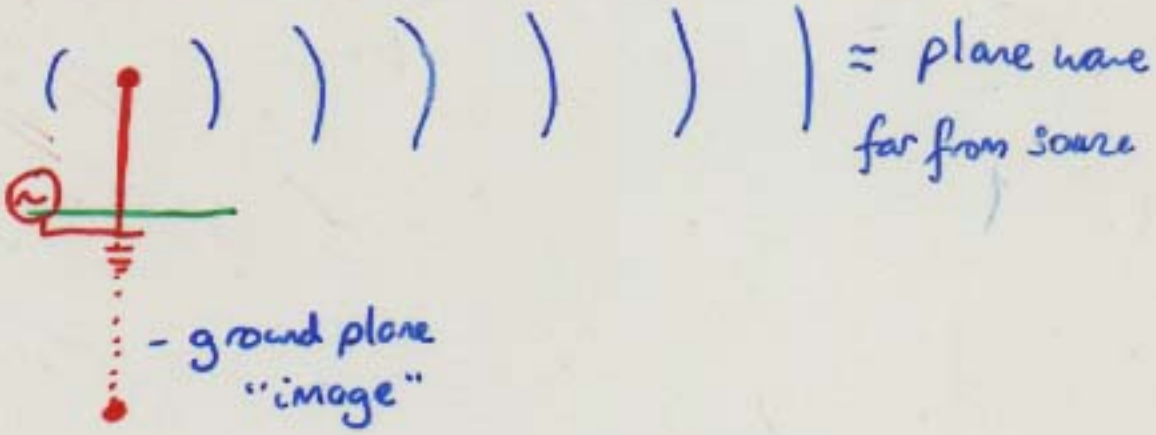
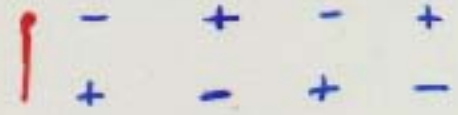
Radio Waves : Dipole antennas

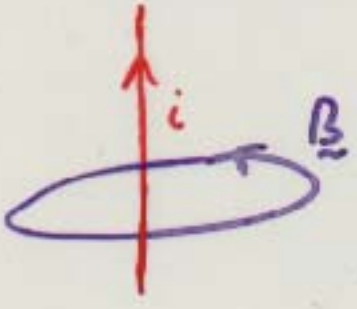


High-freq. AC current alternates polarity in antenna :



with time

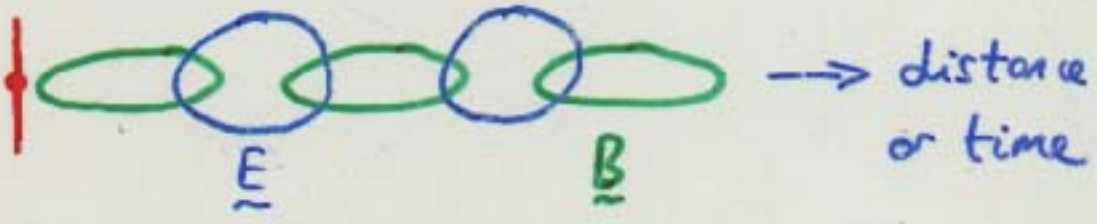
Current produces $\underset{\sim}{B}$ field around it:



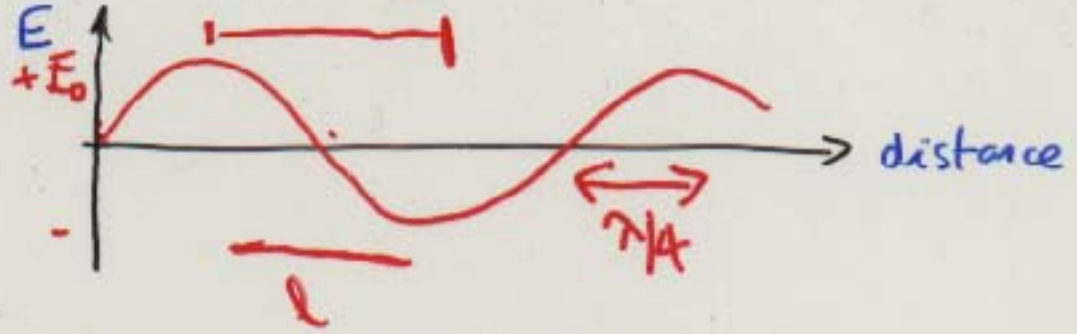
As current reverses

$\Rightarrow \underset{\sim}{B}$ changes

$\Rightarrow \underset{\sim}{E}$ field generated at 90°



Antenna length



For wire placed along EM wave, max. difference in $\underset{\sim}{E}$ between ends is when length $l = \lambda/4$

$\Rightarrow$ "1/4-wave dipole" antenna

e.g. for FM radio station 97.3 MHz (KSON)

$$\lambda = \frac{c}{f} = \frac{2.9979 \times 10^8 \text{ m/s}}{97.3 \times 10^6 \text{ Hz}} = 3.08 \text{ m}$$

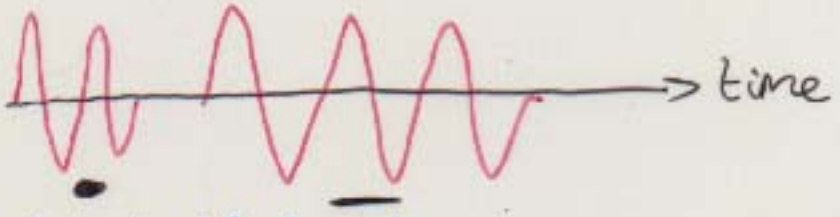
$\Rightarrow$ ideal antenna length $\lambda/4 = 0.77$ m

(In practice: compromise with tuning circuits and "average" length for 88–100 MHz)

Radio Signals:

- Need to modulate the EM wave (plane wave carries no info).

Pulse Modulation (Morse code)

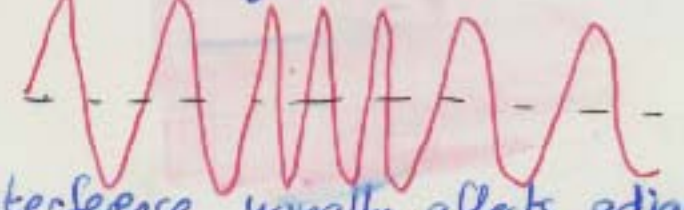


Amplitude Modulation:

Speech / Music superposed on carrier wave

Frequency Modulation (FM)

Frequency changes according to speech / Music signal



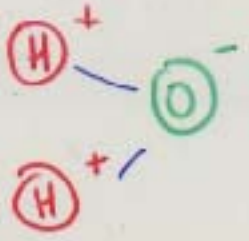
Interference usually affects adjacent frequencies equally

∴ not detected by FM receiver

Microwaves : 1 GHz to ~ 10^{11} Hz

30 cm to ~ 1 mm

- Used in communications and radar
- H_2O molecules act as "antennas"



alternating $\vec{E}$ causes molecule to rotate.

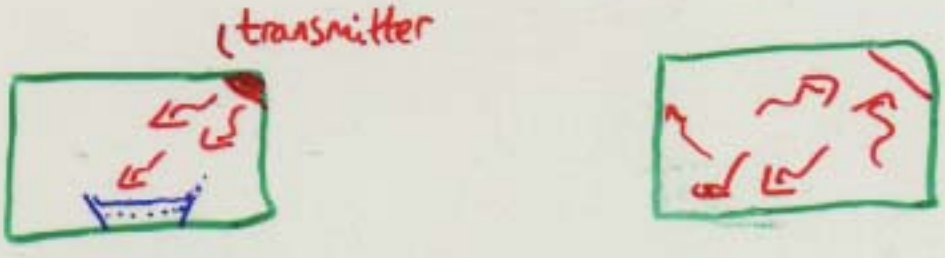
$\Rightarrow$ resonance at 2.45 GHz

K.E. of molecules $\rightarrow$ thermal energy

Microwaves penetrate into non-conductors

BUT reflected by conductors

(metal in microwave oven)



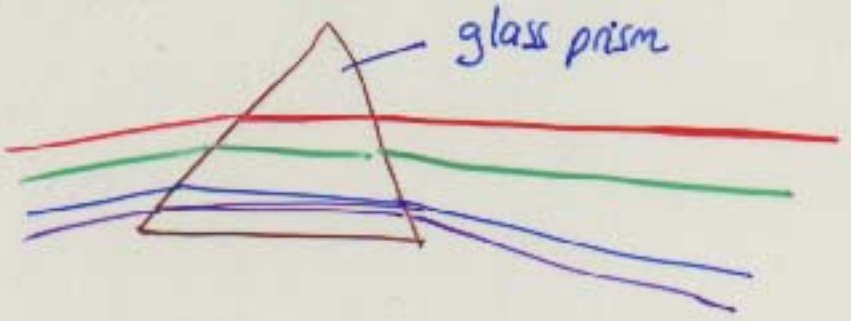
transmitter damaged by reflected microwaves

Infrared Radiation: - 300 GHz - 300 THz
1 mm to 780 nm

Wm. Herschel (1800) - split sunlight into colors (spectrum)
- noticed heating of thermometer "below" visible red.

- emitted by all "warm" objects
  (human body, hood of car, tailpipe of F-16)
- more penetrating (i.e. less scattered) than visible light
  (e.g. through fog, or dust in Galaxy)
  ~ 3 mm into skin
- trapped by glass and "greenhouse" gases

Visible Light : 350 - 750nm



Newton : split white light into spectrum of colors using prism (cf. rainbow) :

Red Orange Yellow Green Blue Indigo Violet

(Richard of York Gave Bottle In Vain)

- eye sensitive to yellow/green : 500 - 600nm
- Sun's energy output peaks at ~ 550nm
- Sodium street lamps : monochromatic ($\lambda = 590$nm)
  → can see contrast, not color
- Color perception not perfect

  e.g. red + green light → perceive as yellow

  (c.f. 2 musical notes)

Ultraviolet : ~10^{15} Hz to 10^{16} Hz

- Discovered 1801: "chemical rays" blacken photographic paper
- Absorbed by molecules - able to break chemical bonds
  e.g. skin: tan, sunburn, activates vitamin D

O_3 (ozone) layer absorbs solar UV.

- UV "black light" → fluorescence

- used in "optical brighteners" in laundry detergent.

- Absorbed by glass
  BUT transmitted / reflected by H_2O
  (clouds, water, snow)

Propagation of Light (Scattering) Ch. 23

- Sunlight, starlight streams through free space at $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s}$

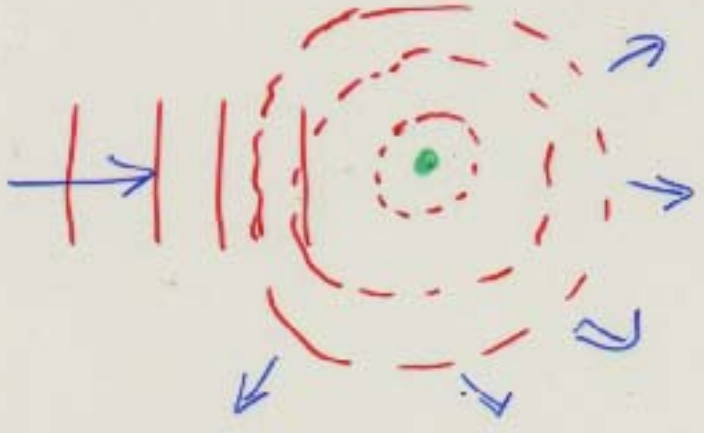
e.g. Andromeda Galaxy : 2.1 million light years

$$\text{distance} = c \times 2.1 \times 10^6 \text{ y} \times 365.25 \text{ d} \times 24 \text{ h} \times 60 \text{ m} \times 60 \text{ s}$$
$$= 2 \times 10^{22} \text{ m}$$

- What happens when light interacts with atmosphere?

Rayleigh (1871) : molecules act as "antennas"

- absorb EM wave, then re-emit in all directions



molecule "antennas"

~ 10 nm

λ light ~ 500 nm

(Hecht fig 23.2)

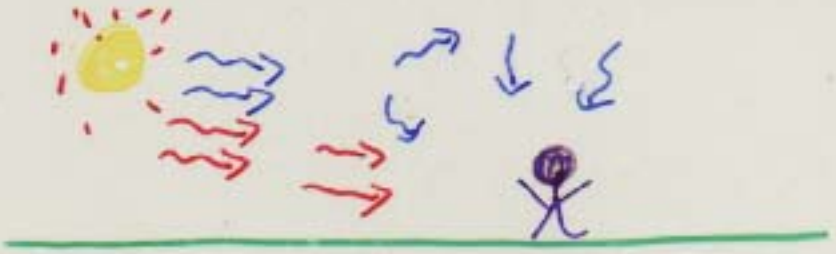
Rayleigh Scattering

Rayleigh found (from Maxwell's eqns)

When scatterer size $<<\lambda$

scattered fraction $\propto 1/\lambda^4$

i.e. more blue light (~400nm) scattered than red (750nm)



So : blue light scattered away from sun

multiple scatterings → bluer light reaches ground

Also: At sunset, sunlight travels through long atmospheric path

→ almost all blue light scattered away from observer — only red light reaches us directly from sun.

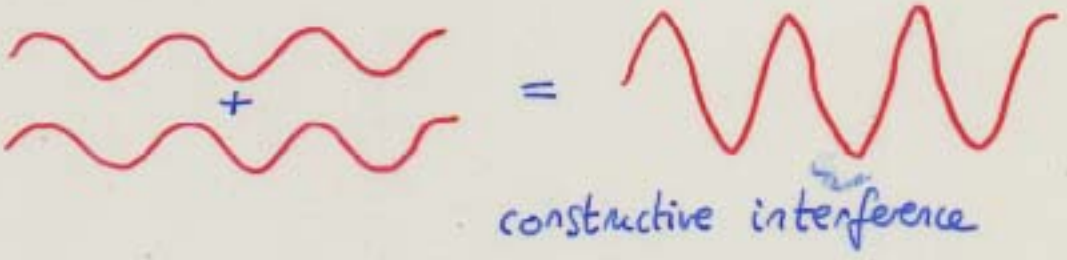
Q: Why isn't sky purple ?, not just blue?

A: Sun does not produce much violet/purple light (solar spectrum).

Superposition of EM Waves, and "Wavelets"

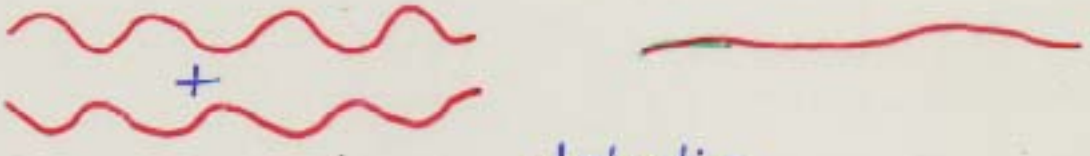
Review: When 2 waves combine, result is the sum of each → new wave:

In phase :



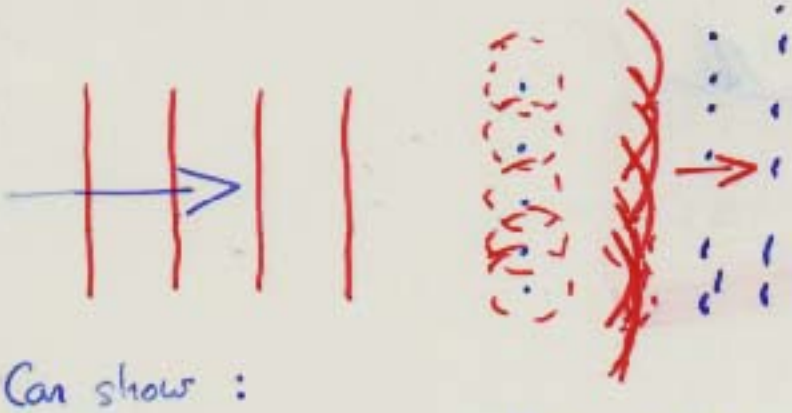
constructive interference

Out of phase:



destructive

When EM wave hits dense medium:



- each molecule scatters a "wavelet"
- wavelets overlap / interfere

Can show :

- wavelets interfere destructively except in forward direction
  ⇒ EM wave advances forwards in medium
- absorption / re-emission delay reduces wave speed : $v < c$