

INDEX OF REFRACTION
changes with FREQUENCY

$$n = n(\omega) \quad \text{"DISPERSION"}$$

AIR

GLASS

$$n_g = \frac{c}{v} = \frac{\sqrt{\frac{1}{\epsilon_0 \mu_0}}}{\sqrt{\frac{1}{\epsilon \mu}}} = \sqrt{\frac{\epsilon}{\epsilon_0}} = \sqrt{K}$$

dielectric constant

ϵ measures the polarizability of the medium

ϵ depends on the frequency ω

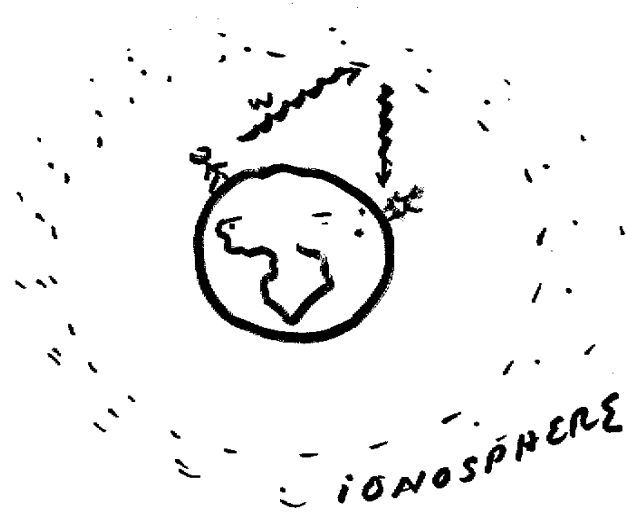
$\epsilon = \epsilon(\omega)$

$V = V_0 \cos(\omega t)$

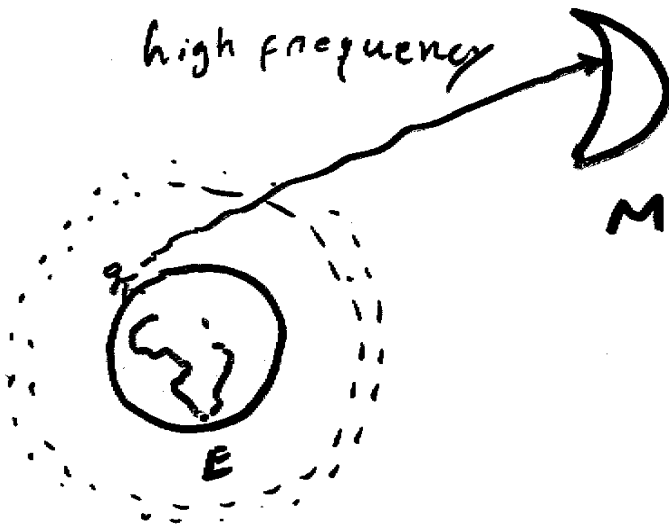
So, $n_g = n_g(\omega)$

$n_a = n_a(\dots)$

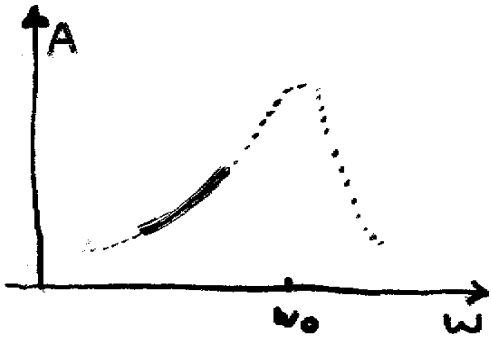
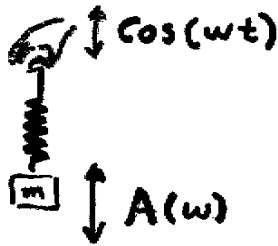
2A



low frequency
signal

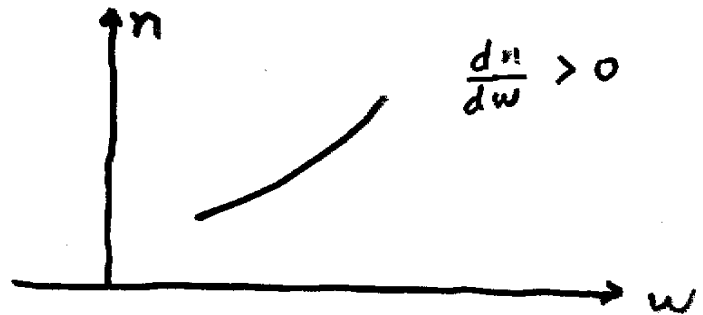


Mechanical analogy

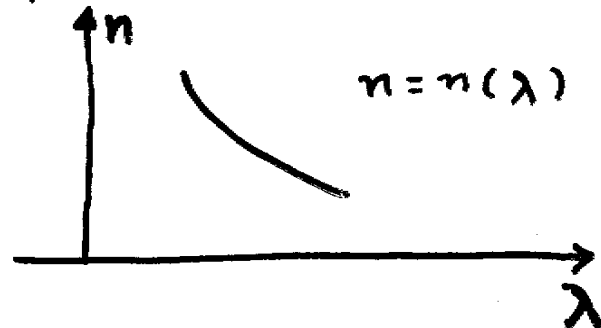


$$n_g = n_g(\omega)$$

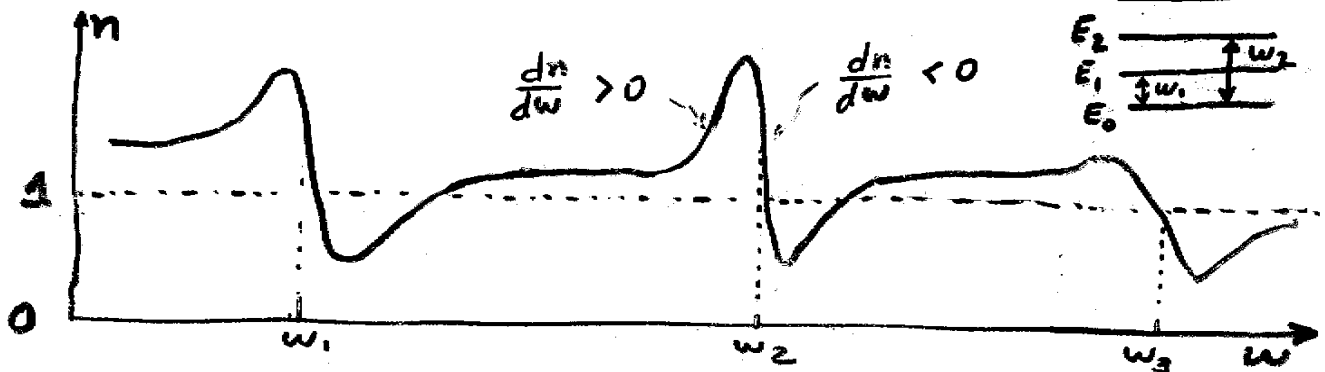
Typical variation of n vs ω
(called "normal" dispersion)



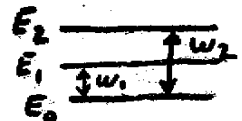
or, equivalent



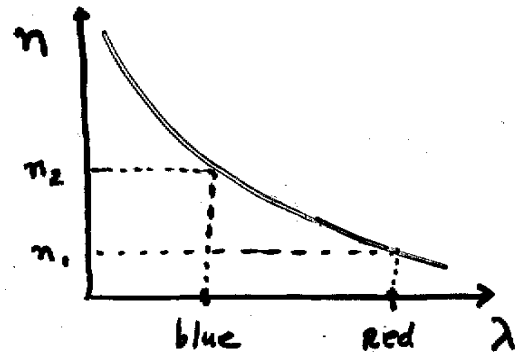
More general case



ATOM



AIR GLASS



λ_1 "sees" an index of refraction n_1 as it enters the glass

Red light

$$c = \lambda_1 f_1$$

$$v_1 = \frac{\lambda_1}{n_1} f_1$$

- frequency f_1 is the same in air than in the glass
- wavelength decreases by a factor of n_1

λ_2 "sees" an index of refraction n_2 as it enters the glass

Blue light

$$c = \lambda_2 f_2$$

$$v_2 = \frac{\lambda_2}{n_2} f_2$$

- frequency f_2 is the same in air and in the glass
- wavelength decreases by a factor of n_2

AIR

GLASS

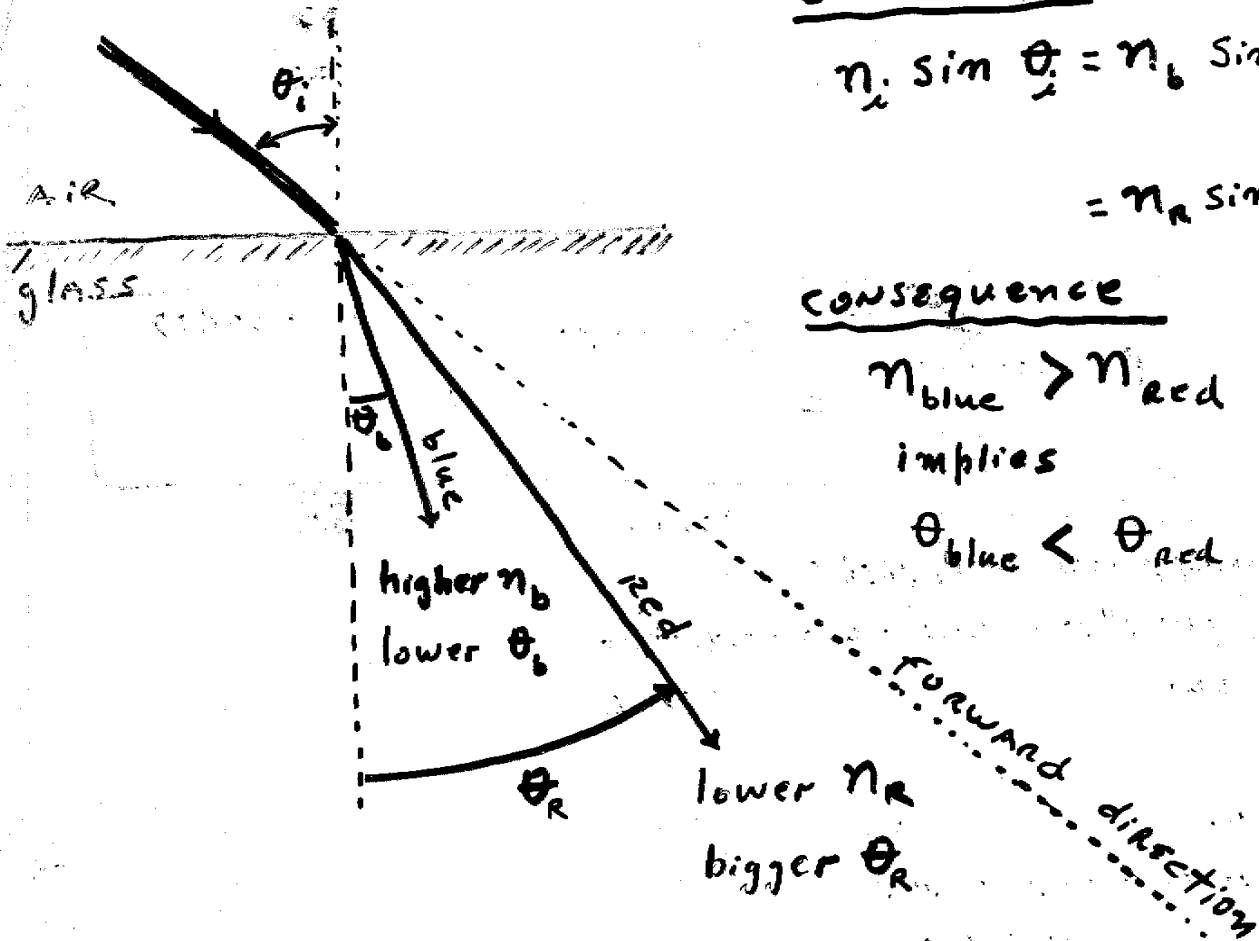
Light dispersion at a air-glass
INTERFACE

Snell's law

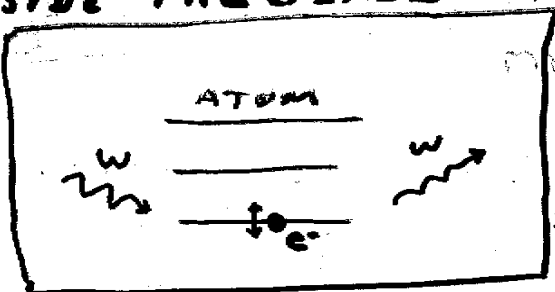
$$n_i \sin \theta_i = n_b \sin(\theta_b) = n_r \sin(\theta_r)$$

consequence

$n_{blue} > n_{red}$
implies
 $\theta_{blue} < \theta_{red}$



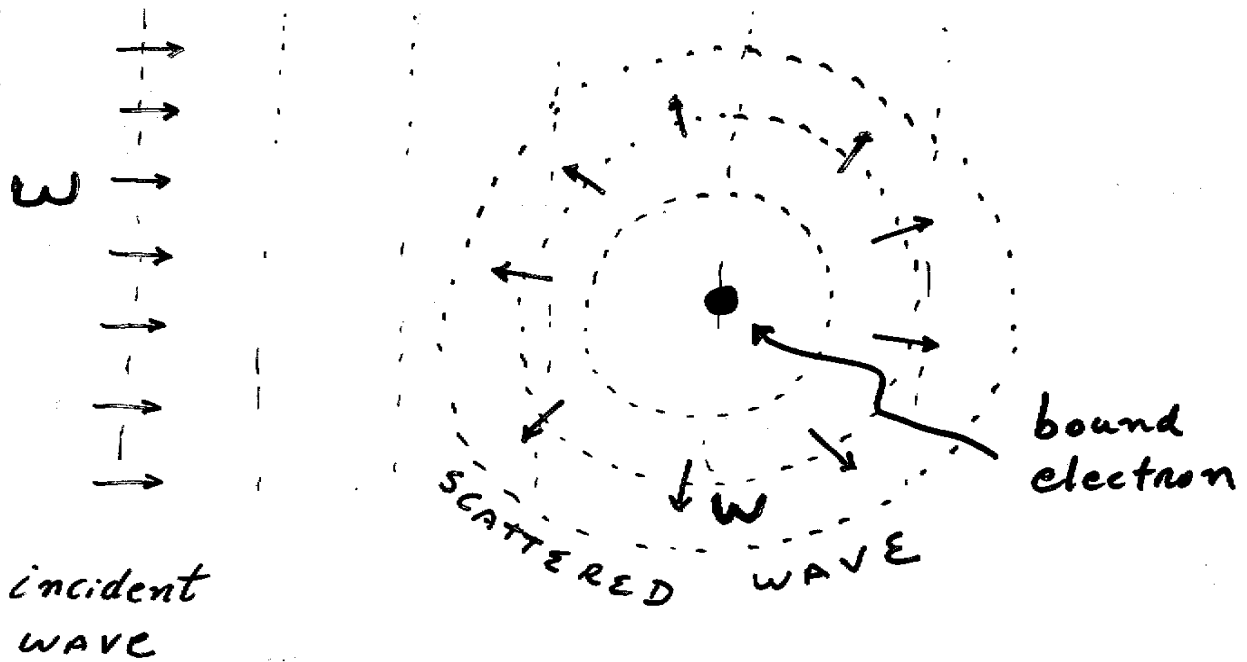
THIS IS WHAT IS GOING ON
INSIDE THE GLASS



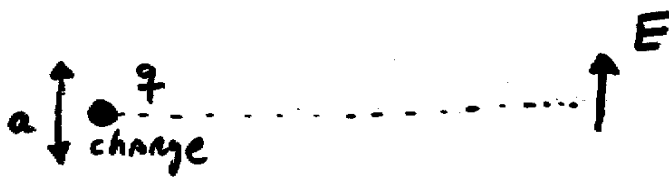
ELASTIC SCATTERING

blue light deviates more from this forward direction

WHY IS THE SKY BLUE ?



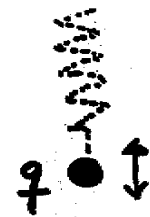
CASE. $\lambda \gg \delta$
particle size



An accelerated charge emits EM radiation

$E \sim a$
 Electric field proportional to the acceleration

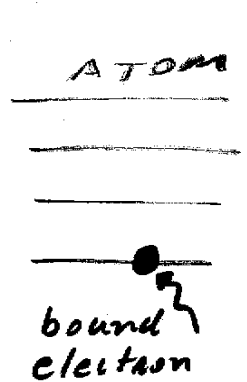
bound
charge



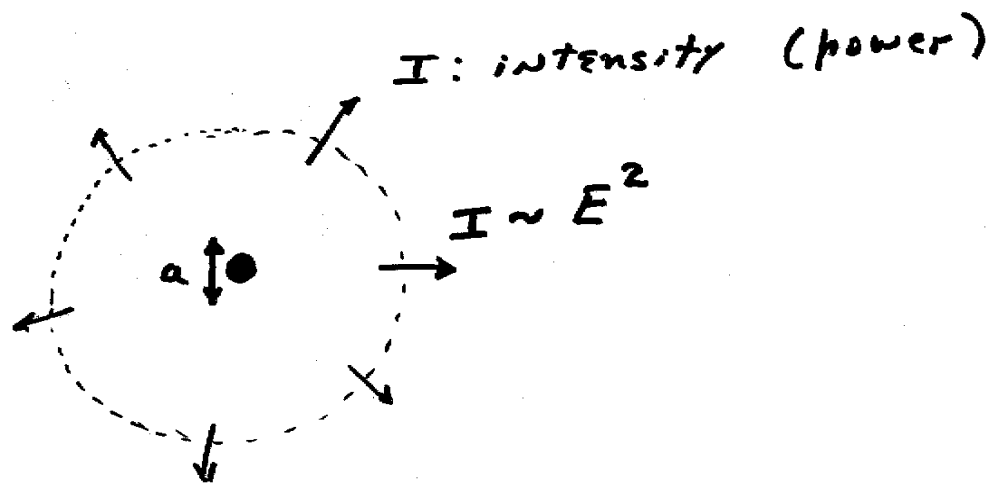
$$x = A \cos(\omega t)$$

$$a \sim \omega^2 \text{ (ACCELERATION)}$$

ATOM ³²



bound
electron

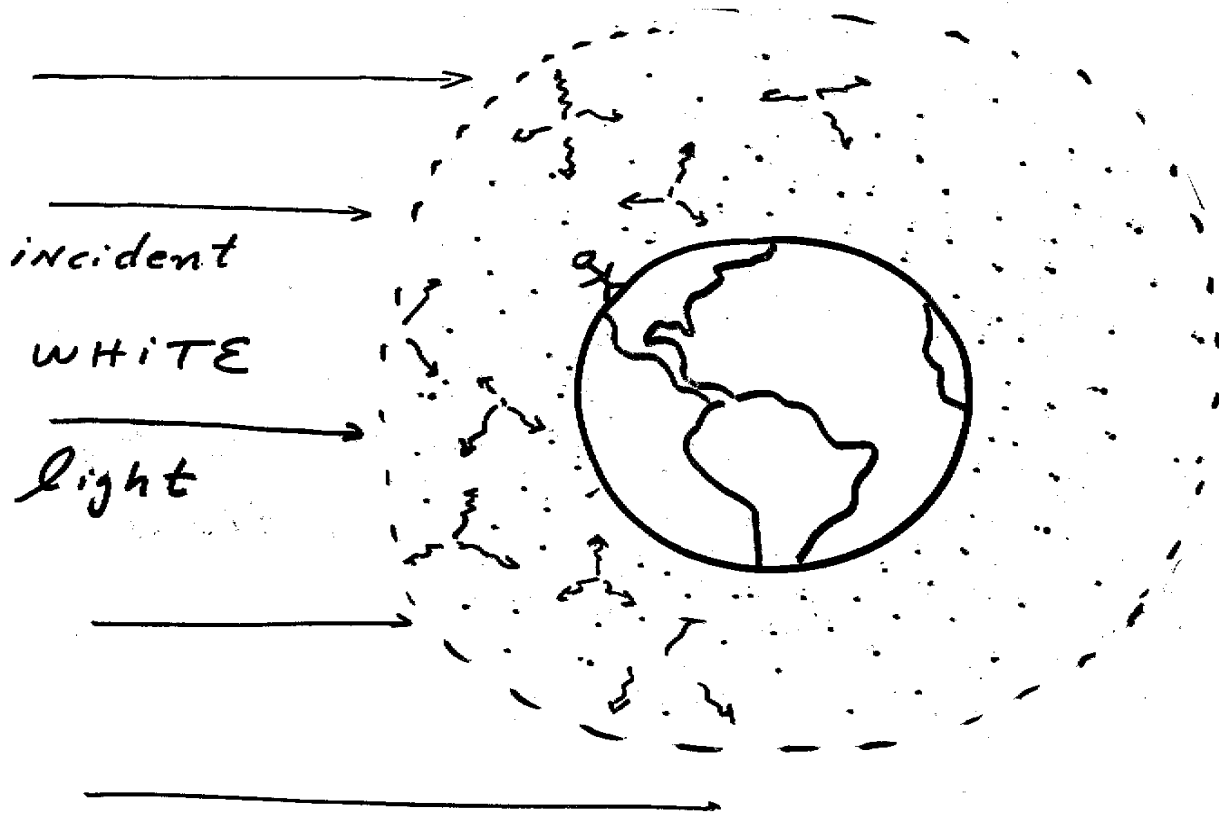


$$I \sim E^2 \sim (a)^2 \sim (\omega^2)^2$$

Thus

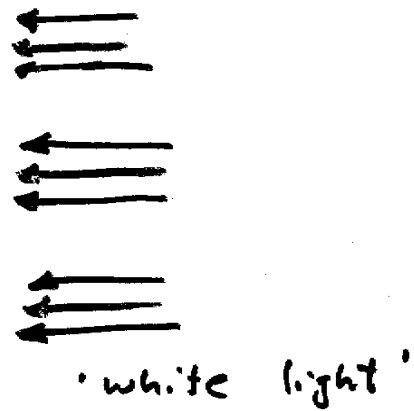
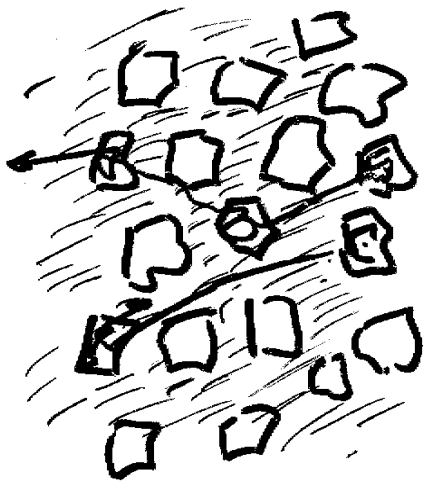
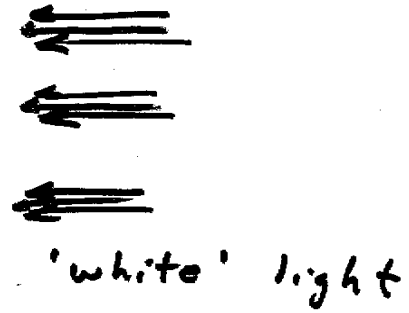
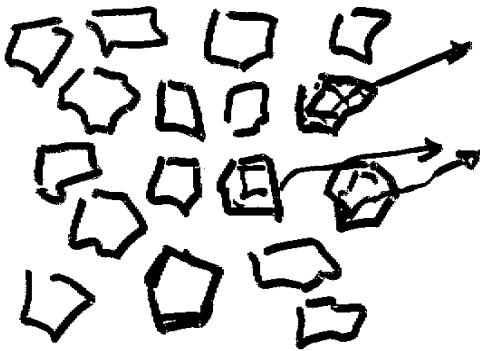
$$I \sim \omega^4$$

Light of higher frequency (i.e. blue) is scattered more efficiently than light of lower frequency (i.e. red)



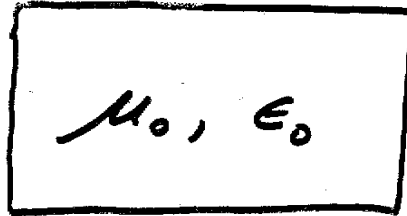
In a bright clear day:
 Sunlight incident in one direction is
 scattered in all direction by the
 molecules in the atmosphere. You will
 receive light from every direction and
 the main color component will be
 blue (because of the w^4 factor

CASE $\lambda < \delta$
particle size



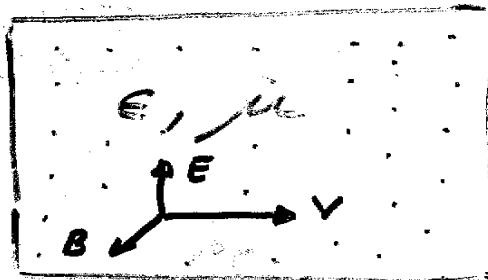
INDEX OF REFRACTION n

VACUUM \rightarrow



$$c = \sqrt{\frac{1}{\epsilon_0 \mu_0}}$$

MATERIAL \rightarrow
(gas, liquid, solid)



Electromagnetic waves travel through matter with speed v

$$v = \sqrt{\frac{1}{\epsilon \mu}}$$

NOTICE

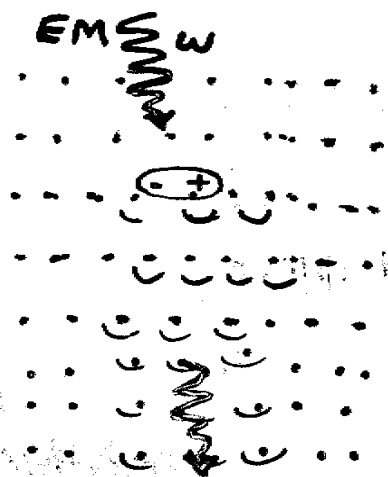
Since $\epsilon > \epsilon_0$, $\mu > \mu_0$ then $v < c$

Since $\epsilon = \epsilon(\omega)$, $\mu = \mu(\omega)$ then $v = v(\omega)$

Definition
index of
refraction

$$n = \frac{c}{v}$$

Electromagnetic waves appear to propagate in matter with $v < c$



When EM waves falls on a piece of matter, it induces oscillations in the charged particles, which then emit secondary or scattered waves

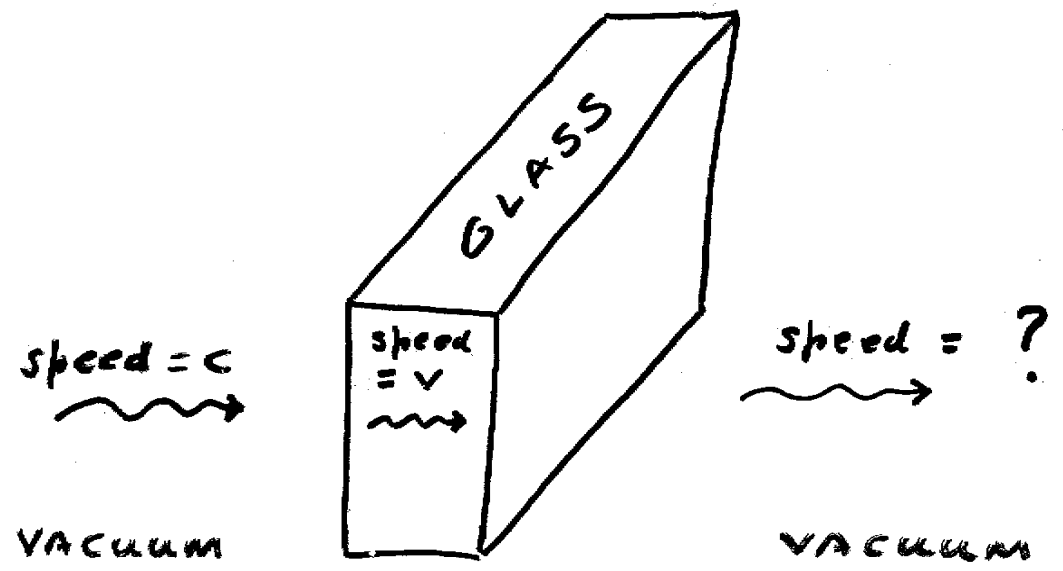
These scattered waves are superposed on the original EM wave, giving a resultant wave.

Incident EM wave (speed c)	+	scattered waves (speed c)	=	RESULTANT WAVE (speed v)
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waves
no necessarily
in phase

This phase difference affects the resultant wave in such a way that this wave appears to have a velocity $< c$.

Does light slow down?



EM RADIATION propagating through different mediums

* frequency remains the same
wavelength changes according to the index of REFRACTION

