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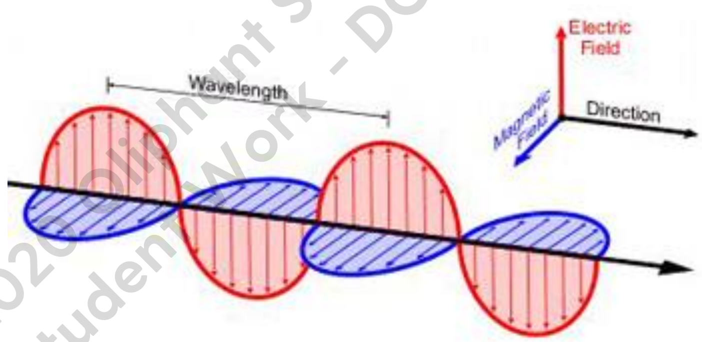
Hidden waves and where to find them by Matthew Lim

Introduction:

Sight, an invaluable ability for humans' perception and exploration of the world, is possible due to light. Visible light is a form of electromagnetic (EM) radiation, a type of energy that propagates as waves (Lucas, 2015). These waves consist of electric and magnetic fields oscillating at right angles to each other periodically while both are perpendicular to the direction of the wave (Lucas, 2015). EM waves travel in straight lines with characteristic amplitude, frequency, and wavelength, which determine their intensity, direction and energy (Parry-Hill, Sutter and Davidson, n.d.). Wavelength is how long each wave is, while frequency is how many oscillations are made per second; as such, they are inversely proportionate to each other (Lucas, 2015). They are measured in metres (m) and oscillations per second, or Hertz (Hz), respectively (Nagaraja, 2020). The anatomy of EM waves is illustrated in the picture in Fig. 1. EM waves have a wide range of wavelengths and are categorized accordingly. There are seven types of EM radiation, all of which travel at the speed of light, *c*, approximately 299,000,000 m/s (Phillips and Fritzsche, 2017). While visible light is the only one that can be seen by humans, the others can still be found and used in a wide variety of applications.

Fig. 1: Anatomy of an electromagnetic wave

(Lucas, J, 2015, representation of an electromagnetic wave, Future US, Inc., New York)

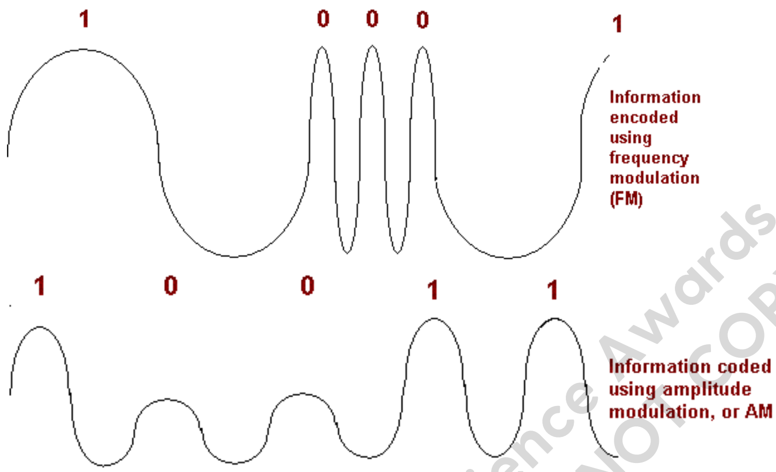


Radio waves:

Radio waves have the longest wavelengths in the EM spectrum, ranging from thousands of metres to 30 cm, with corresponding frequencies from 3Hz to 1 GHz (Lucas, 2015). Due to their long wavelengths, they can penetrate thick layers of non-conducting substances such as wood, bricks and concrete without being absorbed (Phillips and Fritzsche, 2017). Hence, they are ideal for communication systems, including remote-controlled devices, wi-fi and radio and television broadcasting, in which they transmit information between different locations (How is data put on radio waves?, n.d.). Information is often coded into radio waves using either frequency modulation (FM) or amplitude modulation (AM), whereby the frequency or amplitude of radio waves is altered in a certain way, so that they carry data (How does modulation work?, 2020). For example, using FM, a sequence of 0s and 1s may be encoded into radio waves by representing 0s with long waves and 1s with shorter waves (How is data put on radio waves?, n.d.). Using AM, the 0s could be represented by large waves and the 1s by smaller waves (How is data put on radio waves?, n.d.). The images in Fig. 2 exemplify this process. In a transmitting antenna, electrons are pushed back and forth by a current to create such modulated waves, which later push electrons at a receiving antenna to replicate the original current containing the data (How does modulation work?, 2020).

Fig. 2: Information coding using amplitude and frequency modulation

(Qualitative Reasoning Group, n.d., untitled, Northwestern University, Evaniston)



Microwaves

Microwaves have wavelengths ranging from 30 cm to 1 mm, corresponding to frequencies from 1 GHz to 300 GHz (Lucas, 2018). Like radio waves, microwaves are used for communications such as point-to-point communications and satellite communications, likewise conveying information through wave modulation (Phillips and Fritzsche, 2017). Their main advantage over radio waves is that, due to their higher frequency, they can transmit more information quicker (SEI, 2019). Furthermore, many radars emit microwaves, then use information from returning waves that have reflected off objects, to calculate the objects' distance, size and direction (How Do Radars Work? | Earth Observing Laboratory, 2020). Weather forecasting, ship and plane navigation, and missile detection all rely on radars (Lucas, 2018). Some radars, such as those in speed cameras and air traffic radars, also exploit the Doppler effect, a phenomenon caused by the relative motion of an object and wave source (Mauk, 2013). If the distance between the source and object is decreasing, the waves which hit the object and return to the source are compressed, so have a decreased wavelength (Mauk, 2013). However, if the distance is increasing, these waves are stretched, increasing their wavelength (Mauk, 2013). From the difference in wavelength, the velocity of the moving object can be calculated (How Do Radars Work? | Earth Observing Laboratory, 2020). Moreover, microwaves are commonly used to cook food, as fat and water molecules absorb energy from microwaves, thereby heating up (Scientific American, 1999).

Infrared radiation:

Infrared radiation is a type of EM radiation that can be detected by humans- it is felt as heat (Lucas, 2019). They have wavelengths between 700 nm and 1 mm (Infrared Waves | Science Mission Directorate, 2010). All objects emit infrared radiation to some degree, but hotter objects generally emit more and at shorter wavelengths (Infrared Waves | Science Mission Directorate, 2010). This makes infrared radiation useful for imaging technologies, such as night vision goggles and infrared cameras. These contain imaging chips which are sensitive to infrared radiation and reproduce images using visible light (Lucas, 2019). There are also household uses for infrared radiation, as heat lamps and toasters transmit heat using it (Lucas, 2019). Infrared astronomy is also a major application of infrared radiation and allows astronomers to observe objects which are too cool to produce visible light, and those which are obscured by dust and gas particles, as these scatter light (Lucas, 2019). Such objects include comets, asteroids, and newly formed stars in the middle of nebulas (Lucas, 2019).

Visible light:

As aforementioned, visible light is the only type of EM radiation that can be seen by humans. It has a variety of sources, including the sun, flashlights, and light bulbs, which help improve human vision. However, visible light is also used to produce lasers. Lasers are highly concentrated beams of light, some of which are intense enough to slice metals and woods, cut fabrics, and remove cancer tumours (Woodford, 2019). Alternatively, less intense lasers are used for communications; to scan barcodes, read DVDs and CDs, and guide weapons to targets (Nagaraja, 2020). Their extreme precision facilitates their success in these operations (Phillips and Fritzsche, 2017). Furthermore, visible light is the foundation of life on Earth, as the key ingredient to photosynthesis (Nagaraja, 2020). Photosynthesis is the process by which plants and algae convert carbon dioxide and water into oxygen and glucose using energy from sunlight (Phillips and Fritzsche, 2017). Glucose provides sustenance to all organisms on Earth and is therefore vital for life.

Ultraviolet light:

Ultraviolet (UV) light has wavelengths from 380 nm to 10 nm (Lucas, 2017). Like X-rays and gamma rays, it carries enough energy to cause ionization, a process where an electron gains enough energy to break away from an atom (Lucas, 2017). This causes the atom to react with those around it abnormally (Phillips and Fritzsche, 2017). This is detrimental for living tissues, as UV light damaging DNA leads to dysfunctional or malfunctional cells, which may interfere with the function of healthy tissues (Nagaraja, 2020). Since 10% of sunlight is UV light, prolonged exposure can induce this in people’s skin, manifesting as sunburns, carcinomas and melanomas (Lucas, 2017). In contrast, UV light can be instrumental in some applications. Fluorescence occurs when an electron that has absorbed UV radiation and been excited to a higher state returns to its original state, releasing some radiation (Phillips and Fritzsche, 2017). This radiation has a shorter wavelength than the original, so it is sometimes in the visible range (Phillips and Fritzsche, 2017). Its colour can be analyzed to discern the composition of materials, as each fluorescent substance emits a unique colour (Phillips and Fritzsche, 2017).

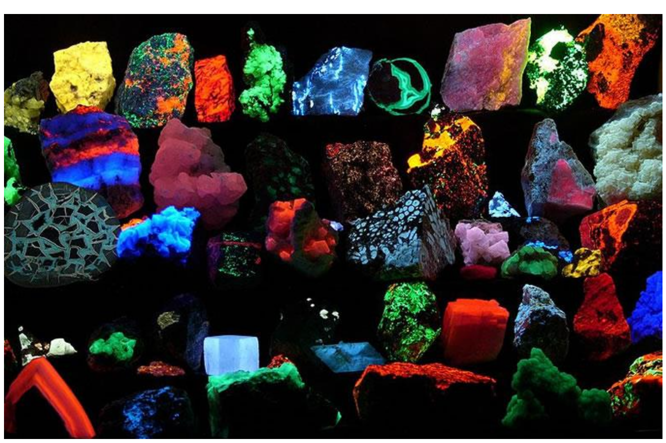


Fig. 3: Fluorescent minerals.

Each mineral emits a unique colour, so different minerals can easily be distinguished. This makes UV light beneficial in mining, gemology and minerology.

(King, H, 2005, Fluorescent Minerals, Geology.com)

X-rays:

With wavelengths between 0.01 and 10 nm, X-rays are also capable of engendering ionization, but small doses are usually unharmful and can be used beneficially, like for X-ray imaging (Lucas, 2015). X-rays are absorbed at different rates by various structures in the body and this is exploited to create an image of patients' bodies (Imaging using X-rays, 2020). As x-rays travel through a patient, some are absorbed and deflected, depending on what is in their path (Imaging using X-rays, 2020). This is called attenuation (Phillips and Fritzsche, 2017). A detector on the other side receives the attenuated waves and generates an image from the pattern of attenuation (Imaging using X-rays, 2020). Another use of x-rays is radiation therapy- although high frequency EM radiation can cause cancer, it can also help treat it (Phillips and Fritzsche, 2017). Radiation therapy works by specifically exposing cancerous cells to x-rays, damaging their DNA and killing them (Radiation Therapy Benefits & Effectiveness - Targeting Cancer, 2017). This is a highly effective method to prevent many cancers from recurring after surgery (Radiation Therapy Benefits & Effectiveness - Targeting Cancer, 2017).

Gamma rays:

Gamma rays are the most energetic of the EM spectrum, and have wavelengths less than 100 pm (Lucas, 2018). Two of the primary sources of gamma radiation are nuclear fusion and nuclear fission (Phillips and Fritzsche, 2017). Nuclear fusion occurs when immense pressure and heat cause two or more atomic nuclei to fuse together (Nuclear Fusion - ANS, 2018). During this process, some mass is lost and converted into energy, about two-thirds of which is emitted as gamma radiation (Nuclear Fusion - ANS, 2018). Nuclear fusion occurs in the centres of stars and additionally produces their light and heat (Lucas, 2018). However, it only produces more energy than it consumes when light elements fuse (Nuclear Fusion - ANS, 2018). On the other hand, nuclear fission is the splitting of a large atomic nucleus into two or more separate nuclei. Again, some mass is converted into energy, part of which is gamma radiation (Lucas 2018). Currently, nuclear fission of uranium and plutonium isotopes in nuclear powerplants provides 10% of the world's energy (Lucas, 2018).

Conclusion

Overall, electromagnetic waves are hidden all throughout the modern world, and are employed in countless ways. Despite all being electromagnetic radiation, these waves are diverse in their sources, properties and applications. Some are emitted from stars, others in microwave ovens; some are harmless to humans, others can be extremely dangerous; and some are used for wi-fi, while others help cure cancer Nonetheless, all these waves can be utilised to the benefit of society, and their differences broaden the horizons of their applications. It is still remarkable though, that the waves that allows humans to see are simply another wavelength of those that are released during nuclear fusion in stars.

By Matthew Lim

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