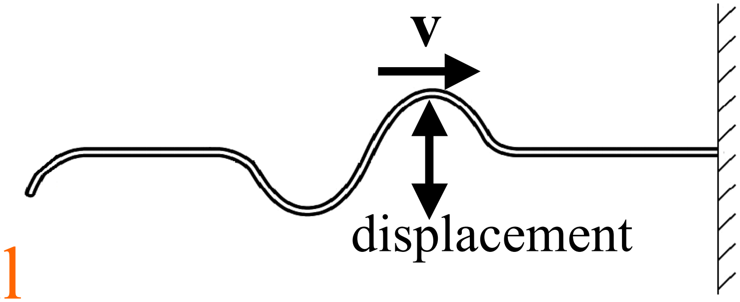
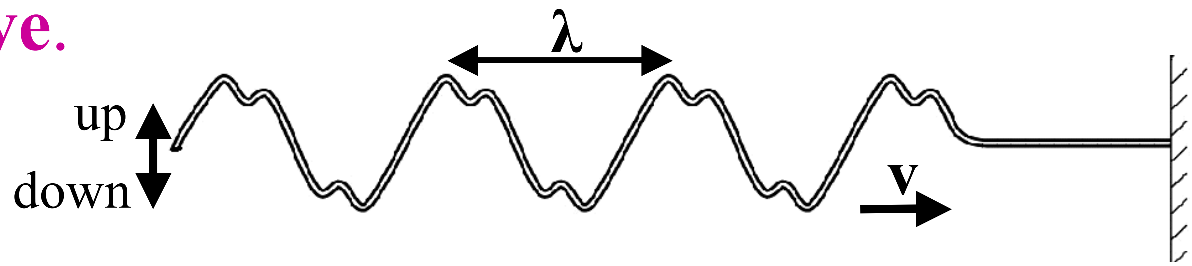
Summary: Waves on a Rope

- By moving **free end up** and **down** we can generate a **transverse** wave '**pulse**'.



Pulse **propagates** down rope to wall **creating** an **instantaneous vertical displacement**.

- A series of '**snap-shots**' would show the **wave moving** down rope at **constant speed 'v'.**
- If we **repeat** up /down motion **regularly** you can make a **periodic wave**.



- A **periodic wave** can have a **complex shape** depending on the **perturbation induced**.
- **Harmonic waves** are very **important** for **everyday wave analysis** as any **complex periodic** wave **motion** can be **broken down** into a **sum** of pure **harmonic waves**.

Speed of Sound

- As with the speed of a wave on a rope, the speed of sound depends on the **medium** it is propagating through.
- In air, at room temperature the speed of sound (at sea level) is approximately 340 m/s. (750 mph)
- The factors that determine speed of sound are related to how rapidly one molecule can transmit **changes in velocity** to another molecule to propagate the wave.
- In air (gases) **temperature** is a major factor as molecules have higher K.E. (ie velocities) at higher temperature.
  - eg. An increase of 10 K (10C) increases speed by ~ 6m/s. (and vice versa).
- For other gases the **mass** of molecules is important.
  - eg., hydrogen molecules are light and easier to accelerate and speed of sound is about 4 times higher than in air (for similar pressure and temperature).

Comparison of Speed of Sound

Medium	Speed
Air	~340 m/s
Water	4-5 times air speed ~1400 m/s
Metal/rock	15-20 times air speed, ~ 6000 m/s

- Speed of sound in liquids and solids is much higher as molecules much closer together.

Example: lighting vs. thunder

- Lighting flash reaches you almost instantaneously but sound travels at **340 m/s.**
- Rules: 1 km takes ~ 3 s (1 mile ~ 5 s)
- By counting seconds between flash and thunder can tell how far storm is away.

Frequency of Sound Waves:

- Frequency range of human hearing is ~ 20 Hz to 20,000 Hz.

frequencies

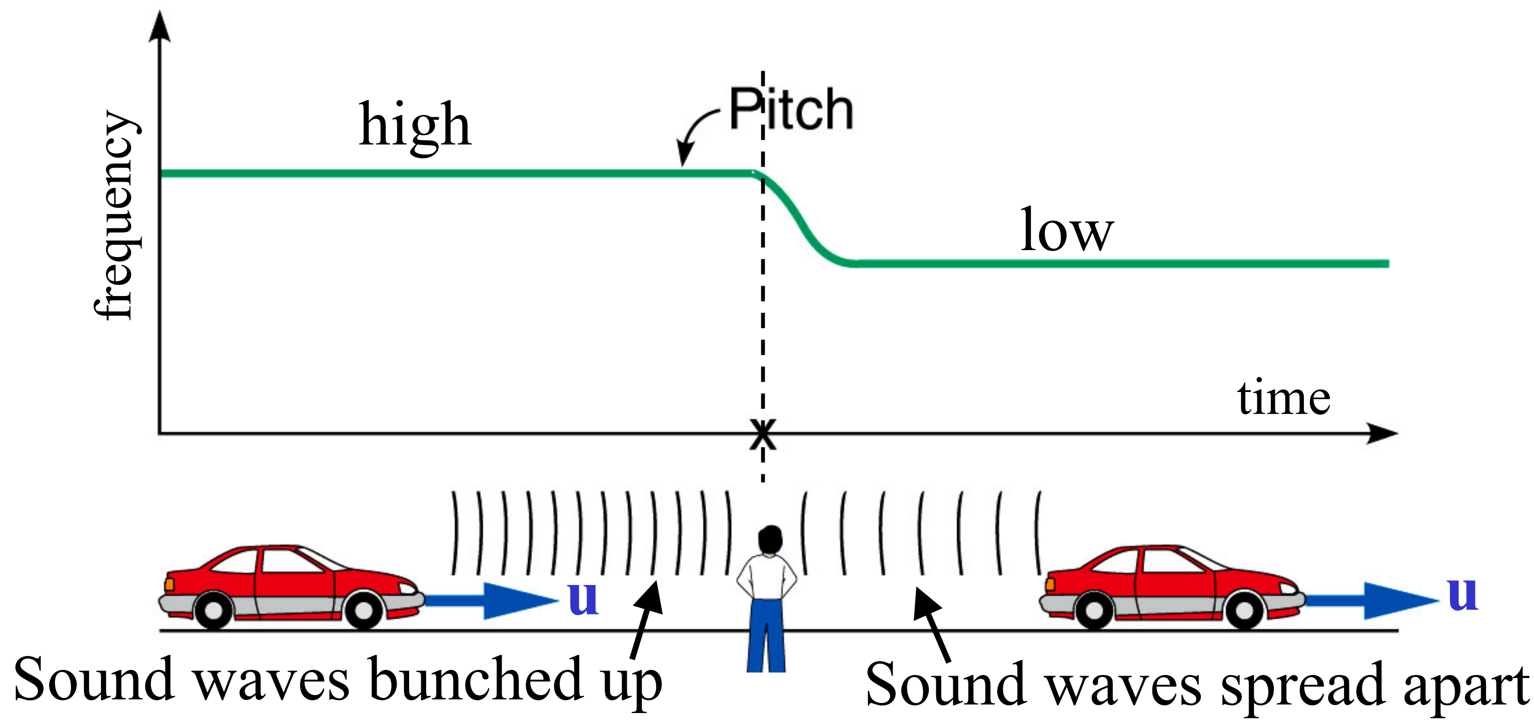
below → **infrasonic**

above → **ultrasonic**

- Ultrasound and infrasound occur commonly in nature but are outside our hearing range.
- Bats, dolphins use ultrasound for echo location.
- Ultrasound used to image babies in womb.
- Whales produce powerful infrasonic calls that can be "heard" over distances of several thousand kilometers.
- Large meteors burning up in atmosphere emit infrasonic waves.

Doppler Effect

- Moving car /train horn **changes pitch** (frequency) as it **passes you**.



- The **sound** from the horn **travels through** the **air** at **constant speed** (340 m/s) regardless of vehicle motion.
- However, as the car moves **towards you** it **catches up** on the **waves** and they **appear** to **bunch together.**

- This motion **reduces** the apparent **wavelength** of the **waves**:

$$\lambda' = vT - uT$$

u = car speed
T = wave period

Distance wave travels in 1 period (vT); Distance car travels in 1 wave period (uT)

- As **speed** of the wave is **constant** a **decrease** in **λ** creates an **increase** in **frequency** (i.e. $v = \lambda . f$) and a **high pitch** is heard.
- Conversely, when **car passes** by you the **pitch decreases** due to the **increase** in the **wavelength** of the **sound waves.**

i.e. $$\lambda' = vT + uT$$

- The **higher** the **speed**, the **larger** the **apparent frequency** (pitch) **change**.

Summary:

f ' = apparent frequency

$$f' = f\left(\frac{v}{v-u}\right)$$ source moving towards observer

$$f' = f\left(\frac{v}{v+u}\right)$$ source moving away from observer

- **There is also a Doppler effect** if the **observer** is **moving** relative to the **source**
- If you are moving **towards** the source, you will **intersect** wave **crests** more **rapidly** (than if stationary) and the **frequency** will **appear higher**.

or $$f' = f\,(1 + \frac{u}{v})$$

$$f' = f\,(1 - \frac{u}{v})$$

f = source frequency
u = observer speed
v = 340 m/s

- If moving **away** from source, the **frequency** will be **lower**.

Example: Violin tone of 440 Hz. What frequency will a cyclist hear when riding by at 11 m/s?

Towards: $f' = f\,(1 + \frac{u}{v}) = 440 \times (1 + \frac{11}{340}) = 454\ \text{Hz}$

Away: $f' = f\,(1 - \frac{u}{v}) = 440 \times (1 - \frac{11}{340}) = 426\ \text{Hz}$

Stellar implications: If a star moving towards us it appears ‘bluer’; if moving away it appears ‘redder’.

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

  Gamma rays ← X-rays ← Ultra violet ← Visible ←┘

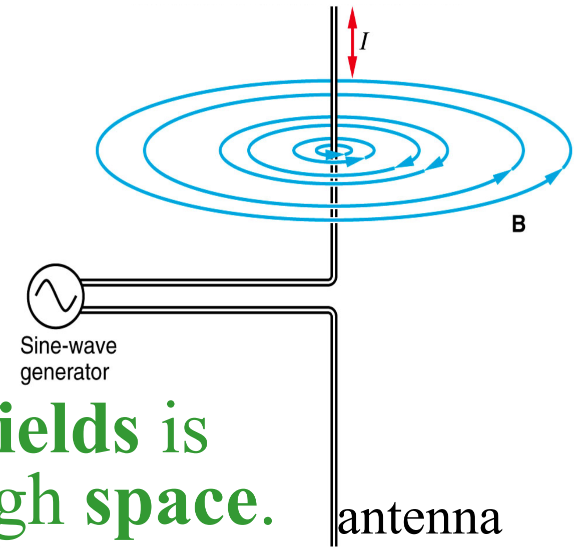
What is an E-M Wave?

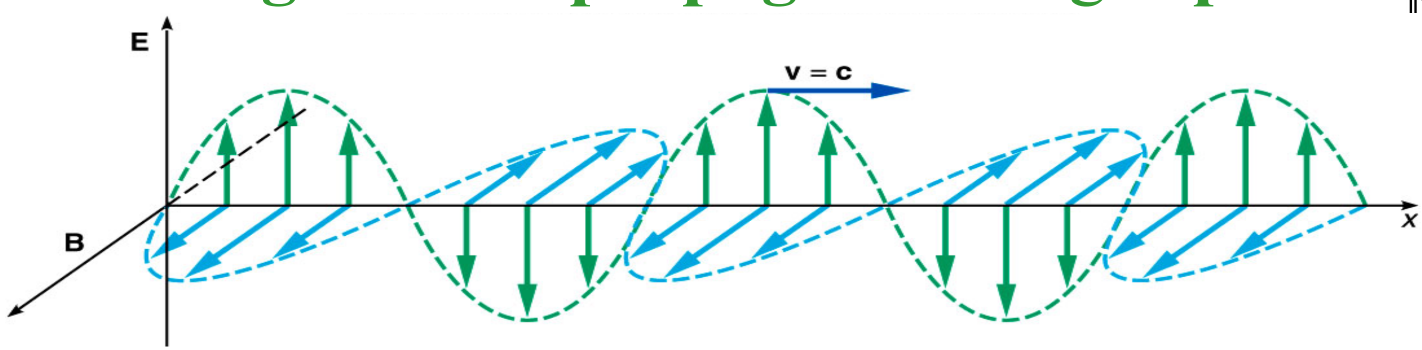
E-M waves consist of **alternating electric** and **magnetic fields** generated by **motion** of **charged particles** (i.e. current).

- **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**.

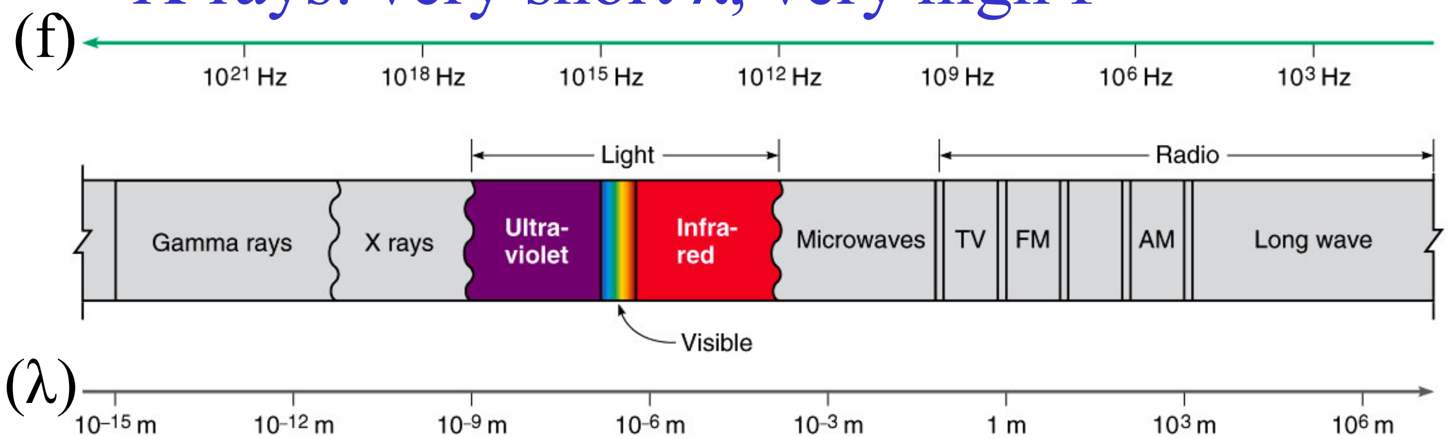
Spectrum of E-M Waves

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

  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).

- Different types of E-M waves generated by different mechanism but all involve an oscillating current (or accelerated charged particle).

  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.`