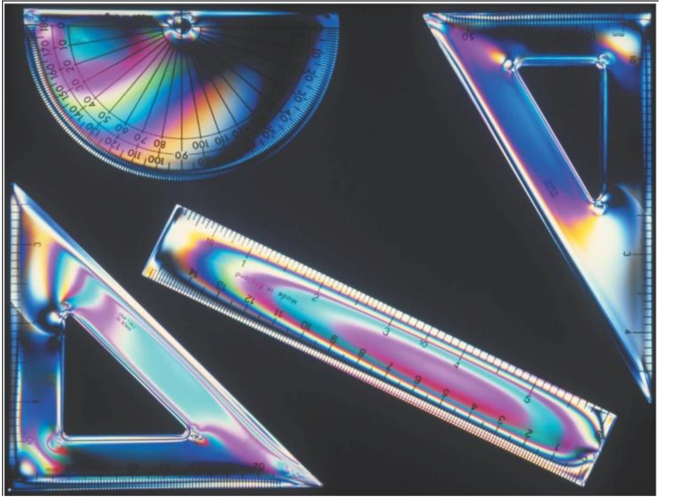
Chapter 33 – Nature and Propagation of Light

From vision to digital camera to rainbows to pictures of the early universe light is all around us

Introduction

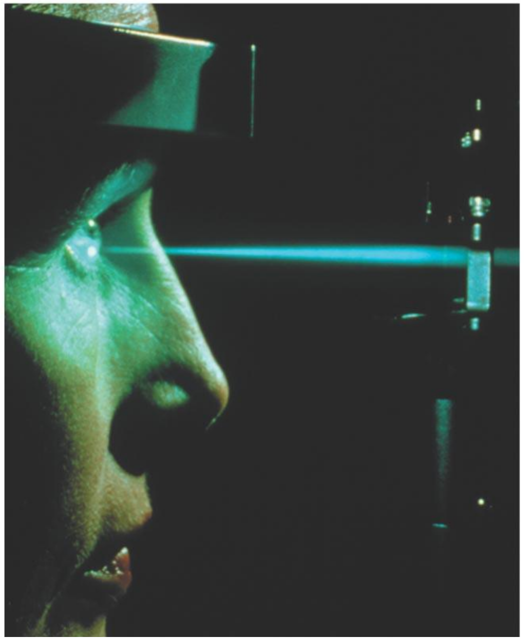
– A coating of oil on water or a delicate glass prism can create a rainbow. A rainstorm among open patches of daylight can cast a conventional rainbow. Both effects arise from the wavelength dependence of refraction angles.

– Eyeglasses or contact lenses both use refraction to correct imperfections in the eyeball’s focus on the retina and allow vision correction.



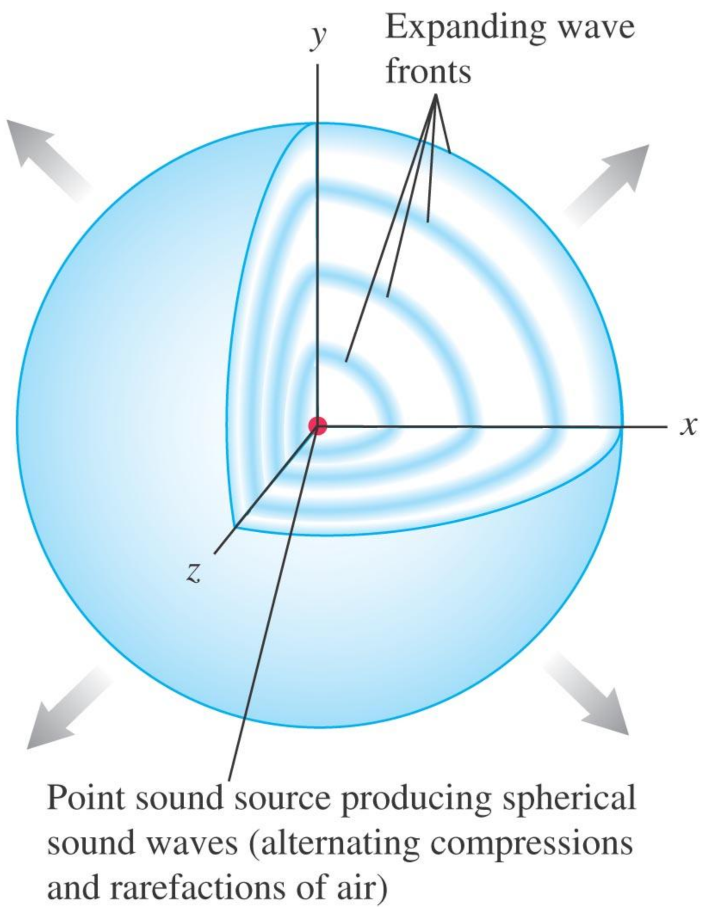
“Light is a wave,” “Light is a particle”

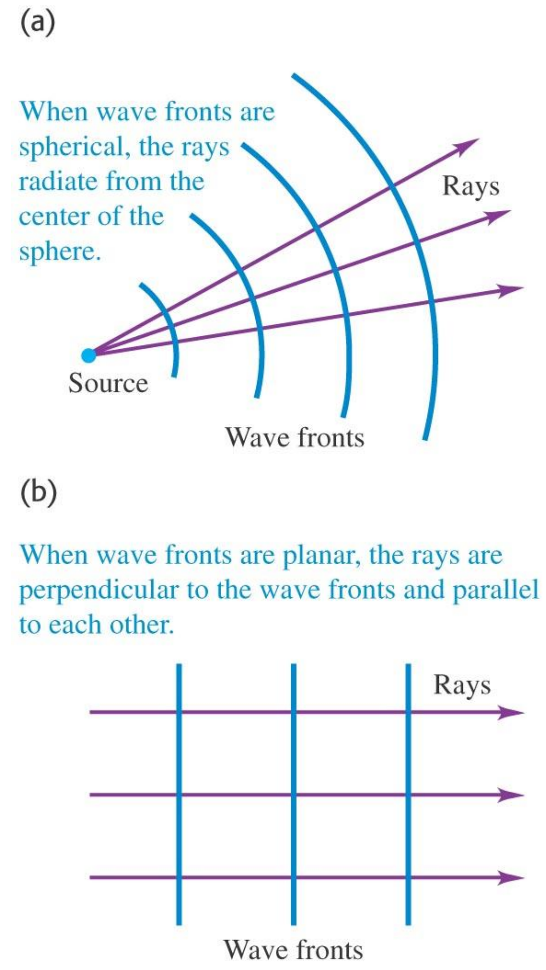
- The wave–particle duality of light was not well understood until Albert Einstein won his Nobel Prize in the early 20th century. It was a tenacious understanding of light that led to quantum mechanics and modern physics.
- Black-body and laser radiation look so different but are the same basic phenomenon



Wave fronts and rays

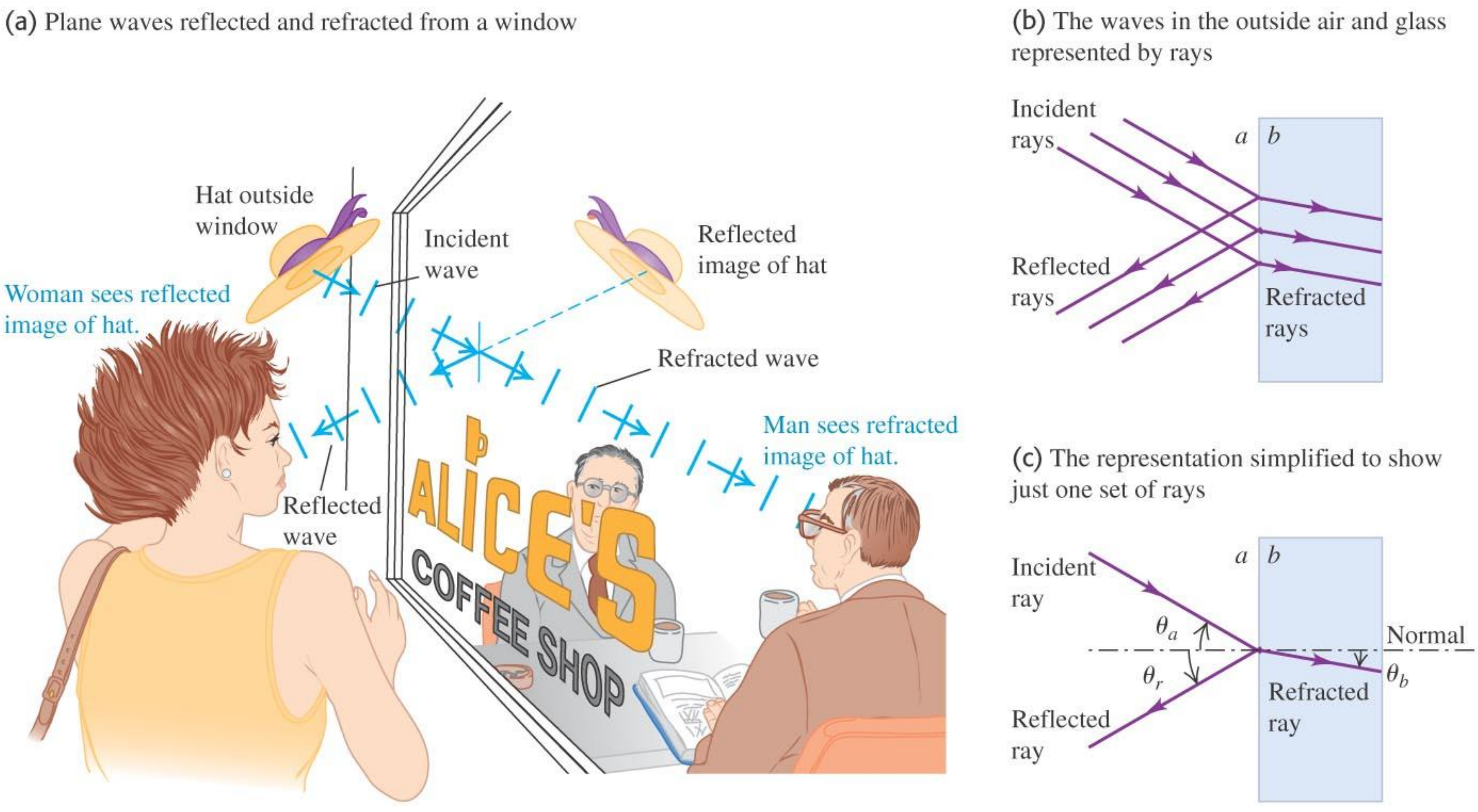
– Light is actually a nearly uncountable number of electromagnetic wave fronts, but analysis of refraction or reflection are made possible by treating light as a ray.





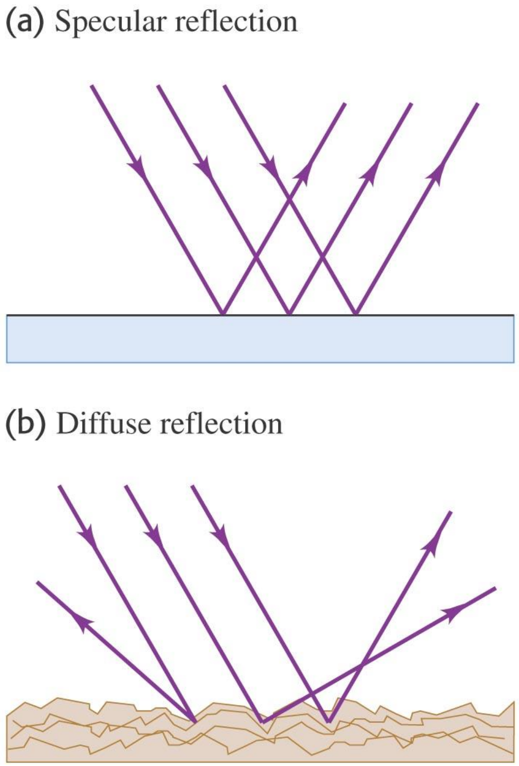
Reflection and refraction

- Reflection and refraction at once. The storefront window both shows the passersby their reflections and allows them to see inside.



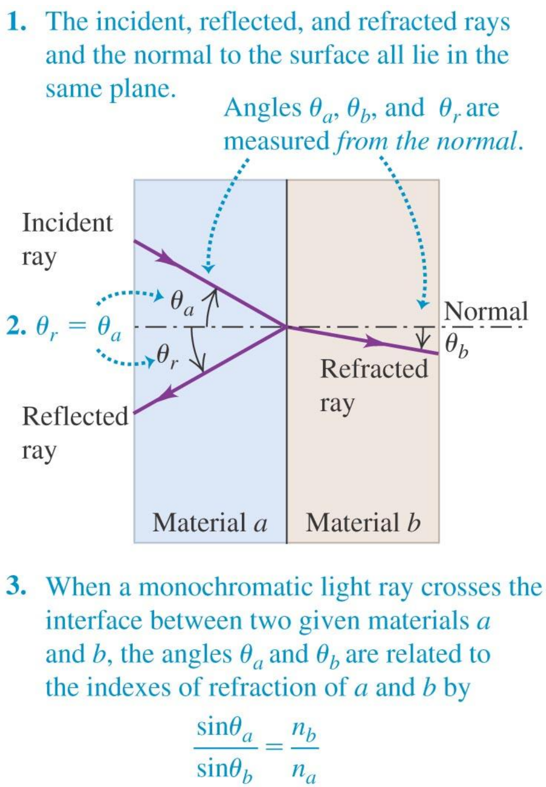
Specular reflections

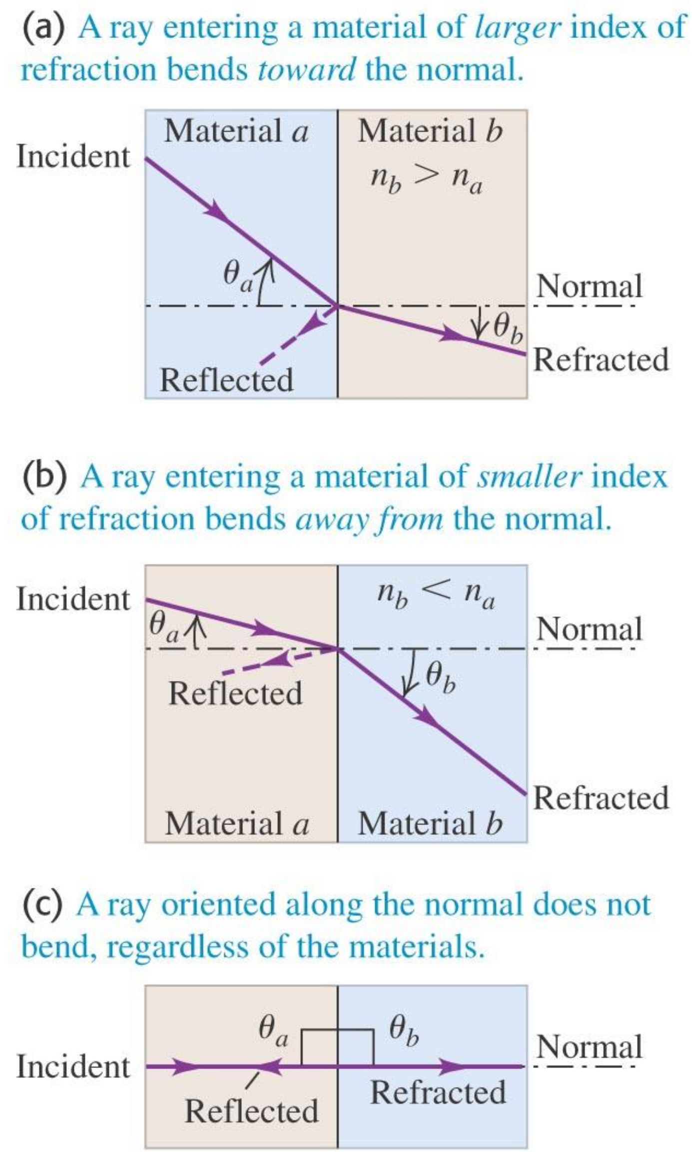
- A real surface will scatter and reflect light. Diffuse reflection is the rule, not the exception. We will use specular reflection as we used the ray approximation, to make a very difficult problem manageable.



Laws of reflection and refraction

- Angle of incidence = angle of reflection.
- Snell’s Law of Refraction considers the slowing of light in a medium other than vacuum … the index of refraction.



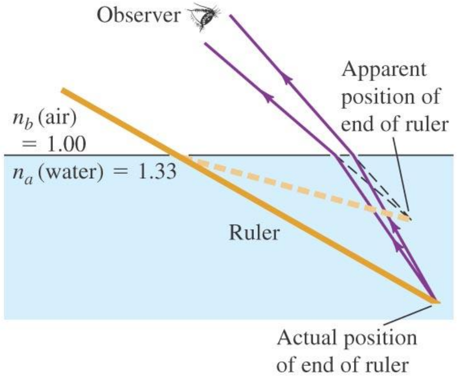


Why does the ruler appear to be bent?

- The difference in index of refraction for air and water causes your eye to be deceived. Your brain follows rays back to the origin they would have had if not bent.

(a) A straight ruler half-immersed in water

(b) Why the ruler appears bent



Why should sunsets be orange and red?

- The light path at sunset is much longer than at noon when the sun is directly overhead.
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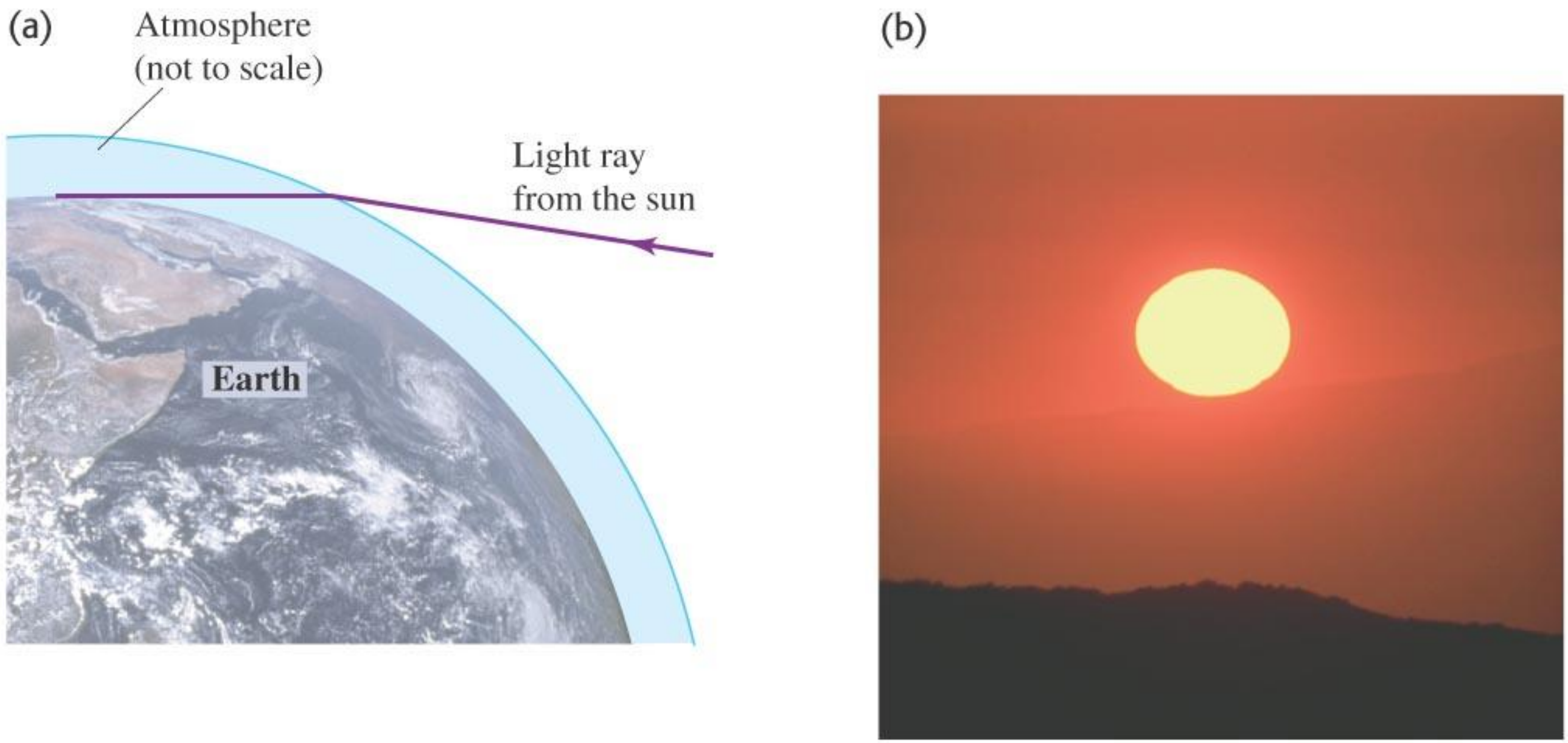


Tabulated indexes of refraction

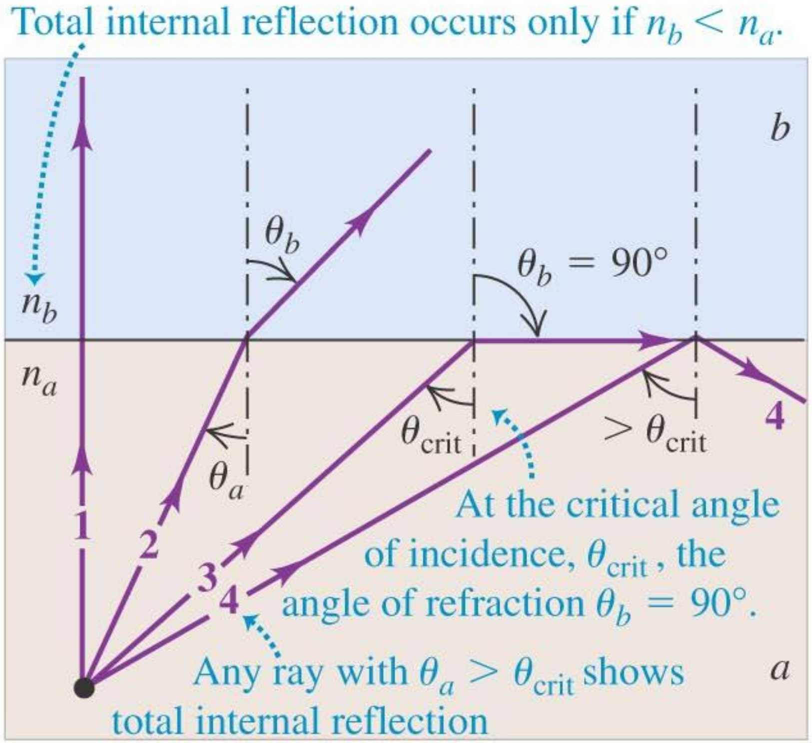
Table 33.1 Index of Refraction for Yellow Sodium Light $\lambda_0 = 589$ nm

Substance	**Index of Refraction, n**
Solids	
Ice (H_2O)	1.309
Fluorite (CaF_2)	1.434
Polystyrene	1.49
Rock salt (NaCl)	1.544
Quartz (SiO_2)	1.544
Zircon ($ZrO_2 \cdot SiO_2$)	1.923
Diamond (C)	2.417
Fabulite ($SrTiO_3$)	2.409
Rutile (TiO_2)	2.62
Glasses (typical values)	
Crown	1.52
Light flint	1.58
Medium flint	1.62
Dense flint	1.66
Lanthanum flint	1.80
Liquids at 20°C	
Methanol (CH_3OH)	1.329
Water (H_2O)	1.333
Ethanol (C_2H_5OH)	1.36
Carbon tetrachloride (CCl_4)	1.460
Turpentine	1.472
Glycerine	1.473
Benzene	1.501
Carbon disulfide (CS_2)	1.628

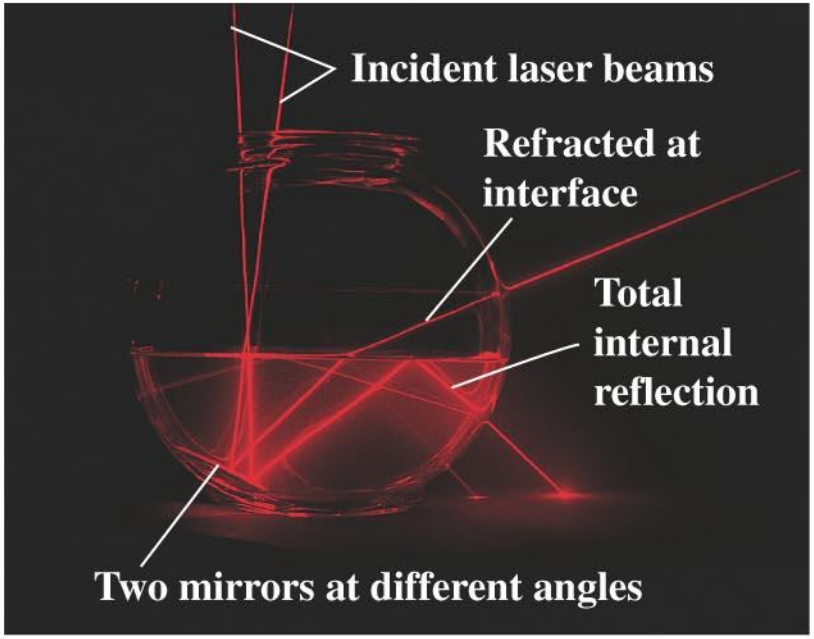
Total internal reflection I

- As the angle of incidence becomes more and more acute, the light ceases to be transmitted, only reflected.

(a) Total internal reflection

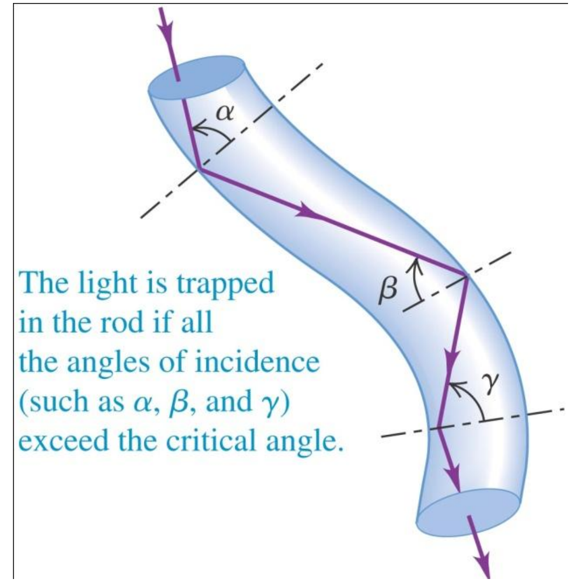


(b) Total internal reflection demonstrated with a laser, mirrors, and water in a fishbowl

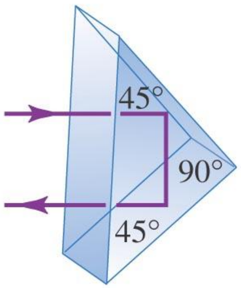


Total internal reflection II

- Using clever arrangements of glass or plastic, the applications are mind boggling.

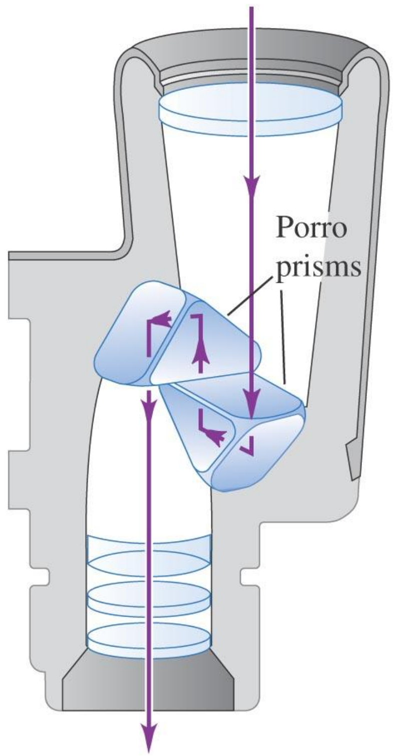


(a) Total internal reflection in a Porro prism



If the incident beam is oriented as shown, total internal reflection occurs on the 45° faces (because, for a glass–air interface, $\theta_{crit} = 41.1°$).

(b) Binoculars use Porro prisms to reflect the light to each eyepiece.

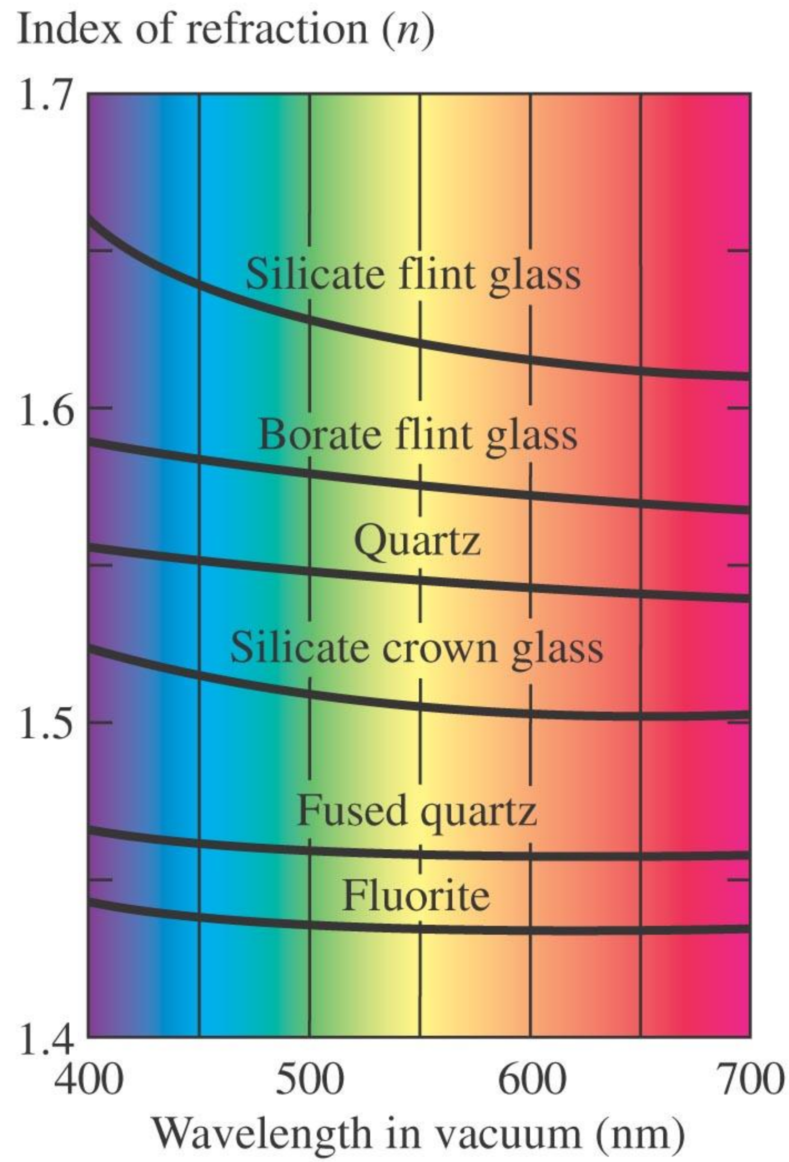


Total internal reflection III

- Diamonds sparkle as they do because their index of refraction is one of the highest a transparent material can have. Nearly all light that enters a surface ends up making many passes around the inside of the stone. The effect is only amplified by cutting the surfaces at sharp angles.

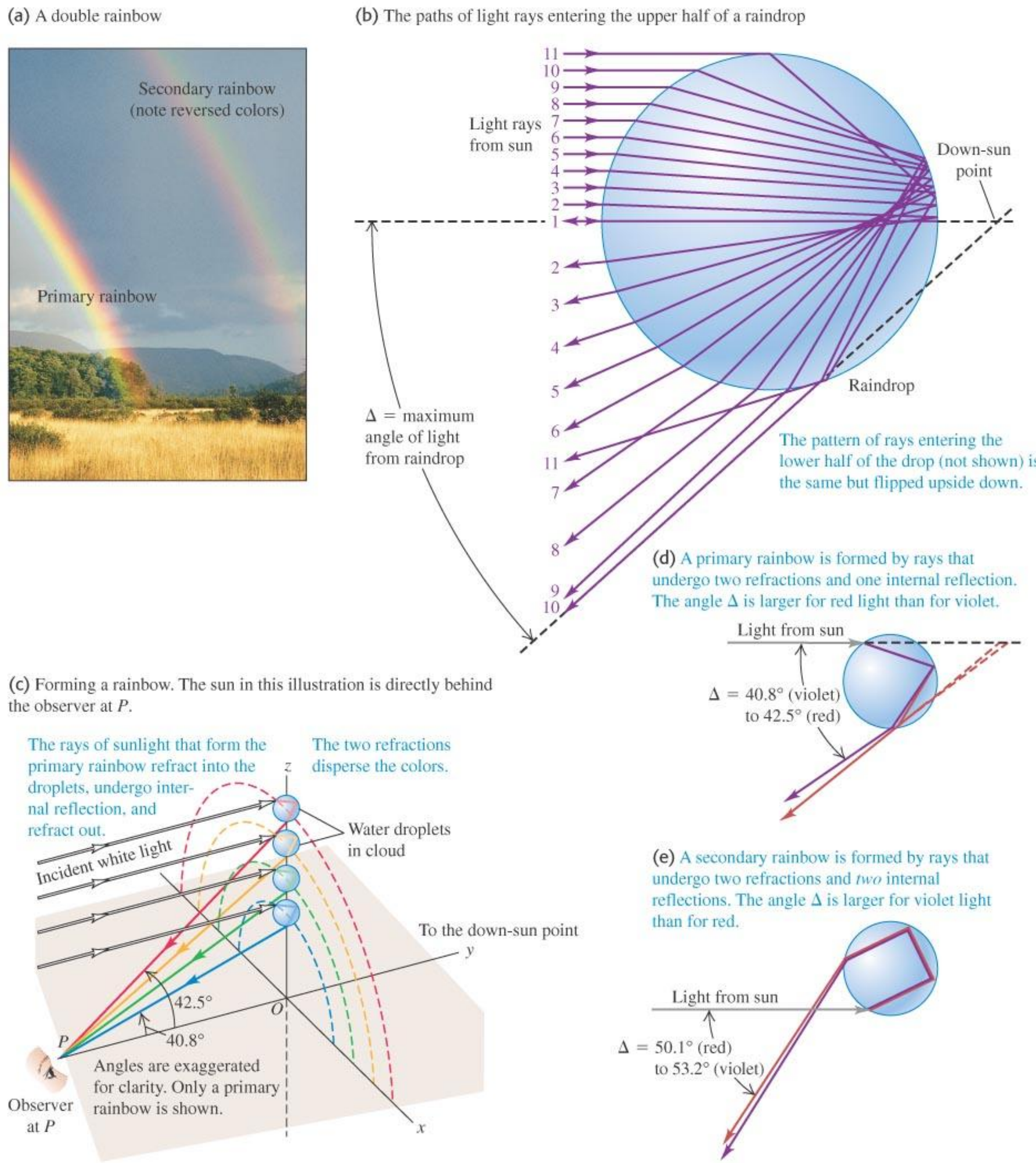
Dispersion – we are below resonance
As we get closer to resonance the index of refraction increases

- From the discussion of the prism seen in earlier slides, we recall that light refraction is wavelength dependent. This effect is made more pronounced if the index of refraction is higher. “Making a rainbow” is actually more than just appreciation of beauty; applied to chemical systems, the dispersion of spectral lines can be a powerful identification tool.



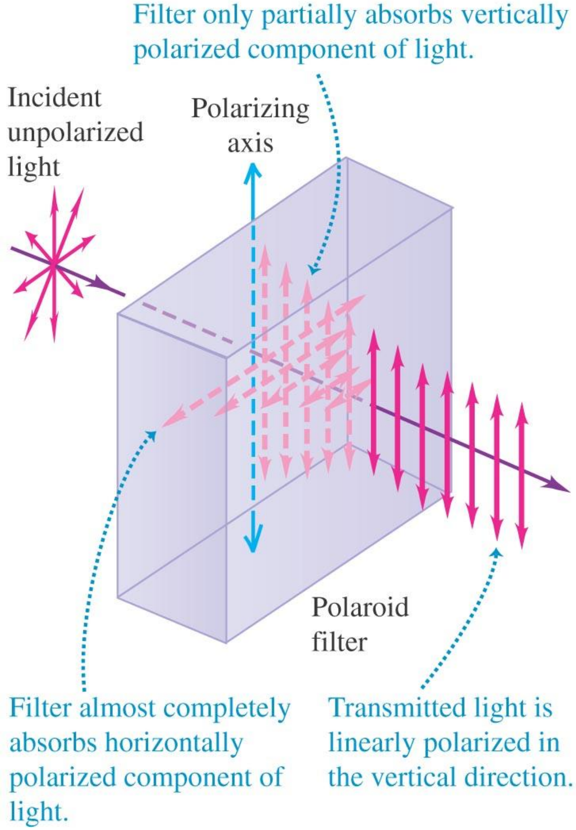
Dispersion and rainbows

- As a person looks into the sky and sees a rainbow, he or she is actually "receiving light signals" from a physical spread of water droplets over many meters (or hundreds of meters) of altitude in the atmosphere. The reds come from the higher droplets and the blues from the lower (as we have seen in the wavelength dependence of light refraction).



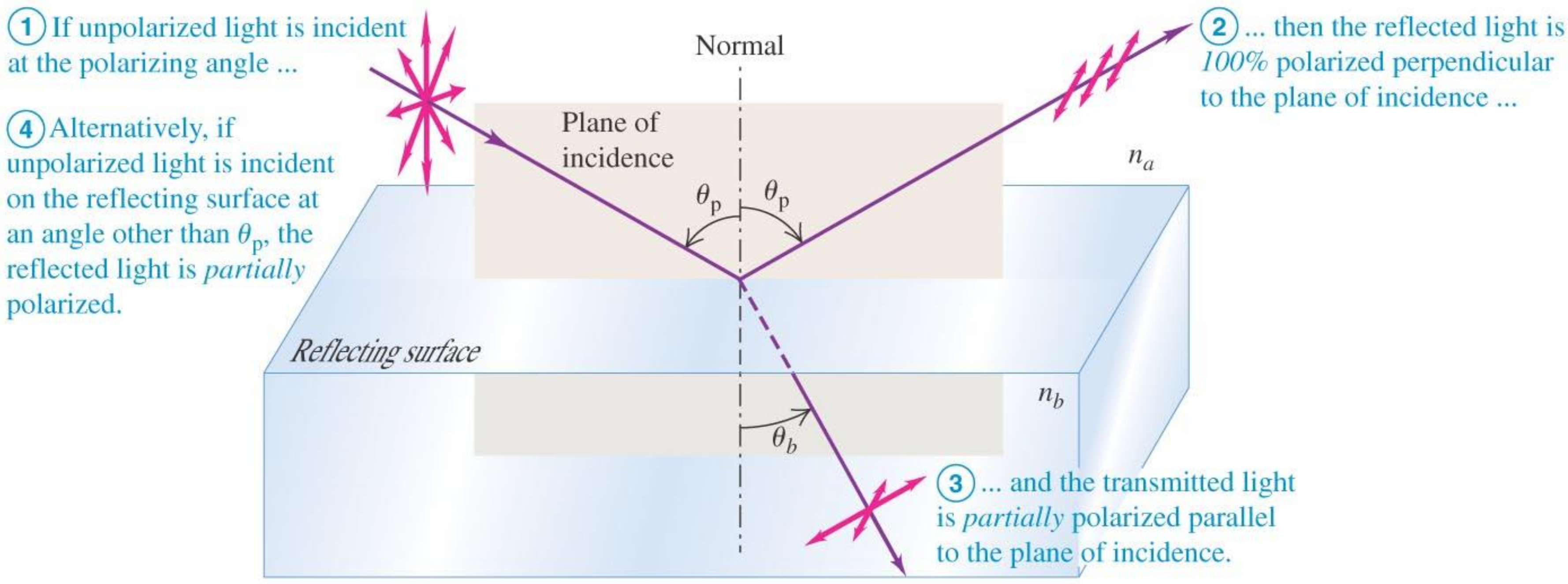
Selecting one orientation of the EM wave—the Polaroid

- A Polaroid filter is a polymer array that can be thought of like teeth in a comb. Hold the comb at arm's length with the teeth pointing down. Continue the mental cartoon and imagine waves oscillating straight up and down passing without resistance. Any "side-to-side" component and they would be blocked.



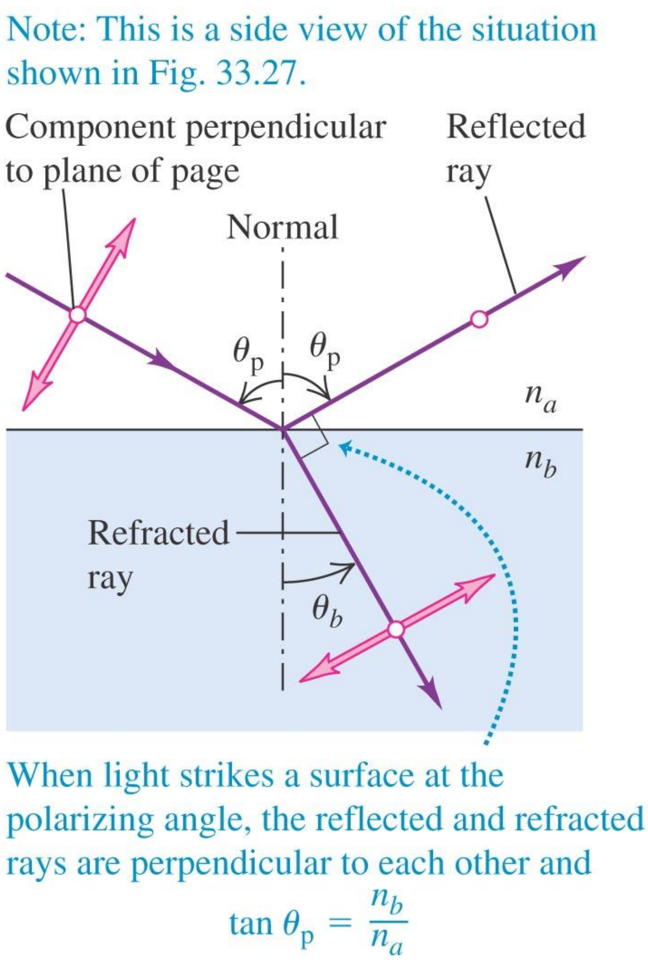
Polarization I

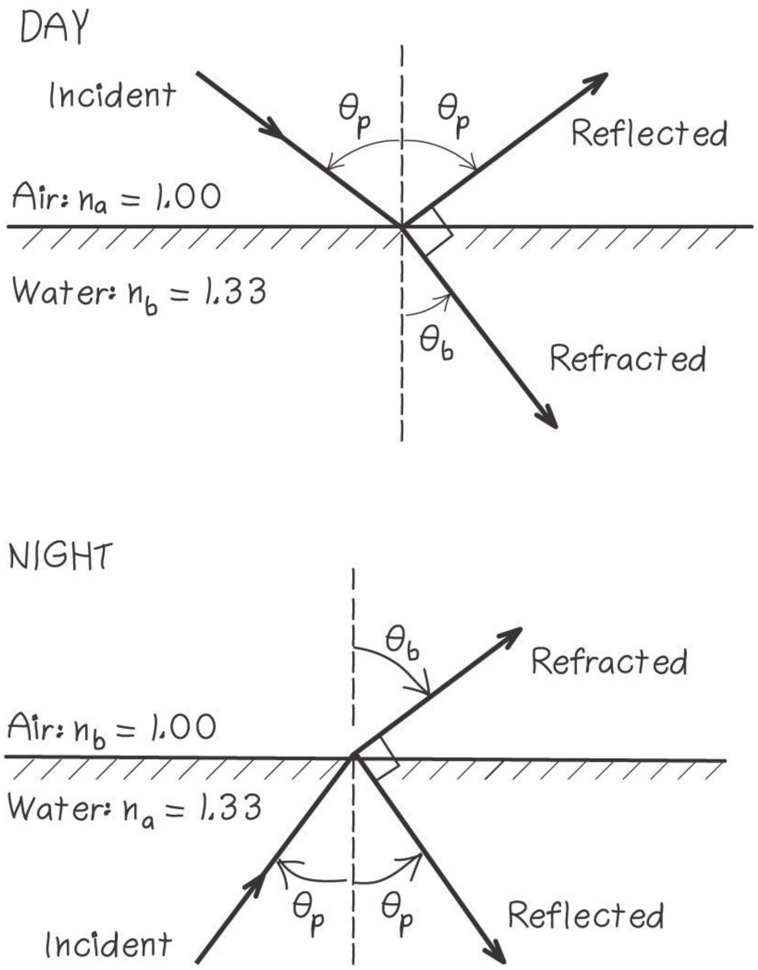
- Recall from Maxwells equations that EM waves are transverse waves.
- The E and B field are perpendicular to the propagation.
- The polarization direction refers to the **E field** direction.



Polarization II

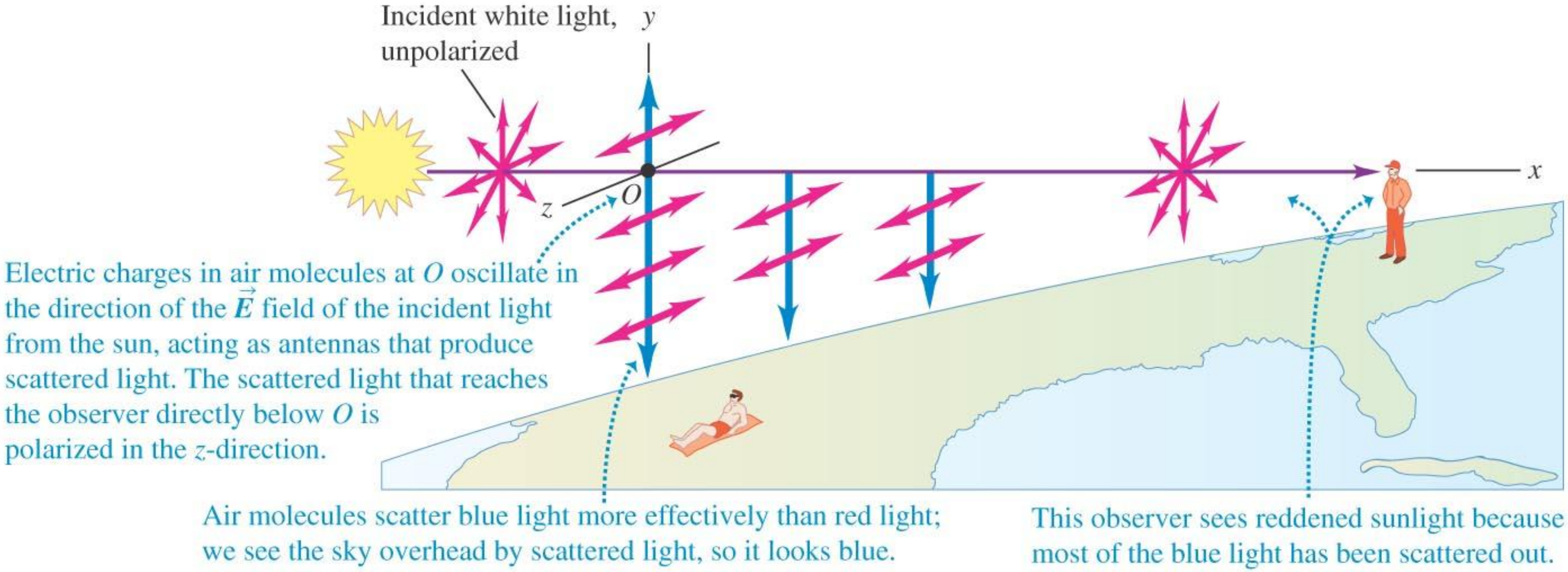
- Reflection and Refraction at a surface.





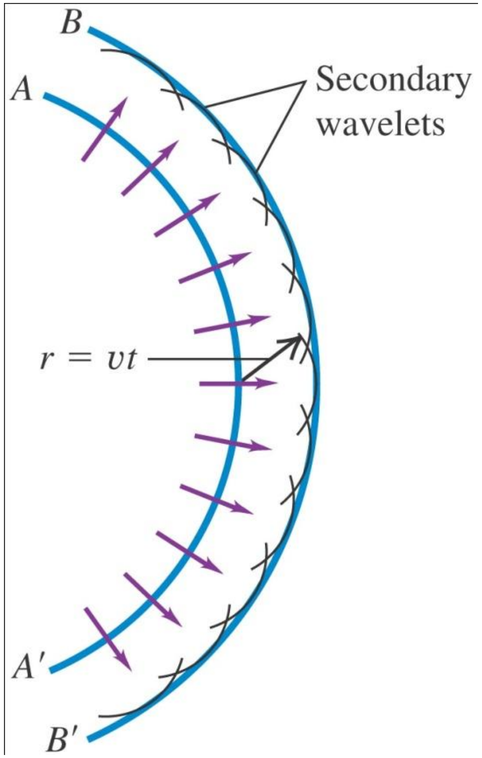
Scattering of light

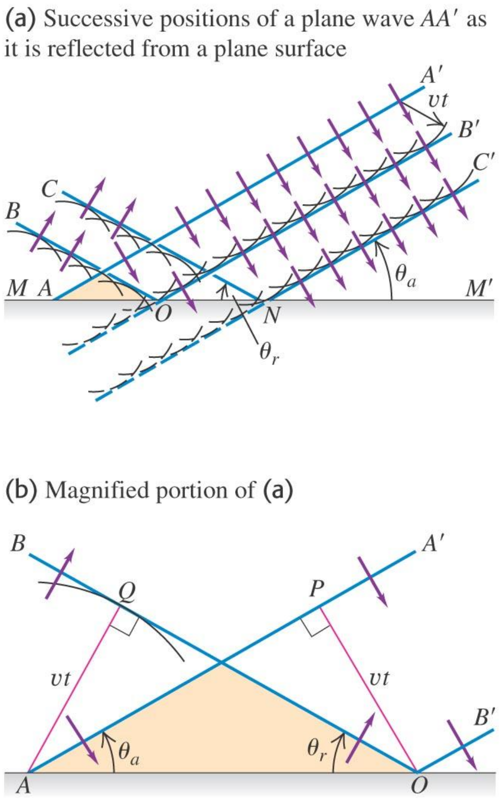
- The observed colors in the sky depend on the scattering phenomenon. Deep blue sky comes from preferential scattering of photons of shorter wavelength in the visible spectrum. Molecules are small compared to the wavelenght.
- Clouds are white because they scatter all wavelengths efficiently. Water drops in clouds are often larger than the wavelength of light



Huygens's Principle

Christian Huygens 1678, we can think of every point of a wave front to be a source of secondary wavelets that spread out as a spherical wave with a speed equal to the speed of propagation of the wave.





Huygens's Principle II

- Huygens's work can help us think about the principles of reflection and refraction

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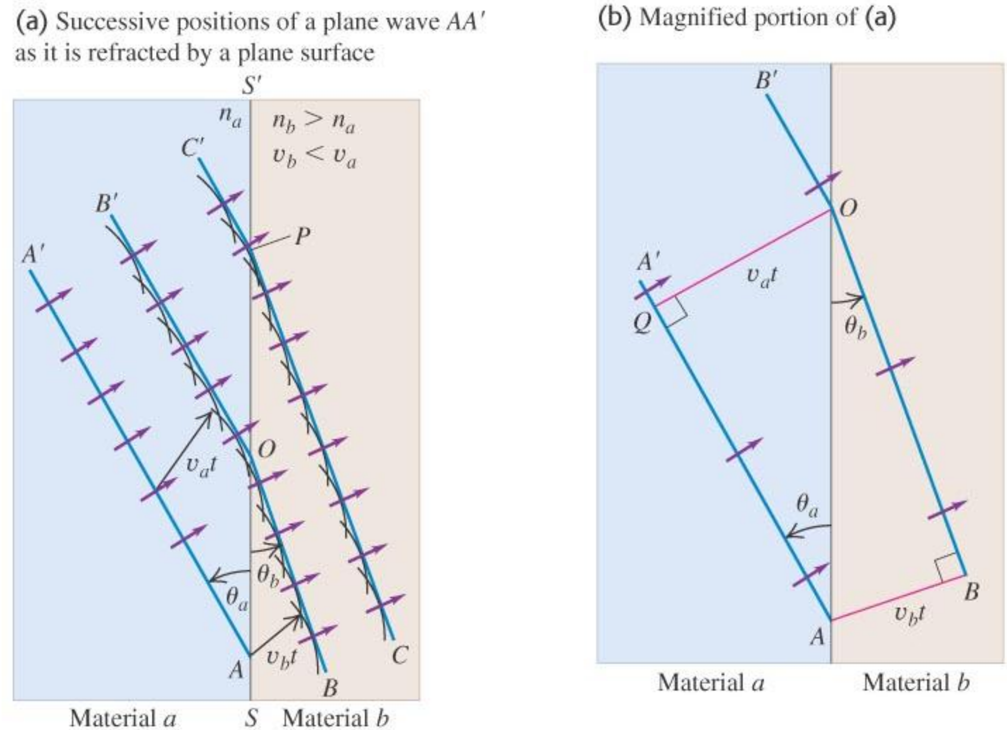

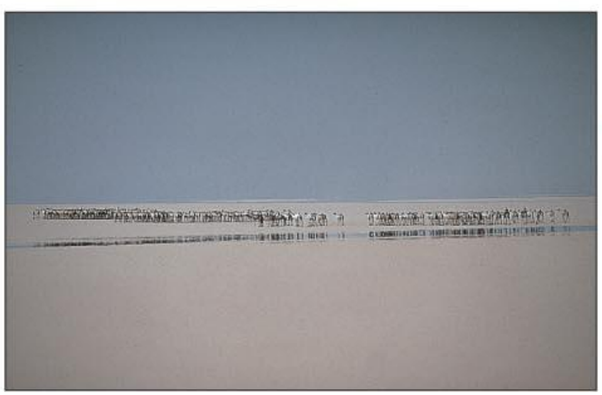

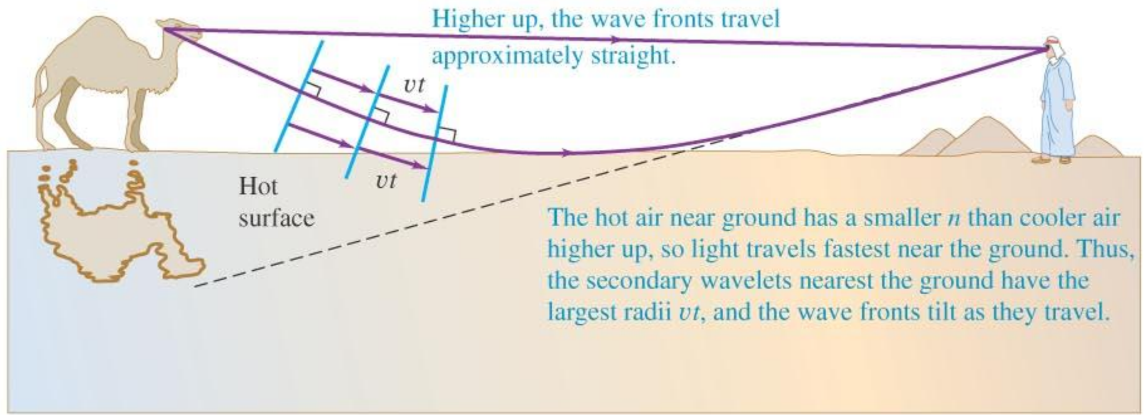

Dispersion in materials – dipole polarization and hence index of refraction depends on wavelength