Meaning of Spectroscopy

Interaction of electromagnetic radiation with matter yields that: energy is absorbed or emitted by matter in discrete quantities (quanta).

Measurement of the frequency or (wave length) of the absorbed or emitted radiation by the matter gives valuable information on the nature and constitution of matter.

The ways in which these measurements are made and the information which they yield constitute the practice of spectroscopy.

THE ELECTROMAGNETIC WAVES

By definition, the propagation of mechanical disturbances—such as:

sound waves, water waves, and waves on a string—requires the presence of a medium.

In this lecture we are concerned with the properties of electromagnetic waves, which (unlike mechanical waves) can propagate through empty space.

Plane Electromagnetic Waves

To understand the prediction of electromagnetic waves more fully, let us focus our attention on an electromagnetic wave that travels in the:

x direction (the *direction of propagation*).

In this wave,

the electric field E is in the ***y*** direction, and

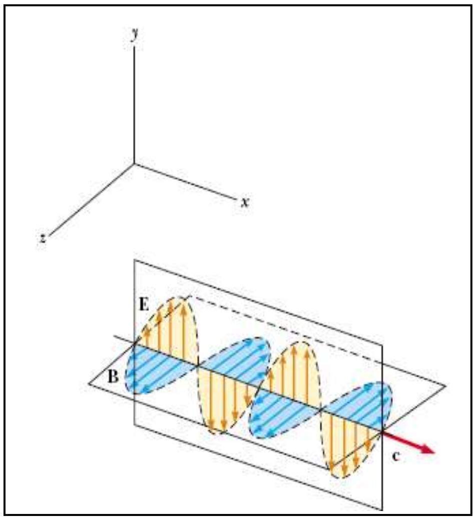
the magnetic field B is in the *z* direction,

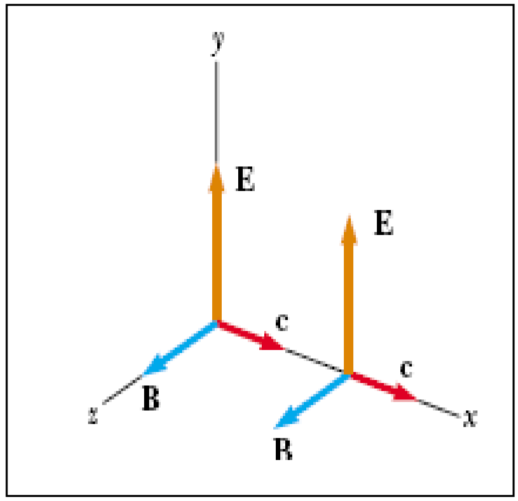
as shown in the Figure.

Waves such as this one, in which the electric and magnetic fields are restricted to being parallel to a pair of perpendicular axes, are said to be

linearly polarized waves.

Furthermore, we assume that at any point in space, the magnitudes *E* and *B* of the fields depend upon *x* and *t* only, and not upon the *y* or *z* coordinate.





Speed of electromagnetic waves

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

Taking $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$ and $\epsilon_0 = 8.854\,19 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$

we find that $c = 2.997\,92 \times 10^8$ m/s. Because this speed is precisely the same as the speed of light in empty space, we are led to believe (correctly) that light is an electromagnetic wave.

The equations of the electric and magnetic fields are as follows:

Sinusoidal electric and magnetic fields

$$E = E_{max}\cos(kx - \omega t)$$

$$B = B_{max}\cos(kx - \omega t)$$

where E_{max} and B_{max} are the maximum values of the fields. The angular wave number is $k = 2\pi/\lambda$, where λ is the wavelength. The angular frequency is $\omega = 2\pi f$, where f is the wave frequency. The ratio ω/k equals the speed of an electromagnetic wave, c:

$$\frac{\omega}{k} = \frac{2\pi f}{2\pi/\lambda} = \lambda f = c$$

wavelength and frequency of these waves are related by

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8\ \text{m/s}}{f}$$

$$\frac{E_{max}}{B_{max}} = \frac{\omega}{k} = c$$

$$\frac{E_{max}}{B_{max}} = \frac{E}{B} = c$$

That is, **at every instant the ratio of the magnitude of the electric field to the magnitude of the magnetic field in an electromagnetic wave equals the speed of light.**

Quick Quiz 34.1 What is the phase difference between the sinusoidal oscillations of the electric and magnetic fields in Figure 34.3? (a) 180° (b) 90° (c) 0 (d) impossible to determine.

In vacuum the speed of light for any E.M radiation is equal to :

$c = 3*10^8\ m.s^{-1}$

In a transparent medium the velocity (c') is less than (c). This reduction is related to the refractive index of medium by:

Refractive index of the medium(n)

=(velocity in vacuum / velocity in medium) = c/c'

so : $c' = c/n$

As the radiation enters a region of higher ref. index, the wavelength is reduced, the frequency remains constant.

Ref. index of air is ~ 1.0028 for visible light, the effect on λ due to air maybe ***ignored*** except for high accuracy work.

Example **An Electromagnetic Wave**

A sinusoidal electromagnetic wave of frequency 40.0 MHz travels in free space in the *x* direction, as in Figure 34.4.

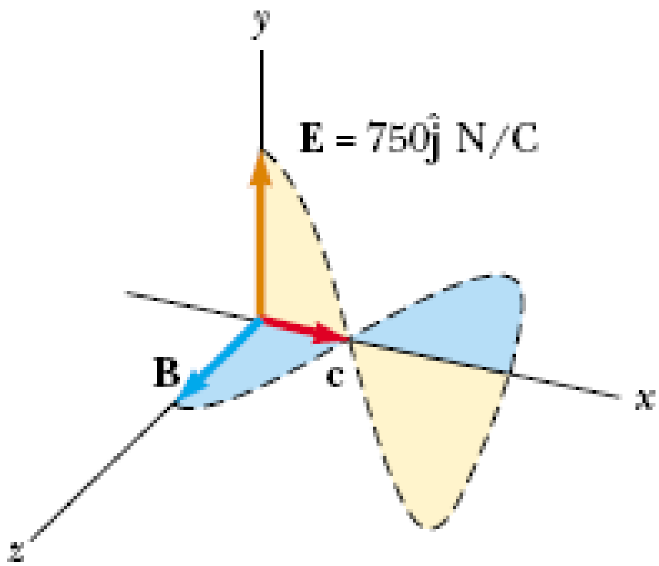
(A) Determine the wavelength and period of the wave.

Solution Using Equation 34.13 for light waves and given that $f = 40.0 \text{ MHz} = 4.00 \times 10^7 \text{ s}^{-1}$, we have

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{4.00 \times 10^7 \text{ s}^{-1}} = 7.50 \text{ m}$$

The period *T* of the wave is the inverse of the frequency:

$$T = \frac{1}{f} = \frac{1}{4.00 \times 10^7 \text{ s}^{-1}} = 2.50 \times 10^{-8} \text{ s}$$



(B) At some point and at some instant, the electric field has its maximum value of 750 N/C and is along the y axis. Calculate the magnitude and direction of the magnetic field at this position and time.

Solution From Equation 34.14 we see that

$$B_{\text{max}} = \frac{E_{\text{max}}}{c} = \frac{750 \text{ N/C}}{3.00 \times 10^8 \text{ m/s}} = 2.50 \times 10^{-6} \text{ T}$$

Because **E** and **B** must be perpendicular to each other and perpendicular to the direction of wave propagation (x in this case), we conclude that **B** is in the z direction.

(C) Write expressions for the space–time variation of the components of the electric and magnetic fields for this wave.

Solution We can apply Equations 34.11 and 34.12 directly:

$$E = E_{max} \cos(kx - \omega t) = (750\ \text{N/C}) \cos(kx - \omega t)$$

$$B = B_{max} \cos(kx - \omega t) = (2.50 \times 10^{-6}\ \text{T}) \cos(kx - \omega t)$$

where

$$\omega = 2\pi f = 2\pi(4.00 \times 10^{7}\ \text{s}^{-1}) = 2.51 \times 10^{8}\ \text{rad/s}$$

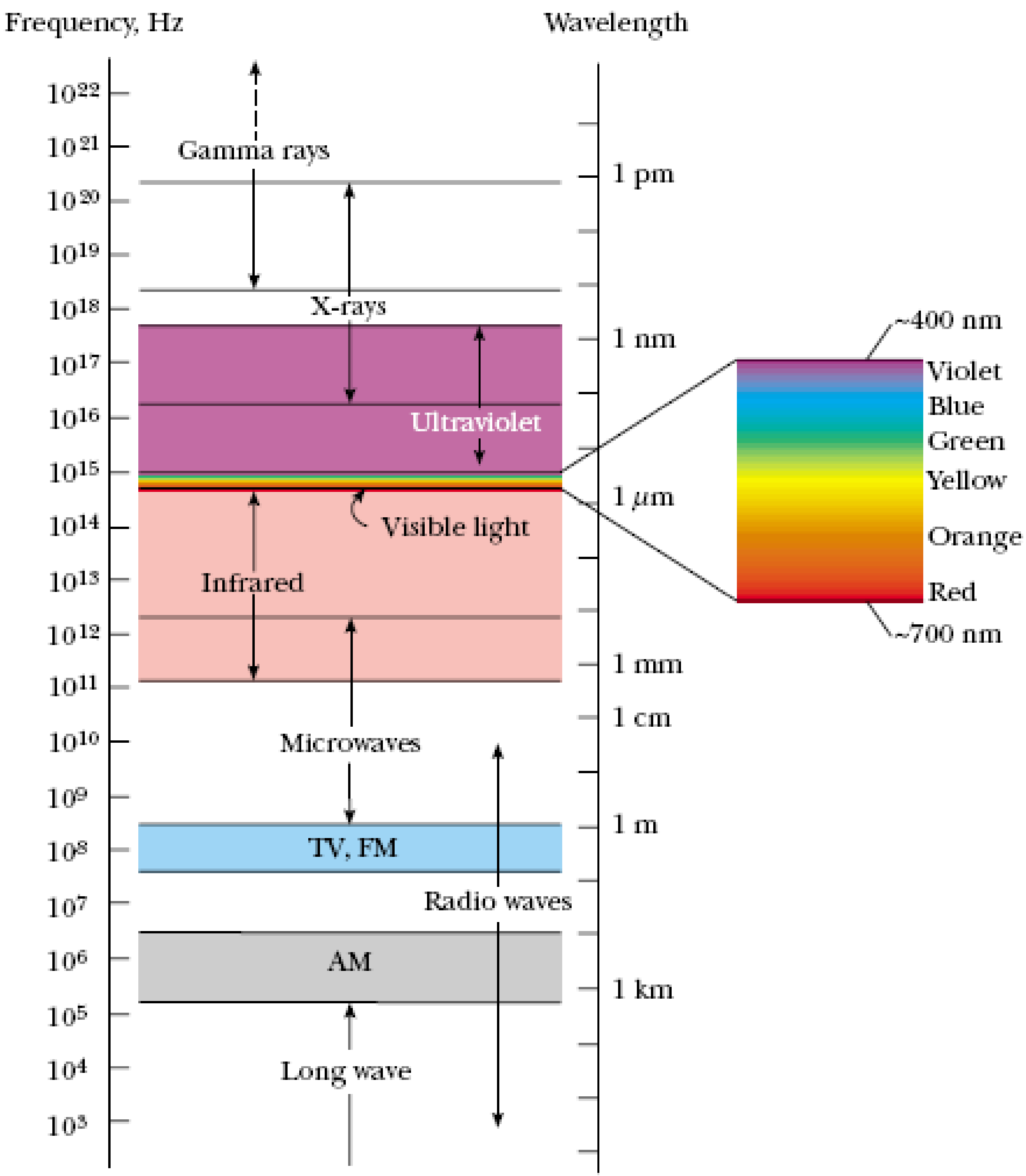
$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{7.50\ \text{m}} = 0.838\ \text{rad/m}$$

The Spectrum of Electromagnetic Waves

The various types of electromagnetic waves are listed in the Figure, which shows the electromagnetic spectrum.

Note the wide ranges of frequencies and wavelengths.

No sharp dividing point exists between one type of wave and the next. The names given to the types of waves are simply for convenience in describing the region of the spectrum in which they lie.


Frequency, Hz
Wavelength
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
Gamma rays
X-rays
Ultraviolet
Visible light
Infrared
Microwaves
TV, FM
Radio waves
AM
Long wave
1 pm
1 nm
1 μm
1 mm
1 cm
1 m
1 km
~400 nm
Violet
Blue
Green
Yellow
Orange
Red
~700 nm

Radio waves, whose wavelengths range from more than 10^4 m to about 0.1 m, are the result of charges accelerating through conducting wires. They are generated by such electronic devices as *LC* oscillators and are used in radio and television communication systems.

Microwaves have wavelengths ranging from approximately 0.3 m to 10^{-4} m and are also generated by electronic devices. Because of their short wavelengths, they are well suited for radar systems. Microwave ovens are an interesting domestic application of these waves.

Infrared waves have wavelengths ranging from approximately 10^{-3} m to the longest wavelength of visible light, 7×10^{-7} m. These waves, produced by molecules and room-temperature objects, are readily absorbed by most materials.

The infrared (IR) energy absorbed by a substance appears as internal energy because the energy agitates

the atoms of the object, increasing their vibrational or translational motion, which results in a temperature increase. Infrared radiation has practical and scientific applications in many areas, including physical therapy, IR photography, and vibrational spectroscopy.

Visible light, the most familiar form of electromagnetic waves, is the part of the electromagnetic spectrum that the human eye can detect. Light is produced by the

Rearrangement of electrons in atoms and molecules. The various wavelengths of visible

light, which correspond to different colors, range from red ($\lambda \approx 7 \times 10^{-7}$ m) to violet ($\lambda \approx 4 \times 10^{-7}$ m). The sensitivity of the human eye is a function of wavelength, being a maximum at a wavelength of about 5.5×10^{-7} m. With this in mind, why do you suppose tennis balls often have a yellow-green color?

Ultraviolet waves cover wavelengths ranging from approximately 4×10^{-7} m to 6×10^{-10} m. The Sun is an important source of ultraviolet (UV) light, which is the main cause of sunburn. **Sunscreen lotions are transparent to visible light but absorb most UV light.**

X-rays have wavelengths in the range from approximately 10^{-8} m to 10^{-12} m. The most **common source of x-rays is the stopping of high-energy electrons upon bombarding a metal target.** X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

Because x-rays damage or destroy living tissues and organisms, care must be taken to avoid unnecessary exposure or overexposure.

Gamma rays are electromagnetic waves emitted by radioactive nuclei (such as 60Co and 137Cs) and during certain nuclear reactions. High-energy gamma rays are a component of cosmic rays that enter the Earth's atmosphere from space. They have wavelengths ranging from approximately 10^{-10} m to less than 10^{-14} m.

They are highly penetrating and produce serious damage when absorbed by living tissues.

Quick Quiz 34.8 In many kitchens, a microwave oven is used to cook food. The frequency of the microwaves is on the order of 10^{10} Hz. The wavelengths of these microwaves are on the order of (a) kilometers (b) meters (c) centimeters (d) micrometers.

Quick Quiz 34.9 A radio wave of frequency on the order of 10^5 Hz is used to carry a sound wave with a frequency on the order of 10^3 Hz. The wavelength of this radio wave is on the order of (a) kilometers (b) meters (c) centimeters (d) micrometers.

The energy of aquantum of light depends on its freq.

$E = h*f = h * \upsilon$ h= planck's constant = $6.63*10^{-34}$ J.s

E in joules & f in $Hz = s^{-1}$

$E\ (joule) = hc/\lambda = (6.63*10^{-34} * 3*10^{8}) / \lambda$ (joules)

But: $1\ ev = 1.6*10^{-19}$ J

So : E in $(ev) = (6.63*10^{-34} * 3*10^{8}) / (\lambda * 1.6*10^{-19})$ ev

$= (1.243*10^{-6}) / \lambda$ ev

Units

Velocity of light C = $3*10^8$ ms^{-1}

Frequency = cycles per sec (cps) or Hz

Since frequency used lie in the range (10^{10} -- 10^{20}) Hz

Frequency usually expressed as *wave number*

wave number (cm^{-1}) = 1/ λ (cm) = f (Hz)/C(=$3x10^{10}$ cm/s)

freq & wave number units have two advantages over wavelength units

1) They are both independent of the medium.
2) They are both directly proportional to the photon energy

Multiplication factor	name	symbol
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	K
10^{-2}	Centi	c
10^{-3}	Milli	m
10^{-6}	Micro	µ
10^{-9}	Nano	n
10^{-12}	Pico	p
10^{-15}	Femto	f
10^{-18}	atto	a