Scattering of electromagnetic waves

An $\vec{E}$ field causes a charge q to accelerate

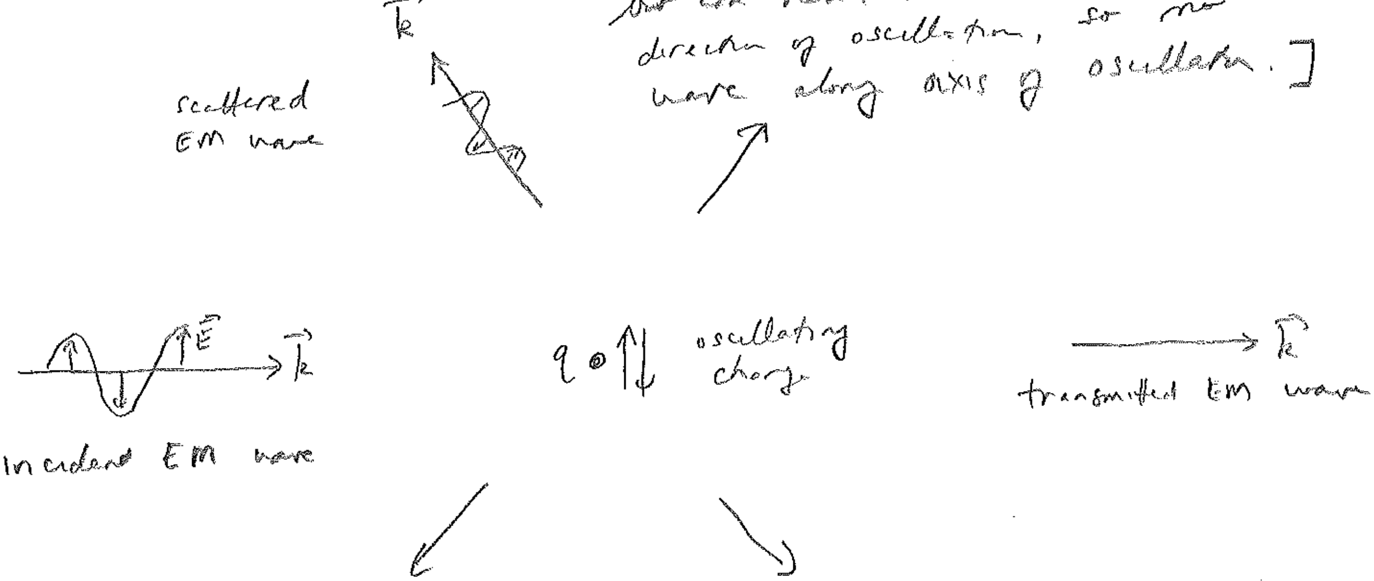
$$\vec{a} = \frac{\vec{F}}{m} = \frac{q\vec{E}}{m}$$

[recall: uniform $\vec{E}$ causes charge in vacuum to undergo const acceleration.
In a conductor, charge achieves const V_d causing a current to flow.]

An oscillating $\vec{E}$ field ($A \sin \omega t$) causes a charge to oscillate at the same frequency

In turn, an oscillating charge emits EM waves in (almost) all directions

[If asked: $\vec{E}$ field of emitted wave is always $\perp$ to wave direction $\vec{k}$ but can never be $\perp$ to the direction of oscillation, so no wave along axis of oscillation.]



We say that part of the incident wave has been scattered.

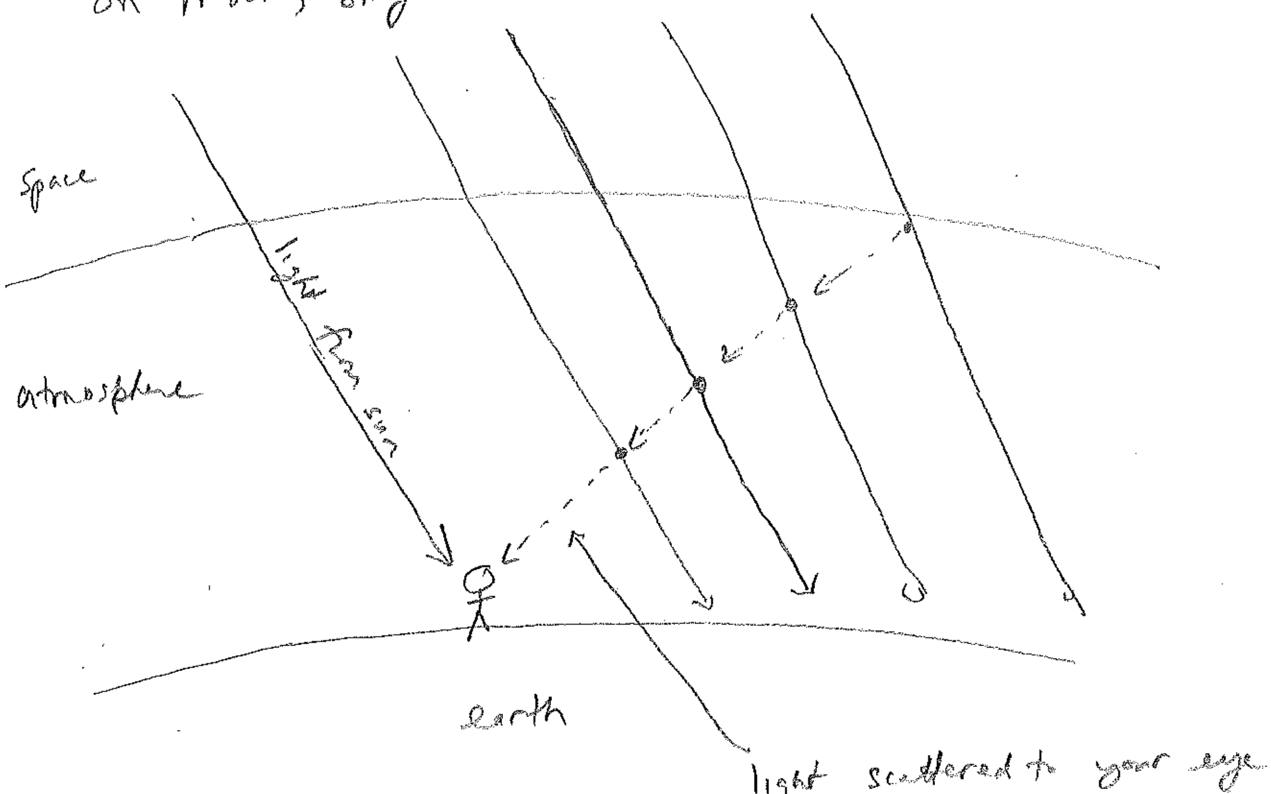
The intensity of transmitted wave is reduced (energy conservation).

[Light from sun is scattered by air in atmosphere.

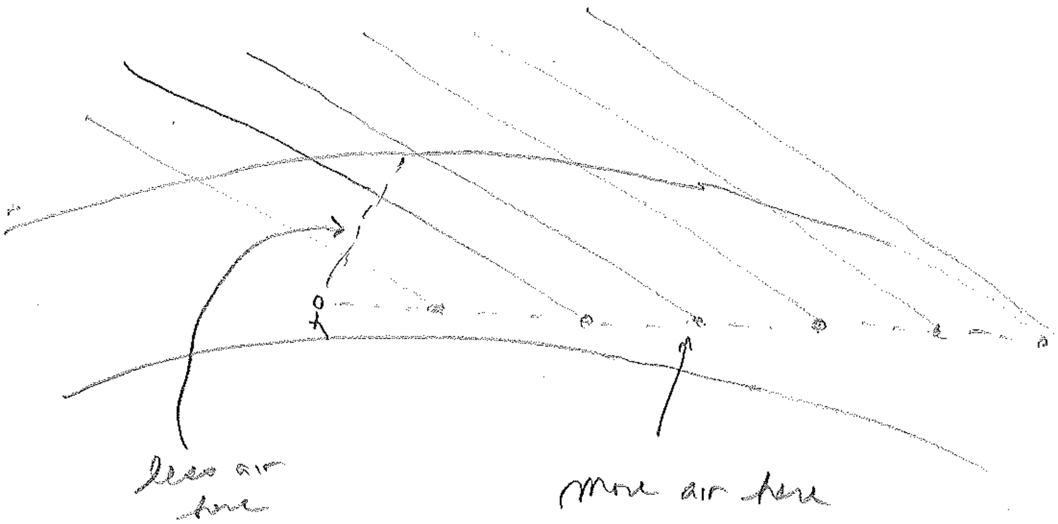
Specifically, $\vec{E}$ field from incident waves causes
electrons in gas molecules to oscillate, emit its own light.

Effect of $\vec{E}$ on protons is much less because more massive.

Can you see this light from air? It looks transparent.
Scattered light from a single gas atom is small,
but strength in numbers! Cumulative effect.
You can see the sky!
On moon, sky is dark because no atmosphere to scatter]



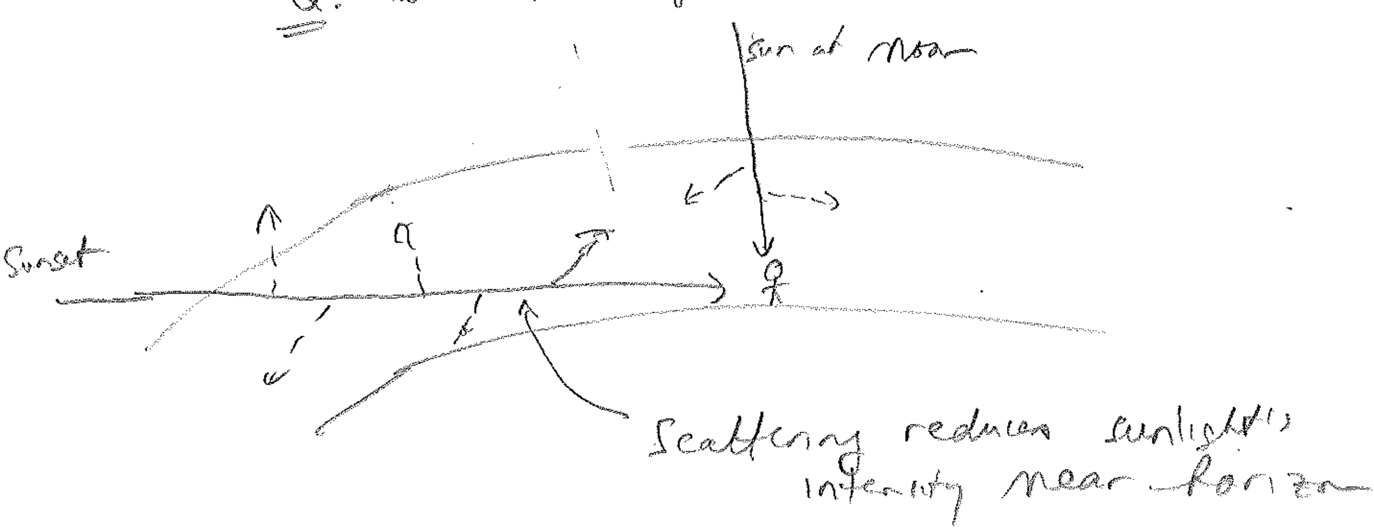
Q: on a clear day, is sky brighter at zenith or near horizon?



Q: which are darker, near or distant mountains?

[There's more air between you and distant mtns]

Q: which is brighter, sun at zenith or near horizon?



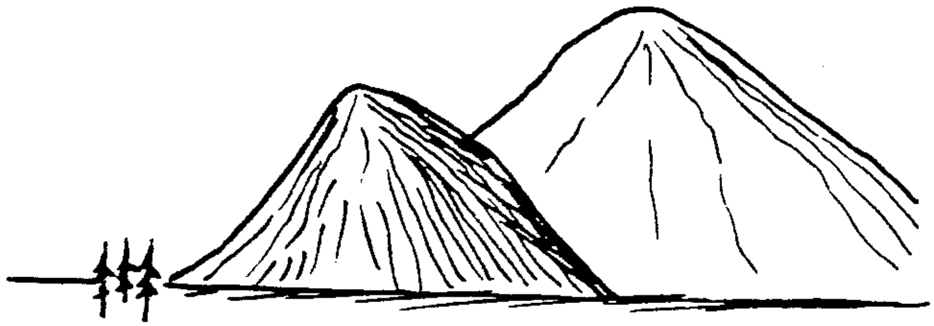
Ask: on a clear day, which is lighter (brighter)? zenith or horizon

expand

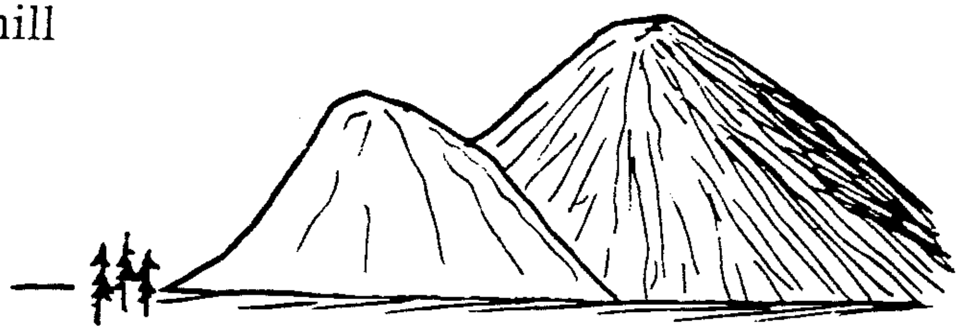
LANDSCAPE

You are looking at two dark hills, one more distant than the other. The hill that appears a bit darker is the

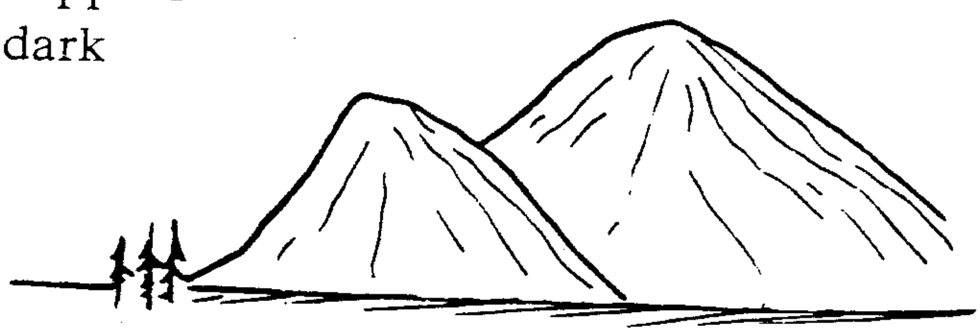
a) near hill



b) distant hill

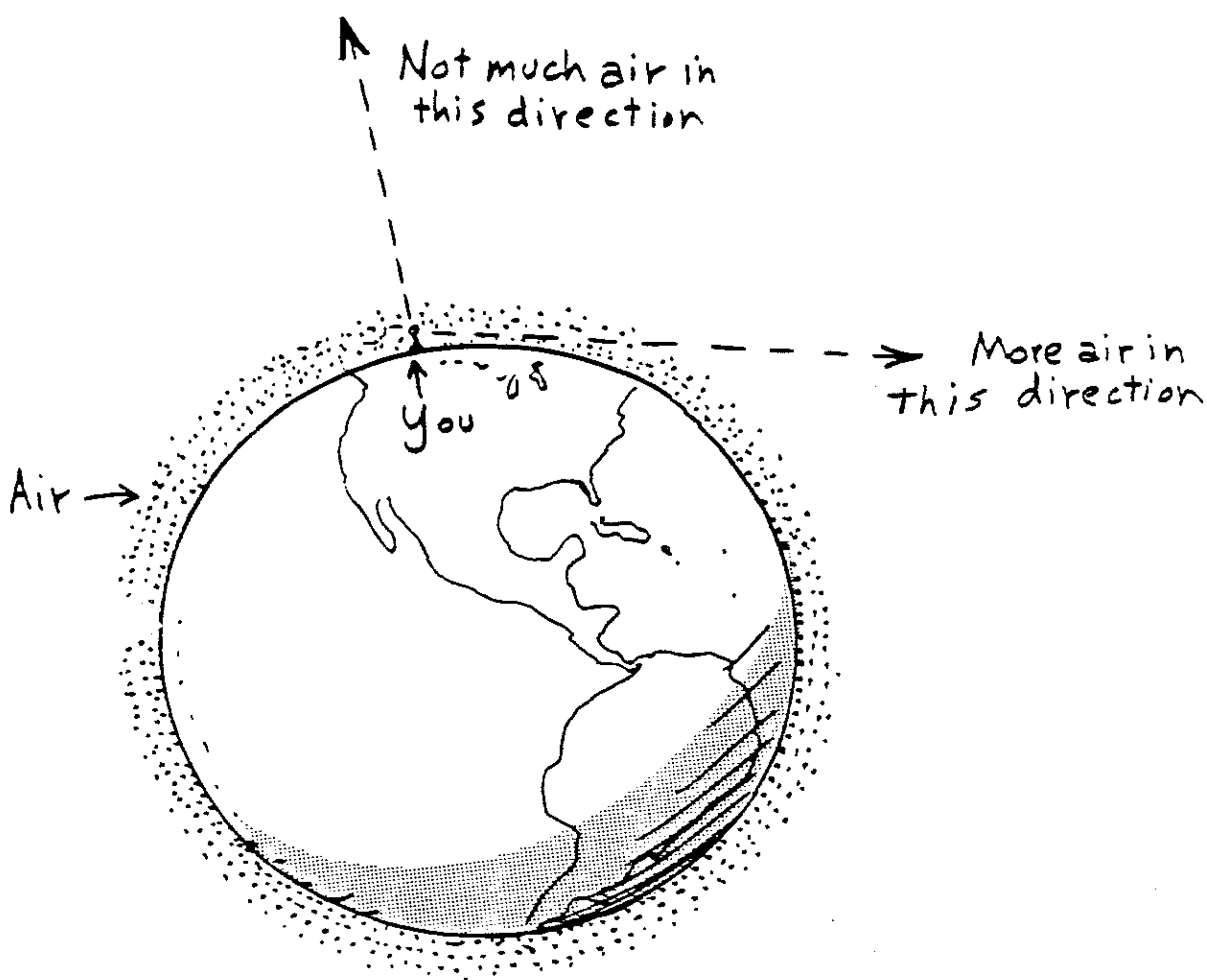


c) . . . both appear equally dark



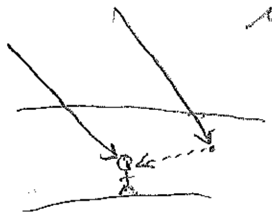
ANSWER: LANDSCAPE

The answer is: a. The closer hill is darker. When you look at the hills, most of the light you see comes from the air between you and the hills. The air scatters light from the sky above and scatters some of it into your eyes. There is more air between you and the distant hill than between you and the near hill, and that means more air to scatter light towards you. So distant mountains appear bluish because the atmosphere between you and the mountains scatters blue light. Similarly, the sky is brighter when you look towards the horizon and darker when you look straight up (unless the sun is straight up).



Wavelength dependence of scattered light

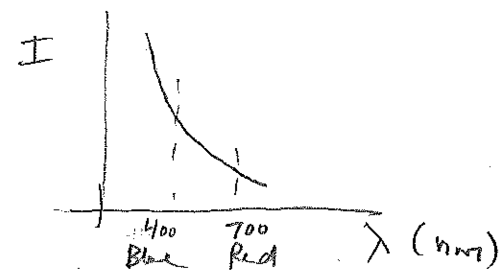
Electrons in air molecules & small particles (e.g. smoke) respond more strongly to higher frequencies. (if size of particles is much less than λ)



$\lambda = \frac{c}{f}$ so shorter wavelengths are scattered more effectively

Intensity of scattered light proportional to $\frac{1}{\lambda^4}$

(Rayleigh scattering)



Blue light scattered more than red.

⇒ The sky is blue

[Blue ridge mountains
Purple mountain majesty
Mtns are blue for same reason sky is blue
Not the mtns! It's the air
between you & mtns
that is purple.]

Smoke looks blue

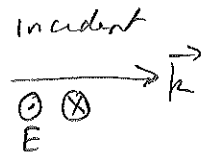
⇒ Sunsets are red.

[you're seeing <u>transmitted</u> light
i.e. what is left after light is scattered]

Polarization of scattered light

Light scattered in a direction 90° from incident wave will be plane polarized

scattered light polarized in yz plane (not in xz plane)

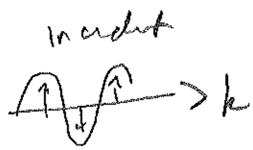


q • ← charge oscillates along z-axis [in + out of board]

[Q: what about light scattered toward us? There is none!]

The E field of the scattered wave cannot be perpendicular to the direction of oscillation of the charge

↑ no scattered light in this direction



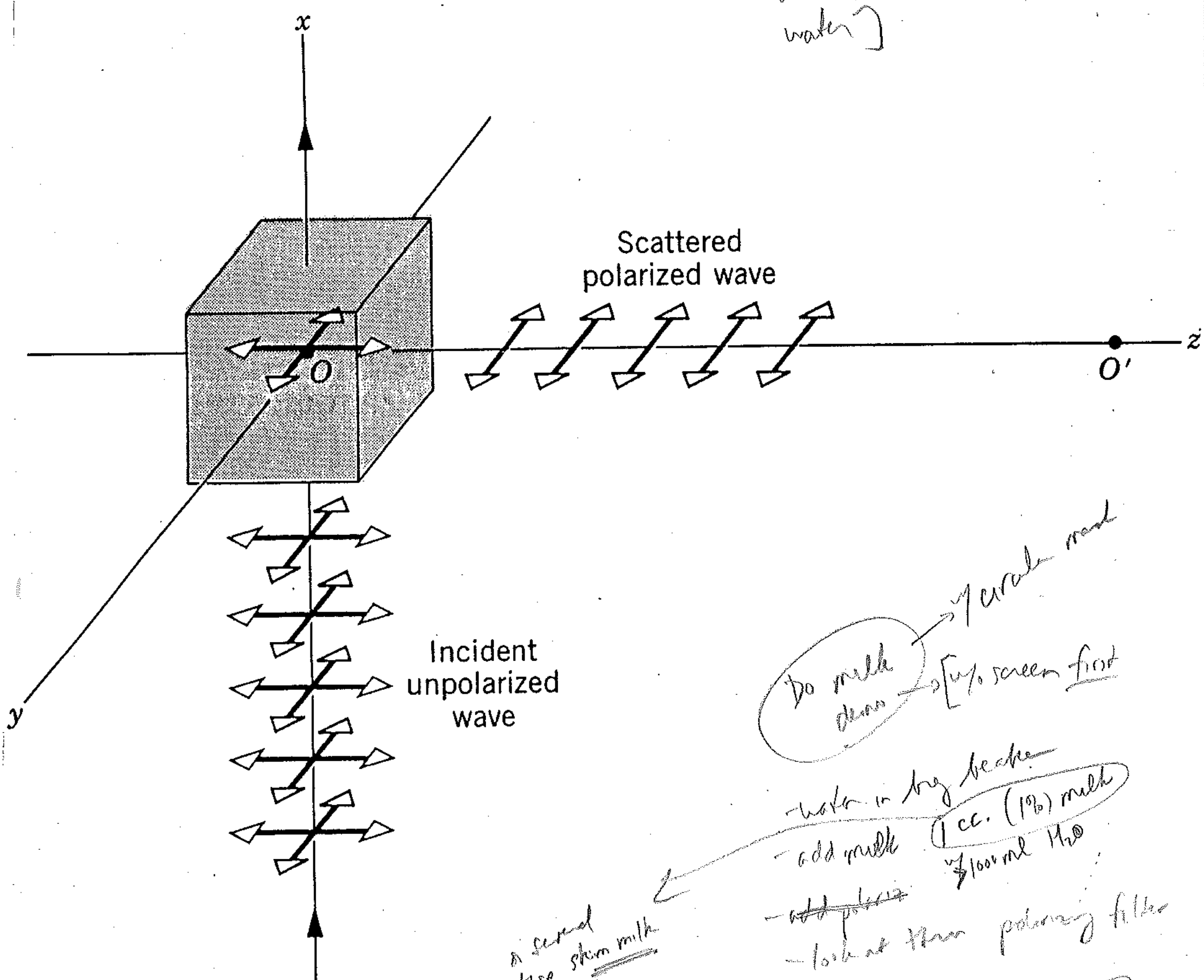
q • ↑↓ charge oscillate along y-axis

Light scattered toward us (out of board) is polarized in yz plane (not xz plane)

Unpolarized incident light is a mixture of these 2 cases.

DEMO: hand out polarizers.
Look at sky.
Milk demo. on overhead project
↳ first observe Rayleigh
→ then look at transmitted light on the screen
→ then observe polarization

[Show this & do demo w/ milk added to water]



Do milk demo → w/ circular mod

→ [w/o screen first

- water in big beaker
- add milk (1 cc. (1%) milk / 100 ml H_2O)
- ~~add polariz~~
- look at thru polarizing filter

[put filter beneath beaker]

a second tbsp skim milk

unpolarized light, when scattered thru 90°, will be completely polarized

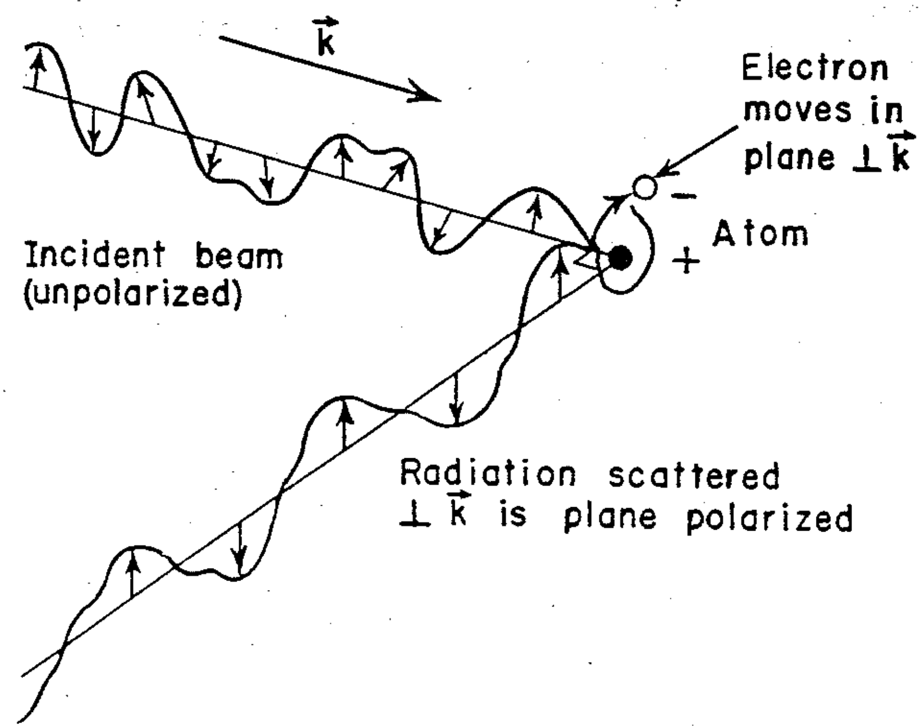


Fig. 32–3. Illustration of the origin of the polarization of radiation scattered at right angles to the incident beam.