Electromagnetic (E-M) Waves

- James Clerk **Maxwell** predicted the existence of **E-M waves** in 1865).
- Unlike sound waves, E-M waves do **NOT** need a **medium** in which to **propagate** (i.e. they can **travel** through a **vacuum**).
- We now know there is a **vast spectrum** of **E-M waves** extending from: Radio waves → Microwaves → Infra red → Visible → Ultra violet → X-rays → Gamma rays

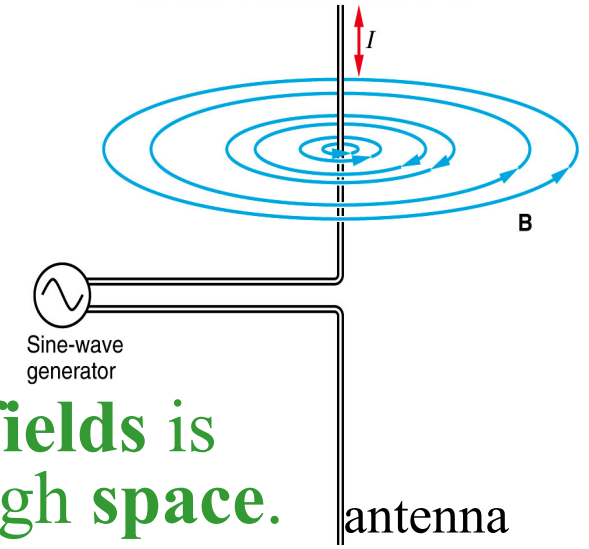
What is an E-M Wave?

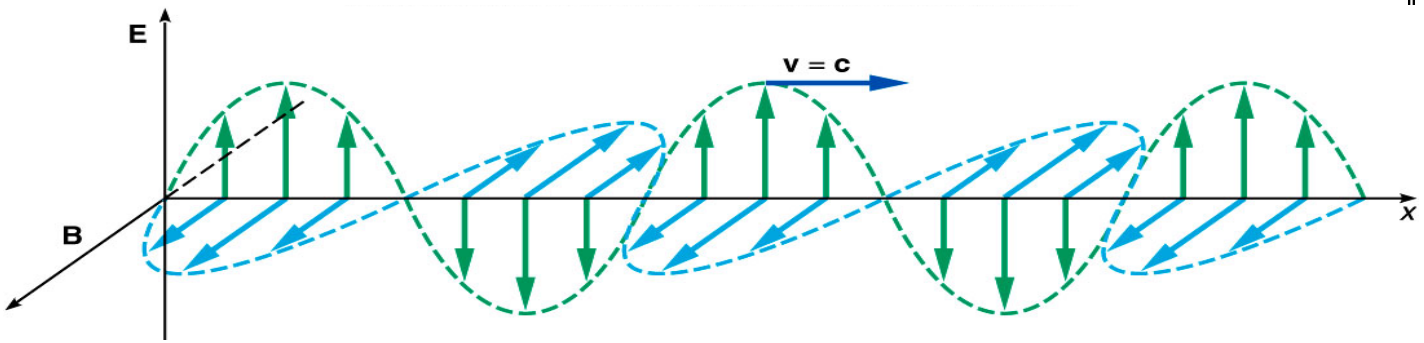
E-M waves consist of **alternating electric** and **magnetic fields** generated by **motion** of **charged particles** (i.e. current).

- **Motion is essential** for **magnetic field** but **electric field** is **present** regardless.
- E-M waves (e.g. radio waves) can be **generated** by an **antenna** connected to a **rapidly varying** AC **current source**.

(Note: E-M waves are generated by any time-varying current.)

- **Rapidly varying current** generates a **constantly changing magnetic field** (magnitude and direction).
- This **magnetic field** induces a **changing electric field** and vice versa.
- A **wave** comprising these **time varying fields** is **self sustaining** that can **propagate** through **space**.





- **Time-varying electric** and **magnetic** fields in E-M wave are **perpendicular** to **each other** and to the **direction of propagation** (E-M waves are **transverse waves**).
- E-M waves can propagate **vast** distances through space.
- As a result of Maxwell's prediction (1865) of E-M waves **Hertz** (1888) discovered **radio waves**.

Velocity of E-M Waves

- Maxwell **predicted** the **velocity** of E-M waves would be determined from **Coulomb's constant** (k) and the **constant** in **Ampere's** expression for force (k').

$$v = \sqrt{k/k'}$$

$k = 9 \times 10^9\ Nm^2/c^2$
$k' = 1 \times 10^7\ N/A^2$

velocity $c = 3 \times 10^8$ m/s

- However, this is also the **known value** of **speed of light** (measured by Fizeau, 1849) and prompted the **discovery** that **light** is an **E-M wave!**

  (Note: This was also the first **direct connection** between **optics** and **electromagnetism**).

- Velocity of light is a **very important constant** in nature:

  $c = 3 \times 10^8$ m/s (in vacuum)

- **Light** (and other forms of E-M waves) **travel more slowly** in other media e.g. glass, H_2O, plastic…
- Velocity of **light in air** is very **close** to its **value** in **vacuum**.

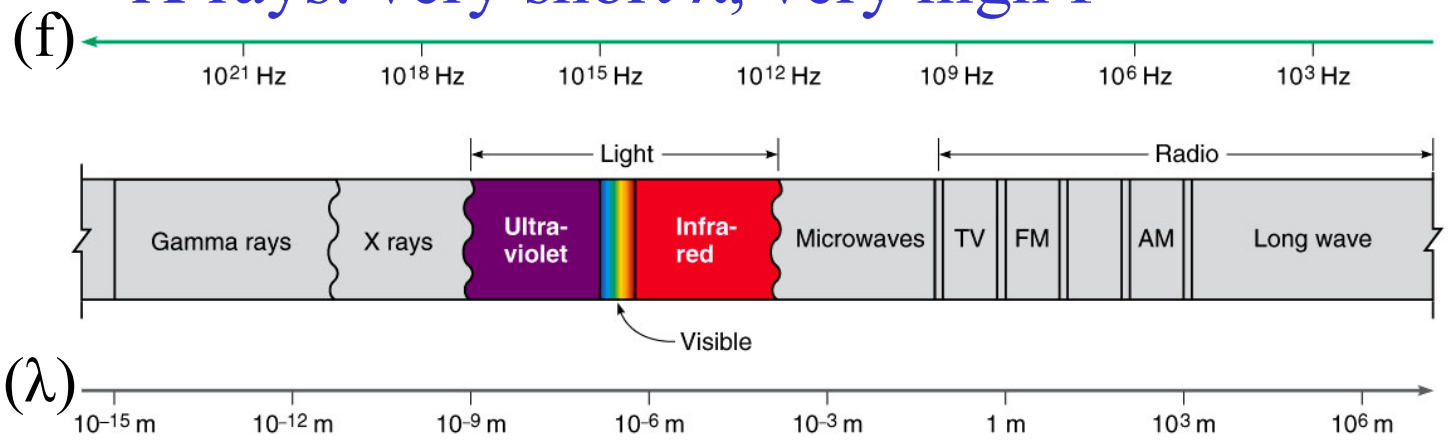
Spectrum of E-M Waves

- All **propagate** at **same speed 'c'** in **vacuum**.
- Main difference is their **wavelengths** and **frequencies** which are **related** by $\underline{v = \lambda f}$.

  E.g. Radio waves: long λ, low f.

  Visible light : $\lambda \sim 10^{-6}$m, $f \sim 10^{14}$ Hz

  X-rays: very short λ, very high f



- **Visible light** only occupies a **tiny fraction** of the **spectrum** from **4 → 7 10^{-7} m**.
- Different types of E-M waves generated by different mechanism but all involve an oscillating current (or accelerated charged particle).

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  E.g. We are **all emitting E-M waves** in **IR spectrum**! (oscillating atoms in our skin act as antennas).
- E-M waves have vastly **varying properties**, e.g. penetrating capability – X-rays and radio waves.`

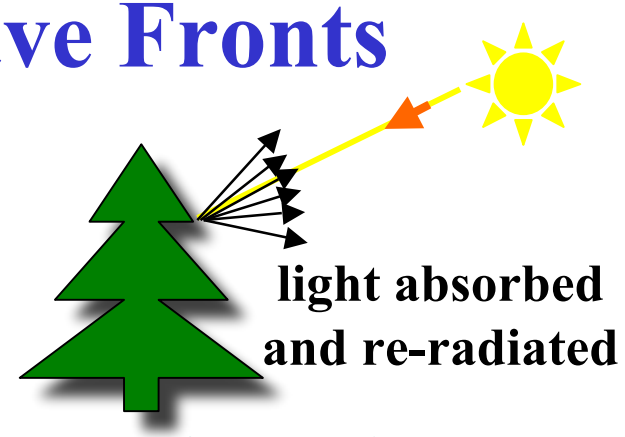
Light and Optics (Chapter 16)

- **Light** is an **electromagnetic wave**.
- We are all very familiar with **light** as we use it to **sense** (i.e. see) our **surrounding**.

Question: How do we see something?

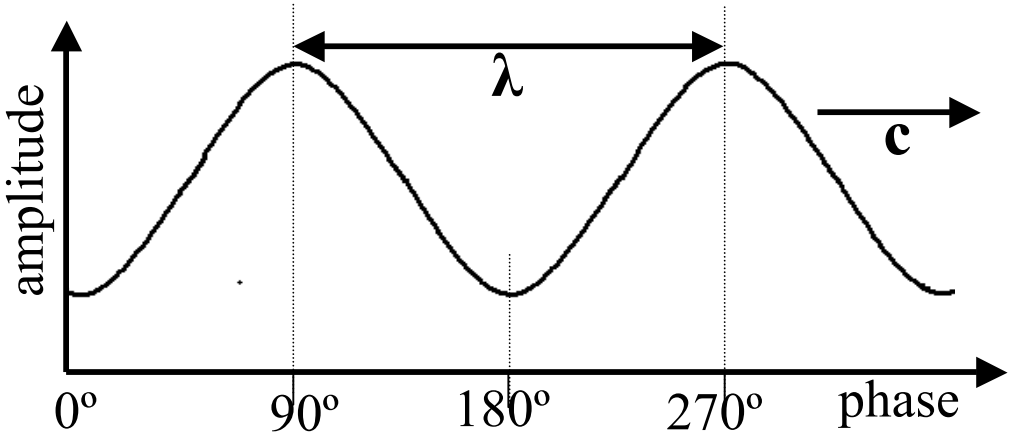
- Need light waves.
- Eye senses light reflected (or scattered) off the objects.

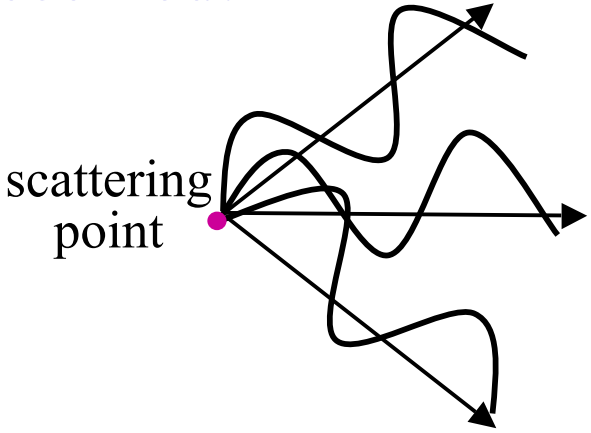
Light "Rays" and Wave Fronts



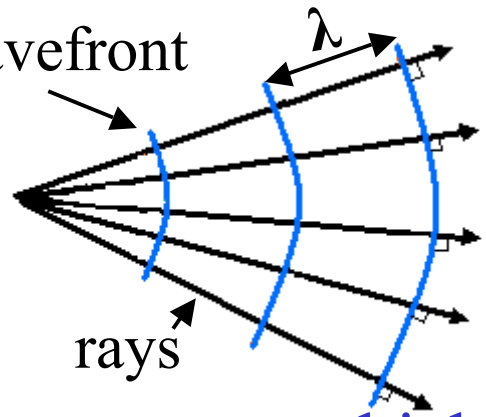
- **Light** from a source is **scattered** in **all directions** from **any** given **point**.
- Each and **every part** of an **object** therefore acts as (secondary) **source** of **light waves** that **radiate uniformly** from that point.
- These waves **spread out** (diverge) as they propagate at the **speed of light** (3×10^8 m/s) **away** from the **object**.

- Like all waves, **light waves** can be **described** by their **frequency** and **wavelength** and are represented:





- If we connect the **points on the wave** that are at the **same point** in **their cycle** (e.g. the crests), we define a **wavefront**:
- Light **rays** are **always perpendicular** to the **wavefronts**.
- Each wavefront is **separated** by **one wavelength**.
- Wavefronts (from all points) **combine together** and **carry** the **information** about the **shape** of the object.

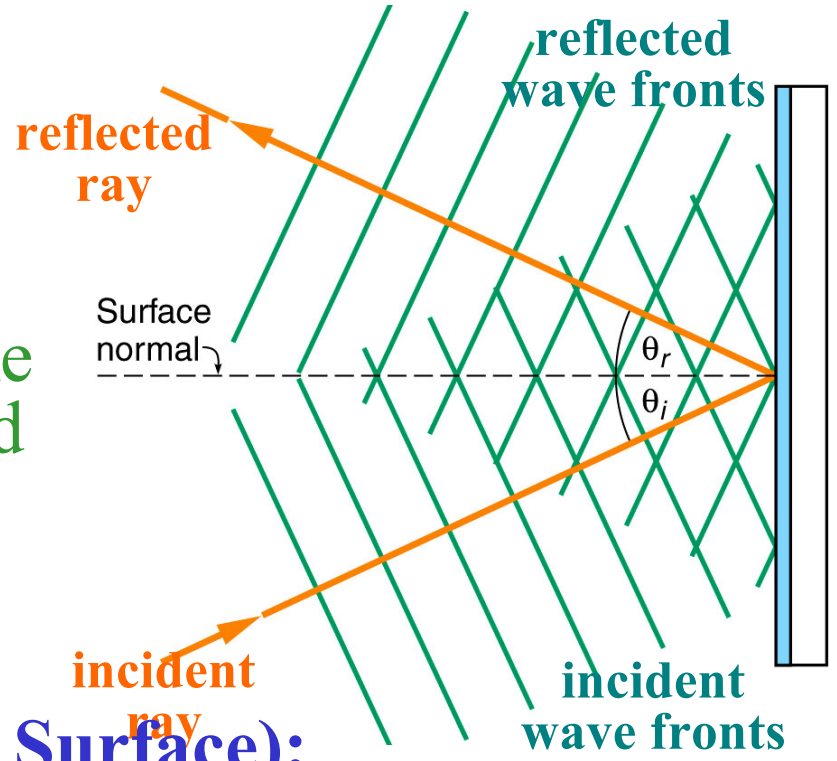


- However, they are complex and it is easier to use rays which are straight lines (for any given medium, e.g. glass, air).

Reflection

Plane waves reflecting in a mirror at an angle:

- The **light rays** (wavefronts) strike mirror at an **incident angle θ_i** and are **reflected** off the mirror at **same speed at angle θ_r** .



Law of Reflection (Smooth Surface):

❖ The **angle** the **reflected ray** makes with the **normal** to the surface of reflection **equals** the **angle of incidence**:

$$\theta_i = \theta_r$$

(Note: This is because the light waves **travel** at **same speed before** and **after reflection**.)

- The **reflected ray** always lies in **same plane** as **incident ray** and the **surface normal**.