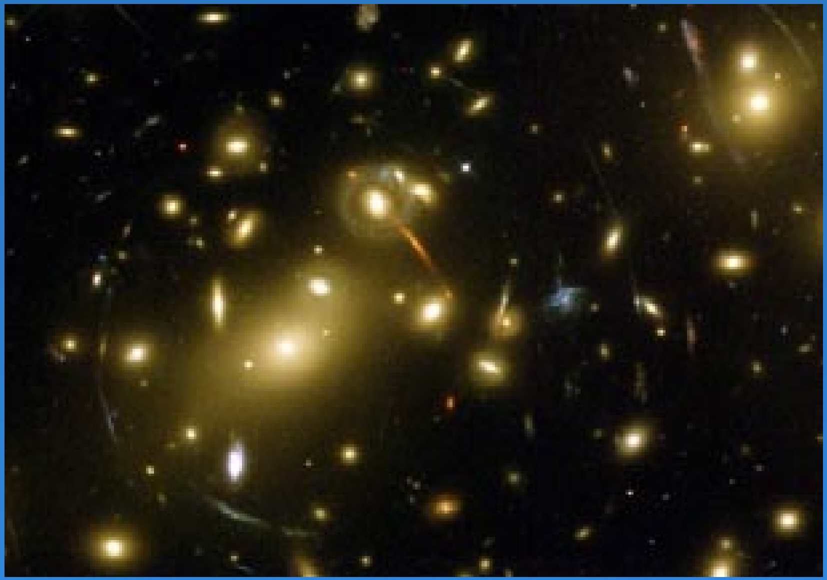


Astronomy 80 B: Light

Lecture 7: Refraction, dispersion, rainbows

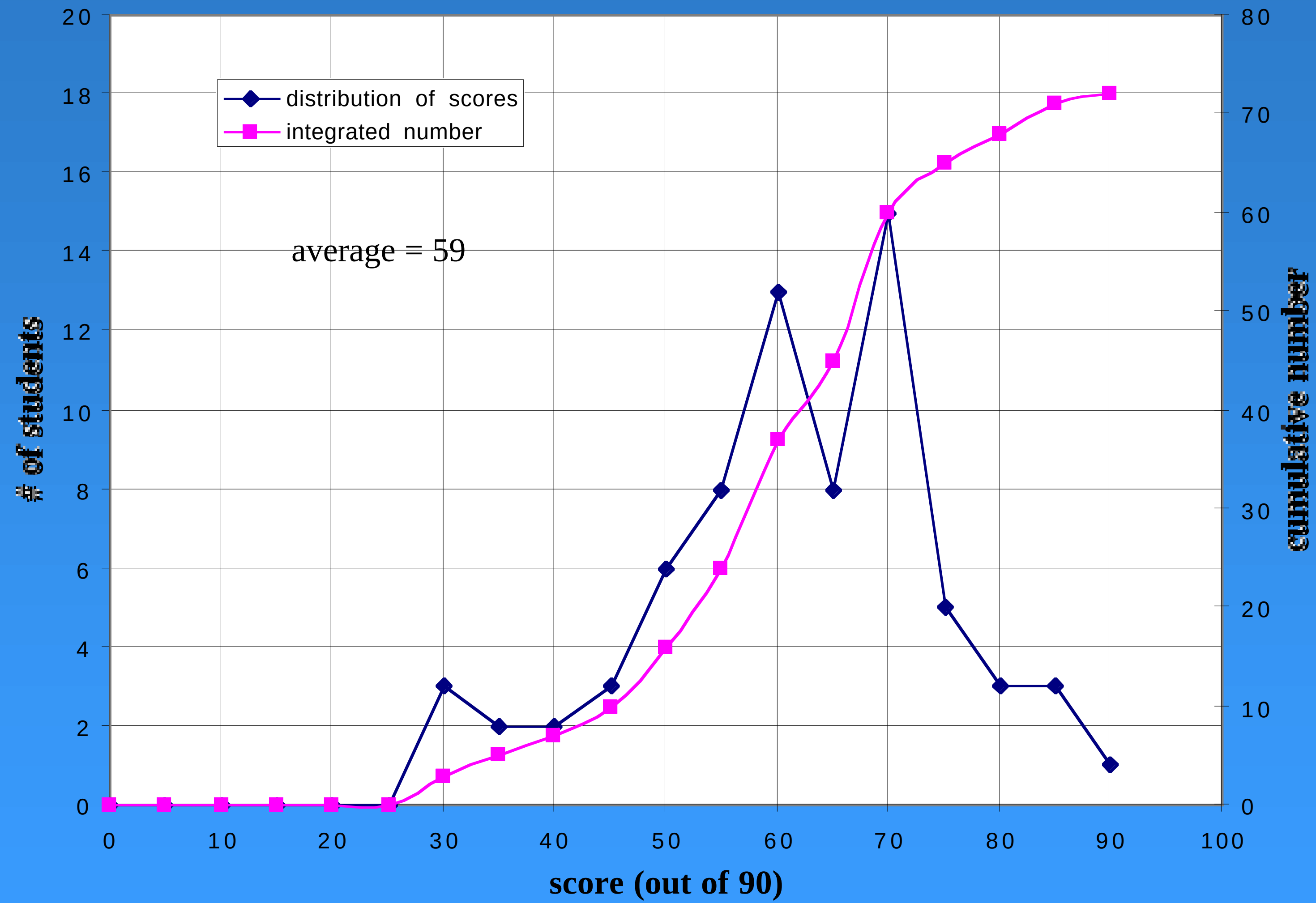
22 April 2003

Jerry Nelson

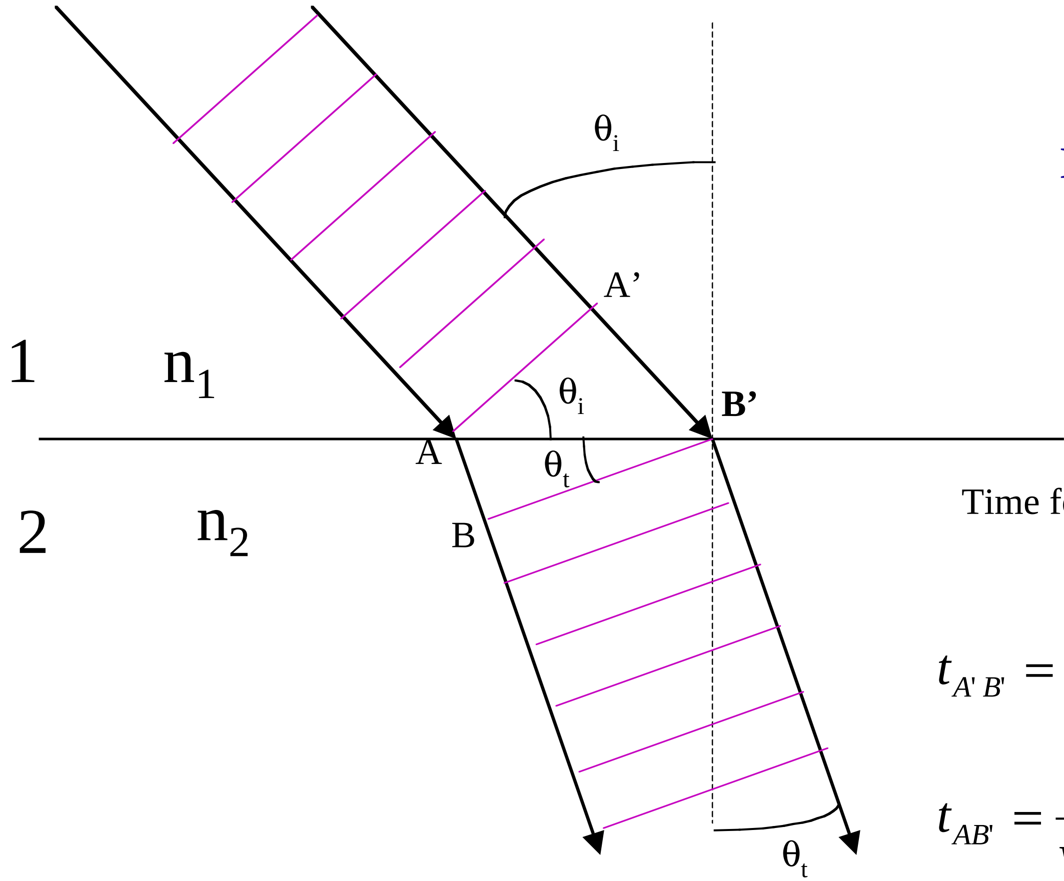
Topics for Today

- **Optical illusion**
- **Review of Quiz**
  - Statistics
  - Solutions
- **Total internal reflection**
- **Mirages**
- **Index of refraction of materials**
- **Dispersion (and a green flash)**
- **Rainbows**
- **Sundogs**
- **Halos**

AY 80B Quiz 1 results



Derivation of Snell's law from wavefront continuity



n=c/v

Time for light to go from A' to B'

$$t_{A'B'} = \frac{d}{v_1} = \frac{A'B'}{c/n_1} = \frac{n_1}{c} AB' \sin\theta_i$$

$$t_{AB'} = \frac{d}{v_2} = \frac{AB}{c/n_2} = \frac{n_2}{c} AB' \sin\theta_t$$

so $t_{A'B'} = t_{AB}$

Which yields $n_1 \sin\theta_i = n_2 \sin\theta_t$

Refraction and Total Internal Reflection

- **When light travels from a higher index of refraction material to a lower one, total internal reflection is possible**

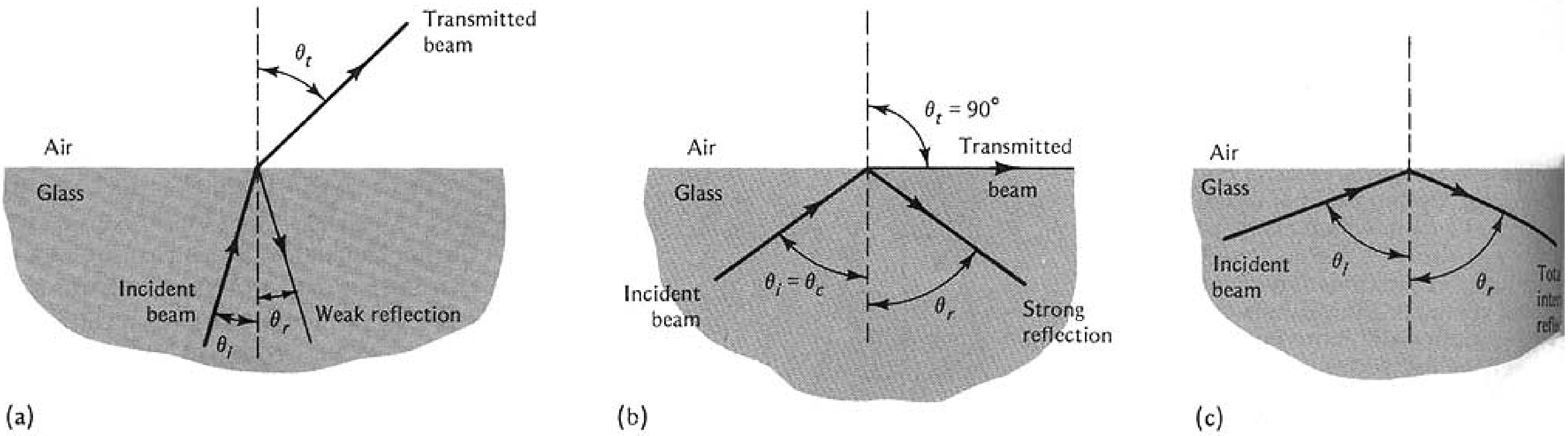
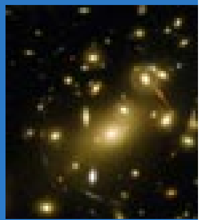
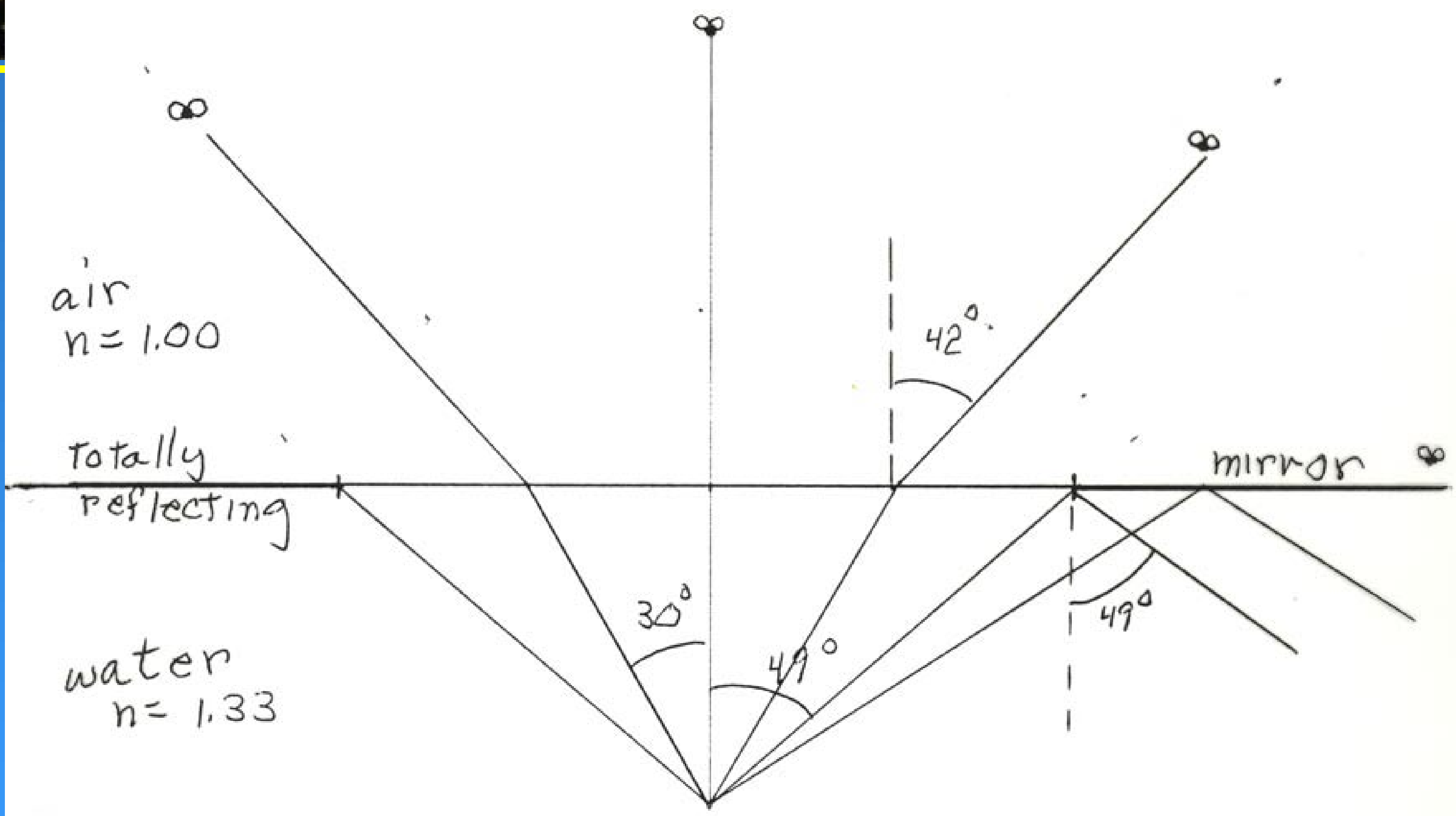


FIGURE 2.53

Reflected and transmitted beams when incident angle is **(a)** smaller than the critical angle, **(b)** equal to the critical angle, **(c)** larger than the critical angle.



Refraction + Total Internal Reflection



$$n \sin\theta_c = 1$$

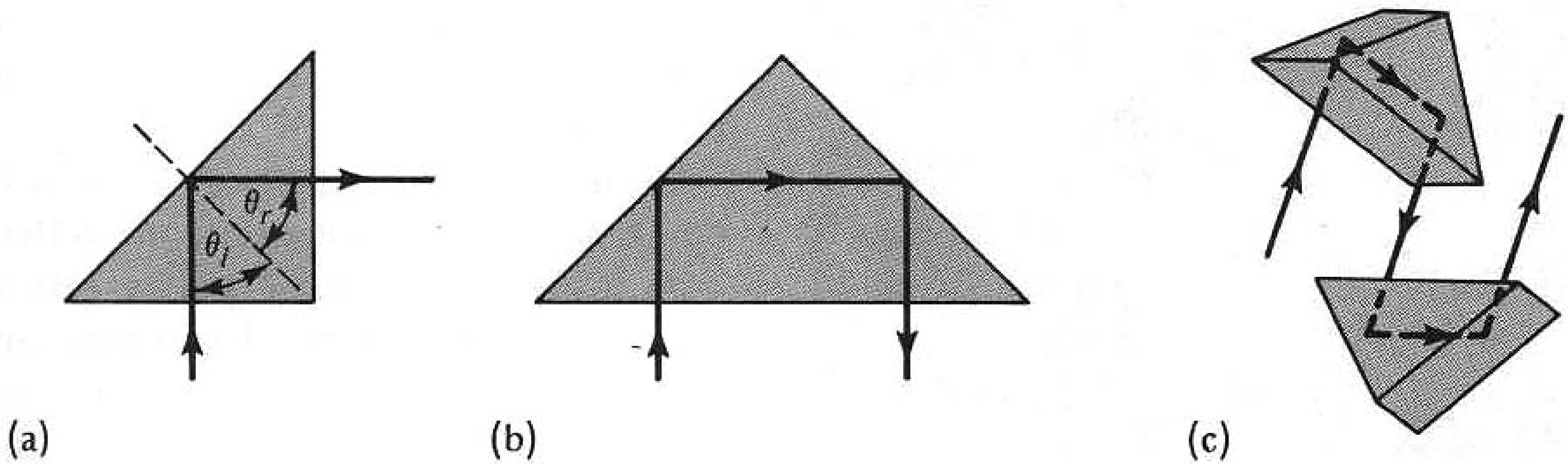
$$\theta_c = \sin^{-1}\left(\frac{1}{n}\right) = 48.8^\circ$$

Application of total internal reflection

- **Binoculars use prisms and total internal reflection to erect the image and shorten the size**

FIGURE 2.56

Use of the total internal reflection to change the direction of a light beam, **(a)** by 90° ($\theta_i = \theta_r = 45°$), **(b)** by 180° using a Porro prism. **(c)** Two Porro prisms as used in binoculars (actually, they would be touching).



Fiber Optics

- **Fiber optics employ total internal reflection to transmit light with negligible losses over large distances and (with bundles) to transmit images**

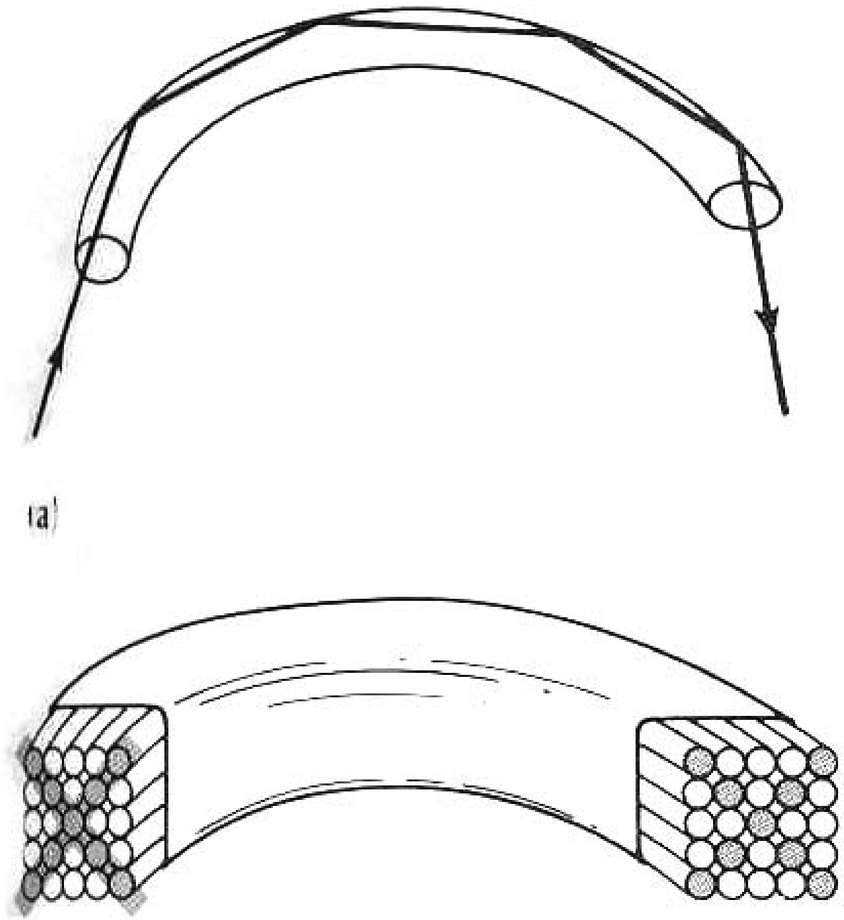


FIGURE 2.57

(a) A glass or plastic fiber can be used as a light pipe. (b) Many light pipes packed together can transmit an image.

Refraction through multiple parallel layers (atmosphere)

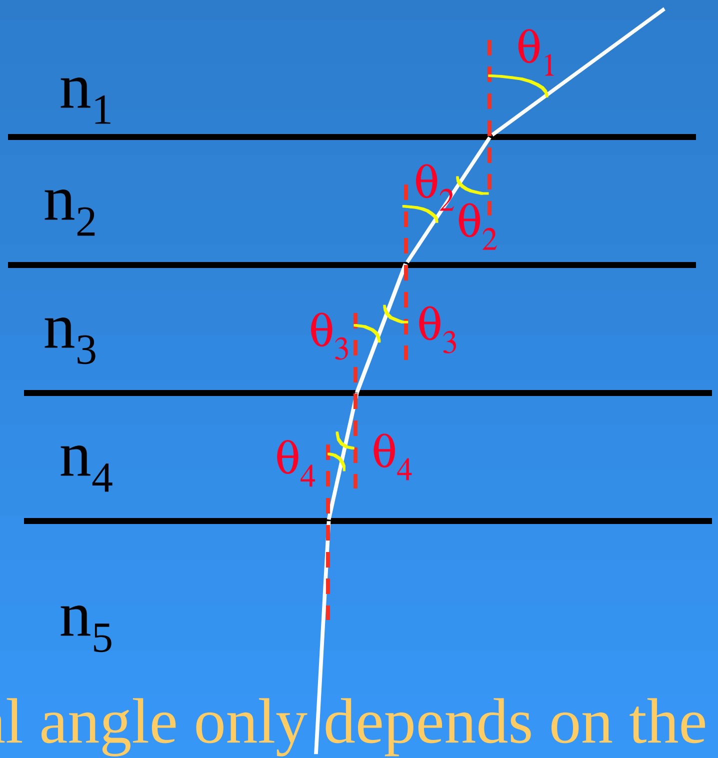
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n_2 \sin\theta_2 = n_3 \sin\theta_3$$

$$n_3 \sin\theta_3 = n_4 \sin\theta_4$$

-
-
- so

$$n_{1.} \sin\theta_1 = n_k \sin\theta_k$$



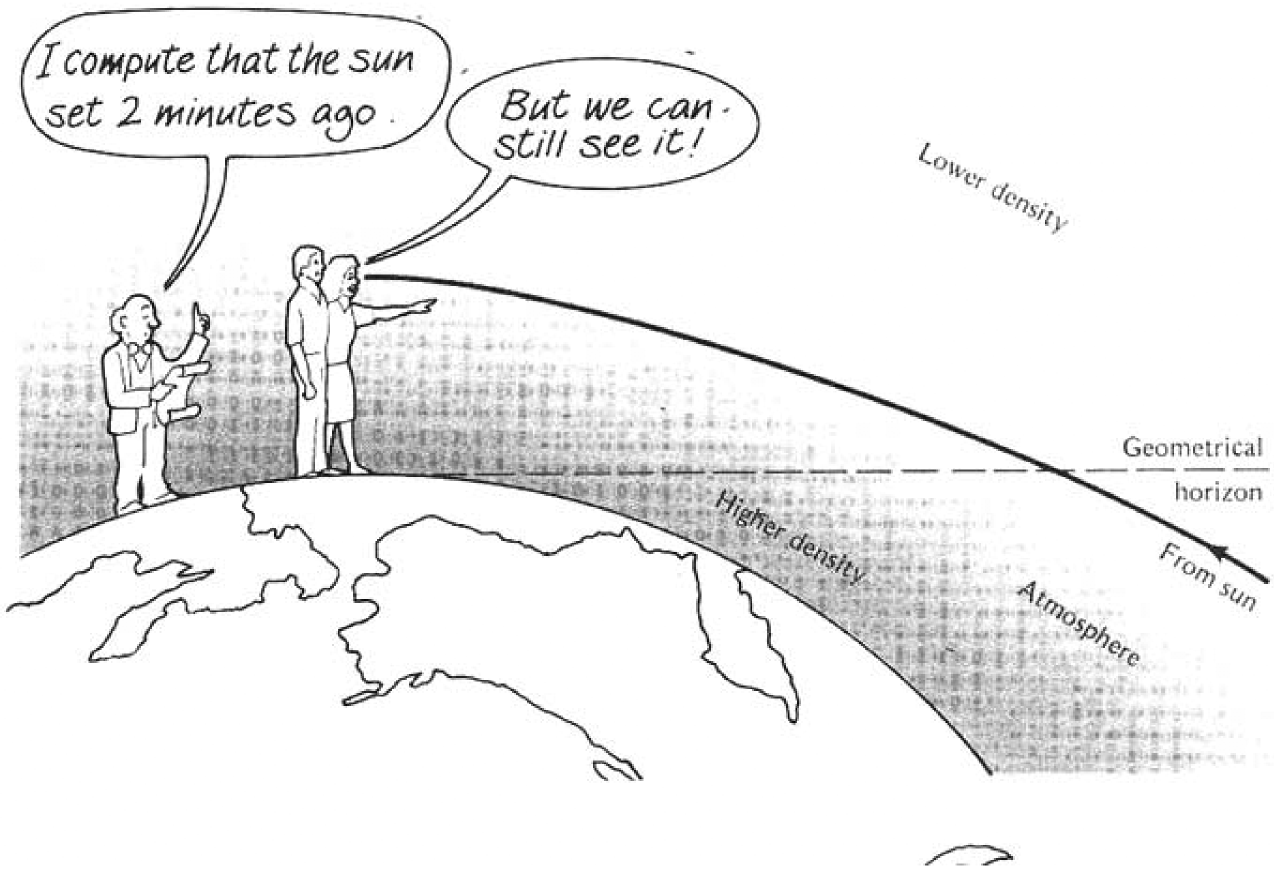
So, the final angle only depends on the initial angle and index of refraction and the final index of refraction, not on the intermediate indices

Refraction Gradients bend light

- When the index of refraction changes gradually, light bends, moving towards the higher index region

FIGURE 2.60

We can see the sun after it has set below the geometrical horizón, even if we're not in love. The atmosphere is denser toward the bottom, less dense toward the top. The gradual change in density produces a gradual change in index of refraction, which bends the light.



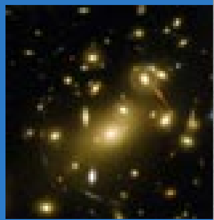
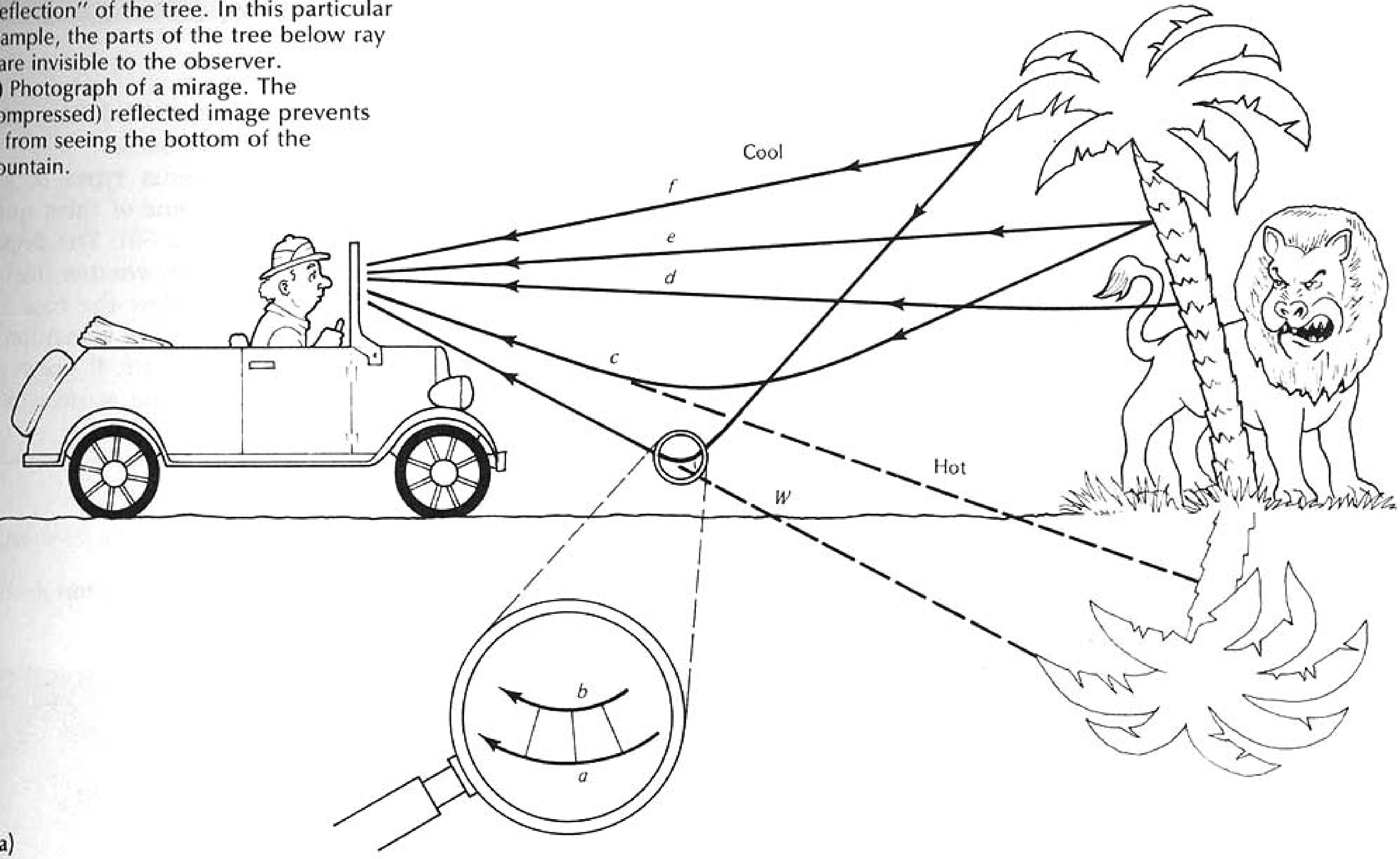


FIGURE 2.61

(a) A (rather extreme) mirage created by cool air above hot air. To analyze the mirage in detail, look through the magnifying glass; since ray *a* travels faster through the hotter air than ray *b*, *a* gets ahead of *b*, hence the beam gradually bends upward. The observer sees the tree both directly by means of rays *d*, *e*, *f*, through the cool air, and indirectly by means of the bent rays *a*, *b*, *c*. Thus, he sees a (somewhat compressed) "reflection" of the tree. In this particular example, the parts of the tree below ray *d* are invisible to the observer.
(b) Photograph of a mirage. The (compressed) reflected image prevents us from seeing the bottom of the mountain.



(a)

2003

Mirage on a hot road

FIGURE 2.62

Photograph of a mirage as frequently seen on a hot road. Note the snow in the background. You don't need a hot day for a mirage—only a temperature *difference*.

- **Index variations can cause unusual and beautiful effects**

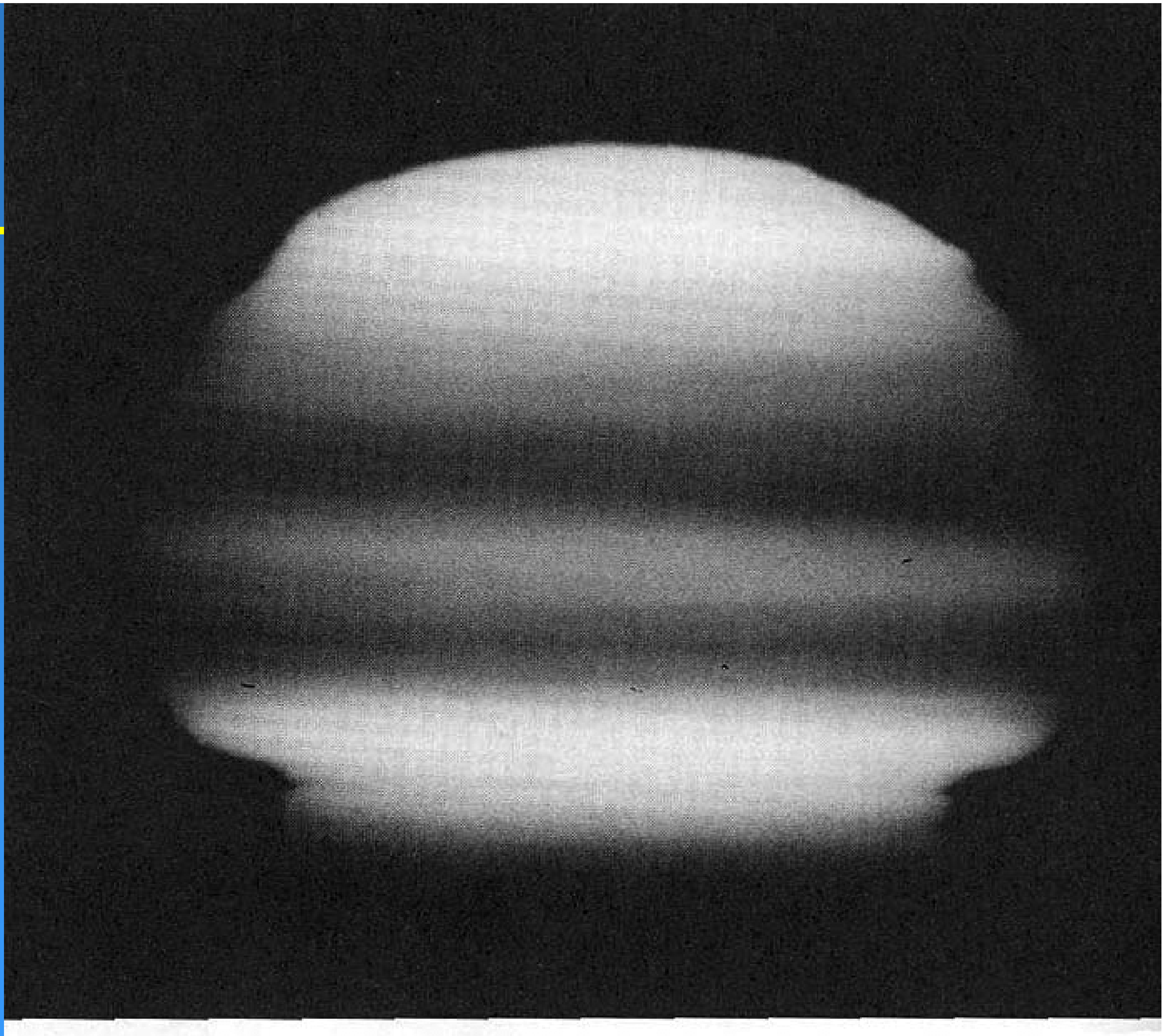


FIGURE 2.64

Photograph of setting sun shows both flattening and corrugations of solar limb due to uneven inversion layer.

Dispersion

- **Dispersion in glass, along with a prism geometry, produces colors from a white light source**

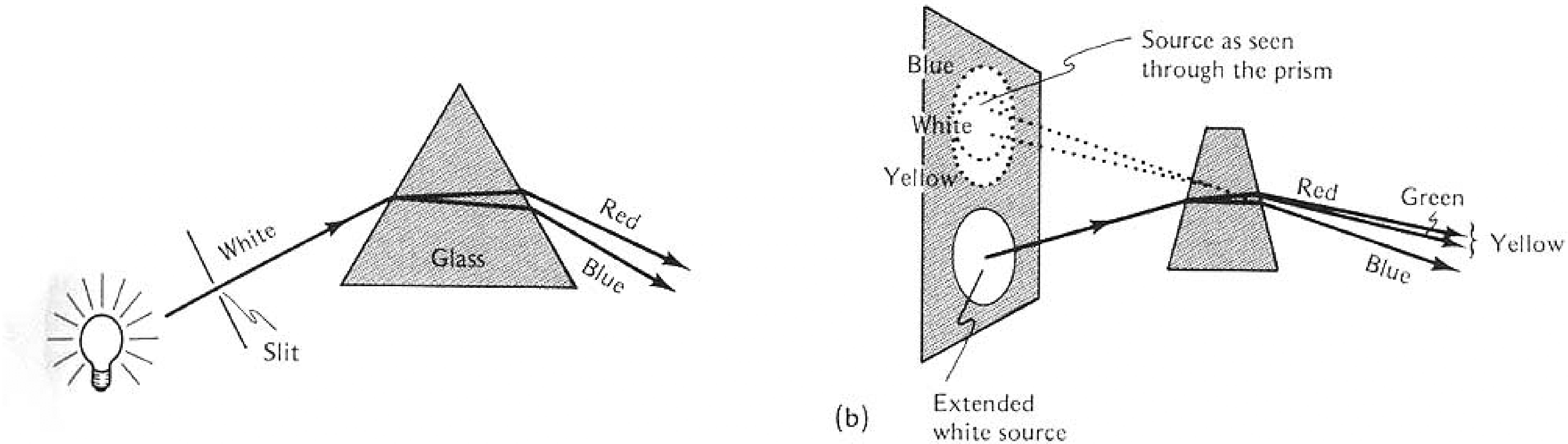
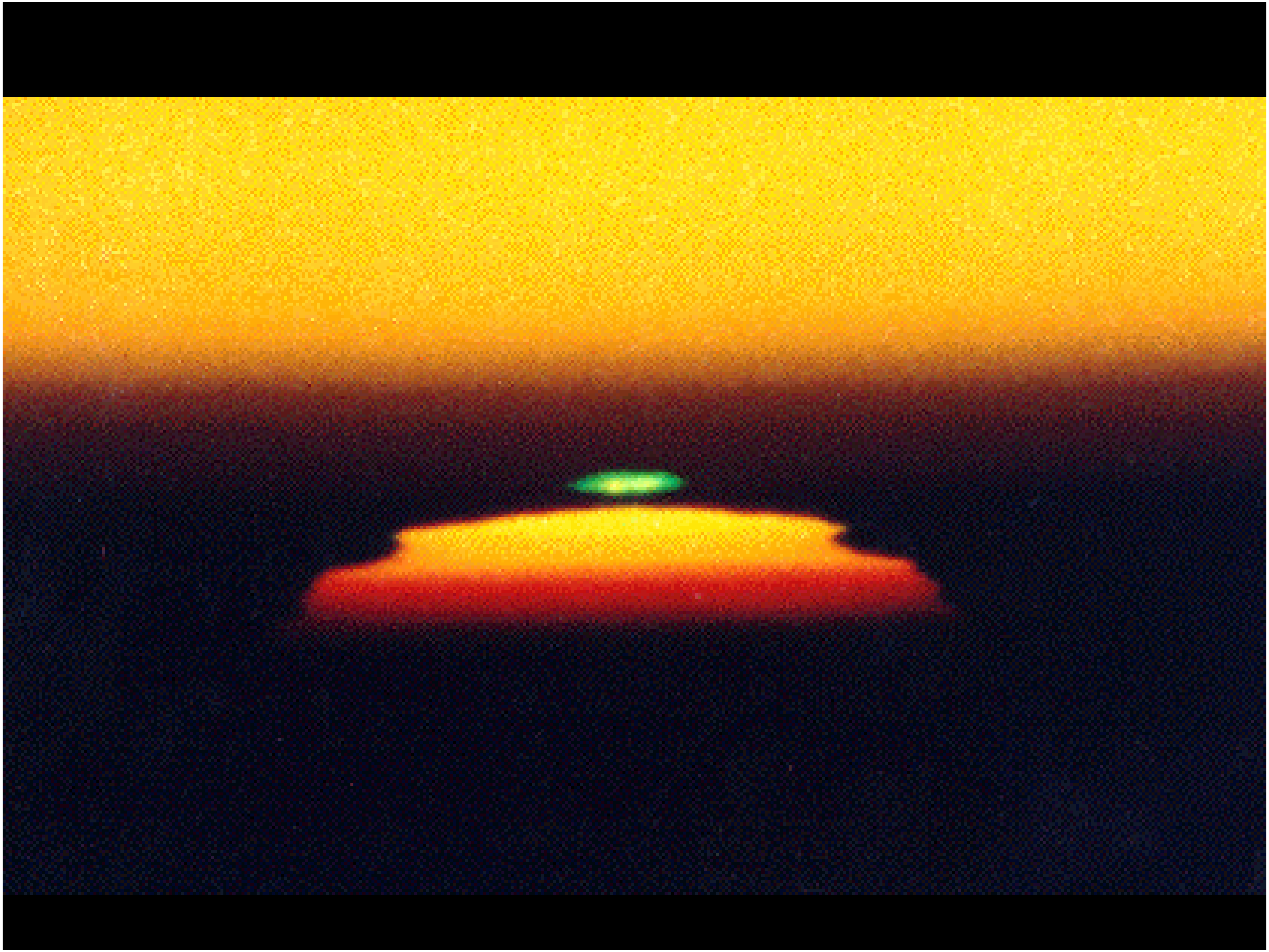


FIGURE 2.65

(a) Dispersion of colors by a prism—narrow source (also see Plate 2.1).
(b) View of *extended* white source through a prism.



Prisms and color

- A prism separates white light into its constituent colors
- These colors cannot be separated any more
- These colors can be recombined into "white" light

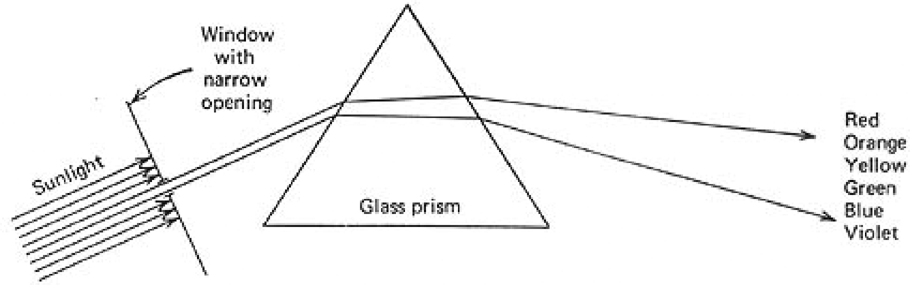


Figure 1.2 A prism separating the white light of the sun into the spectrum of colors.

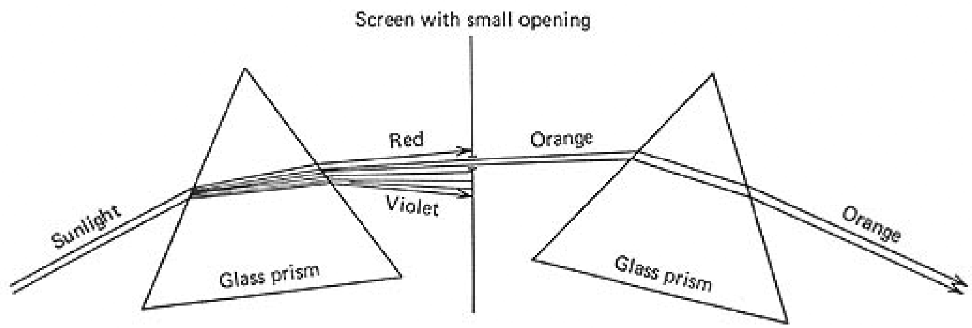


Figure 1.3 A second prism has no effect on the pure orange light.

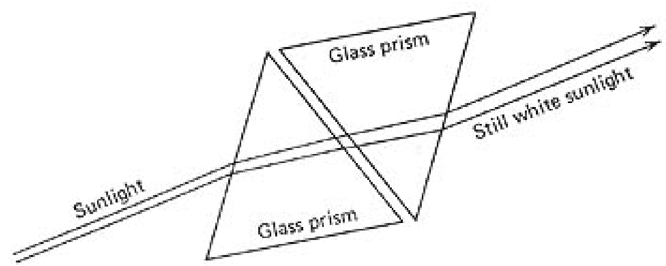


Figure 1.4 Inverted second prism puts the colors back together again, resulting in white light.

Common Indices of Refraction

Material	Index
Vacuum	1.0
Air	1.0003
Ice	1.31
Water	1.33
Alcohol (ethyl)	1.37
Plastics	~ 1.5
Glass	1.5
Cubic Zirconia	2.15
Diamond	2.4