Electromagnetic Wave

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Learning Outcome

I highly recommend you to finish this checklist to determine whether you've achieved the learning objectives.

- ☐ describe and understand *electromagnetic waves*
- ☐ recall that wavelengths in the range 400 nm to 700 nm in free space are visible to the human eye
- ☐ describe and understand *polarisation*
- ☐ use Malus's law to determine the intensity of transmitted light through a polarising filter.

Leadin

Sound waves and string waves are easy to understand, since the wavelength and wave speed is not too large to be shown. However, there do exist another type of wave which has tiny tiny wavelength and extraordinary large wave speed, and most dramatical thing about such wave is that they do not need any medium[1]. And this type of wave is called *Electromagnetic Wave*. Lots of physicists have made their own contributions to the EM waves, but only one man has ruled the field—James Clerk Maxwell[2], Maxwell's equations in describing EM fields was included as one of the most beautiful equations.[3].

Figure 1: James Maxwell
1831-1879

[1] although during some period, scientist believe that *Ether* is the medium

[2] undergraduate studies at Edinburgh, graduate studies at Cambridge. But died at a young age

[3] quite simple and beautiful yet powerful in ruling electromagnetic theory, we'll learn the four equations later

EM waves

Maxwell has combined the laws of describing *electric field*, *magnetic field* and the interaction between the two fields. Hence has predicted that EM waves do exist and it travels at the **speed of light**[4] in 1864. Thus visible light is since included as a type of EM waves.[5]

[4] $c = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}}$ derived from the Maxwell's Equation

[5] why not the opposite way — EM waves belongs to light?

the nature of EM waves

A wave is the perioidic disturbance travellinig through the medium. while an electromagnetic wave is a combined disturbance in both the electric and magnetic fields. Since the propagation of fields do not need medium, the EM waves do not either. As shown in Fig.2. As far as what is electric field

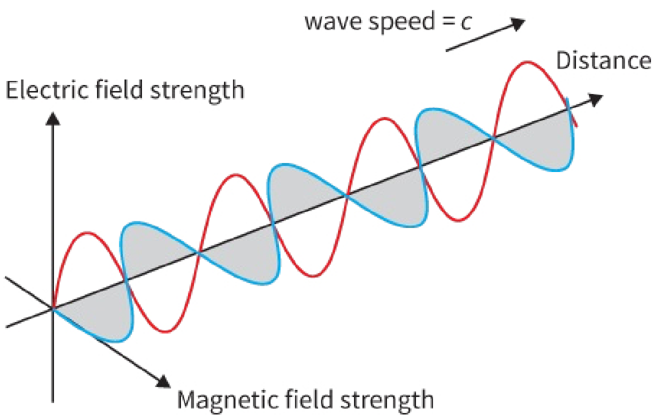


Figure 2: a periodic variation in electric and magnetic fields

and magnetic field, this would be discussed in Chapter 21, 22 & 24.

Discrete Findings in EM waves

By the end of 19th century, there are several EM waves found by various scientists, which strongly proves the correctness of Maxwell. there are listed below:

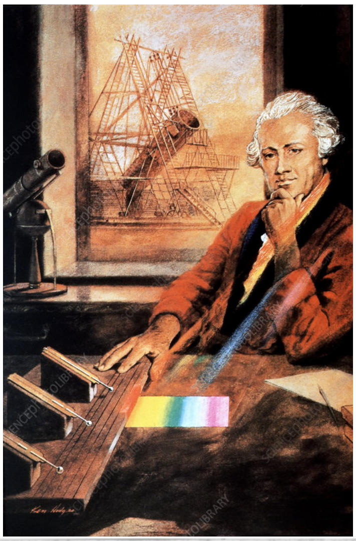
- Radio wave, which is found by __________ in 1879. The main application of radio wave is **the broadcast and signaling system**.
- infrared and ultravilet(UV) light, Herschel found infrared waves around 1800, and Ritter discovered UV light just 1 year after Hershcel when he

want to find the cooling light. Infrared and UV has wide range of usage in our daily life.

- X-ray, found by ___________ in 1895, has been greatly used in medical imaging. At that time, X means unkown mysteries.
- γ-ray was first discovered by Paul Villard around 1900[6]. It comes naturally when nucleus experience γ decay.
- Microwave, Robert N. Hall and Percy Spencer were given credit to for the invention of microwave oven. But this great invention was first debut after the WWII. It was first discovered accidentally in 20th century, and the inventors passed away in 2016 and 1970 respectively. RIP

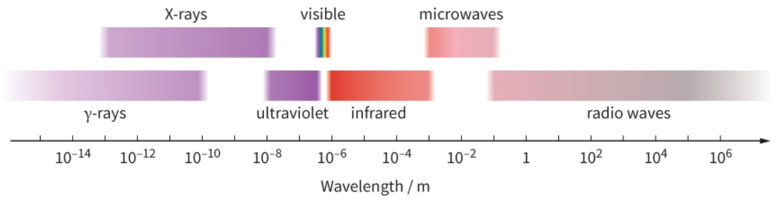
[6] Henri Becquerel is famous for the term "radioactivity" and equipment for measuring it

Here are some famous images relating to the discoveries of such **Nonvisible** EM waves.



EM spectrum

Then, All types of EM waves have been found, and are now included in the *electromagnetic spectrum*[7]. It is shown in Fig.3.



[7] def: the family of waves that travel through a vacuum at a speed of c

Figure 3: some regions between two types are fuzzy.

And the spectrum for visible light is shown in Fig.4.

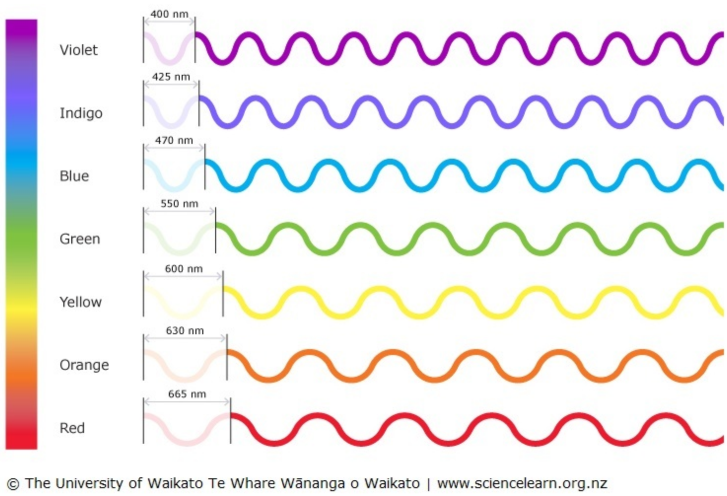


Figure 4: A rainbow is just a spectrum of visible light

Frequency or Wavelength

The speed of the light(EM waves) in vacuum is determined to be

$$c = 299\,792\,458\,\mathrm{m\,s^{-1}}$$

Since all kinds of EM waves tends to have same travelling speed, according to the formular $c = f \cdot \lambda$. We can distinguish different types of EM waves based on either 1)the wavelength, 2) the frequency.

However, the speed of light will change in different media, for example, if light is transmitted in water, the speed will decrease to $c_w = 225\,000\,000\,\mathrm{m\,s^{-1}}$. and decrease to $c_f = 199\,861\,638\,\mathrm{m\,s^{-1}}$ if glass optical fiber is the medium[8].

[8] here, the existance of medium negatively influence the transmission of electromagnetic field, hence the speed is greates when EM waves are in vacuum or in air

However, the thing is that, when the speed of light decreases as visible light travels in water, the visible light does not change the color, according to $c_w = f \cdot \lambda$, which means the either the frequency, the wavelength or both will change.

Task

When a beam of red light pass through water, determine whether the frequency, or wavelegth or both change as the red light travels.

Typical Magnitude for EM waves

Search the book, fill in the tables below:

types of EM waves	frequency range/Hz	wavelength range/m
radio wave		
microwave		
infrared		
visible light		
ultraviolet		
X-ray		
γ-ray		

Several points to note:

- the exact value does **NOT** matter, the order and magnitude **DO** matter.
- $1\,\text{nm} = 1 \times 10^{-9}\,\text{m}$
- the visible light from red to purple is 400 nm to 700 nm
- for convience, MHz or GHz sometimes are used in describing the radio waves or visible light.

Polarisation

Polarisation is a wave property associated with transverse waves only. It is actually a filtration of waves. The mechnism of polarisation is not required

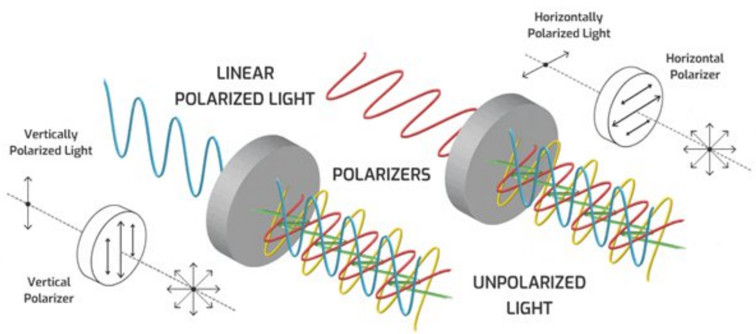


Figure 5: Polarisation happens after the Polaroid

by A-Level syllabus, but if you are interested, you can refer to this reading material

The phenonmenon and Application

Unpolarised light(waves)[9] will pass the filter, maybe a slit or a polaroid,

[9] which means the vibration of particles/fields have all various directions

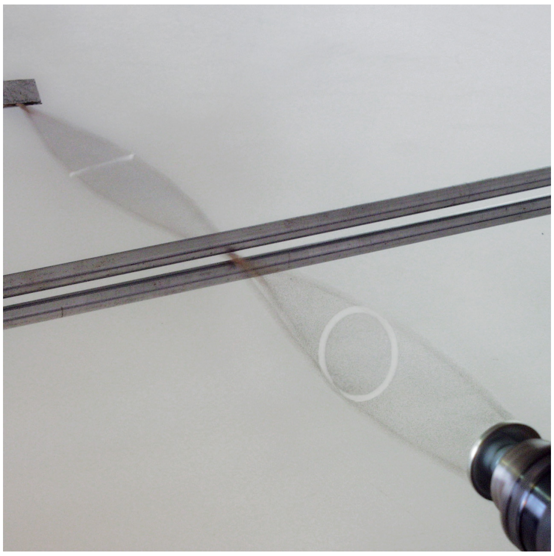


Figure 6: polarisation of transeverse waves

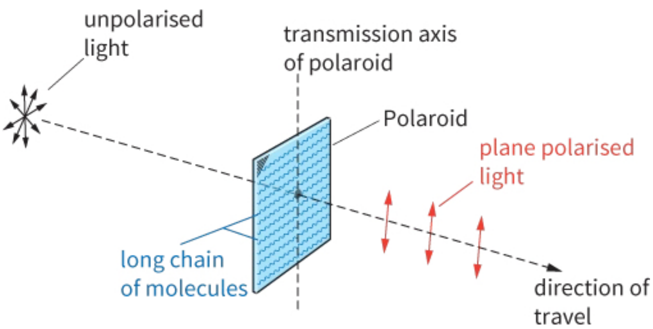


Figure 7: polarisation of unpolarised light

and only when the direction is consistent with the direction of the slit or transmission axis, the wave could pass. As shown below:

So, generally speaking, the polarisation of waves is just a filtration of waves/light which only allows certain waves to pass through. And a famous application is the polaroid glass in sunglasses and photograph. Check those pictures

Figure 8: some light did not pass the polaroid lense

Malus's Law

The first man ever describe the phenomenon of polarisation is Louis Malus, who rotated the polaroid and observed that the intensity of light will change with the angles.

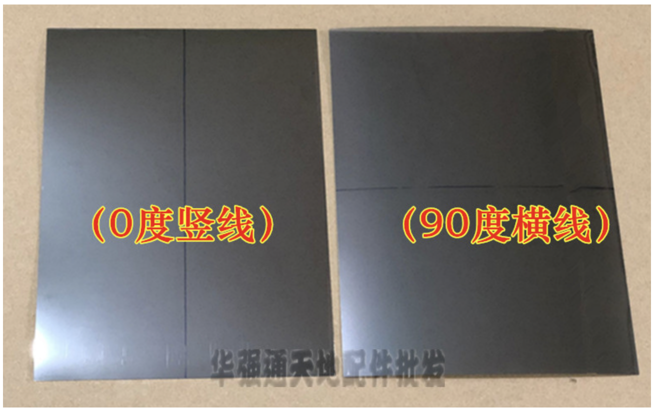


Figure 9: All screens have polaroid membrane installed

Figure 10: Etienne Louis Malus 1775-1812

The experiment is quite simple, by rotating the analyser polaroid and measures the intensity of light after it I. Compare such intensity with the original intensity I_0, to check the variation, we found that:

$$I = I_0 \cdot \cos^2 \theta \tag{1}$$

in which, θ is the angle between the transmission axis and the plane of incident light.

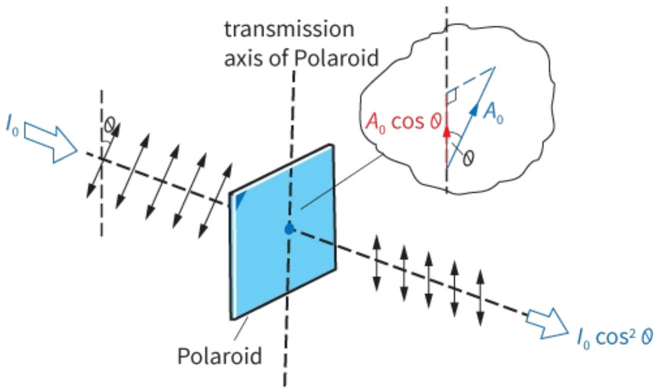


Figure 11: The intensity varies with the angle θ

The most significant result is that, when $\theta = 90°$, there is no light passing. The intensity becomes 0. As shown in the figure below:

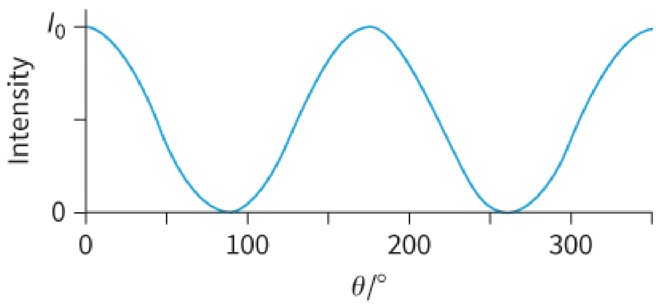


Figure 12: The intensity varies with the angle θ

Example

use the desmos and the double angle formula $\cos 2\theta = 2\cos^2\theta - 1$, to validate that Malus law can be rewrite into: $I = \frac{I_0}{2} \cdot \cos 2\theta + \frac{I_0}{2}$.

And know the sinosodial wave property.