By Ian Poole, G3YWX

Understanding Solar Indices

When someone tells you that the flux is up to 200 and the K is 3, do you know what they are talking about? You will after you read this article!

NASA

An ultra-close view of a sunspot taken by the NSO Sacramento Peak Vacuum Tower Telescope.

One of the key skills for any HF DXer is to know how to judge what band conditions may be like. Conditions may be excellent one day with many stations audible from all over the world, but a few days later it may be that only a few stations are audible. To be able to gain an idea about conditions, three main indices are used: solar flux, and the Ap and Kp indices. A good working knowledge of what these numbers represent and what they mean is an advantage even for the ham with most well-equipped station.

Synopsis

The ionosphere can be visualized as containing a number of layers. In fact, there is ionization throughout the ionosphere; the layers are really peaks in the levels of ionization, as we can see from Figure 1. The ionosphere affects radio waves because according to the level of ionization, the signals are refracted, i.e., bent away from traveling in a straight line. Often the level of ionization is sufficiently high to enable the signals to be returned to Earth.

Conditions are continually varying on the HF bands as a result of the varying levels of ionization in the ionosphere. The radiation coming chiefly from the Sun hits the upper ionosphere, causing molecules to ionize, creating positive ions and free electrons. A state of "dynamic equilibrium" exists. The free electrons that affect radio waves recombine with the positive ions to reform molecules. When levels of ionization are higher (when there are more free electrons) the ionosphere is more capable of bending back radio signals to Earth. Also, high levels of ionization mean high maximum usable frequencies and better HF conditions.

The level of ionization at any given point above the Earth is dependent upon a number of factors including the time of day, the season and most important of all the sunspot cycle. It is found that the level of radiation from the Sun increases as the number of sunspots increases. Accordingly, the level of radiation received from the Sun peaks around the top of the sunspot cycle. In fact, it is the bright area just around the sunspot called the *plage* that emits most of the extra radiation.

It is not all good news, though. At the sunspot peak the level of geomagnetic activity also rises. This happens as the Sun emits vast quantities of particles. There is normally a steady flow of these

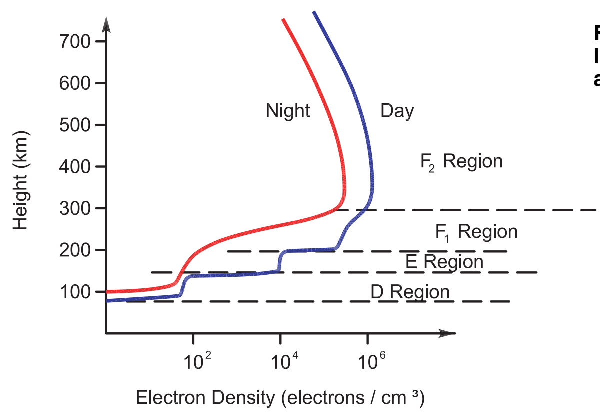


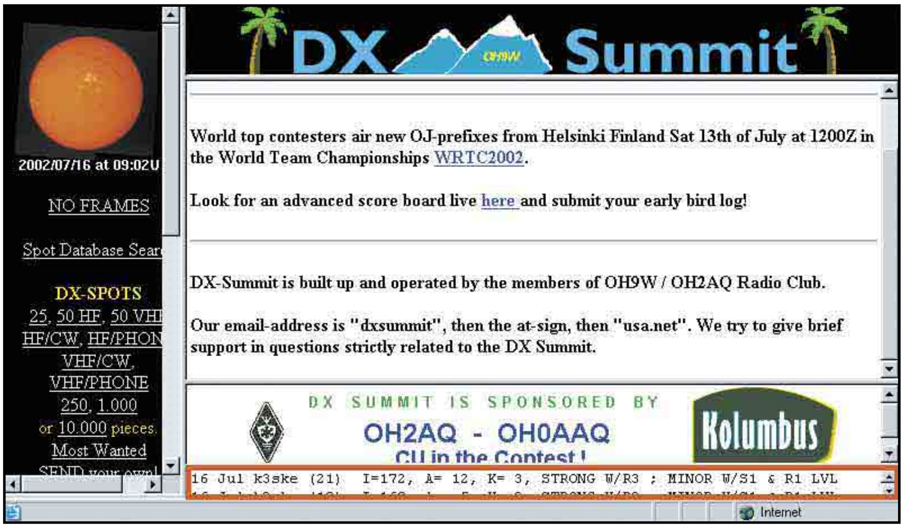
Figure 1—Approximate levels of ionization in the atmosphere

particles, but at times such as when there are solar flares the level of these emissions greatly increases. When they hit the Earth's magnetic field it becomes disturbed, creating a magnetic storm that can be detected at points around the globe. Another effect is that the ionosphere itself can be disturbed, giving rise to an ionospheric storm. This will degrade HF communications and when particularly bad it can lead to a total HF blackout. For a more in-depth recap on radio propagation, get on the Web and go to **www.radio-electronics.com/info/propagation/radio_prop_list.html**, or just visit **www.radio-electronics.com** and navigate from there.

Solar Flux

A measure known as the *solar flux* is used as the basic indicator of solar activity, and to determine the level or radiation being received from the Sun. The solar flux is measured in solar flux units (SFU) and is the amount of radio noise or flux that is emitted at a frequency of 2800 MHz (10.7 cm). The Penticton Radio Observatory in British Columbia, Canada reports this measure daily. The solar flux is closely related to the amount of ionization and hence the electron concentration in the F2 region. As a result it gives a very good indication of conditions for long-distance communication.

The figure for the solar flux can vary from as low as 50 or so to as high as 300. Low values indicate that the maximum useable frequency will be low and overall conditions will not be very good, particularly on the higher HF bands. Conversely, high values generally indicate there is sufficient ionization to support long-distance communication at higher-than-normal frequencies. However, remember that it takes a few days of high values for conditions to improve. Typically values in excess of 200 will be measured during the peak of a sunspot cycle with high values of up to 300 being experienced for shorter periods.



The DX Summit Webcluster at oh2aq.kolumbus.com/dxs/ provides solar activity reports in the frame near the bottom of the window (framed in red).

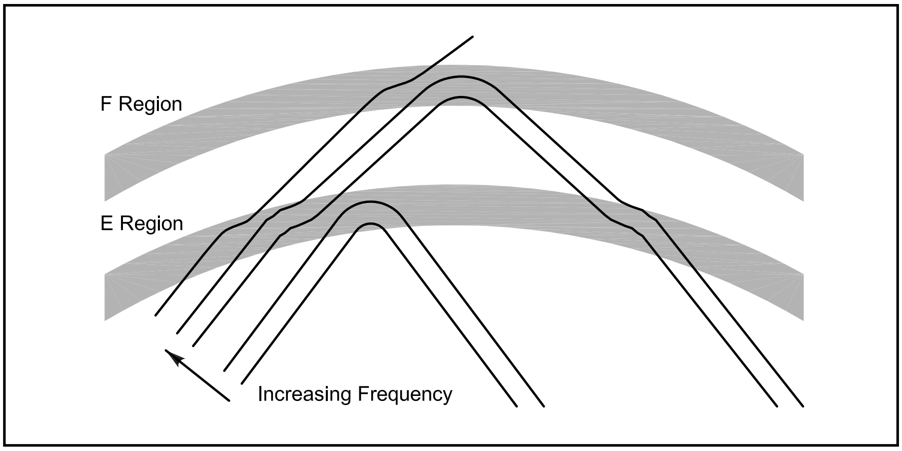


Figure 2—Signals traveling through the ionosphere will be refracted and may be returned to Earth.

Geomagnetic Activity

There are two indices that are used to determine the level of geomagnetic activity: the *A index* and the *K index*. These give indications of the severity of the magnetic fluctuations and hence the disturbance to the ionosphere.

The first of the two indices used to measure geomagnetic activity is the K index. Each magnetic observatory calibrates its magnetometer so that its K index describes the same level of magnetic disturbance, no matter whether the observatory is located in the auroral regions or at the Earth's equator. At three hourly intervals starting at 0000 UTC each day, the maximum deviations from the quiet day curve at a particular observatory are determined and the largest value is selected. This value is then manipulated mathematically and the K index is calculated for that location.

The K index is a "quasi logarithmic" number and as such cannot be averaged to give a longer-term view of the state of the Earth's magnetic field. Thus was born the A index, a daily average. At each 3-hour increment the K index at an observatory is converted to an equivalent "a" index using Table 1, and the 8 a-index values are averaged to produce the A index for that day. It can vary up to values around 100. During very severe geomagnetic storms it can reach values of up to 200 and very occasionally more. The A-index reading varies from one observatory to the next, since magnetic disturbances can be local. To overcome this, the indices are averaged over the globe to provide the Ap index, the planetary value.

Similarly, the Kp index is the planetary average of all the K indices at observatories around the globe. Values between 0 and 1 represent quiet magnetic conditions and this would indicate good HF band conditions, subject to a sufficient level of solar flux. Values between 2 and 4 indicate unsettled or even active magnetic conditions, and are likely to be reflected in a degradation of HF conditions. Moving up the scale, 5 represents a minor storm, 6 a larger storm and 7 through 9 represents a very major storm that would result in a blackout of HF communications.

Although geomagnetic and ionospheric storms are interrelated, it is worth noting that they are different. A geomagnetic storm is a disturbance of the Earth's magnetic field and an ionospheric storm is a disturbance of the ionosphere.

Table 1
The General Relationship between A and K Values

A	*K*	*Comments*
0	0	Quiet
2	1	Quiet
3	1	Quiet
4	1	Quiet to unsettled
7	2	Unsettled
15	3	Active
27	4	Active
48	5	Minor storm
80	6	Major storm
132	7	Severe storm
208	8	Very major storm
400	9	Very major storm

Glossary of Solar Index Terms

ap index: A measure of the general level of geomagnetic activity over the globe for a given day. A mean, 3-hourly "equivalent amplitude" of magnetic activity based on K index data from 11 Northern and 2 Southern Hemisphere magnetic observatories between the geomagnetic latitudes of 46 and 63 degrees.

Ap index: A daily index determined from eight ap index values.

Geomagnetic activity: Natural variations in the geomagnetic field classified into quiet, unsettled, active and geomagnetic storm levels.

Geomagnetic storm: A worldwide disturbance of the Earth's magnetic field, distinct from regular diurnal variations. A storm occurs when the Ap > 29, a minor storm when 29 < Ap < 50, a major storm when 50 <= Ap < 100 and a severe storm when Ap >= 100.

K index—A quasi-logarithmic local index of the 3-hourly range in magnetic activity relative to an assumed quiet-day curve for a single geomagnetic observatory site. First introduced by J. Bartels in 1938, it consists of a single-digit 0 through 9 for each 3-hour interval of the universal time day (UT).

Kp index—The planetary 3-hour-range index Kp is the mean standardized K-index from 13 geomagnetic observatories between 44 degrees and 60 degrees northern or southern geomagnetic latitude. The scale is 0 to 9 expressed in thirds of a unit; e.g., 5– is $4\frac{2}{3}$, 5 is 5 and 5+ is $5\frac{1}{3}$. This planetary index is designed to measure solar particle radiation by its magnetic effects. The 3-hourly ap (equivalent range) index is derived from the Kp index.

Note: Kp, Ap and other indices can be downloaded via FTP at **ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/**. Indices can also be downloaded from **www.sec.noaa.gov/Data/alldata.html**.

From "A Glossary of Space Weather Terms" (**www.irfl.lu.se/HeliosHome/spacew9.html**) and the National Geophysical Data Center Web site (**www.ngdc.noaa.gov/stp/GEOMAG/kp_ap.html**).

Interpreting the Figures

The easiest way to use these figures is to enter them into a propagation prediction program. This will provide the most accurate prediction of what might be happening. These programs will take into account factors such as signal paths because some will cross the poles and they will be far more affected by storms than will those across the equator.

If you don't own propagation software, it is still possible to gain a good insight into what the figures mean purely by assessing them mentally. Obviously, high levels of solar flux are good news. Generally the higher the flux the better the conditions will be for the higher HF frequencies and even 6 meters. However, the levels need to be maintained for some days. In this way the overall level of ionization in the F2 layer will build up. Typically values of 150 and more will ensure good HF band conditions, although levels of 200 and more will ensure they are at their peak. In this way the maximum usable frequencies will rise, thereby providing good conditions.

The level of geomagnetic activity has an adverse affect, depressing the maximum usable frequencies. The higher the level of activity as reflected in higher Ap and Kp indices, the greater the depression of the MUFs. The actual amount of depression will depend not only on the severity of the storm, but also its duration.

Summary

As a broad rule of thumb, check out the levels of solar flux and the K index. These figures can be found at a variety of places, including on the Internet at a variety of sites including **www.eham.net**, **www.qrz.com/**, DX Summit at **oh2aq.kolumbus.com/dxs/** and in the K7VVV Solar Updates that are posted regularly on *ARRLWeb* at **www.arrl.org**. If you connect by radio or telnet to a DX spotting network, you can obtain this information by sending the command SHOW/WWV. Please note that the A and K indices broadcast by WWV represent the "mid-latitude" values for Boulder, Colorado, and may not be representative of conditions around the whole world.

For best conditions, the solar flux should remain above about 150 for a few days with the K index below 2. When these conditions have been met, check out the bands and expect some good DX to be about!

Ian Poole has been licensed as a radio ham for over 30 years and has been active on many bands favoring HF SSB and CW. He is also author of several books including Your Guide to Propagation *(and* VHF/UHF Antennas*) that is available through the ARRL bookstore. You can contact Ian at 5 Meadway, Staines, TW18 2PW, United Kingdom;* **ian_poole@lineone.net**.

NEW PRODUCTS

MINUTEMAN 20 PORTABLE HF ANTENNA

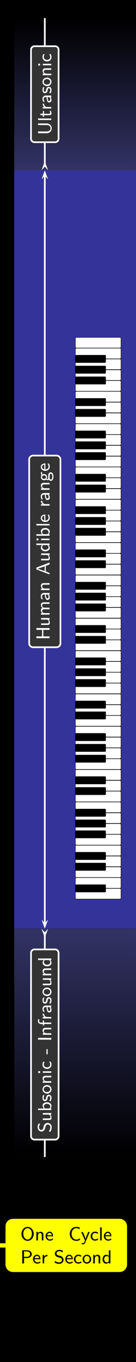
◊ Quicksilver Radio Products has introduced its new MinuteMan 20 portable HF antenna. The antenna covers 20-10 meters with no tuner necessary in most cases. According to company owner John Bee, N1GNV, "On 15, 12, and 10 it's a full quarter-wavelength vertical. On 17 and 20 we use a small amount of high-efficiency coil loading. We designed this antenna to be efficient, lightweight and affordable." While the MinuteMan is primarily intended for portable operation, it's also a solution for hams facing antenna restrictions of any type.

The antenna comes preassembled and needs no tools or other supports for setup. With no piece longer than 17 inches, the MinuteMan fits easily into a briefcase, backpack, airplane carry-on, etc. It weighs just 5 pounds and will handle 100 W of power (although the photo shows N1GNV operating QRP).

Contact Quicksilver Radio Products, PO Box 146, Williston Park, NY 11596; **johnbee@qsradio.com**; **www.qsradio.com**. List price is $130 plus $10 shipping.

Next New Products

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 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

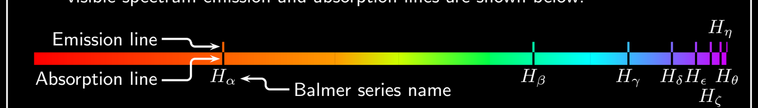
- Ultraviolet light is beyond the range of human vision.
- Physicists have divided ultraviolet light ranges into Vacuum Ultraviolet (VUV), Extreme Ultraviolet (EUV), Far Ultraviolet (FUV), Medium Ultraviolet (MUV), and Near Ultraviolet (NUV).
- UV-A, UV-B and UV-C were introduced in the 1930's by the 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 sunburn. 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 320nm.
- 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.

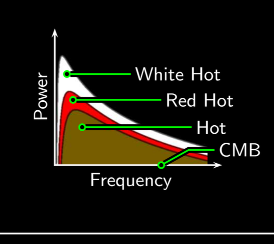
Emission and Absorption

- 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 (λ); where m is the initial electron energy level and n is the final electron energy level:

$$\lambda = 364.56nm\left(\frac{m^2}{m^2-n^2}\right)$$

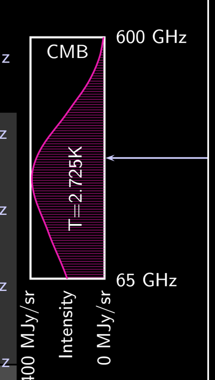
- Much of the interstellar matter is made of the simplest atom hydrogen. The hydrogen visible-spectrum emission and absorption lines are shown below:





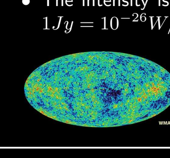
- Max Planck determined the relationship between the temperature of an object and its radiation profile; where R_λ is the radiation power, λ is the wavelength, T is the temperature:

$$R_\lambda = \frac{37418}{\lambda^5\epsilon\left(\frac{14388}{\lambda T}-1\right)}$$



Cosmic Microwave Background Radiation

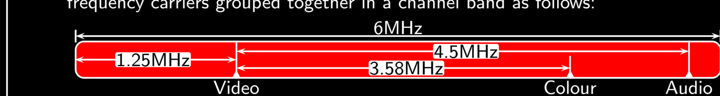
- CMB radiation is the leftover heat from the hot early universe, which last scattered about 400,000 years after the Big Bang.
- CMB permeates the entire universe at a temperature of 2.725 $\pm$ 0.001K.
- CMB was predicted in the 1940's by Ralph Alpher, George Gamow and Robert Herman.
- Arno Penzias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



Close examination of slight CMB intensity variations in different parts of the sky help cosmologists study the formation of galaxies.
WMAP photo by NASA

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 frequency carriers grouped together in a channel band as follows:



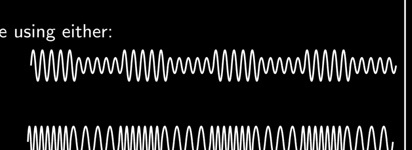
- Satellite channels broadcast in the C-Band are depicted as TV. These stations are broadcast in alternating polarities (Ex. Ch 1 is vertical and 2 is horizontal and vice versa on neighbouring satellites).
- The 15.7 kHz horizontal sweep signal produced by a TV can be heard by some young people. This common contaminant signal to VLF spectra listening is depicted as .

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)

  OR

  - Frequency Modulation (FM)

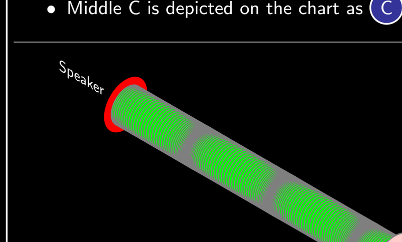


- Each country has its own rules and regulations for allotting bands in this region. For more information, look up the radio communications authority in your area (Ex. FCC in the US, DOC in Canada).
- Not all references agree on the ULF band range, the HAARP range is used here.
- **RA**dio **D**etecting **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.
- Schumann resonance is produced in the cavity between the Earth and the ionosphere. The resonant peaks are depicted as S
- Hydrogen gas emits radio band EMR at 21cm H
- Some individual frequencies are represented as icons:

xxHz Submarine communications
Time and frequency standards
xxm Ham radio and international meter bands
Miscellaneous short wave radio
W Weather stations
CP 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 ≈20Hz to ≈20kHz.
- 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 ≈50kHz.
- 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 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 then travelling through the tube towards the ear.

Gravity Waves

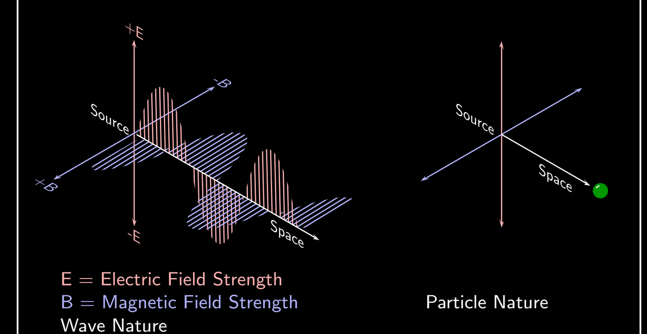
- Gravity is the mysterious force that holds large objects together and binds our planets, stars and galaxies together. Many people have unsuccessfully theorized about the details of gravity and its relationship to other forces. There have been no links between gravity waves and electromagnetic radiation.
- Gravity is theorized to warp space and time. In fact, gravity is responsible for bending light as observed by the gravity-lens example of distant galaxies.
- "Gravity waves" would appear as ripples in space-time formed by large objects moving through space that might possibly be detected in the future by very sensitive instruments.
- The speed that gravity propagates through space has been theorized to be the same as the speed of light.

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.

Electro**m**agnetic **R**adiation (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 (2.997 924 58 $\times 10^8$ m/s). EMR consists of an oscillating electrical and magnetic field which are at right angles to eachother 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:



E = Electric Field Strength
B = Magnetic Field Strength
Wave Nature

Particle Nature

- 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.
- 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 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.
- 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 let it naturally escape (ex. uranium decay).
- We can only see the visible spectrum. All other bands of the spectrum are depicted as hatched colours .

Système International d'unité prefixes (SI unit prefixes)

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

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

Gamma Rays

- Gamma radiation is the highest energy radiation (up to $\approx 10^{20}$ eV) that has been measured. At this energy, the radiation could be from 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 bumble-bees 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 X

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 lamp 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

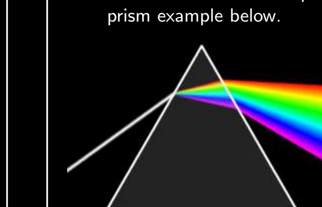
- LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.
- A LASER is a device that produces monochromatic EMR of high intensity.
- With proper equipment, any EMR can be made to operate like a LASER. For example, microwaves are used to create a MASER.

Polarization

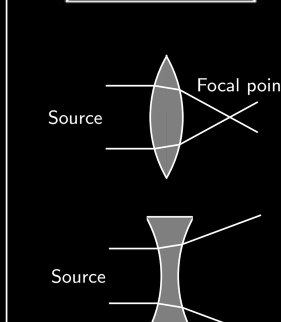
- As a photon (light particle) travels through space, its axis of electrical and magnetic fluctuations does not rotate. Therefore, each photon has a fixed linear polarity of somewhere between 0°to 360°. Light can also be circularly and elliptically polarized.
- Some crystals can cause the photon to rotate 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°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™sunglass 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.



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



Convex lenses make objects appear closer and are used to correct far-sitedness.

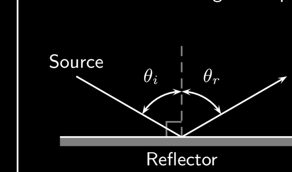
Concave lenses make objects appear farther away and are used to correct near-sitedness.

Photo by STScI

Heavy objects like dense galaxies and large planets cause light to bend due to gravitational lensing.

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