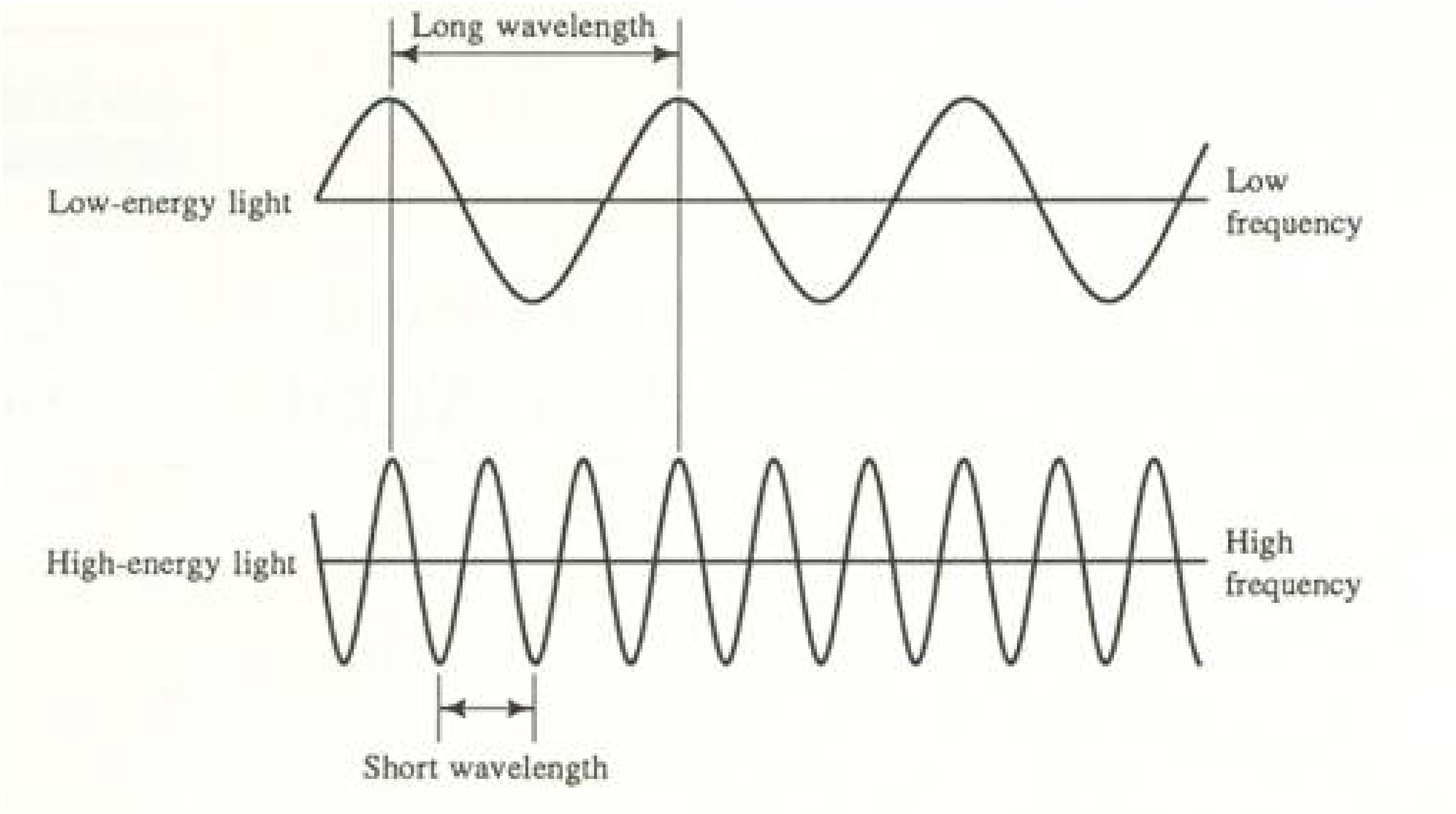
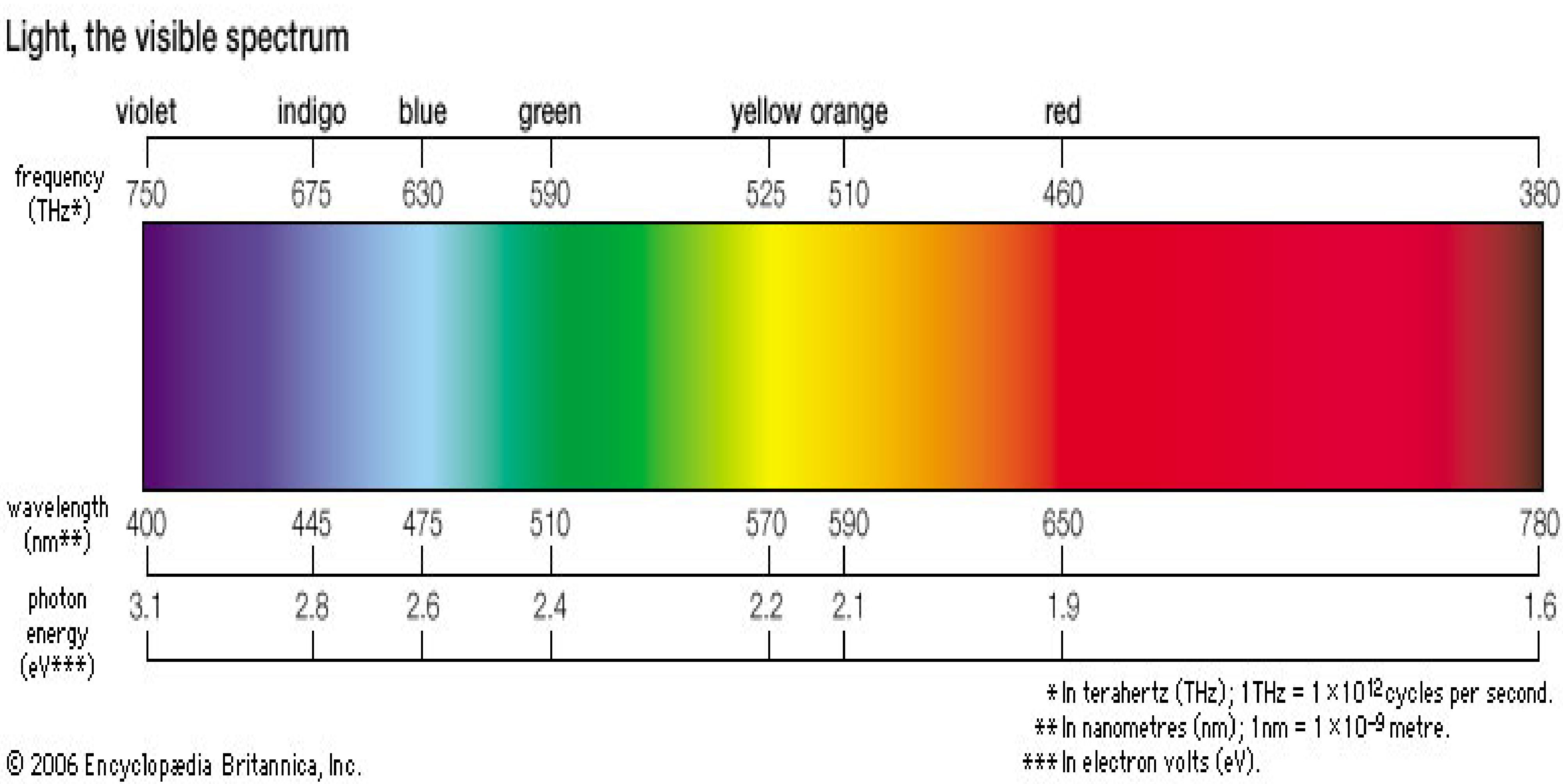
Wave properties of light

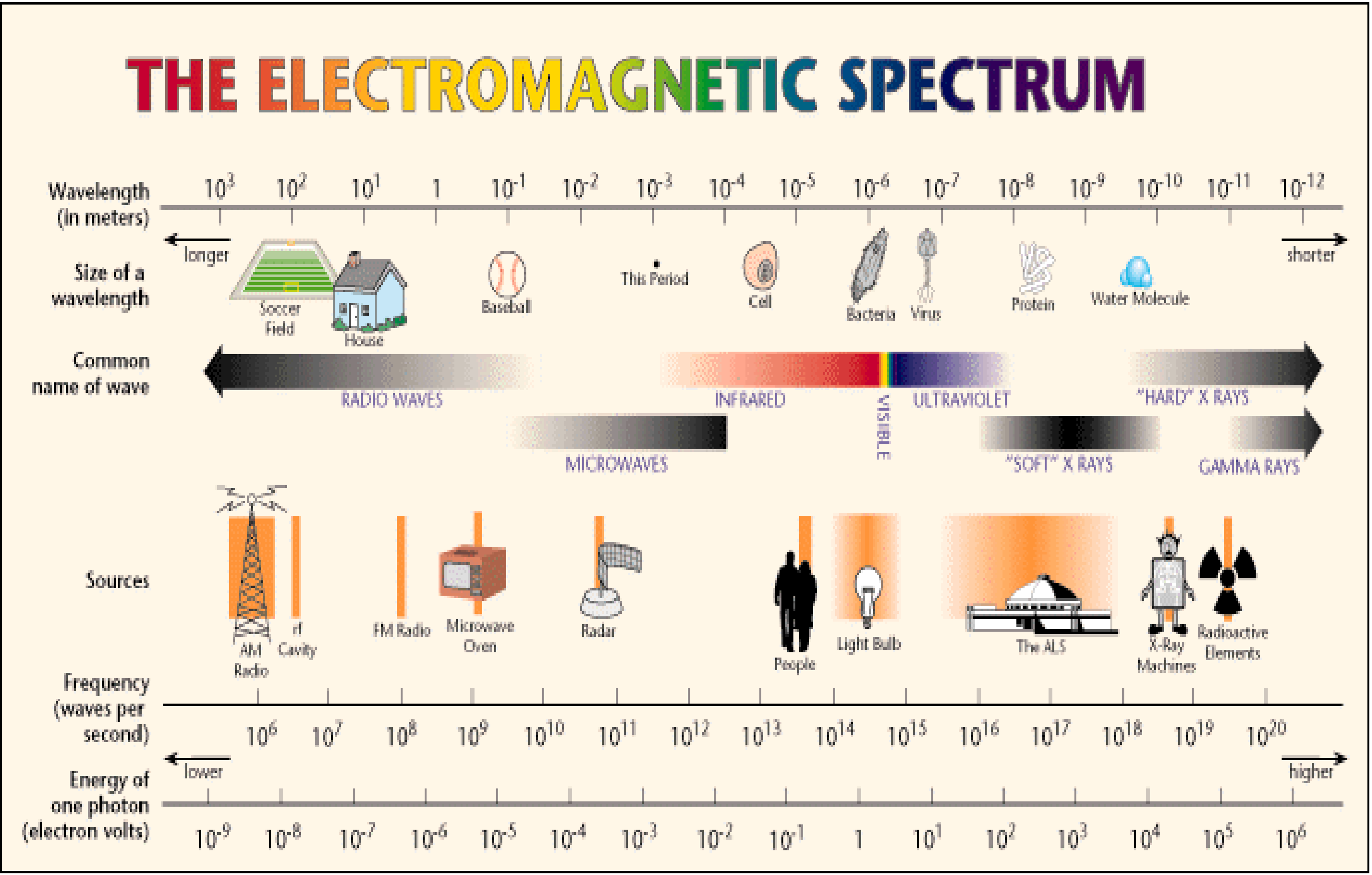


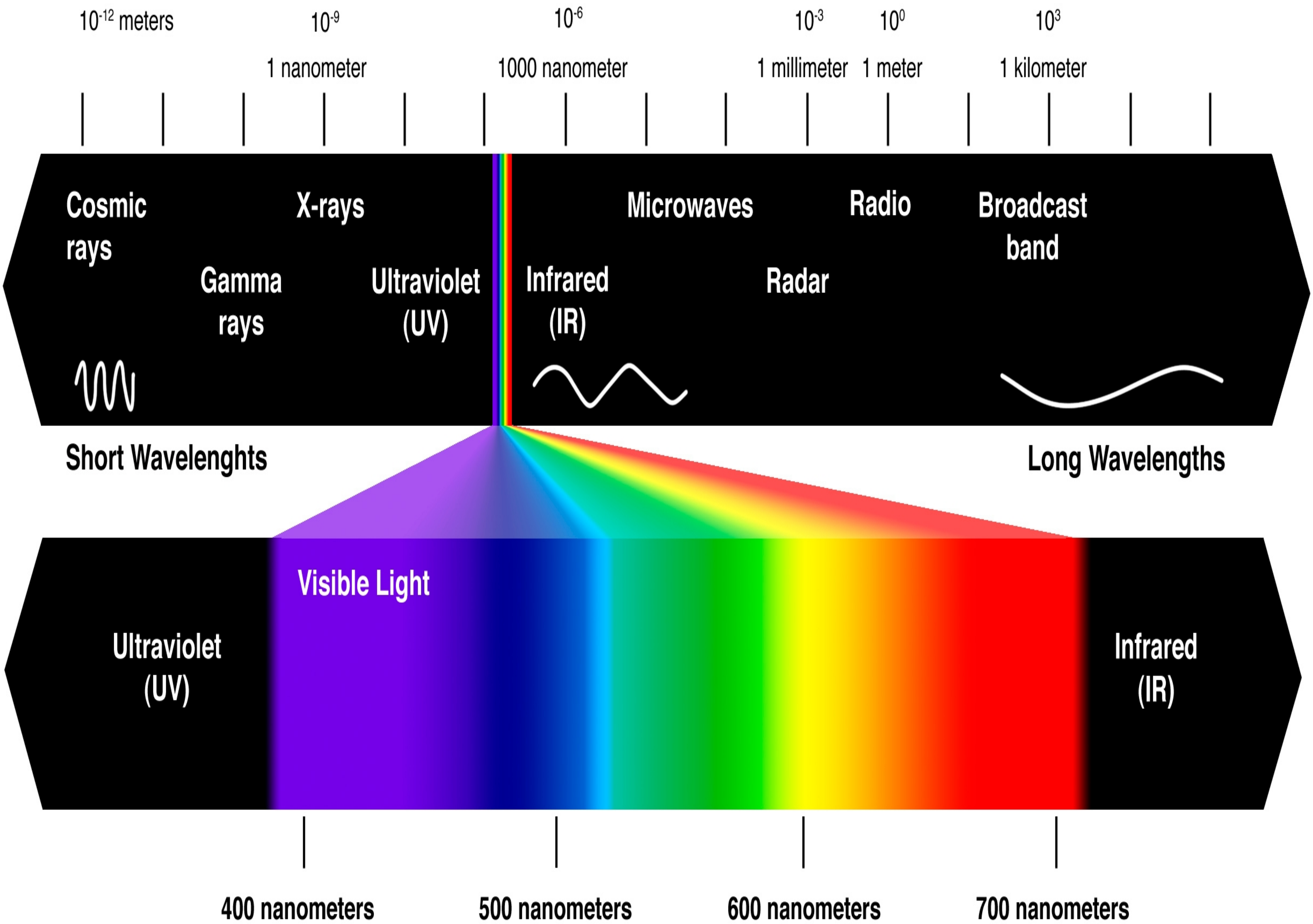
Light is energy whose wavelength is the distance traveled in order to complete one cycle.
The frequency of light refers to the number of cycles in one second.
Low-energy light has a long wavelength and a low frequency.
High-energy light has a short wavelength and a high frequency.

The **color** of light is determined by its wavelength, or equivalently its energy.
Most visible light is composed of a wide, continuous range of colors (energies)



Visible light only represents a small portion of the light encountered in every day life.
Low energy radio, TV, and microwave signals have **longer** wavelengths than visible light
High energy UV-rays, X-rays, and Gamma rays have **shorter** wavelengths than visible light





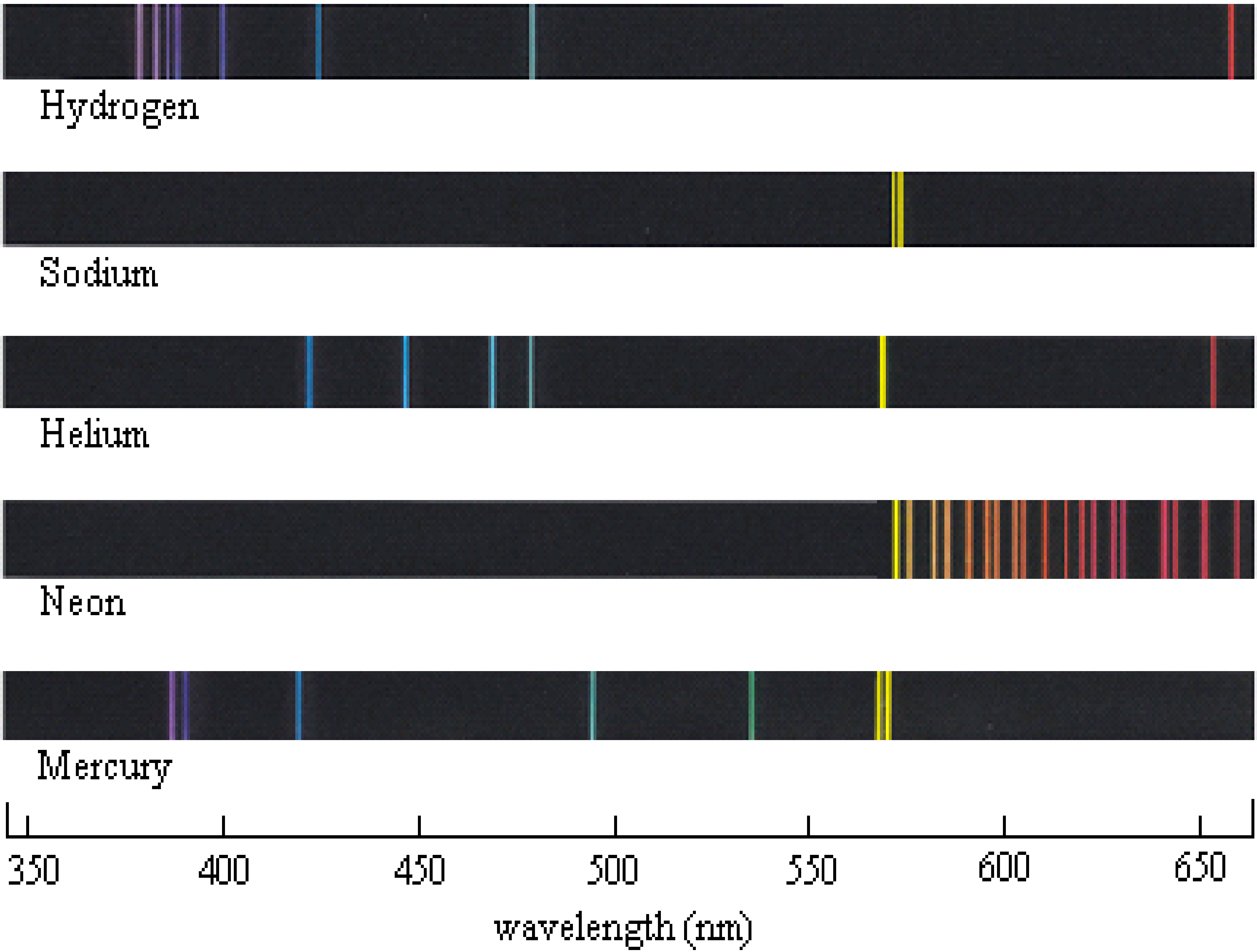
10-12 meters
10-9
10-6
10-3
100
103
1 nanometer
1000 nanometer
1 millimeter
1 meter
1 kilometer
Cosmic rays
X-rays
Microwaves
Radio
Broadcast band
Gamma rays
Ultraviolet (UV)
Infrared (IR)
Radar
Short Wavelenghts
Long Wavelengths
Visible Light
Ultraviolet (UV)
Infrared (IR)
400 nanometers
500 nanometers
600 nanometers
700 nanometers

Spectroscopy

The light emitted by a lightbulb or a star is formed from a **continuum** of different wavelengths. But how is light of **single** wavelength emitted?

Quantum mechanics says that the electrons surrounding the nucleus in an atom can only have certain energies characteristic of the type of atom. Each element on the periodic table has its own set of possible energy levels.

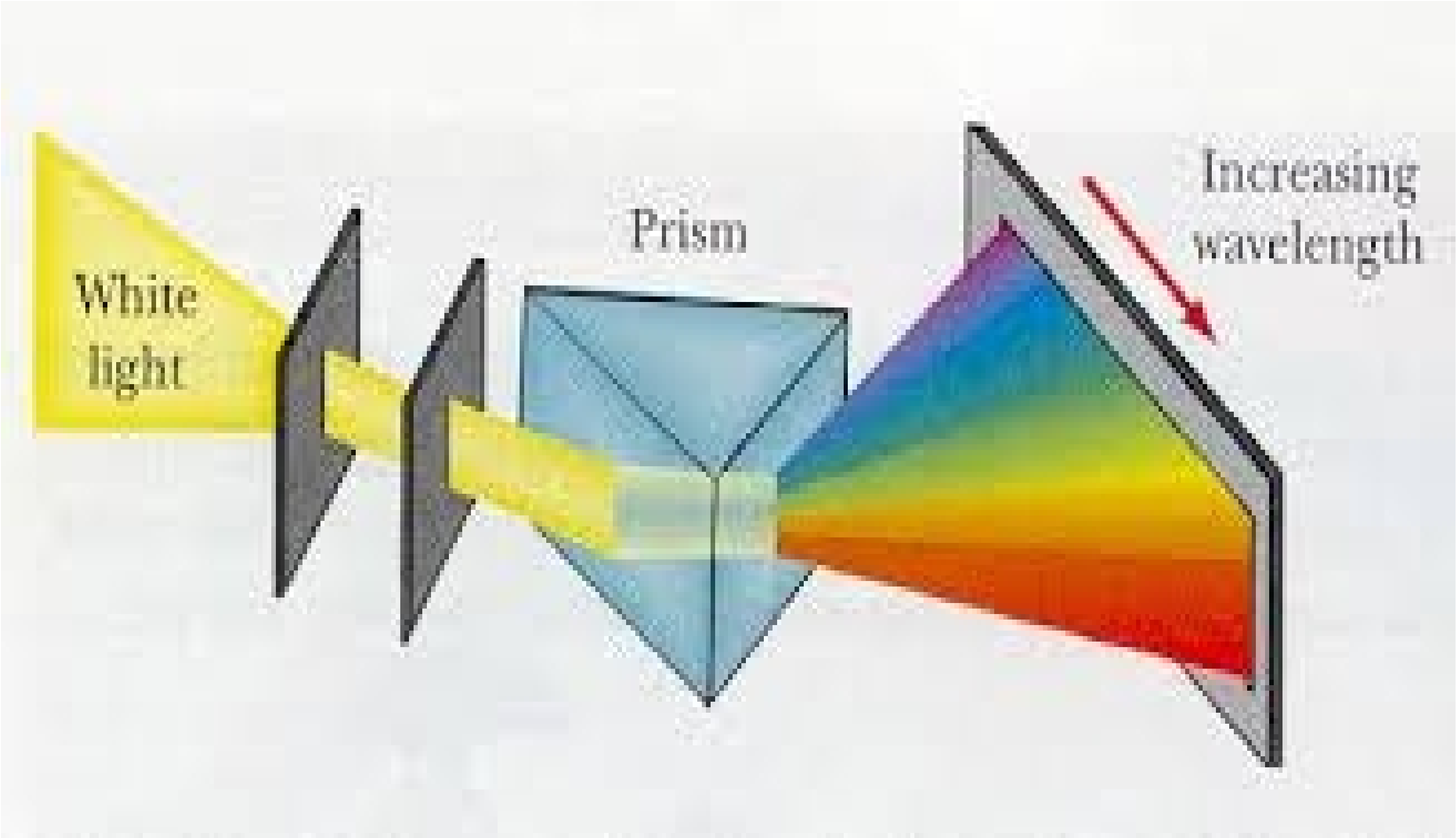
The energy of an atom can jump or down but it has to land at one of
these special values. Each jump corresponds to the emission or absorption of light at a wavelength dictated by how big the jump is. This is like the fingerprint of an element because different elements have different jumps.

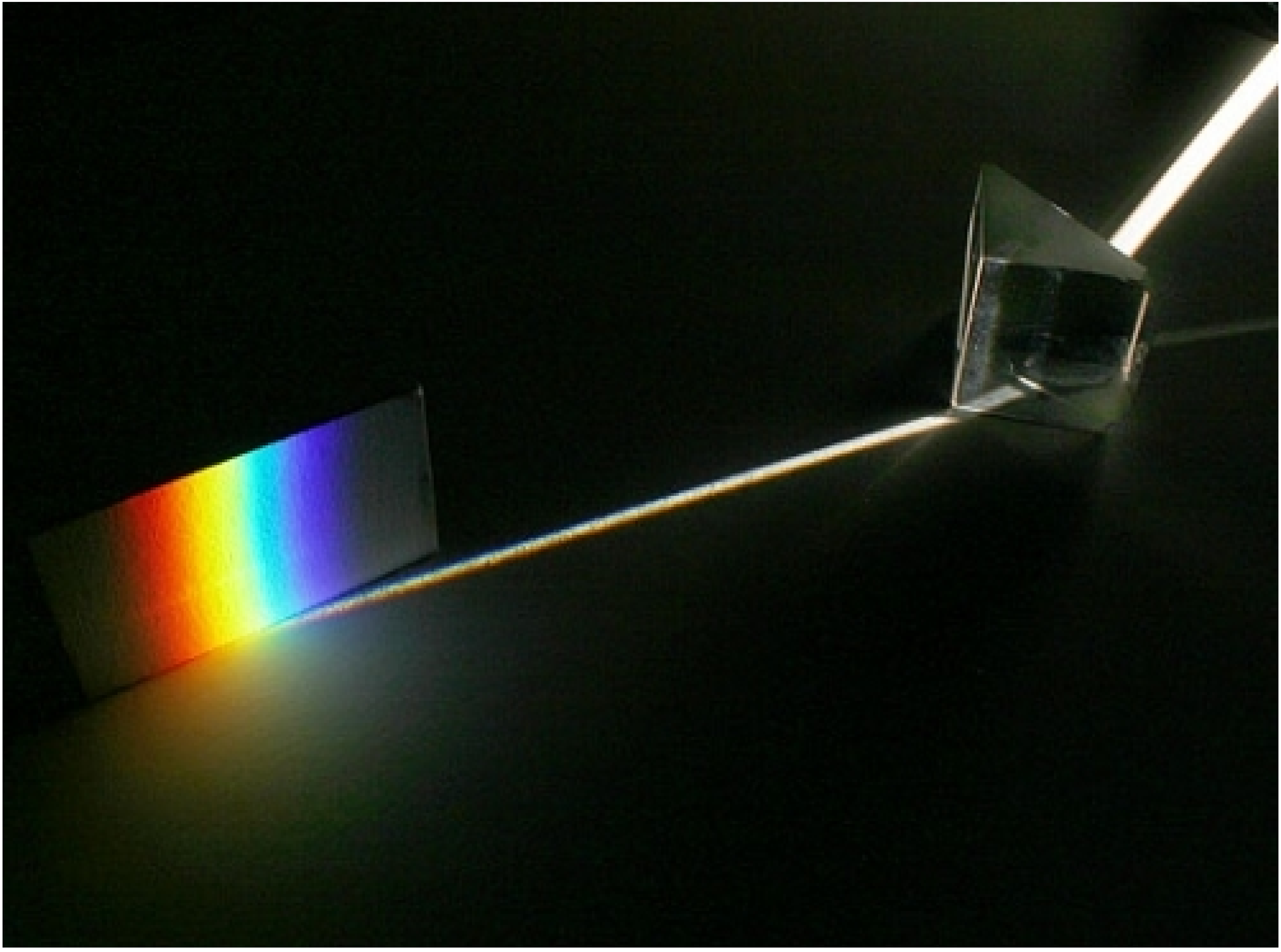

Hydrogen
Sodium
Helium
Neon
Mercury
350
400
450
500
550
600
650
wavelength (nm)

Spectroscopy is the study of the different wavelengths in light (emitted by a star for example).

Since we know how different types of atoms emit and absorb light at different wavelengths, astronomers can try to figure out what atomic elements a certain star is composed of.
It can also give information about the temperature and mass of a star. Historically none of this was easy! The first ever Astronomy PhD at Harvard was awarded in 1925 for a thesis which showed the Sun consisted mostly of hydrogen.

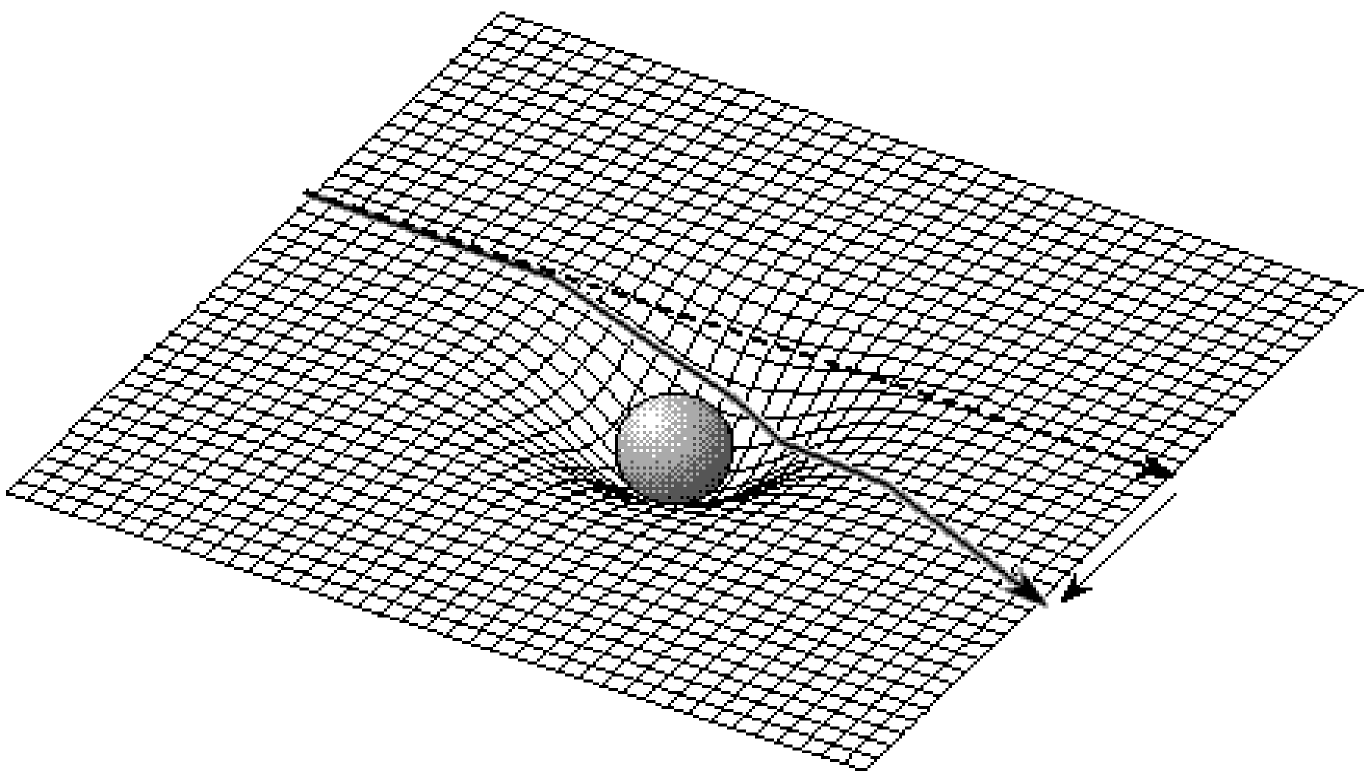
In order to





Gravitational Waves

According to Einstein's General Theory of Relativity (1916), **gravity** is the result of curvature in spacetime. Spacetime becomes curved in the presence of mass. The more massive an object the more spacetime becomes curved near the object. Light is bent by this curvature, or equivalently, by gravity.



light is deflected from its original straight path

When a massive object accelerates, it creates “waves” in the curvature of spacetime which propagate outwards at the speed of light like the ripples in a pond. In theory, someone observing a gravitational wave would therefore see the distances between objects increasing and decreasing at a certain frequency, which is the frequency of the gravitational wave.

Unfortunately, the magnitude of this effect decreases with distance and since we are so far away from any truly massive stellar objects, this effect has never been observed.

LIGO detector ($365M) collected data from 2002-2010 with no findings.

Although there is no definitive evidence for gravitational waves, we can still ask what sorts of massive objects could produce them. One theorized source is black holes.

After a black hole is perturbed (for instance if it collides with another black hole), it will slowly relax to its original state by emitting energy. This is completely analogous to what we discussed before with atoms: after an atom is excited, it will have a tendency to relax to its original state by emitting light. The frequency of light emitted by the atom in the process of relaxing could only take on certain values which depended only on the type of atom. A star for instance then emits light which is made up of wavelengths which depend on the composition of the star

The same is true for a perturbed black hole. In the process of relaxing, it will emit gravitational waves which are made up of waves of certain frequencies characteristic of the black hole. These characteristic frequencies depend only on the mass of the black hole, and not on the nature of the perturbation.

The interesting thing is that even after the original perturbation has died down, the black hole will continue emitting gravitational radiation. This is analogous to tapping a glass with a spoon: even though you are no longer tapping the glass, it continues to vibrate. Eventually these vibrations stop as energy escapes to infinity. Similarly, the black hole will continue to vibrate, but these vibrations will **damped** as time goes on, since energy will disappear to infinity, or even fall into the event horizon.

We therefore say that a black hole has characteristic **quasinormal frequencies** which describe both the frequency of the oscillation, and a damping factor which describes how quickly the oscillation decays in time.