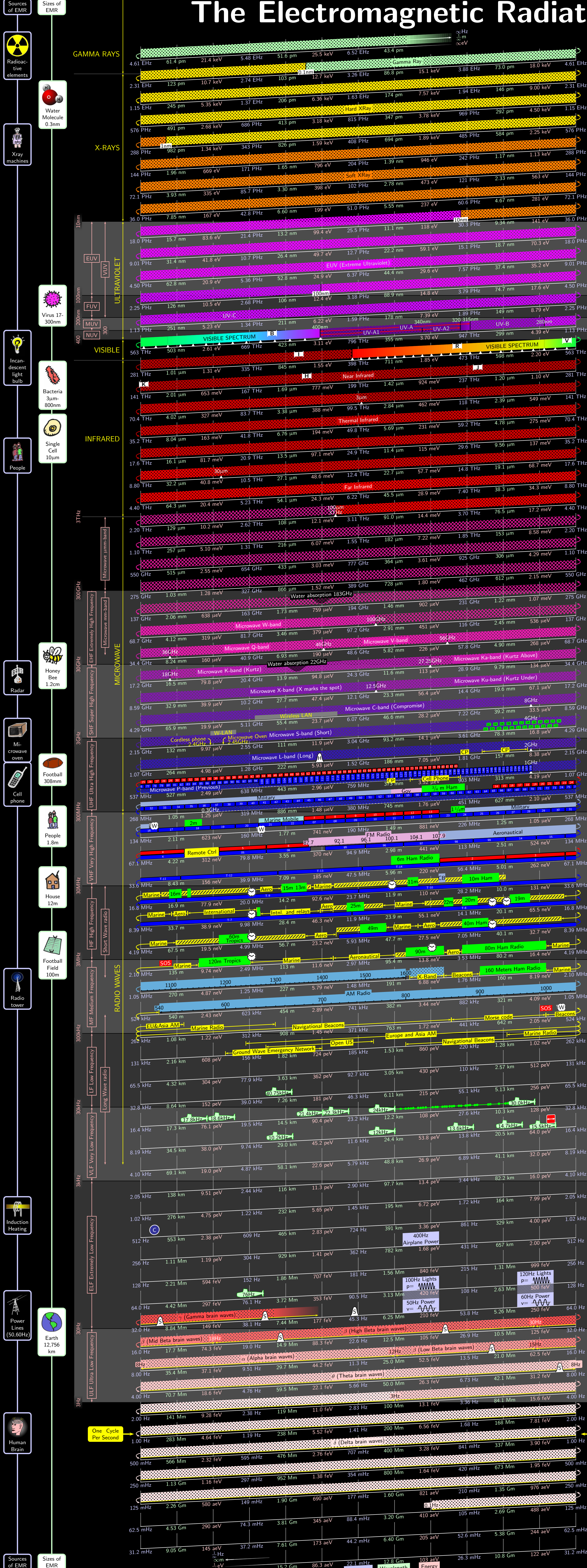


# The Electromagnetic Radiation Spectrum



## How to read this chart

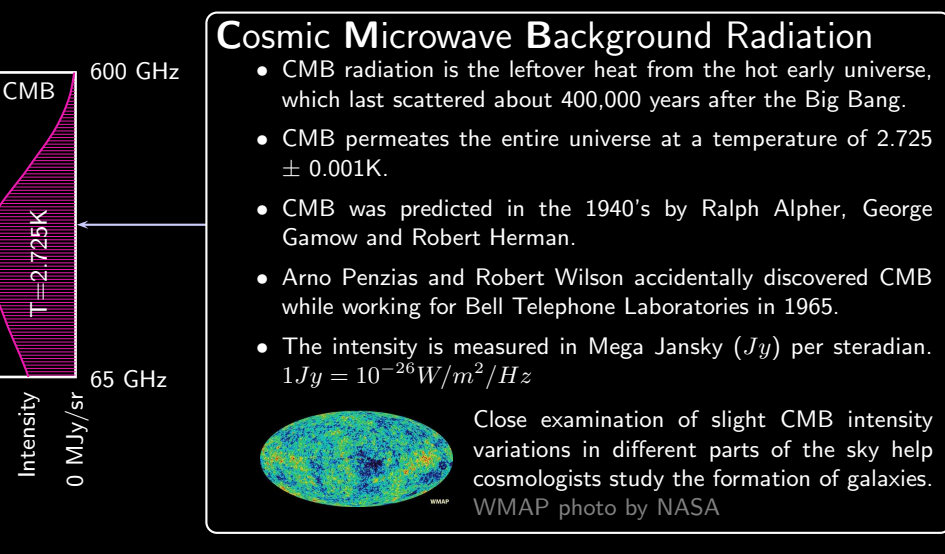
- This chart is organized in octaves (frequency doubling/halving) starting at 1Hz and going higher (2,4,8, etc) and lower (1/2, 1/4, etc). The octave is a natural way to represent frequency.
- Frequency increases on the vertical scale in the upward direction.
- The horizontal bars wrap around from right to left as the frequency increases upwards.
- There is no limit to either end of this chart, however, due to limited space only the "known" items have been shown here. A frequency of 0Hz is the lowest possible frequency but the method of depicting octaves used here does not allow for ever reaching 0Hz, only approaching it. Also, by the definition of frequency (Cycles per second), there is no such thing as negative frequency.
- Values on the chart have been labelled with the following colours: [Frequency] measured in Hertz, [Wavelength] measured in meters, [Energy] measured in electronVolts.

## Ultraviolet Light

- Ultraviolet light is beyond the range of human vision.
- Physicists have divided ultraviolet light ranges into Vacuum Ultraviolet (VUV), Extreme Ultraviolet (EUV), Far Ultraviolet (FUV), Medium Ultraviolet (MUV), and Near Ultraviolet (NUV).
- UV-A, UV-B and UV-C were introduced in the 1930's by the Commission Internationale de l'Éclairage (CIE, International Commission on Illumination) for photobiological spectral bands.
- Short-term UV-A exposure causes sun-tanning which helps to protect against sun-burn. Exposure to UV-B is beneficial to humans by helping the skin produce vitamin D. Excessive UV exposure causes skin damage. UV-C is harmful to humans but is used as a germicide.
- The CIE originally divided UVA and UVB at 315nm, later some photo-dermatologists divided it at 330nm.
- UVA is subdivided into UVA1 and UVA2 for DNA altering effects at 340nm.
- The sun produces a wide range of frequencies including all the ultraviolet light, however, UVB is partially filtered by the ozone layer and UVC is totally filtered out by the earth's atmosphere.
- A bumblebee can see light in the UVA range which helps them identify certain flowers.

## Emission and Absorption

- As EMR passes through elements, certain wavelength bands get absorbed and some new ones get emitted. This absorption and emission produces characteristic spectral lines for each element which are useful in determining the makeup of distant stars. These lines are used to prove the red-shift amount of distant stars.
- When a photon hits an atom it may be absorbed if the energy is just right. The energy level of the electron is raised - essentially holding the radiation. A new photon of specific wavelength is created when the energy is released. The jump in energy is a discrete step and many possible levels of energy exist in an atom.
- Johann Balmer created this formula defining the photon emission wavelength ( $\lambda$ ), where  $m$  is the initial electron energy level and  $n$  is the final electron energy level.
 
$$\lambda = 364.506 \text{ nm} \left( \frac{m^2}{m^2 - n^2} \right)$$
- Much of the interstellar matter is made of the simplest atom hydrogen. The hydrogen visible-spectrum emission and absorption lines are shown below:



## Cosmic Microwave Background Radiation

- CMB radiation is the leftover heat from the hot early universe, which last scattered about 400,000 years after the Big Bang.
- CMB permeates the entire universe at a temperature of  $2.725 \pm 0.001$  K.
- CMB was predicted in the 1940's by Ralph Alpher, George Gamow and Robert Herman.
- Arno Penzias and Robert Wilson accidentally discovered CMB while working for Bell Telephone Laboratories in 1965.
- The intensity is measured in Mega Jansky ( $10^6$ ) per steradian.  $1 \text{ Jy} = 10^{-26} \text{ W/m}^2/\text{Hz}$

## Television

- Television is transmitted in the VHF and UHF ranges (30MHz - 3GHz).
- TV channels transmitted over the air are shown as **TV**.
- TV channels transmitted through cable (CATV) are shown as **TV**. CATV channels starting with "T" are channels fed back to the cable TV station (like news feeds).
- Air and cable TV stations are broadcast with the separate video, colour, and audio carriers grouped together in a channel band as follows:

## Radio Bands

- The radio spectrum (ELF to EHF) is populated by many more items than can be shown on this chart, only a small sampling of bands used around the world have been shown.
- Communication using EMR is done using either:
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
- Each country has its own rules and regulations for allocating bands in this region. For more information, look up the radio communications authority in your area (Ex: FCC in the US, DOC in Canada).
- Not all references agree on the UHF band range, the HAARP range is used here.
- Radio Detecting And Ranging (RADAR) uses EMR in the microwave range to detect the distance and speed of objects.
- Citizens Band Radio (CB) contains 40 stations between 26.965-27.405MHz.
- Schumann resonance is produced in the cavity between the Earth and the ionosphere. The resonant peaks are depicted as **A**.
- Hydrogen gas emits radio band EMR at 21cm **A**.
- Some individual frequencies are represented as icons:
  - Submarine communications
  - Time and frequency standards
  - Ham radio and international meter bands
  - Miscellaneous short wave radio
  - Weather stations
  - Cellular and PCS Phones (including: FDMA, TDMA, CDMA ranges)

## Sound

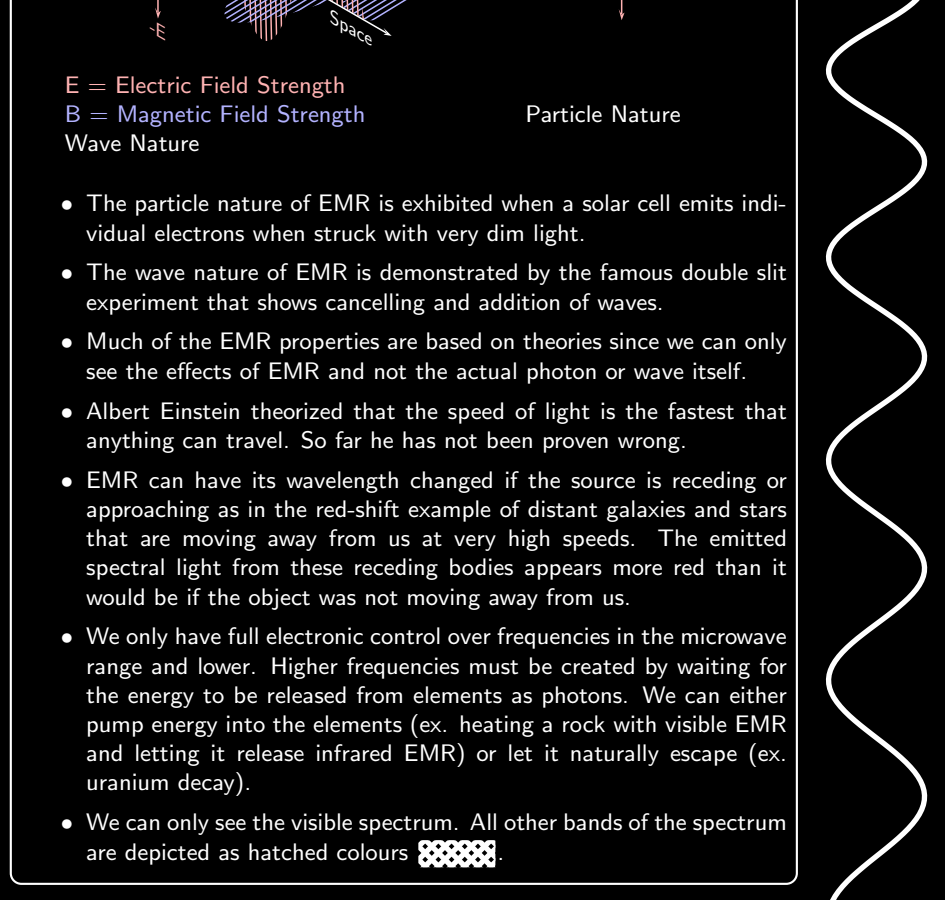
- Although sound waves are not electromagnetic they are included on this chart as a reference in frequency only. All other properties of electromagnetic waves are different from sound waves.
- Sound waves are caused by an oscillating compression of molecules. Sound cannot travel in a vacuum such as outer space.
- The speed of sound in air is 1240kph (770mph).
- Humans can only hear sound between  $\approx 20$ Hz to  $\approx 20$ kHz.
- Infrasound (below 20Hz) can be sensed by internal organs and touch. Frequencies in the 0.2Hz range are often the cause of motion sickness.
- Bats can hear sound up to  $\approx 50$ kHz.
- The 88 piano keys of the Equal Temperament scale are accurately located on the frequency chart.
- Over the ages people have striven to divide the continuous audio frequency spectrum into individual musical notes that have harmonic relationships. Microtonal musicians study various scales. One recent count lists 4700 different musical scales.
- Middle C is depicted on the chart as **C**.

## Brain Waves

- By connecting electrodes from the human head to an electroencephalograph (EEG), it is possible to measure very small cyclic electrical signals.
- There has been much study on this topic, but like all effects on humans, the science is not as exact as the science of materials.
- Generally, lower brain wave frequencies relate to sleep, and the higher frequencies relate to alertness.
- Devices have been made for measuring and stimulating brain waves to achieve a desired state.

## Electromagnetic Radiation (EMR)

- EMR is emitted in discrete units called photons but has properties of waves as seen by the images below. EMR can be created by the oscillation or acceleration of electrical charge or magnetic field. EMR travels through space at the speed of light ( $2.99792458 \times 10^8 \text{ m/s}$ ). EMR consists of an oscillating electrical and magnetic field which are at right angles to each other and spaced at a particular wavelength. There is some controversy about the phase relationship between the electrical and magnetic fields of EMR, one of the theoretical representations is shown here:



Symbol	Name	Exp.	Multiplier
Y	yotta	$10^{24}$	1,000,000,000,000,000,000,000,000
Z	zetta	$10^{21}$	1,000,000,000,000,000,000,000,000
E	exa	$10^{18}$	1,000,000,000,000,000,000,000,000
P	peta	$10^{15}$	1,000,000,000,000,000,000,000,000
T	tera	$10^{12}$	1,000,000,000,000,000,000,000,000
G	giga	$10^9$	1,000,000,000,000,000,000,000,000
M	mega	$10^6$	1,000,000,000,000,000,000,000,000
k	kilo	$10^3$	1,000,000,000,000,000,000,000,000
		$10^0$	1
m	milli	$10^{-3}$	0.001
μ	micro	$10^{-6}$	0.000 001
n	nano	$10^{-9}$	0.000 000 001
p	pico	$10^{-12}$	0.000 000 000 001
f	femto	$10^{-15}$	0.000 000 000 000 001
a	atto	$10^{-18}$	0.000 000 000 000 000 001
z	zepto	$10^{-21}$	0.000 000 000 000 000 000 001
y	yocto	$10^{-24}$	0.000 000 000 000 000 000 000 001

Symbol	Name	Value
c	Speed of Light	$2.99792458 \times 10^8 \text{ m/s}$
h	Planck's Constant	$6.6261 \times 10^{-34} \text{ J}\cdot\text{s}$
h	Planck's Constant (freq)	$1.054592 \times 10^{-34} \text{ J}\cdot\text{s}$
f	Frequency (cycles / second)	Hz
λ	Wavelength (meters)	m
E	Energy (Joules)	J

## Gamma Rays

- Gamma radiation is the highest energy radiation (up to  $\approx 10^{20}$  eV) that has been measured.
- Gamma rays, protons, electrons, or something else.
- Alpha, beta, and delta radiation are not electromagnetic but are actually parts of the atom being released from a radioactive atom. In some cases this can cause gamma radiation. These are not to be confused with brain waves of similar names.

## Visible Spectrum

- The range of EMR visible to humans is also called "Light". The visible spectrum also closely resembles the range of EMR that filters through our atmosphere from the sun.
- Other creatures see different ranges of visible light, for example bumblebees can see ultraviolet light and dogs have a different response to colours than do humans.
- The sky is blue because our atmosphere scatters light and the shorter wavelength blue gets scattered the most. It appears that the entire sky is illuminated by a blue light but in fact that light is scattered from the sun. The longer wavelengths like red and orange move straight through the atmosphere which makes the sun look like a bright white ball containing all the colours of the visible spectrum.
- Interestingly, the visible spectrum covers approximately one octave.
- Astronomers use filters to capture specific wavelengths and reject unwanted wavelengths, the major astronomical (visual) filter bands are depicted as **A**.

## Infrared Radiation

- Infrared radiation (IR) is sensed by humans as heat and is below the range of human vision. Humans (and anything at room temperature) are emitters of IR.
- IR remote control signals are invisible to the human eye but can be detected by most camcorders.
- Night vision scopes/goggles use a special camera that senses IR and converts the image to visible light. Some IR cameras employ an IR lens to help illuminate the view.
- IR LASERS are used for burning objects.
- A demonstration of IR is to hold a metal bowl in front of your face. The IR emitted by your body will be reflected back using the parabolic shape of the bowl and you will feel the heat.

## LASER

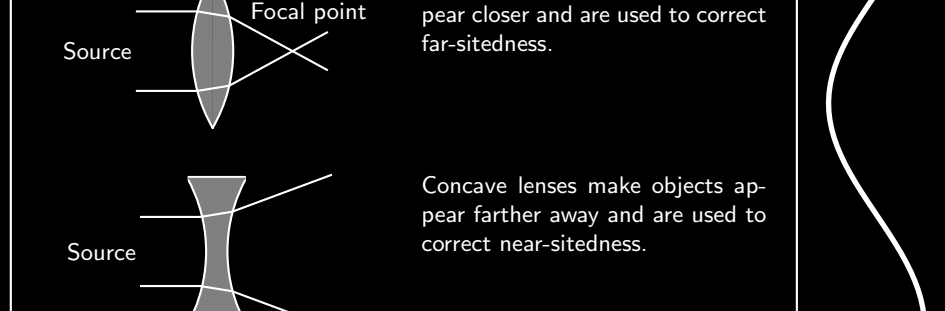
- LASER is an acronym for Light Amplification by Stimulated Emission of Radiation.
- A LASER is a device that produces monochromatic EMR of high intensity.
- With proper equipment, any EMR can be made to operate like a LASER. For example, microwaves are used to create a MASER.

## Polarization

- As a photon (light particle) travels through space, its axis of electrical and magnetic fluctuations does not rotate. Therefore, each photon has a fixed linear polarity of somewhere between  $0^\circ$  to  $360^\circ$ . Light can also be circularly and elliptically polarized.
- Some crystals can cause the photon to rotate its polarization.
- Receivers that expect polarized photons will not accept photons that are in other polarities. (ex: satellite dish receivers have horizontal and vertical polarity positions).
- A polarized filter (like Polaroid sunglasses) can be used to demonstrate polarized light. One filter will only let photons that have one polarity through. Two overlapping filters at right angles will almost totally block the light that exits, however, a third filter inserted between the first two at a  $45^\circ$  angle will rotate the polarized light and allow some light to come out the end of all three filters.
- Light that reflects off an electrical insulator becomes polarized. Conductive reflectors do not polarize light.
- Perhaps the most reliably polarized light is a rainbow.
- Moonlight is also slightly polarized. You can test this by viewing the moonlight through a Polaroid sunglasses lens, then rotate that lens, the moonlight will dim and brighten slightly.

## Refraction

- Refraction of EMR is dependent on wavelength as can be seen by the prism example below.



## Reflection

- Reflection of EMR is dependent on wavelength as demonstrated when visible light and radio waves bounce off objects that X-Rays would pass through. Microwaves, which have a large wavelength compared to visible light, will bounce off metal mesh in a microwave oven whereas visible light will pass through.
- EMR of any wavelength can be reflected, however, the reflectivity of a material depends on many factors including the wavelength of the incident beam.
- The angle of incidence ( $\theta_i$ ) and angle of reflection ( $\theta_r$ ) are the same.