The Electromagnetic Radiation Spectrum

How to read this chart

- This chart is organized in octaves starting at 1Hz and going higher (2,4,8, etc) and lower (1/2, 1/4, etc). The octave (frequency doubling/halving) is a natural way to represent frequency.
- Frequency increases on the vertical scale in the upward direction.
- The horizontal bars wraparound from far right to far 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 into Vacuum Ultraviolet (VUV), Extreme Ultraviolet (EUV), Far Ultraviolet (FUV), Medium Ultraviolet (MUV), 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.
- UV-A causes sun-tanning which protects against sunburn. Short term exposure to UV-B is beneficial to humans in helping produce Vitamin D. Excessive UV exposure causes skin damage. UV-C can be used for germicidal purposes.
- The CIE originally divided UVA/B at 315nm, later some photo-dermatologists divided it at 320nm.
- UVA has also been subdivided into UVA1/2 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 by our atmosphere.
- Bumble-bees can see light in the UVA range to help them identify certain flowers.

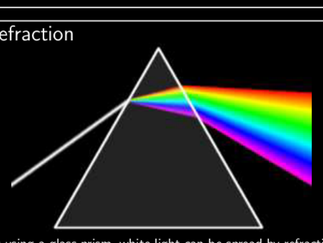
Infrared Radiation

- Infrared radiation (IR) is sensed by humans as heat and is below the range of human vision.
- 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 lamp to help illuminate the view.
- IR LASERs are used for burning objects (Ex. product best-before date-codes).
- 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.

Polarization

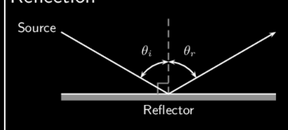
- As the photon travels through space its axis of electrical and magnetic fluctuations does not rotate. Therefore, each photon has a fixed polarity of somewhere between 0°to 360°.
- Some crystals can cause the photon to rotate its polarization.
- Receivers that expect polarized photons will not accept photons that are in other polarities. (ex. satellite dish receivers have horizontal and vertical polarity positions).
- A polarized filter (like those found on polarized sunglasses) can be used to demonstrate polarized light. One filter will only let photons that have one polarity through. Two filters at right angles will almost totally block the light that exits, however, a third filter inserted between the first two at a 45°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.
- Moonlight is also slightly polarized. You can test this by viewing the moonlight through a polarized sunglass lens then rotate that lens, the moonlight will dim and brighten slightly.

Refraction



By using a glass prism, white light can be spread by refraction into a spectrum its composite colours. All wavelengths of EMR can be refracted by using the proper materials.

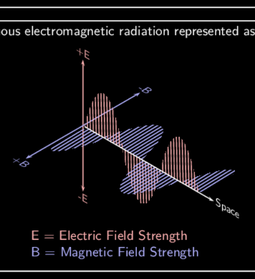
Reflection



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 (θ_i) and angle of reflection (θ_r) are the same.

Continuous electromagnetic radiation represented as a wave.

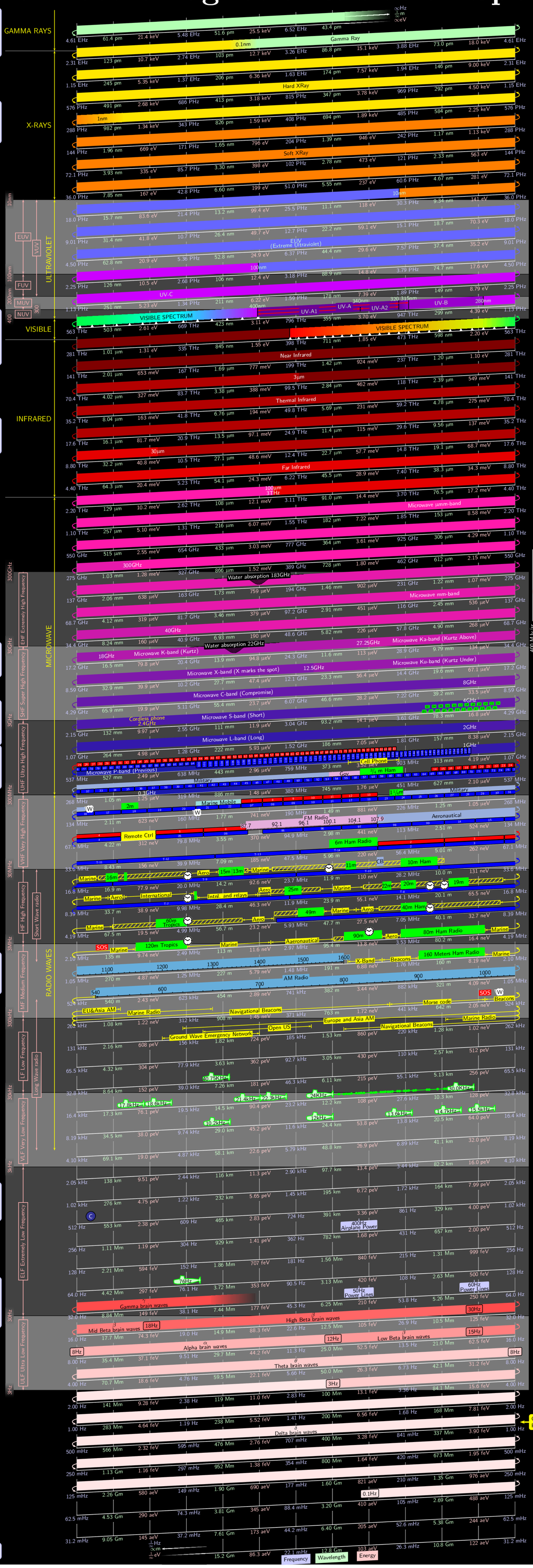


E = Electric Field Strength
B = Magnetic Field Strength

Electro**m**agnetic **R**adiation (EMR)

- EMR is emitted in discrete units called photons but has properties of waves as seen by the image above. EMR can be created by the oscillation or acceleration of electrical charge or magnetic field. EMR travels through space at the speed of light (2.997 924 58 $\times 10^8$ 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 above.
- The particle nature of EMR is exhibited when a solar cell emits individual electrons when struck with very dim light.
- The wave nature of EMR is demonstrated by the famous double slit experiment that shows cancelling and addition of waves.
- Much of the EMR properties are based on theories since we can only see the effects of EMR and not the actual photon or wave itself.
- EMR has properties like refraction and reflection that are dependent on wavelength. An example of refraction is the prism. An example of reflection differences is that visible light and radio waves bounce off things that X-Rays would go through, also microwaves which have a large wavelength compared to visible light will bounce off metal mesh in a microwave oven that light will go through.
- Albert Einstein theorized that the speed of light is the fastest that anything can travel, so far he has not been proven wrong.
- EMR can be bent by gravity as seen by gravity lens examples of distant starlight bending around other large bodies in space.
- EMR can have its wavelength changed if the source is receding or approaching as in the red-shift example of distant galaxies and stars that are moving away from us at very high speeds. The emitted spectral light from these receding bodies appears more red than it would be if the object was not moving away from us.
- 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 is useful in determining the makeup of distant stars. It is also used to prove the red-shift amount of distant stars.
- We only have full electronic control over frequencies in the microwave range and lower, higher frequencies must be created by waiting for the energy to be released from elements as photons, we can either pump energy into the elements (ex. heating a rock with visible EMR and letting it release infrared EMR) or letting it naturally escape (ex. Uranium decay).
- Although many of the bands of the spectrum are depicted here in colour, the only band that we can see is the visible spectrum.
- 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. This is not to be confused with brain waves of similar names.

Radioactive elements
Xray machines
Incandescent light bulb
People
Radar
Microwave oven
Cell phone
Radio tower
Induction Heating
Power Lines (50,60Hz)
Sources of EMR



CMR
T=2.725°K
600 GHz
65 GHz
400 MJy/sr
0 MJy/sr
Intensity

Système International d'unités (SI Units)			
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
E	exa	10^{18}	1,000,000,000,000,000,000
P	peta	10^{15}	1,000,000,000,000,000
T	tera	10^{12}	1,000,000,000,000
G	giga	10^{9}	1,000,000,000
M	mega	10^{6}	1,000,000
k	kilo	10^{3}	1,000
		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

Measurements on this chart		
Symbol	Name	Value
c	Speed of Light	2.997 924 58 $\times 10^8$ m/s
h	Planck's Constant	6.626 1 $\times 10^{-34}$ J·s
$\hbar$	Planck's Constant (freq)	1.054 592 $\times 10^{-34}$ J·s
f	Frequency (cycles / second)	Hz
λ	Wavelength (meters)	m
E	Energy (Joules)	J

Conversions:

$$E = h \cdot f$$
$$\lambda = \frac{c}{f}$$
$$1\text{Å} = 0.1\text{nm}$$
$$1\text{nm} = 10\text{Å}$$
$$1 Joule = 6.24 \times 10^{18}\text{eV}$$

Visible Spectrum

- The range of EMR visible to humans is also called "Light". It 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 bumble-bees can see Ultraviolet light and dogs have a different response to colours than 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.

LASER

- LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.
- A device that produces monochromatic EMR of high intensity.
- With proper equipment, any EMR can made to operate like a LASER. For example, microwaves are used to create a MASER.

Cosmic Microwave Background Radiation

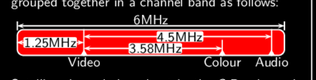
- CMR is the leftover heat emitted 400,000 years after the big bang.
- It permeates the entire universe at a temperature of 2.725 ± 0.001°K.
- Close examination of slight CMR intensity variations in different parts of the sky help cosmologists study the formation of galaxies.
- George Gamow predicted CMB in 1948 and Ralph Alpher and Robert Herman in 1950.
- Arno Penzias and Robert Wilson accidentally discovered CMB while working for Bell Telephone Laboratories in 1965.
- The intensity is measured in Mega Jansky per steradian.

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 allotting bands in this region. For more information, look up the radio communications authority in your area (Ex. FCC in the US).
- Not all references agree on the ULF band range, the HAARP range is used here.
- **RA**dio **D**etecting **A**nd **R**anging (RADAR) uses EMR in the Microwave range to detect the distance and speed of objects.
- **C**itizens **B**and Radio (CB) contains 40 stations between 26.965-27.405MHz.
- Some individual frequencies are represented as icons:
  - xxHz — Submarine communications
  - Time and frequency standards
  - xxm — Ham radio and Internal meter bands
  - Miscellaneous Short wave radio
  - W — Weather stations

Television

- Television stations are transmitted in the VHF and UHF frequency 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 frequency carriers grouped together in a channel band as follows:

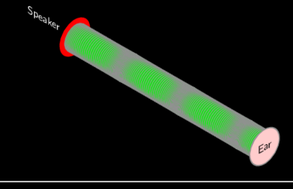


- Satellite channels broadcast in the C-Band are depicted as TV. These stations are broadcast in alternating polarities (Ex. Ch 1 is vertical and 2 is horizontal and visa versa on neighbouring satellites).

Sound

- Although sound waves are not electromagnetic they are included on this chart as a reference in frequency only, all the 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 like outer space.
- The speed of sound in air is 1240kph (770mph).
- Humans can only hear sound between ≈20Hz to ≈20kHz.
- Bats can hear sound up to ≈50kHz.
- The 88 piano keys of the Equal Temperament scale are accurately located on the frequency chart.
- Over the ages people have strived to divide the continuous audio frequency spectrum into individual musical notes that have harmonious relationships. Microtonal musicians study various scales. One recent count lists 4700 different musical scales.
- Middle C is depicted on the chart as C

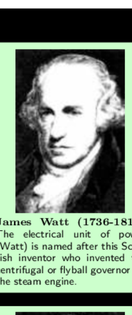
This image depicts air being compressed as sound waves in a tube from a speaker and travelling through the tube towards the ear.



Brain Waves

- By connecting electrodes to the human head, 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.

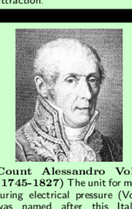
Water Molecule 0.3nm
Virus 17-300nm
Bacteria 3μm-800nm
Single Cell 10μm
Honey Bee 1.2cm
Football 308mm
People 1.8m
House 12m
Football Field 100m
Earth 12,756 km
Sizes of EMR



James Watt (1736-1819) The electrical unit of power (Watt) is named after this Scottish inventor who invented the centrifugal or flyball governor for the steam engine.



Charles Augustin de Coulomb (1736-1806) The unit of quantity used to measure electrical charges, the coulomb, was named after this French physicist who invented the torsion balance for measuring the force of magnetic and electrical attraction.



Count Alessandro Volta (1745-1827) The unit for measuring electrical pressure (Volt) was named after this Italian physicist who studied electric currents and invented the voltaic pile.



André Marie Ampère (1775-1836) The unit of electric current (Ampere) is named after this French scientist who demonstrated the attractive and repulsive properties of electromagentism in current carrying conductors.



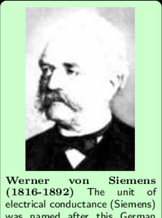
Georg Simon Ohm (1789-1854) The unit of electrical resistance (Ohm) is named after this German physicist who experiemented with electrical currents.

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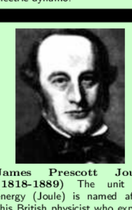
The metre was originally defined in 1791 by the French Academy of Sciences as 1/10,000,000 of the distance along the Earth's surface from the North Pole to the Equator along the meridian of Paris
It is now defined as the length of the path traveled by light in a vacuum in the time interval of 1/299,792,458 of a second.



Michael Faraday (1791-1867) The unit for measuring capacitors (Farad) was named after him. He discovered electromagnetic induction, diamagnetism, and the fact that a magnetic field has the power to rotate the plane of polarized light passing through certain types of glass.



Werner von Siemens (1816-1892) The unit of electrical conductance (Siemens) was named after this German engineer who invented the electric dynamo.



James Prescott Joule (1818-1889) The unit of energy (Joule) is named after this British physicist who experimented with the conversion of electrical and mechanical energy into heat energy.



James Clerk Maxwell (1831-1879) Scottish physicist demonstrated that electric and magnetic forces are two aspects of electromagnetism. He showed that electric and magnetic fields travel through space in the form of waves at a speed of 3.0×10^8m/s, and argued that light was a form of electromagnetic radiation.



Alexander Graham Bell (1847-1922) The unit for loadness of sound (Bel or deciBel) was named by this Scottish born American inventor who studied the relationships of sound and electricity. Antonio Meucci invented a telephone before Bell, but it was Bell's telephone that was commercialized.



Nikola Tesla (1856-1943) The unit of magnetic flux density (Tesla) is named after this Croatian born American engineer who invented the first practical system of generating and transmitting alternating current for electric power.



Heinrich Rudolf Hertz (1857-1894) The unit of frequency (Hertz) is named after this German physicist who was the first to demonstrate the existence of electromagnetic radiation with a spark-gap transmitter and receiver.



Max Planck (1858-1947) The unit for the relationship between energy and frequency (Plancks's constant) was named by this German physicist who derived the thermal radiation curve of matter.

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