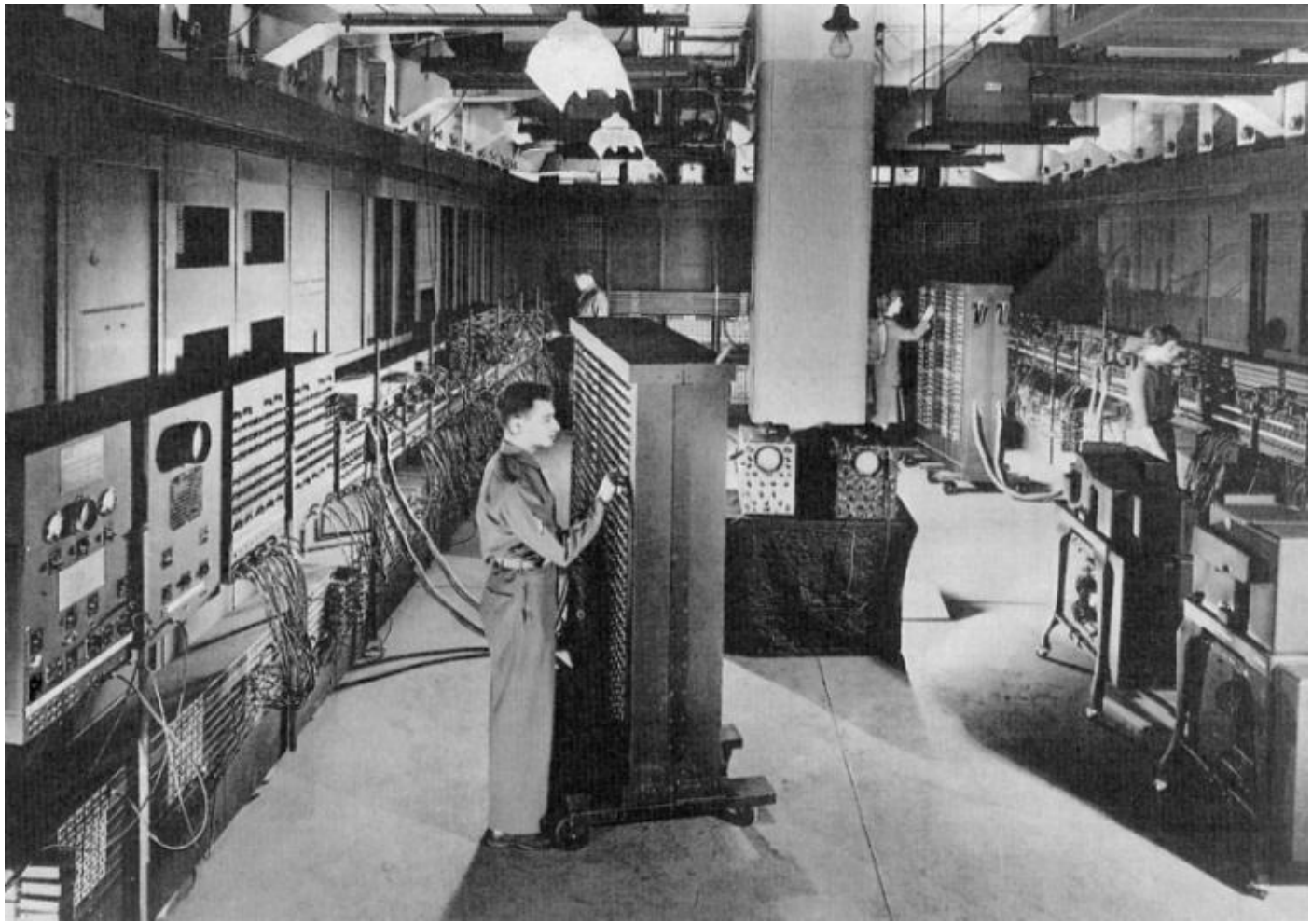
Why is it important to develop this type of technology?

Because technological progress is based on miniaturization

In the last fifty years,
progressive miniaturization
of the components employed for
the construction
of devices and machines has
resulted in outstanding
technological achievements

This is particularly true for the
field of information processing

ENIAC: the first electronic computer (1944)
30 ton 19000 valves 200 kW



Today Electronic Computers (2005)

~ 2 kg

42 milions transistors (Pentium IV)

~ 100 W

Miniaturization is a must

Further progress in miniaturization will be important not only in the field of information processing, but also in the fields of medicine, environment, energy, and materials

Now we can come back to the main topic

LIGHT and MATTER INTERACTION: chemical aspects

Why chemical aspects?

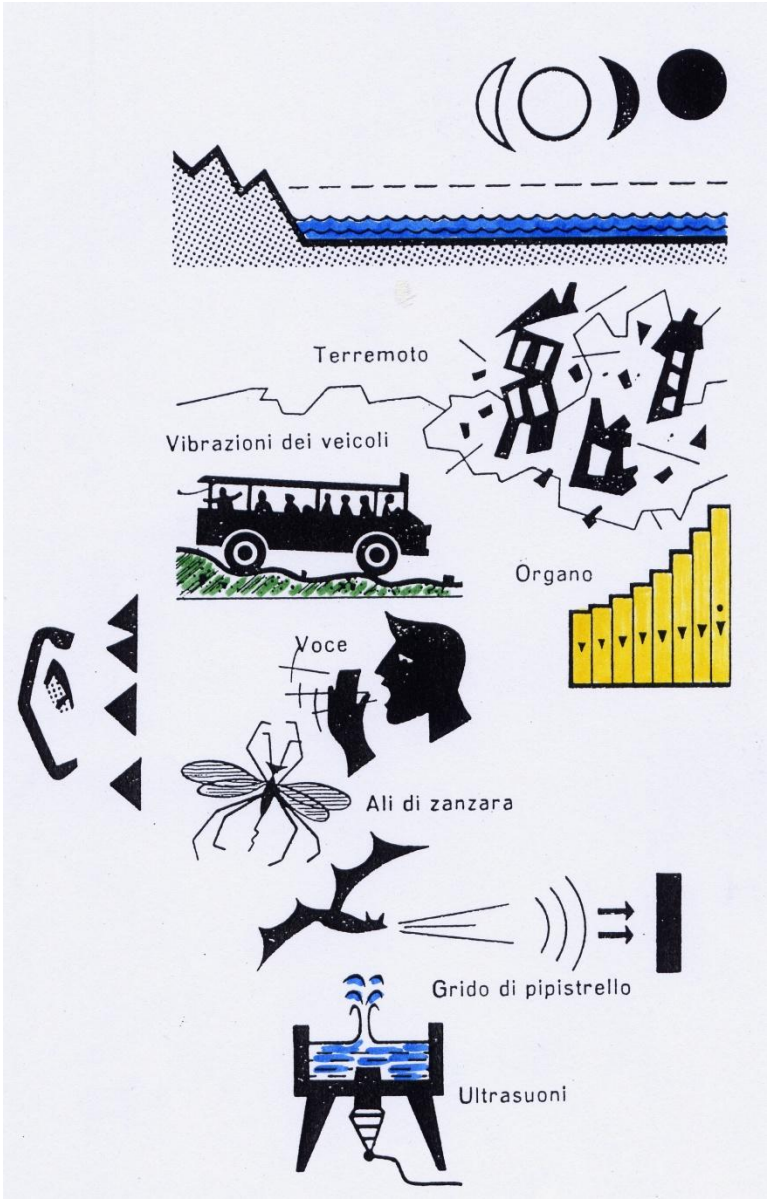
Because, concerning light, chemists and physicists raise different questions that concern two complementary aspects of light

Physicist question: what is light?

Chemist question: what are the effects of light?

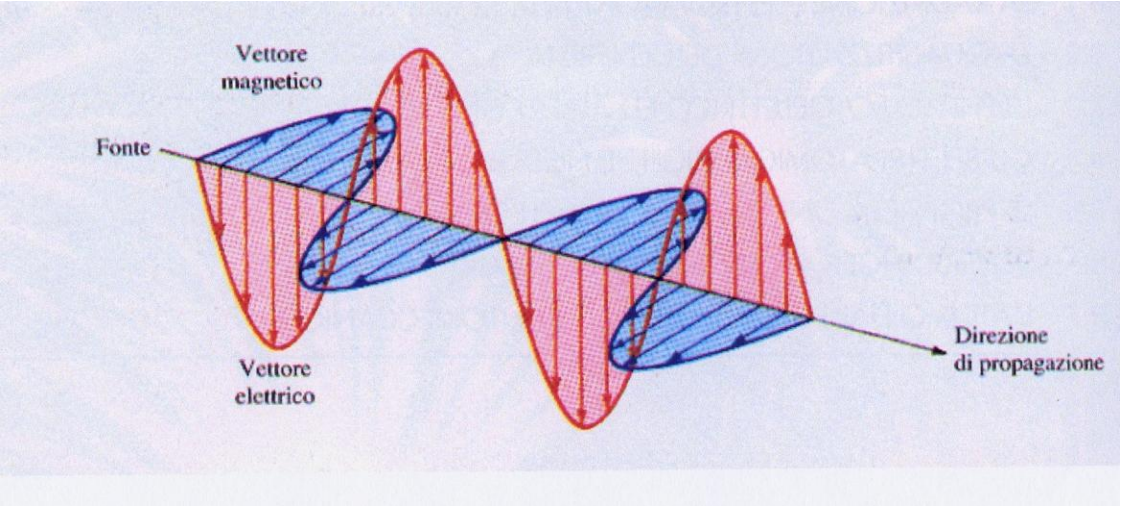
What is light?

Light is made of radiations that are waves

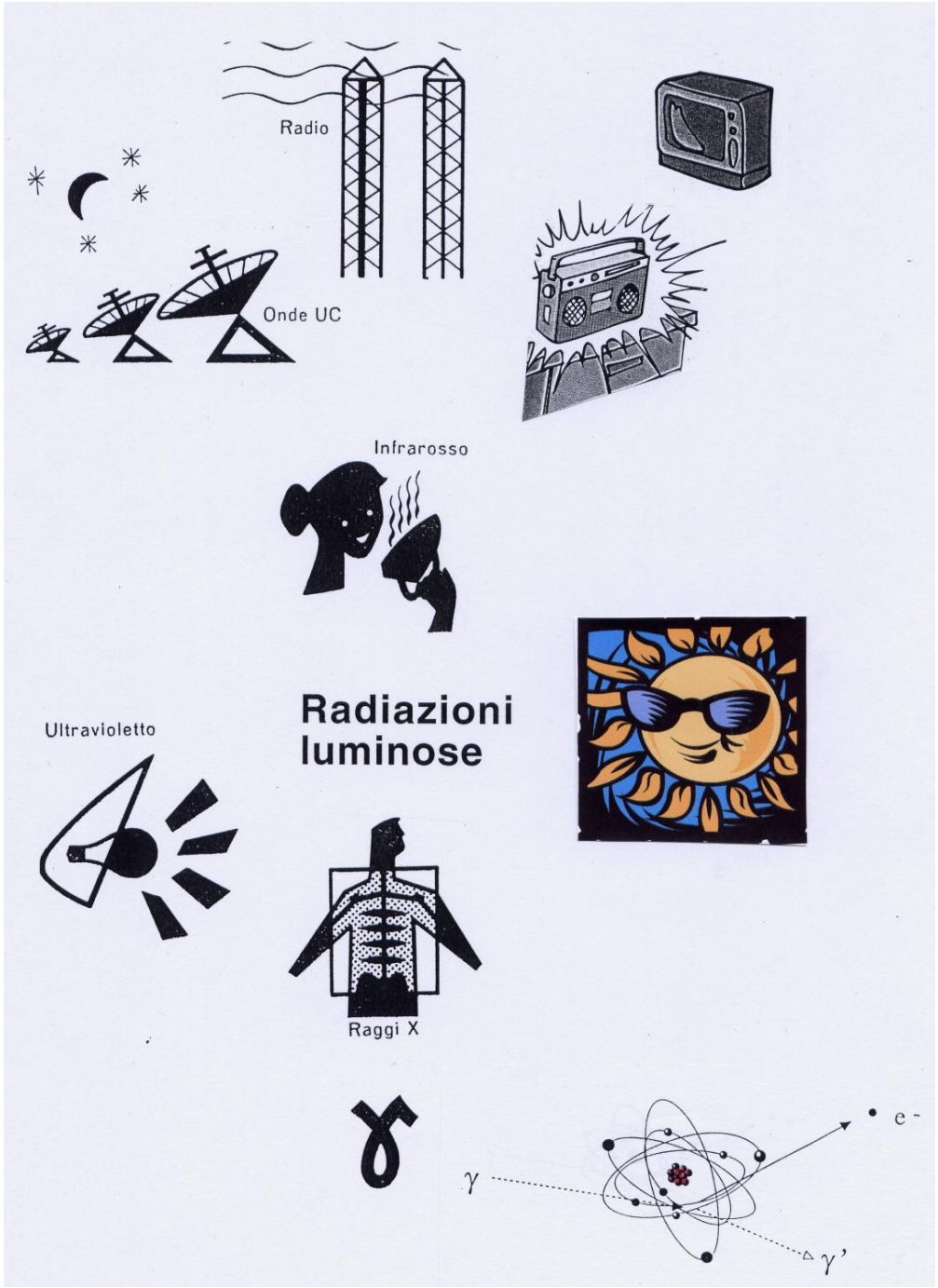


Mechanical waves

Radiations are waves called electromagnetic because they can be decomposed in an electric field and a magnetic field oscillating in two orthogonal planes

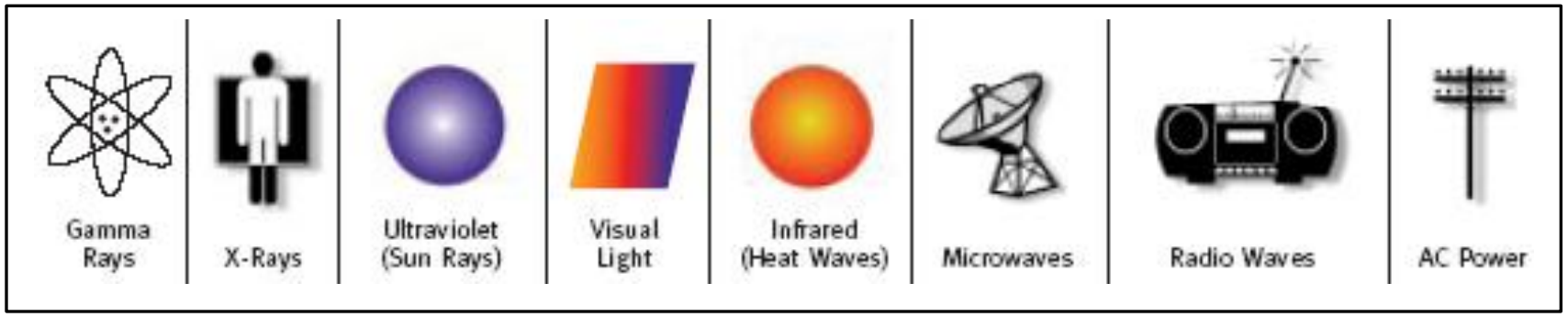


The electromagnetic radiations are able to propagate in vacuum

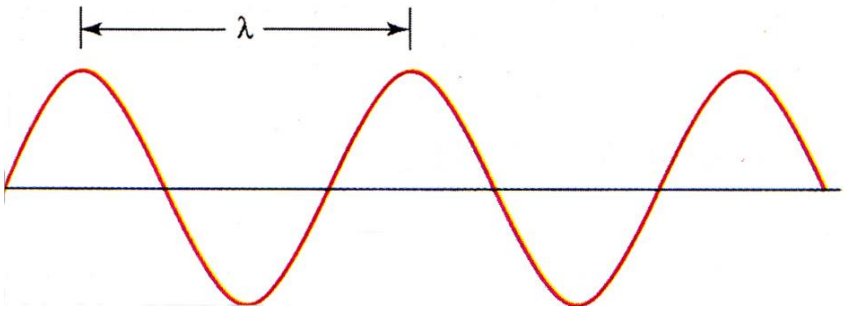


We are surrounded by the electromagnetic radiations that are of very different types and thereby have different uses

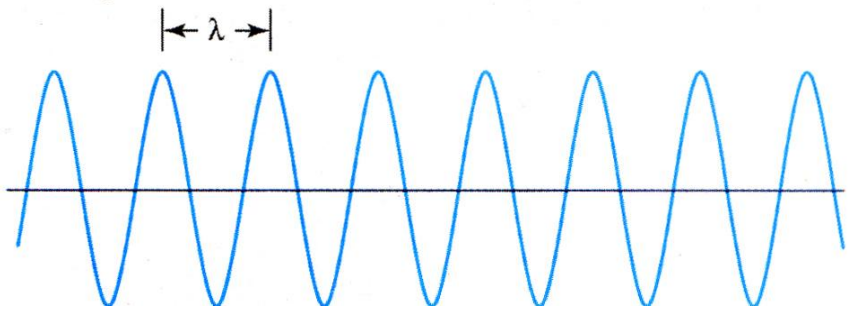
ELECTROMAGNETIC SPECTRUM



Wavelength, λ, a characteristic parameter



higher wavelength



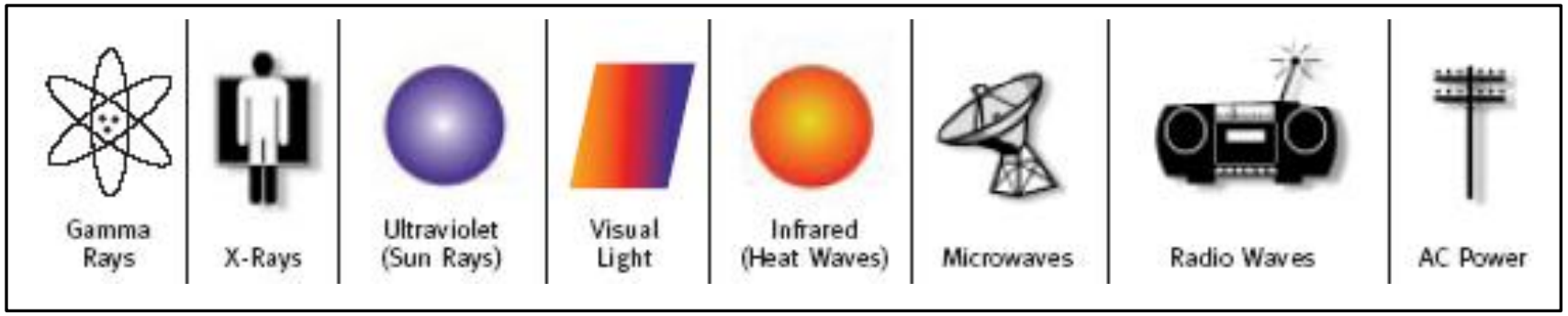
lower wavelength

Wavelength is related to the energy of the radiation:
the greater is the wavelength the smaller the energy

Wavelength →

$\lambda < 10^{-9}$ m = nm

λ = m



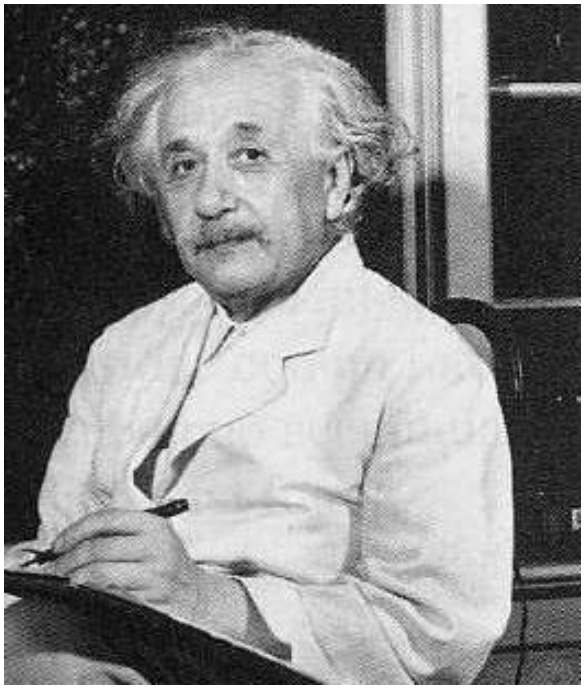
← Energy

Wavelength is related to the radiation energy by the following inverse proportion

$$E = hc/\lambda$$

c = light speed in vacuum (300.000 km/s)
h = Plank constant

Photonic interpretation of radiations: energy quanta



"… What are energy quanta? All the fifty years of conscious brooding have brought me no closer to the answer to this question. Of course, today every rascal thinks he knows the answer, but he deluding himself"

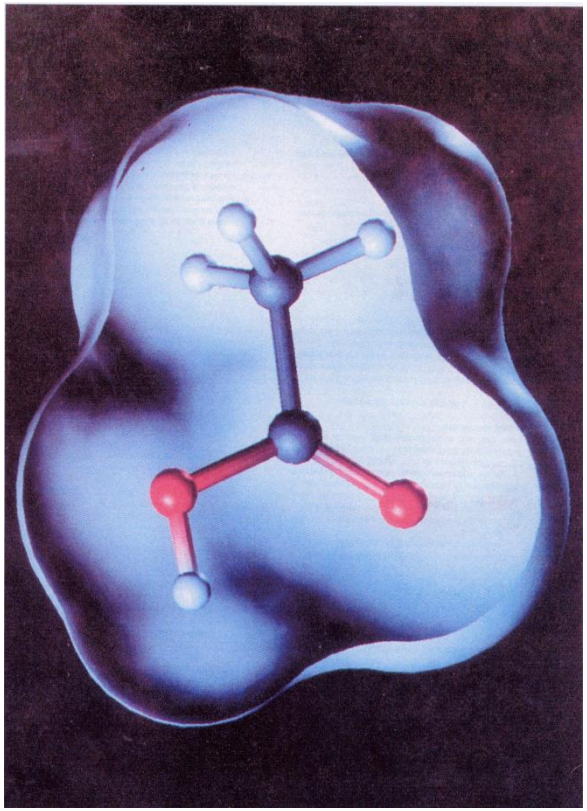
A. Einstein, Letter to N. Besso, 12 december 1951

The energy factor is important because when radiations pass through matter they yield part or all of their energy

What happens in this energy exchange?

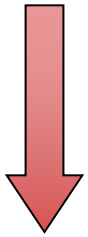
Chemist question:
What are the effects of radiations?

To understand what happens in this energy exchange it is necessary to enter in the inner structure of matter



The exchange occurs indeed with the molecules that make up everything around us, including our body

Radiations-matter interaction



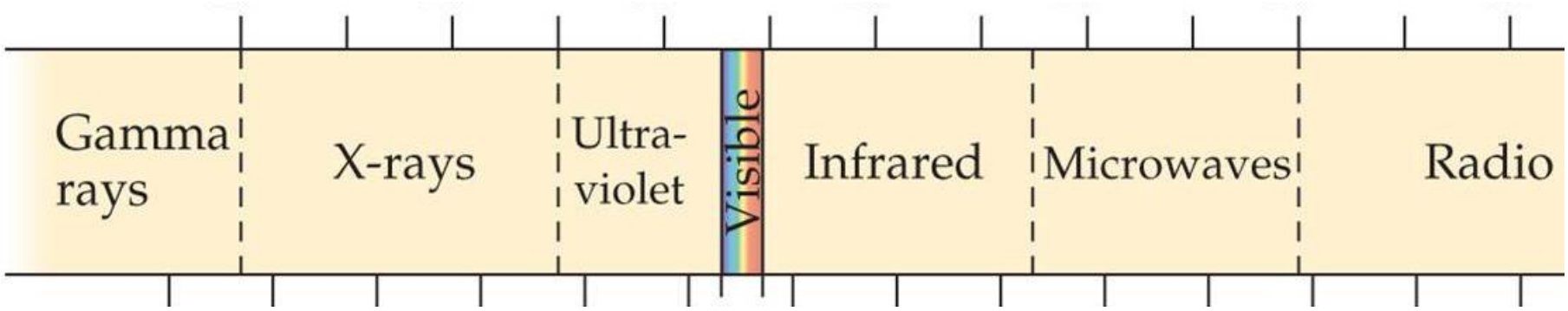
Energy exchange with molecules

If radiations have little energy,
in the energy exchange molecules acquire
little energy and undergo small and
temporary changes

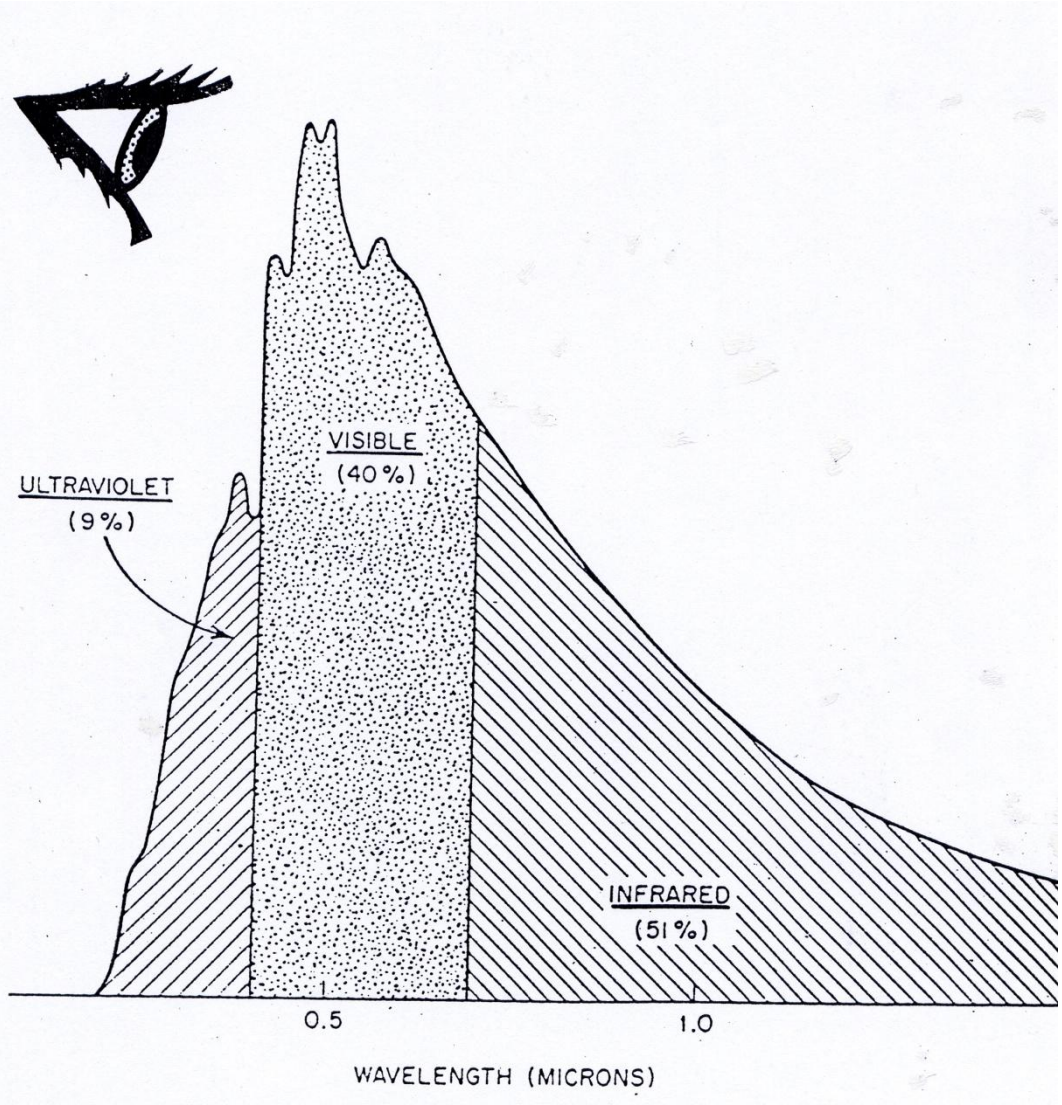
If radiations have much energy,
molecules acquire a high quantity of
energy and undergo drastic and
permanent changes

The changes that molecules undergo are often the only way we have to evidence the presence of radiations because most of them is invisible

Our eyes are indeed capable of seeing only the very small part of the electromagnetic spectrum constituted by the light radiations. For this reason it is called "visible zone"



Radiations emitted by the Sun



As we will see later, the visible zone, although it is small part of the electromagnetic spectrum, is very important

Light