Electromagnetic Radiation

EMR

Light: Interference and Optics

I. Light as a Wave
- wave basics review
- electromagnetic radiation

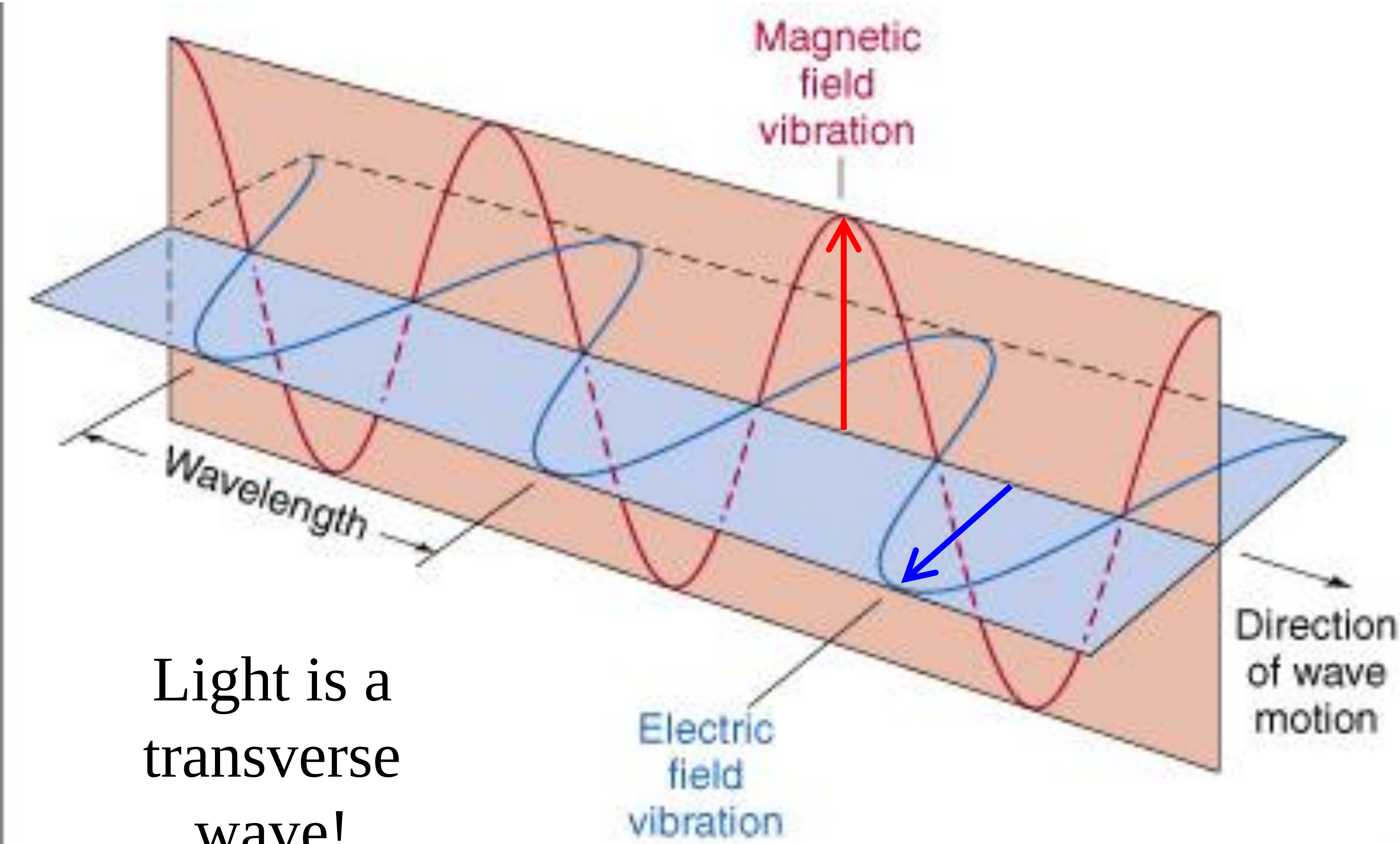
II. Diffraction and Interference
- diffraction, Huygen's principle
- superposition, interference
- standing waves, slits & gratings

III. Geometric Optics
- reflection, refraction, Snell's Law
- images, lenses, and mirrors

	The student will be able to:	HW:
1	Model light and other types of electromagnetic radiation as a transverse wave of electric and magnetic fields and analyze graphs and/or functions to solve related problems and explain related phenomena such as polarization, absorption, production, intensity, etc.	1 – 5
2	Model diffraction and interference of light involving slits or gratings by Huygen's principle and analyze and solve problems relating geometry of openings to patterns of interference.	6 – 18
3	State and apply laws of reflection and refraction, Snell's Law, and solve related problems and/or describe qualitatively the phenomena of absorption, transmission, and reflection of light undergoing a change in medium.	19 – 25
4	Apply the ray model of light to explain and analyze formation of real and virtual images by plane, concave, and convex mirrors and solve related problems involving object and image distance, magnification, focal length and/or radius of curvature.	26 – 31
5	Apply the ray model of light to explain and analyze formation of real and virtual images by converging or diverging thin lenses and solve related problems involving object and image distance, magnification, focal length and/or radius of curvature.	32 – 36

What *is* Light?

- Visible light is one example of what scientists call electromagnetic radiation.
- It is called this because its medium consists of oscillating electric and magnetic fields.
- An electron or proton will experience force when subject to fields such as these.
- Therefore light can be viewed as a disturbance of electric and magnetic force.



Light is a transverse wave!

Modeling Light as a Wave

- There is no physical medium but rather mutually oscillating electric and magnetic fields.
- E is always perpendicular to B and the velocity of the wave is always perpendicular to both fields.
- Just as a changing magnetic field can induce an electric field a changing electric field can induce a magnetic field. This mutual induction results in propagation of the wave through space.

Speed of Light

- Light can exist in a vacuum (such as "outer space") or within certain gases, liquids or solids.
- The speed of light in a vacuum is:
  c = 299,792,458 m/s
- This is an important "constant" in physics that can be related to permittivity and permeability!
- The speed of any electromagnetic wave is always equal to the ratio of E to B!

$$v = c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \qquad c = \frac{E}{B}$$

Energy and Power of Light

- One way to quantify the energy inherent to light is in terms of its intensity.
- The intensity of a wave is the amount of power per unit area impingent on a real or imagined surface.
- For a sinusoidal wave form the average intensity of electromagnetic radiation can be related to the amplitude of the field oscillations by:

$$I = \frac{P}{A} = \frac{E_{max} B_{max}}{2\mu_0} = \frac{c\varepsilon_0 E_{max}^2}{2}$$

Sinusoidal Example Functions

If an electromagnetic wave happens to be sinusoidal in form then it can be modeled by the following functions of position and time.

fields given by:

$$E = E_{\text{max}} \sin(kx \pm \omega t)$$
$$B = B_{\text{max}} \sin(kx \pm \omega t)$$

wave number: $k = \dfrac{2p}{l}$

angular frequency: $w = \dfrac{2p}{T} = 2pf$

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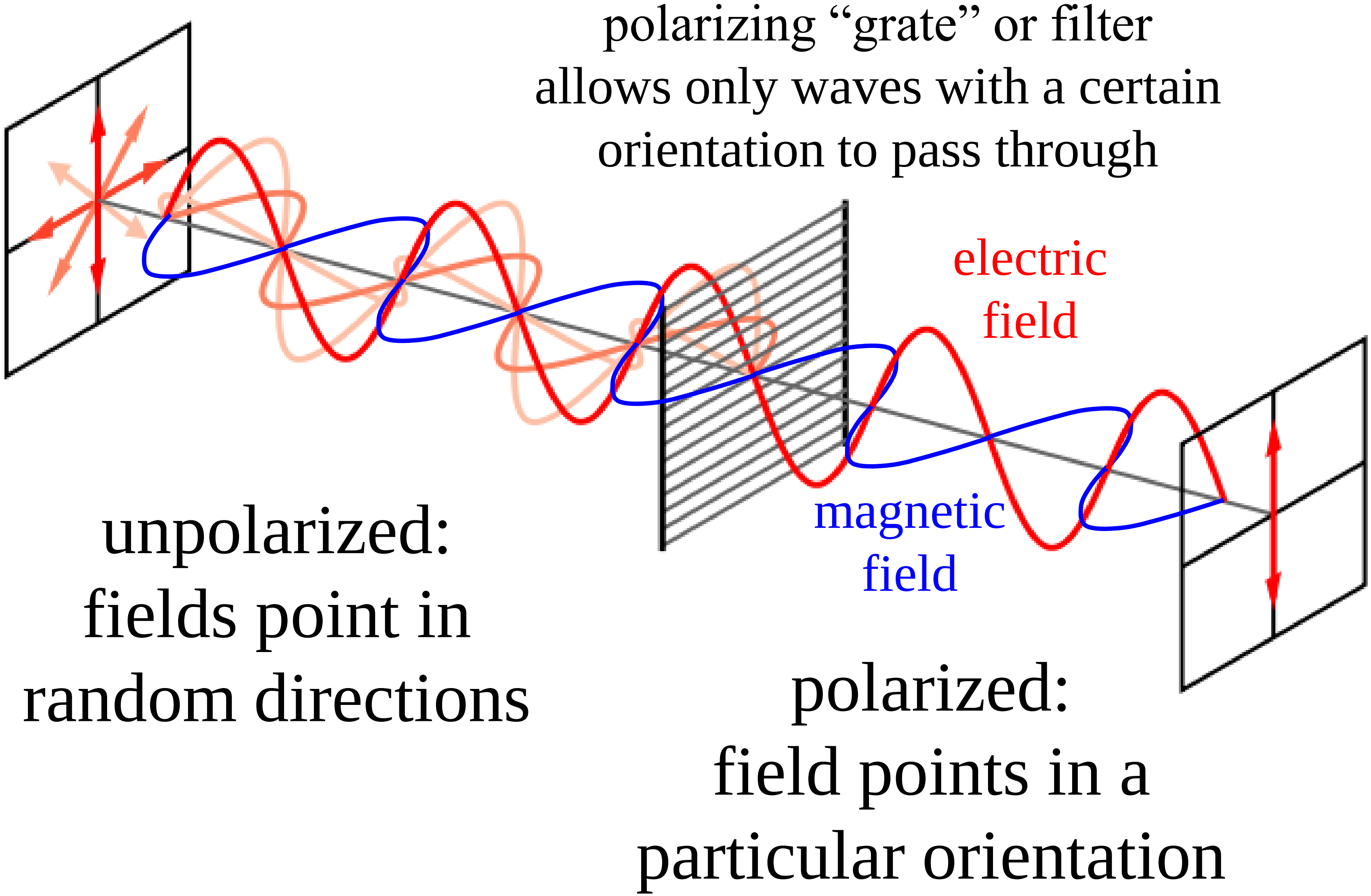
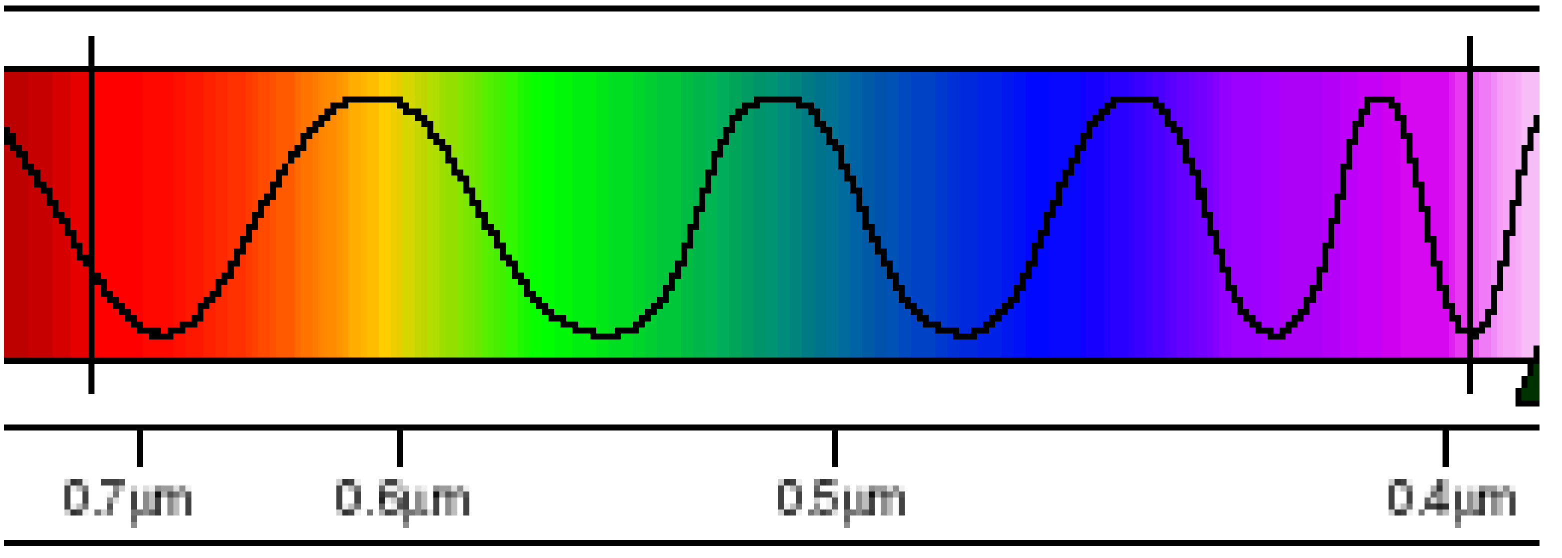
Polarization

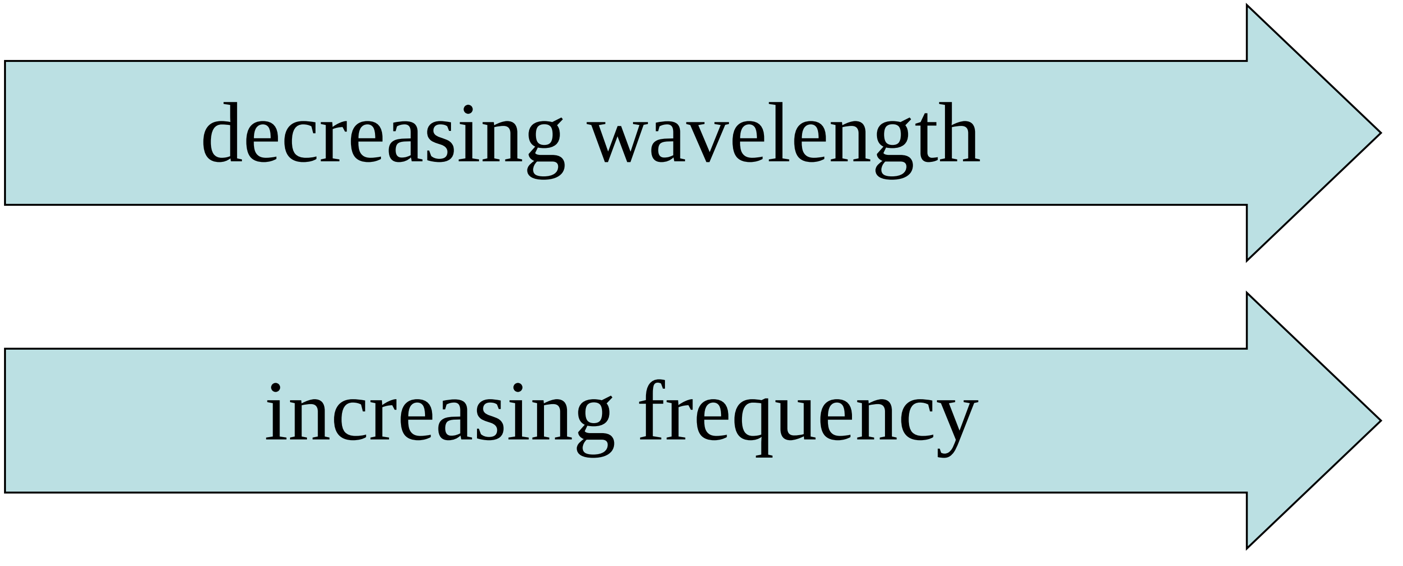
- Polarization refers to the orientation of oscillations in a transverse wave, such as light.
- Light is said to be polarized if its oscillations share a certain orientation.
- For example the electric field might be confined to say a vertical plane and the magnetic to a horizontal plane.
- Unpolarized light is randomly oriented.
- Only transverse waves can be polarized – longitudinal waves such as sound cannot.



note: the magnetic field is shown only for the one wave that "makes it through" the polarizing "grate". Waves with electric field aligned with the lines in the grate do work on electrons and lose energy at the grate.

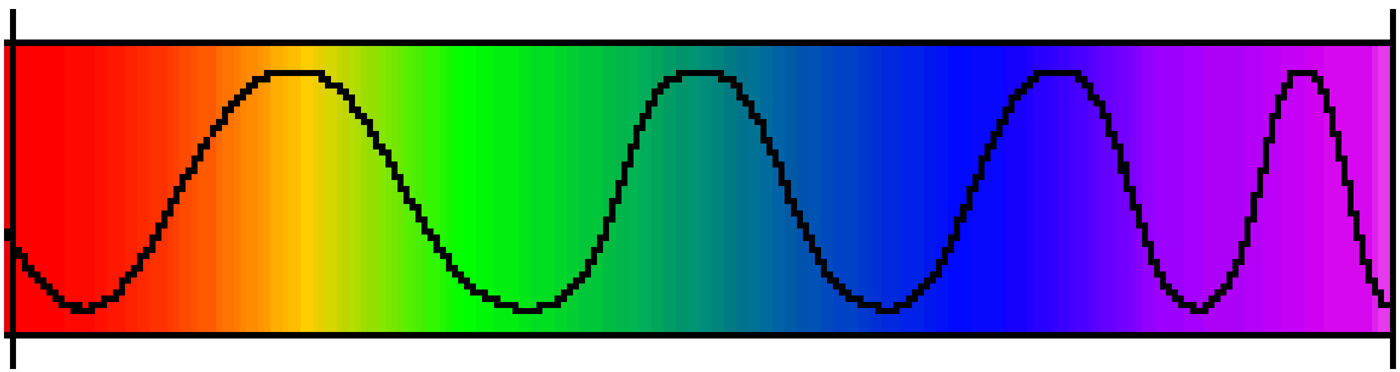
Visible Light Region of the Electromagnetic Spectrum





The range of visible wavelengths of light is from 400 nm to 750 nm (approximately). Determine the range of visible *frequencies*.

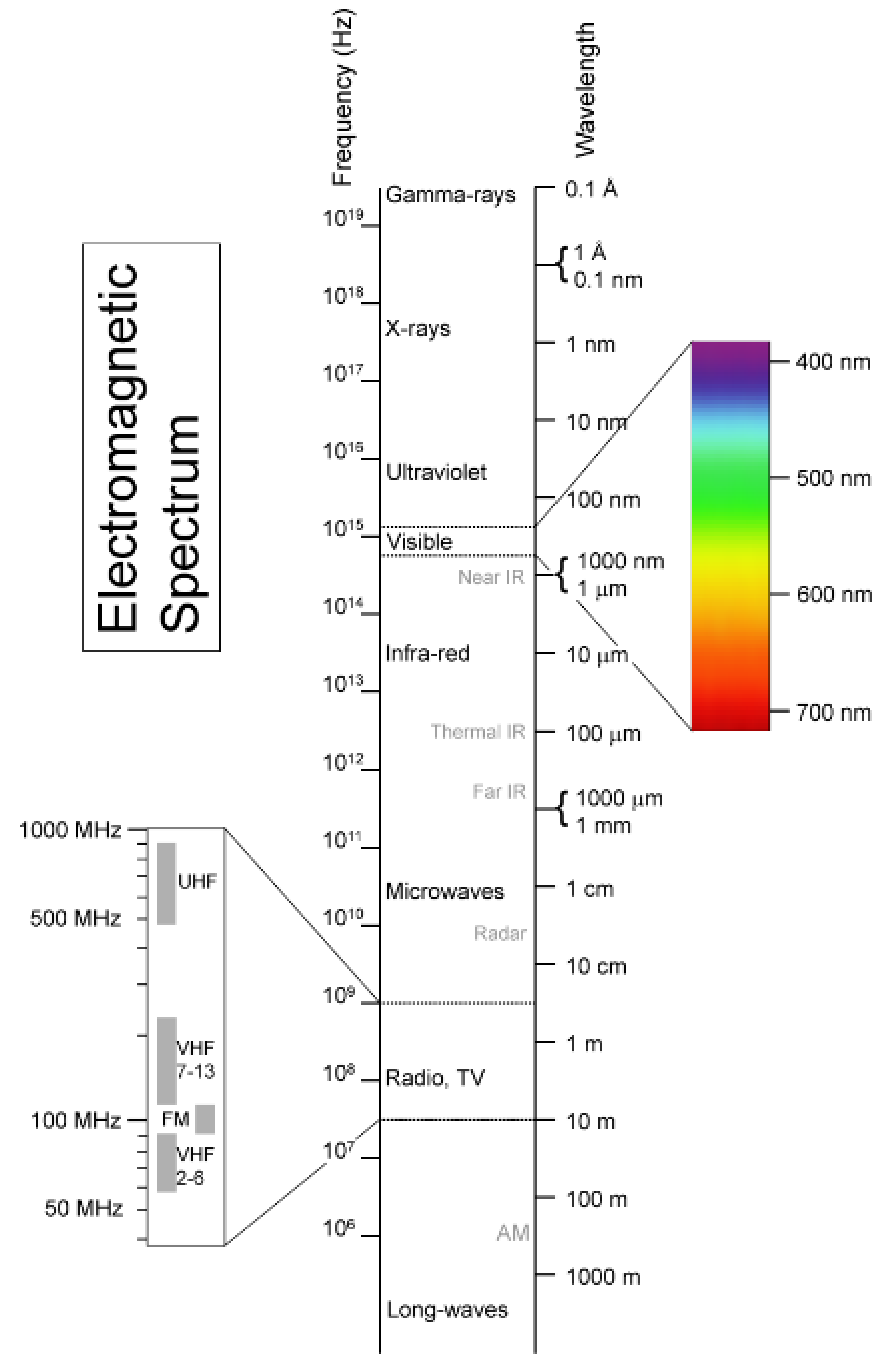
750 nm - - - - - - wavelength - - - - - - 400 nm



4.0×10^{14} Hz - - - - frequency - - - - 7.5×10^{14} Hz

Beyond Light

- Electromagnetic waves can exist at virtually any frequency or wavelength.
- Our eyes are only sensitive to a certain range of wavelengths.
- EMR with wavelengths outside this range can *exist* but cannot be *seen*.



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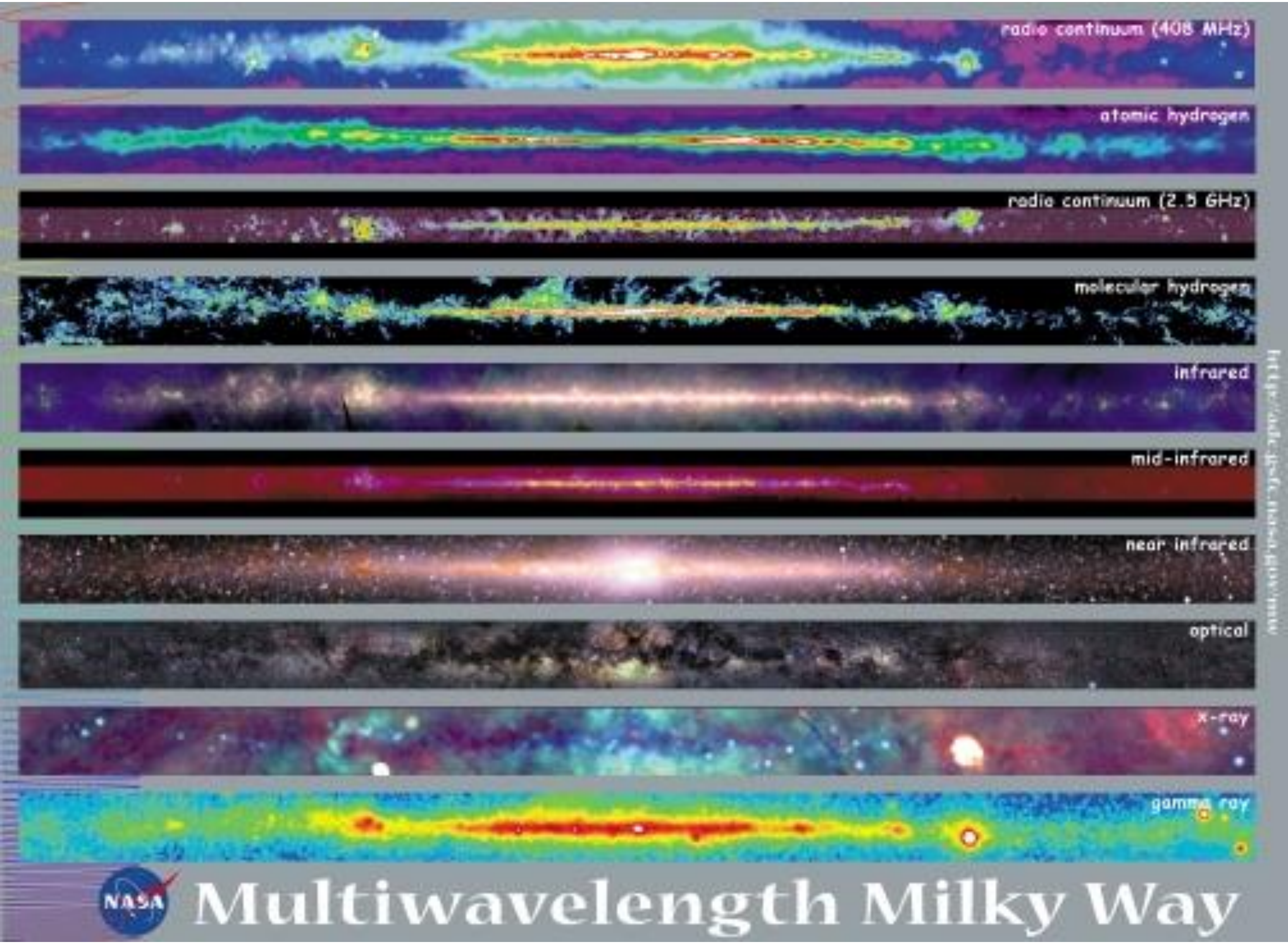
What is the "speed of infrared"?

- Because all EMR is essentially the same kind of wave it all travels at the same speed through a vacuum (or air).
- The speed of infrared is the same as the speed of light or the speed of radio or the speed of any EMR: 3.00×10^8 m/s. This same speed also applies to microwave, ultraviolet, X-ray, gamma.

	Example	Frequency	Wavelength
Radio	AM (WNOX)	990 kHz	303 m
	FM (WIMZ)	103.5 MHz	2.897 m
	TV (VHF ch 10)	195 MHz	1.54 m
	Cell Phone bands	900, 1800 MHz	0.33, 0.17 m
Microwave	microwave oven	2450 MHz	0.122 m
	classroom generator	10.525 GHz	0.0285 m
Infrared	human (98.6 °F)	3.21×10^{13} Hz	9.35 μm
	hot oven (300 °F)	4.36×10^{13} Hz	6.87 μm
	remote control	3.19×10^{14} Hz	940 nm

Visible Light	far red	4.00×10^{14} Hz	750 nm
	red laser pointer	4.61×10^{14} Hz	650 nm
	green laser pointer	5.64×10^{14} Hz	532 nm
	deep violet	7.50×10^{14} Hz	400 nm
Ultraviolet	UVA	8.21×10^{14} Hz	365 nm
	UVC	3.00×10^{15} Hz	100 nm
X-ray	"soft"	3×10^{17} Hz	1 nm
	"hard" (medical)	1.21×10^{19} Hz	2.48×10^{-11} m
Gamma	radioactive cobalt-60	3.22×10^{20} Hz	9.31×10^{-13} m


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
NASA
Multiwavelength Milky Way