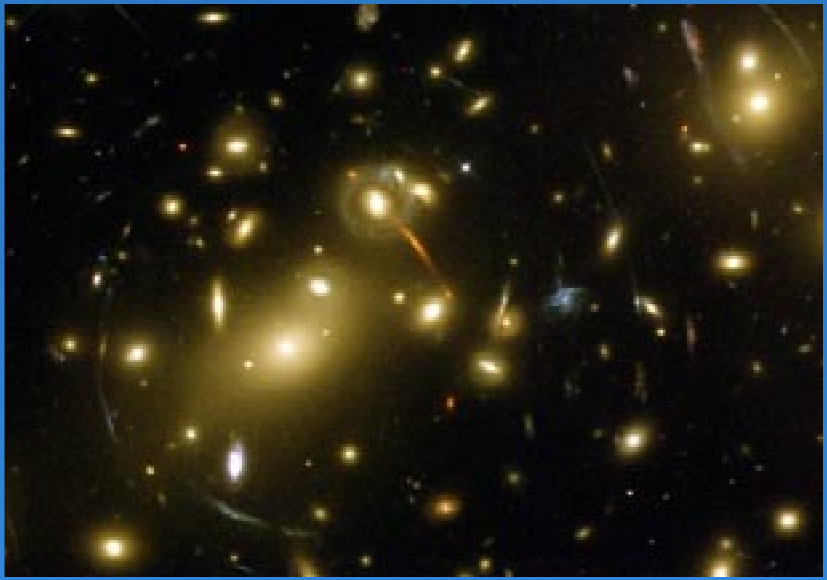
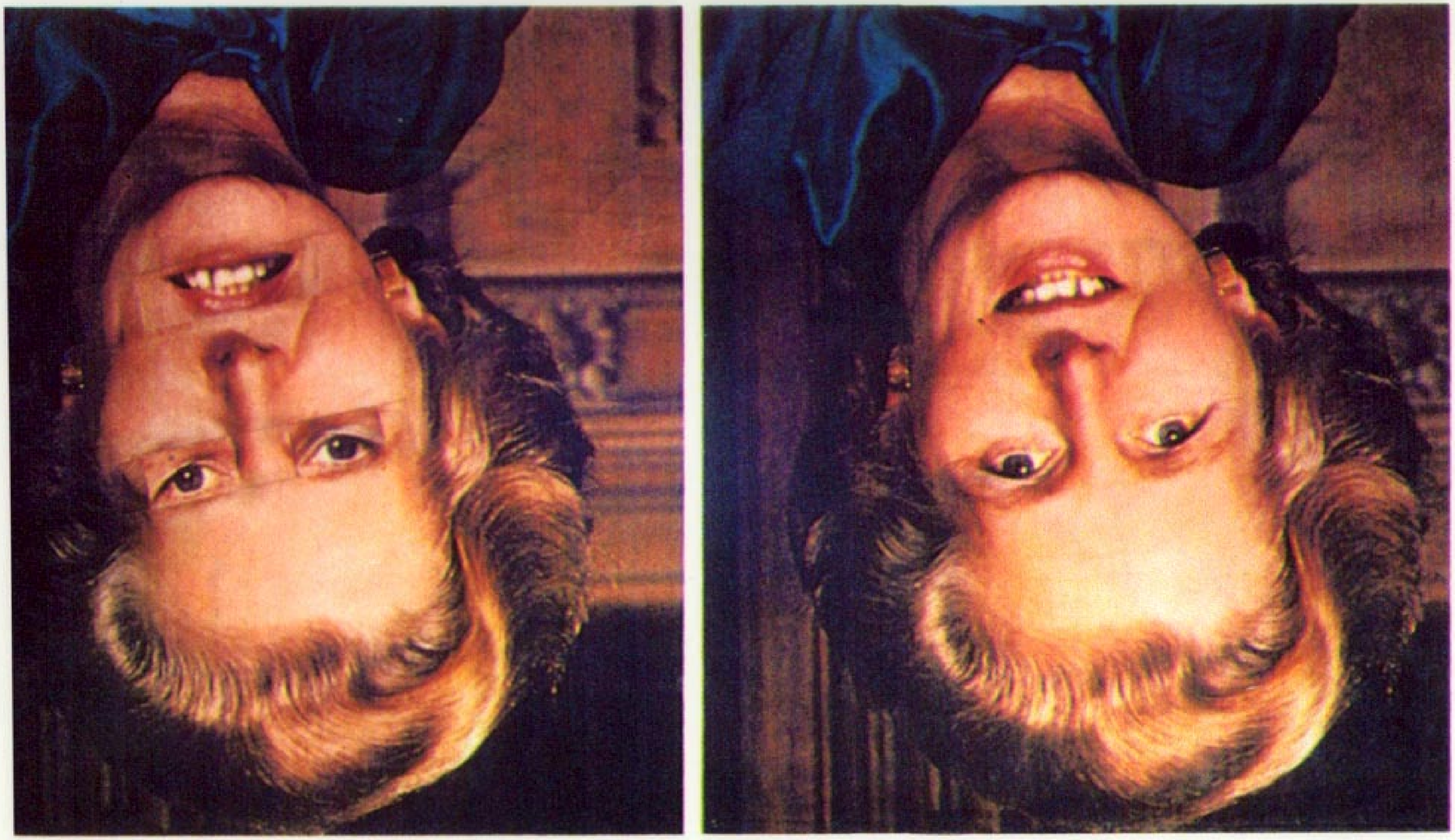


Astronomy 80 B: Light

Lecture 4: shadows, pinholes, reflection

10 April 2003

Jerry Nelson



Quiz

- **There will be a quiz on Tuesday, 15 april**
- **Topics will include**
  - Lectures
  - Ch 1
  - Ch 2 up to and including 2.5
  - Appendices A,B

Black Body Radiation

- **A "black body" is an object that completely absorbs any radiation that falls on it.**
  - Objects that appear black to us are good candidates, but our eyes only see in certain wavelength ranges, so its not foolproof. Copper is a good black body (its black in the infrared).
  - Black bodies with finite temperature radiate away their thermal energy by giving off radiation.
    - $F = \sigma T^4$ (Watts/m^2)

F = radiant flux from black body (Watts/m^2

σ (Stefan - Boltzmann constant) = 5.68×10^{-8} Watts/m^2/K^4

T = Temperature (°K)

Also, the wavelength carrying the most power * the temperature, is a constant!

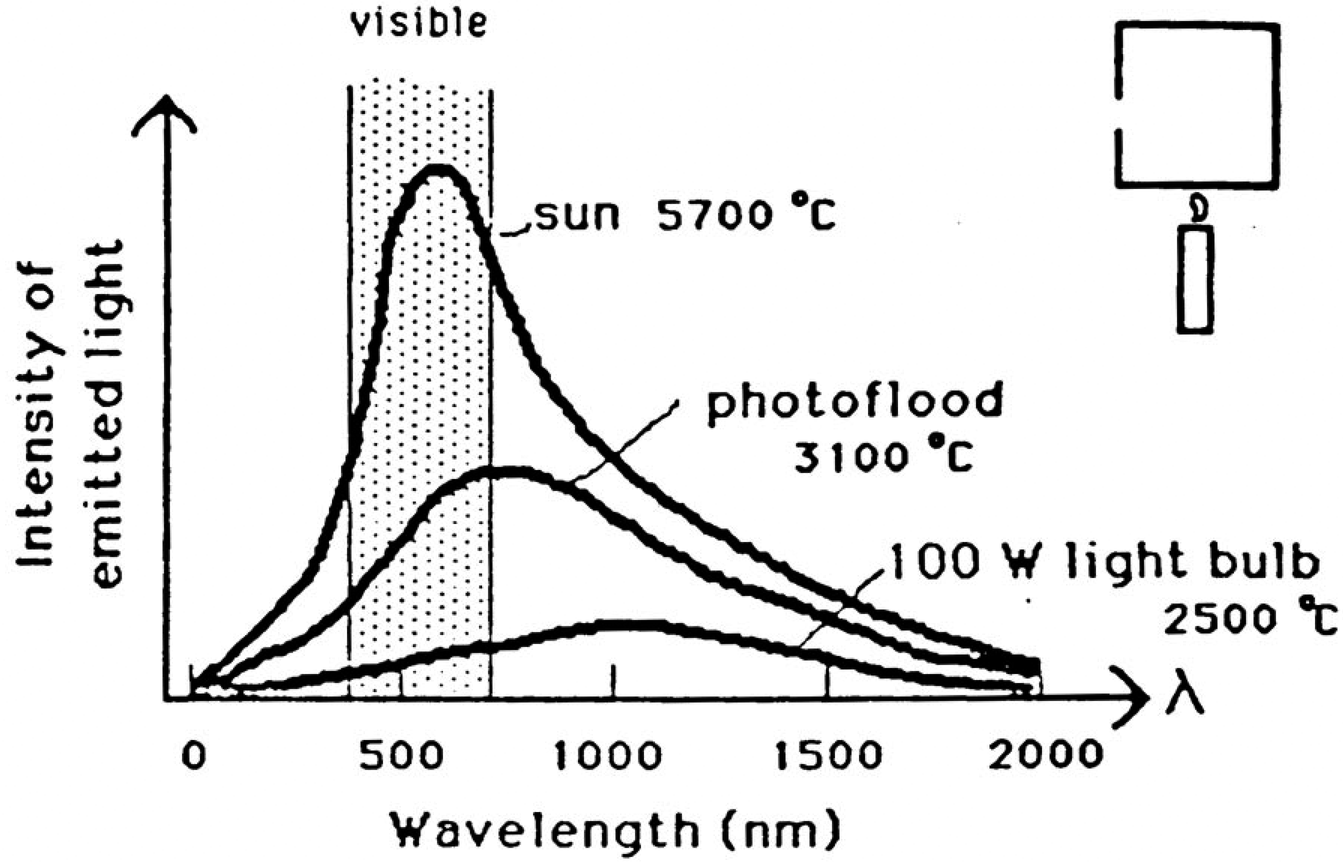
$\lambda max\ T_{BB}$ = constant = 2.9×10^{-3} m·K

Black Body Radiation-2

- **example: Our bodies ($A = 2m^2$, $T = 300°K$) radiate**
  - $P = 2*\sigma*T^4 = 920$ W.
  - They radiate most profusely at $\lambda_{max} = 9.6\ \mu m$
  - Fortunately, our bodies also absorb radiant energy from the environment, so the net heat loss is usually small.

  - Suppose our environment is 10°C colder than our bodies
    - Then power absorbed is
    - $P = 2*\sigma*T^4 = 803$ W
    - Thus the net power we would need to generate to maintain our body temperature is 117W (or about 2400 kcal/day)

Blackbody spectra



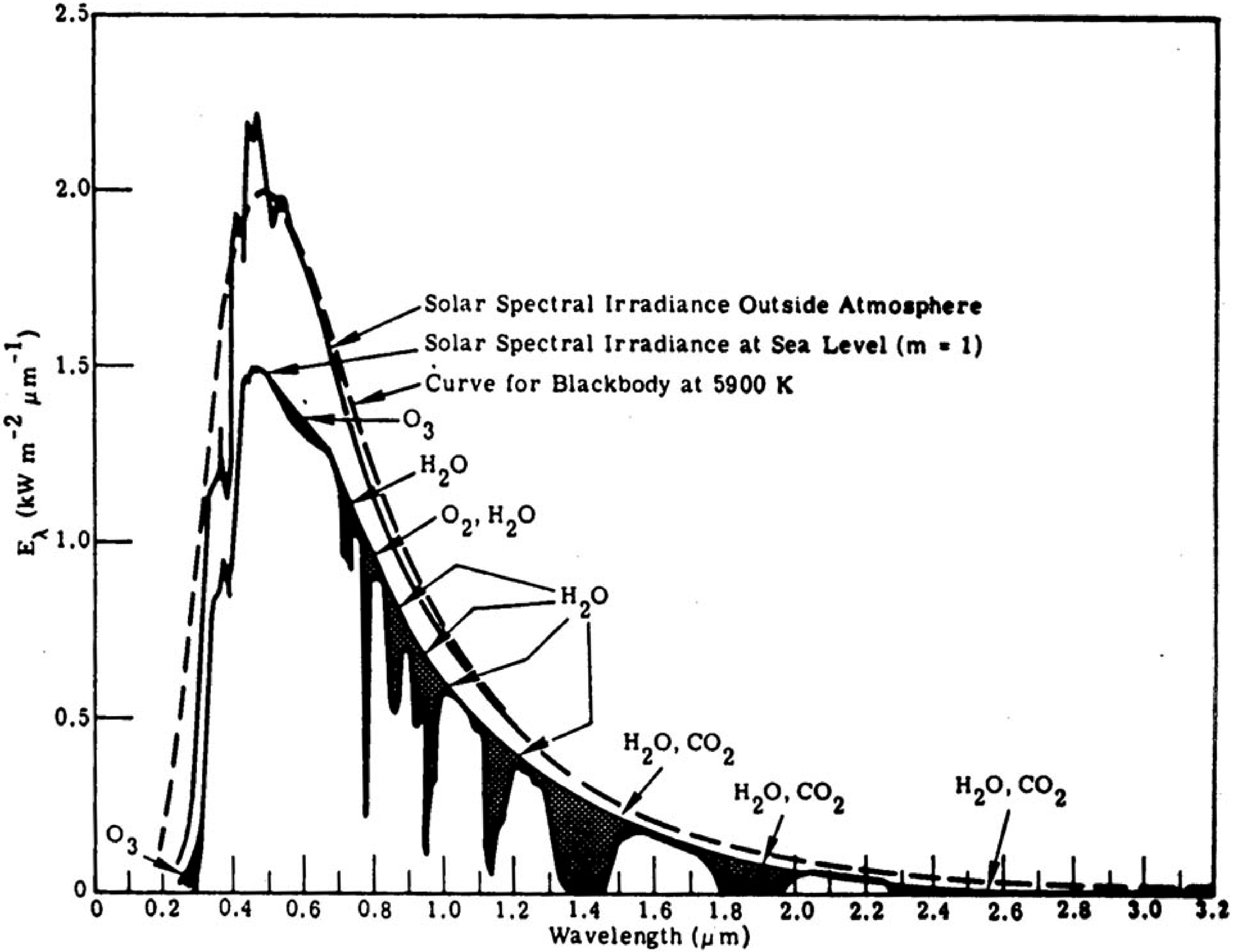


Fig. 3.3 Spectral distribution curves related to the sun. The shaded areas indicate absorption at sea level due to the atmospheric constituents shown.

Demos

- **Demo of luminescent eye and string**

Tungsten Bulb

-

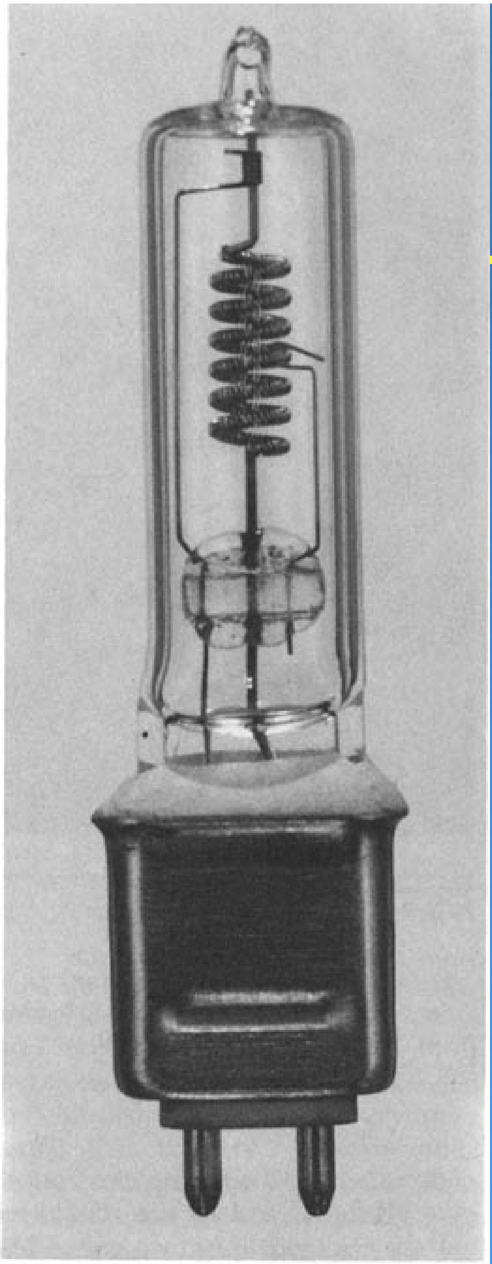
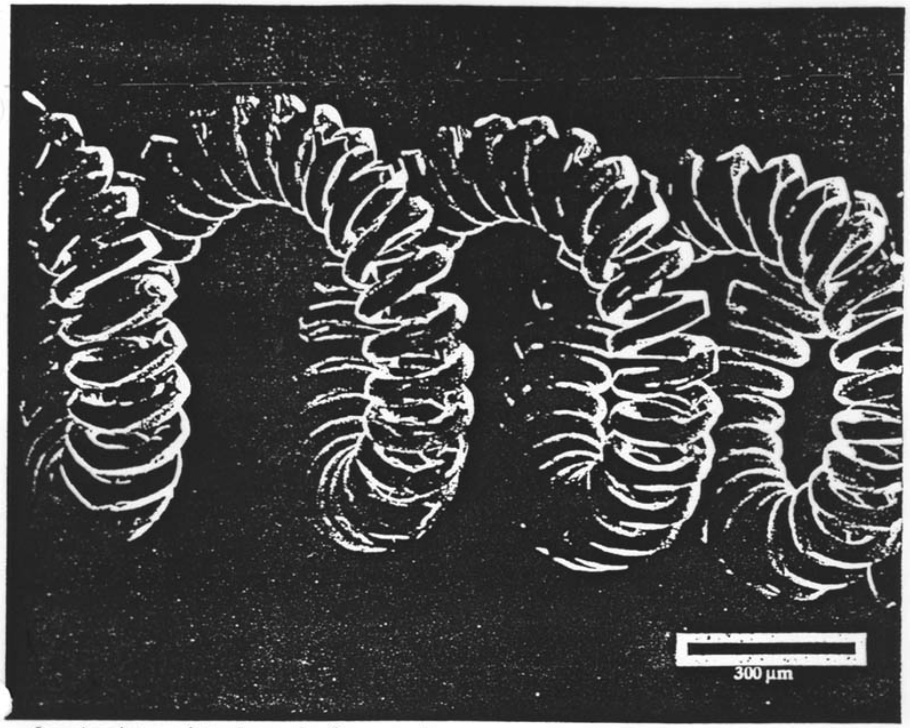


FIGURE 1.23

Tungsten-halogen lamp.

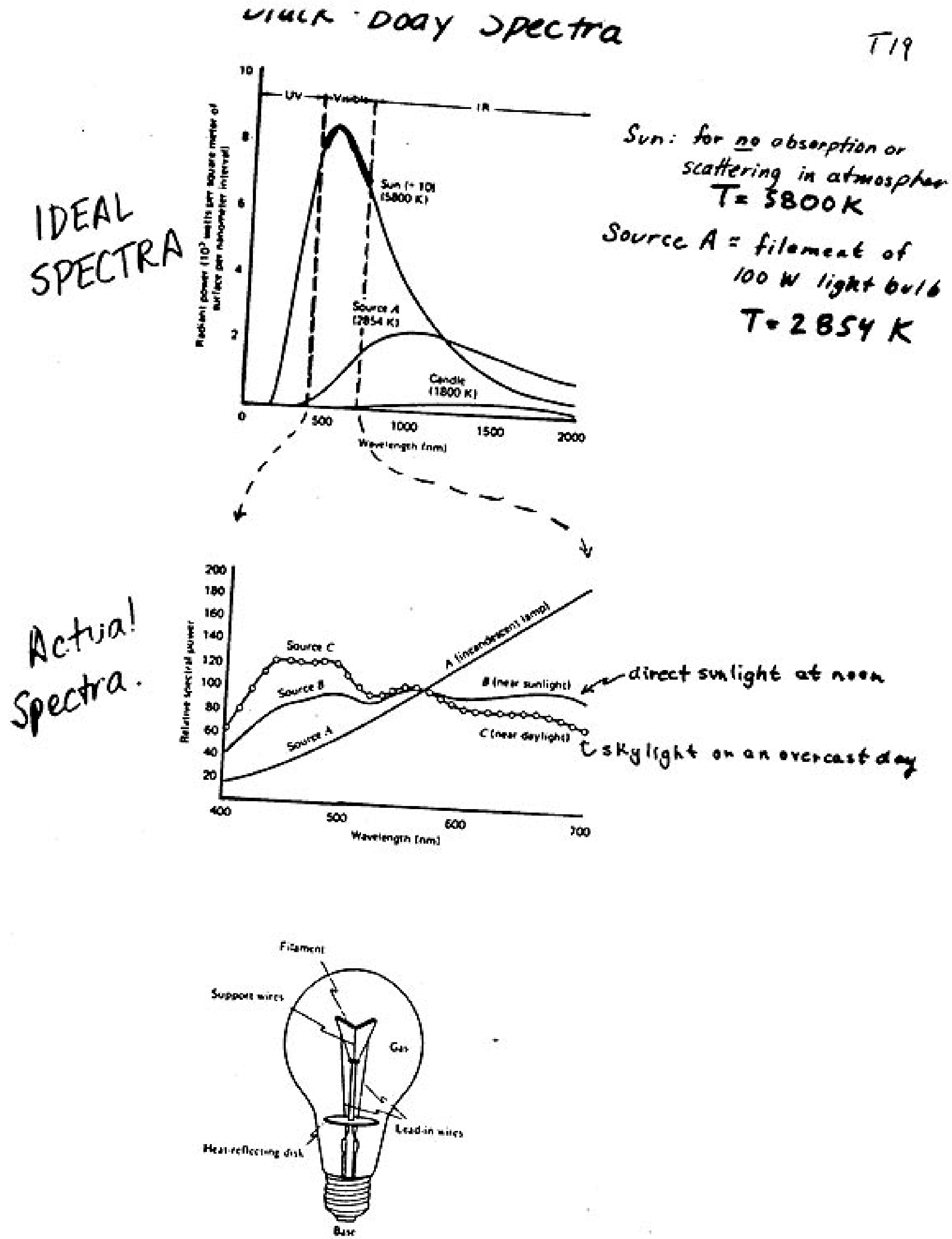
T20



AKS tungsten is used to make nonsagging light-bulb filaments.

Scanning electron photomicrographs of a nonsagging AKS tungsten filament after several hundred hours of operation at 2500°C (4530°F) in a common 60 W light bulb. Shown above is the "coiled coil" geometry of the filament, which is made possible by the availability of ductile, Coolidge-process tungsten wire. During filament operation, some of the tungsten evaporated, revealing, in the SEM close-up at right, atomic facets of the individual tungsten grains (the filament was originally round) and characteristic interlocking grain boundaries (chevron features). This grain boundary structure prohibits creep deformation (sagging) via grain boundary sliding, which results in a longer-lasting filament.

Incandescent light



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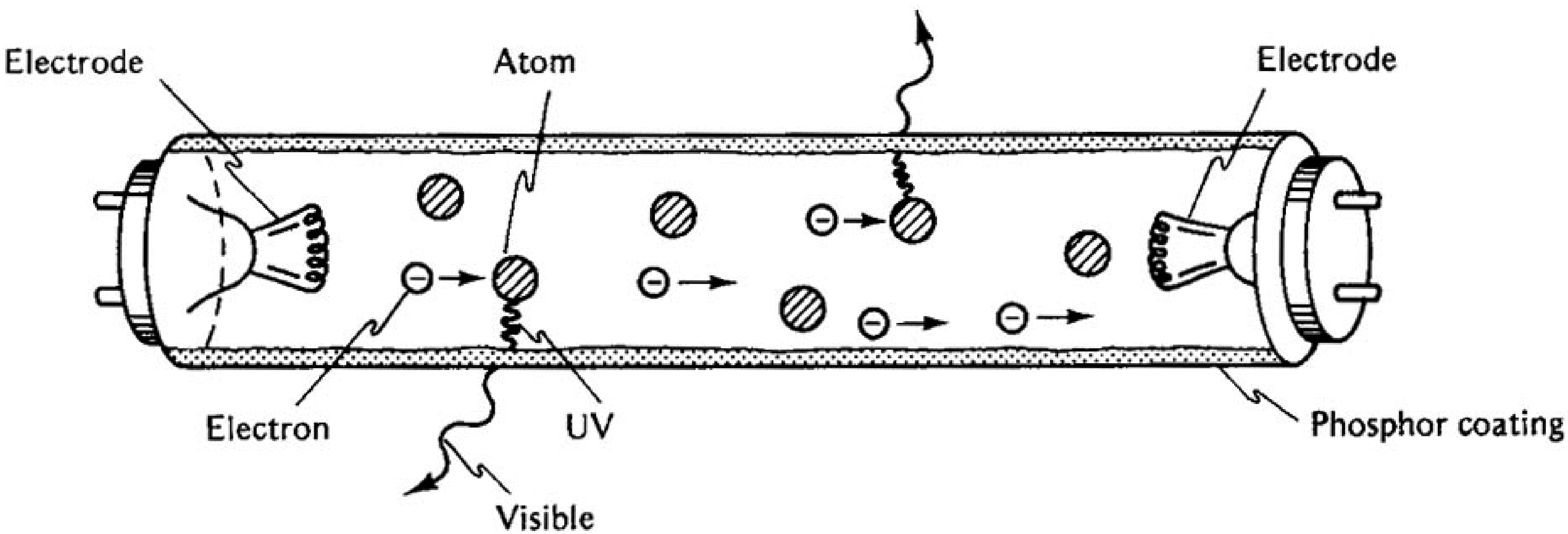
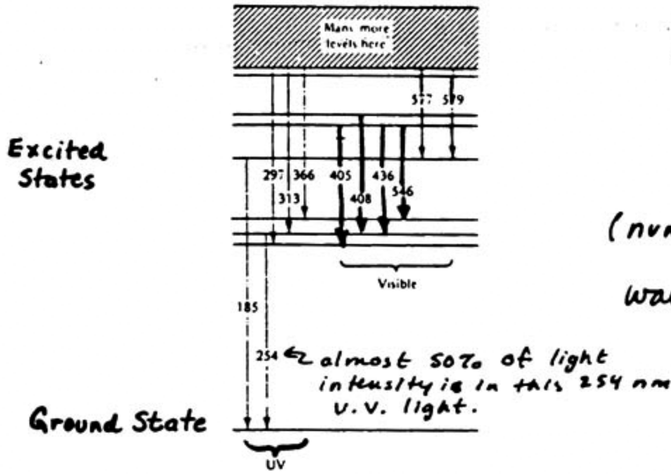
Fluorescent Light

FIGURE 1.24

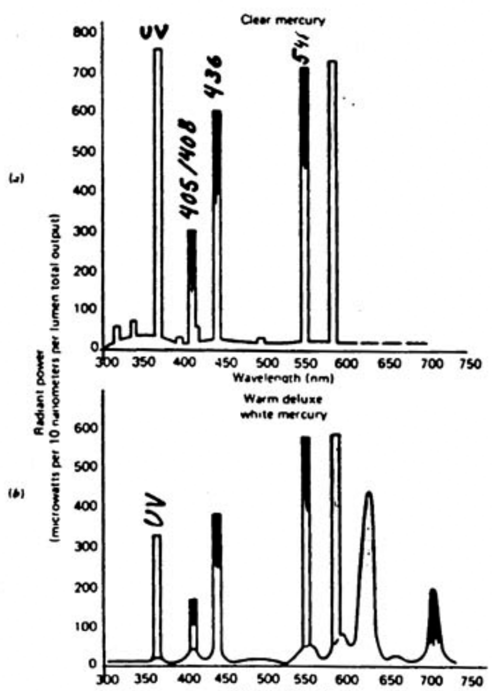
A fluorescent tube first makes UV light in an electric gas discharge and then converts most of the UV to visible light.





Energy level diagram for Mercury.

(numbers represent wavelength in nm)



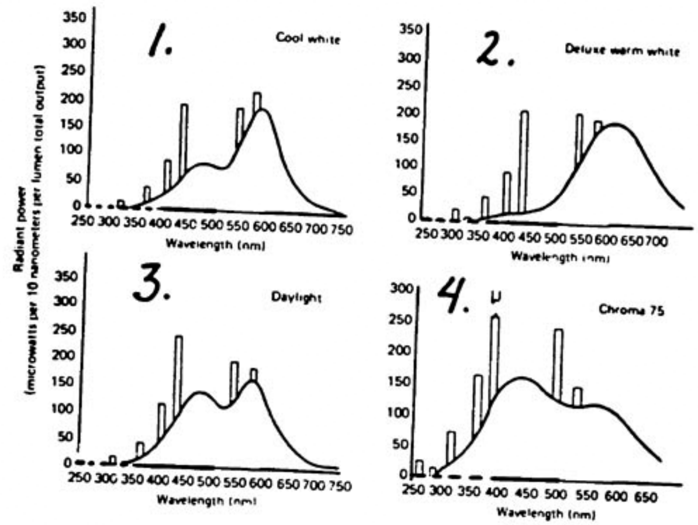
Mercury arc lamp with transparent bulb.

Bulb coated with phosphor.

Fluorescent lamp spectra

•

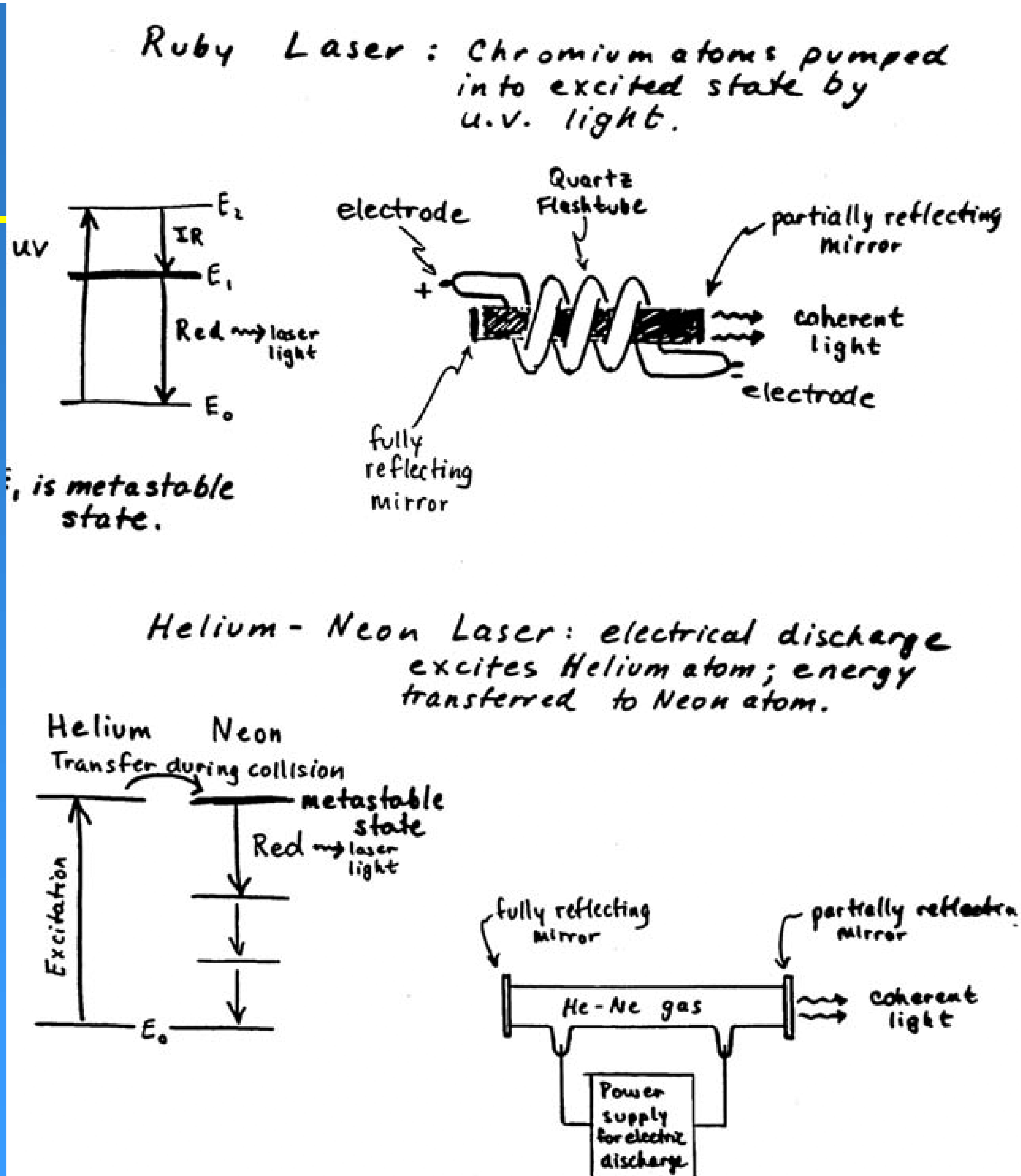
Spectra emitted by four different Fluorescent Lamps T23



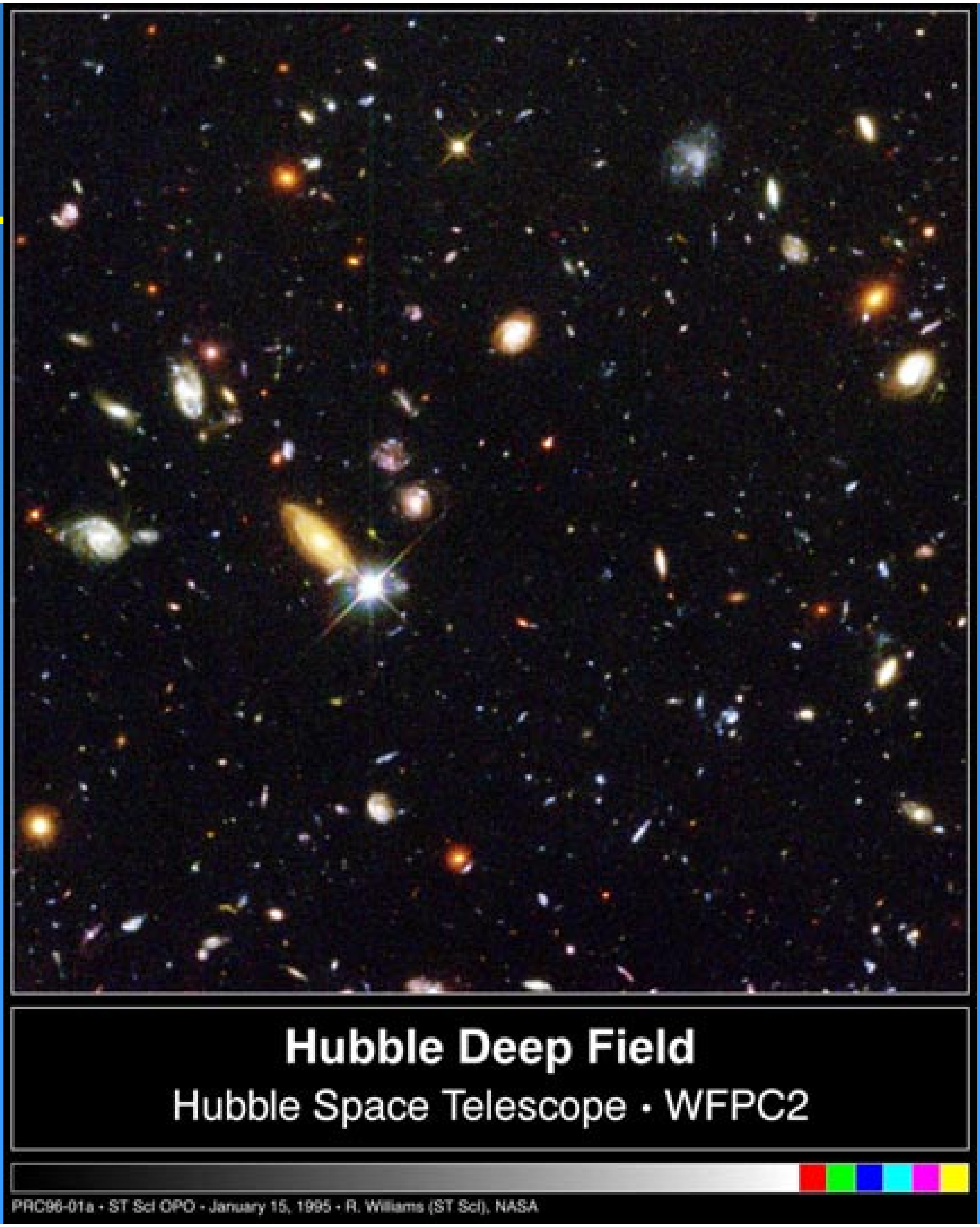
1. "Cool white": highest efficiency consistent with acceptable color rendition in many applications.
2. "Deluxe warm white": skin tones appear more natural because of extra power in red.
3. "Daylight": more even spectral power distribution.
4. "Chroma 75": approximates north sky light (peaks in the blue).

Lasers

•



Ruby Laser: Chromium atoms pumped into excited state by u.v. light.
UV
IR
E_2
E_1
E_0
Red ⇝ laser light
, is metastable state.
electrode
Quartz Flashtube
partially reflecting mirror
coherent light
electrode
fully reflecting mirror
Helium - Neon Laser: electrical discharge excites Helium atom; energy transferred to Neon atom.
Helium
Neon
Transfer during collision
metastable state
Red ⇝ laser light
Excitation
E_0
fully reflecting mirror
partially reflecting mirror
He - Ne gas
coherent light
Power supply for electric discharge



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Geometric Optics

- **Geometric optics approximates the properties of light**
  - Wave properties generally neglected
  - Light moves in straight lines (in a vacuum)
  - Light in general follows the shortest time between source and detection (principle of least time)

Light goes in straight lines

- Opaque objects make shadows
- With multiple light sources can get multiple shadows
- The shadow common to all light sources is called the **umbra**
- Partial shadows are called the **penumbra**

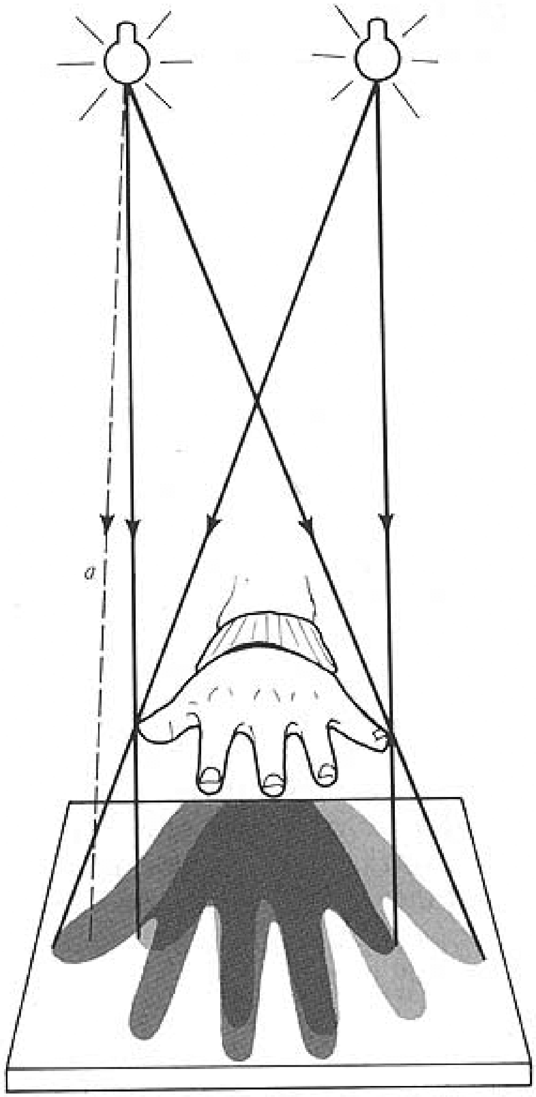


FIGURE 2.2

Two light sources throw two shadows. Their overlap, reached by no ray from either source, is the umbra. The penumbra is illuminated by rays, such as ray a, from only one of the sources.

Eclipses

- **Extended light sources such as the sun can create**
  - Shadows
  - Umbras
  - Penumbras

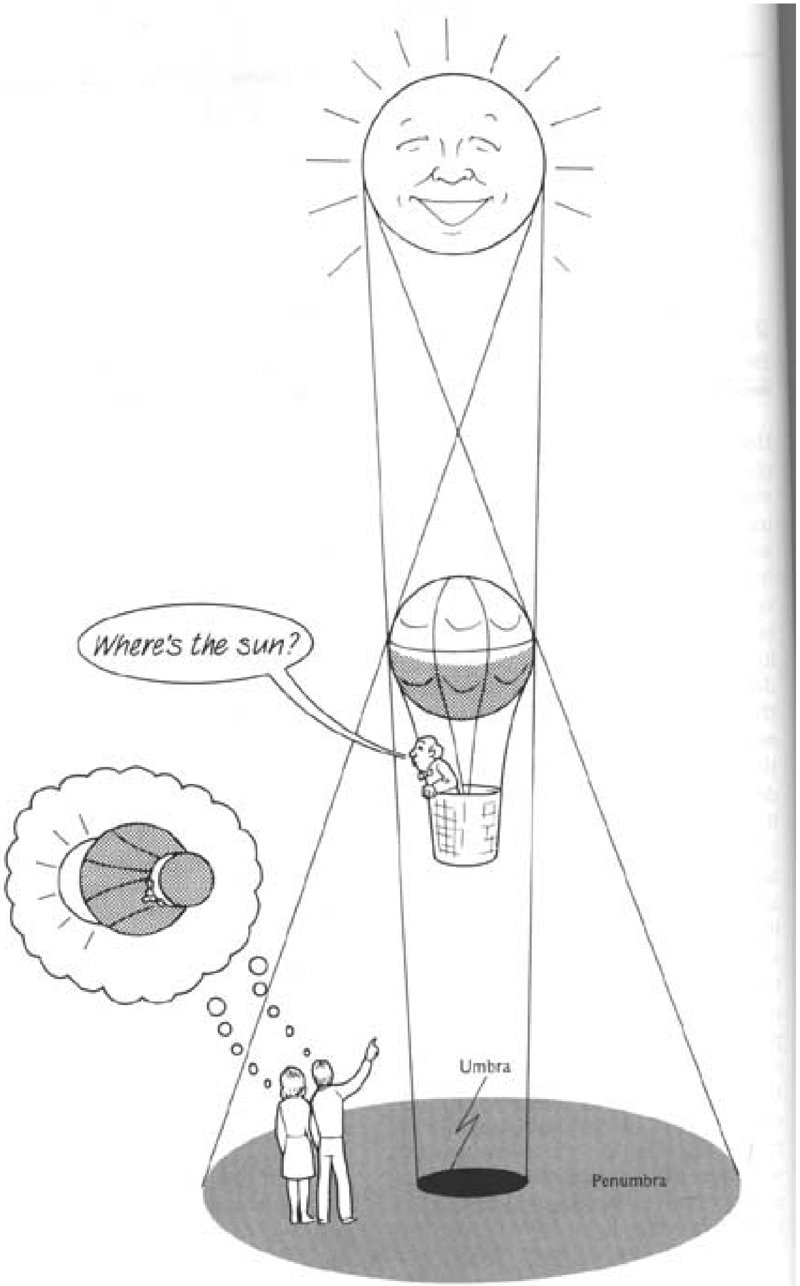


FIGURE 2.3

Looking back at the source from places in the penumbra and umbra.

Solar eclipse principles

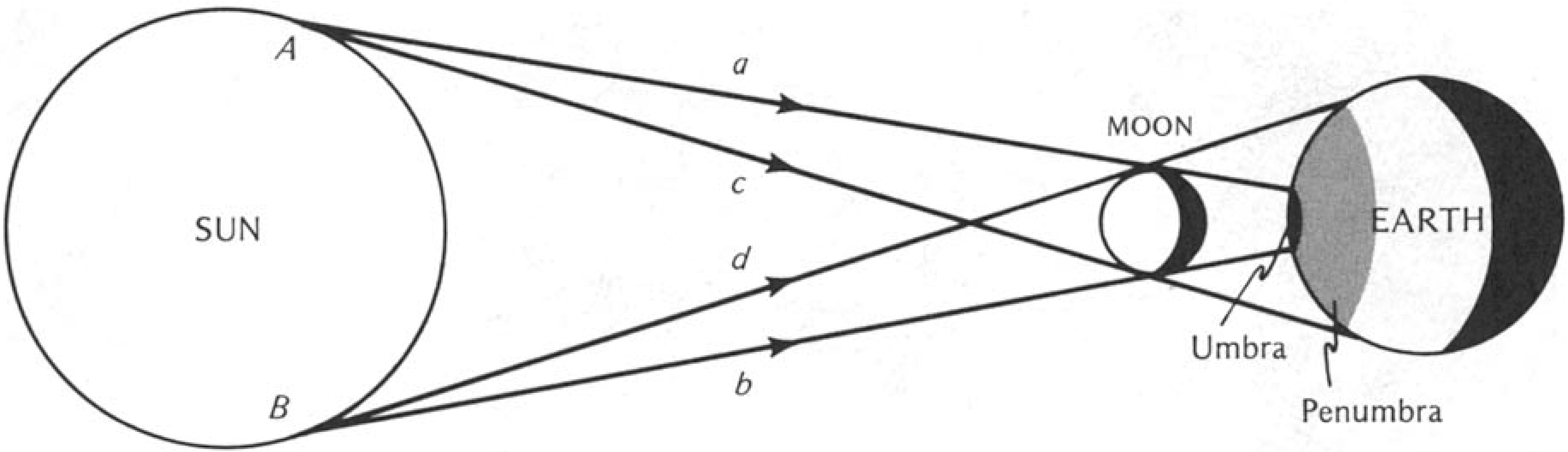
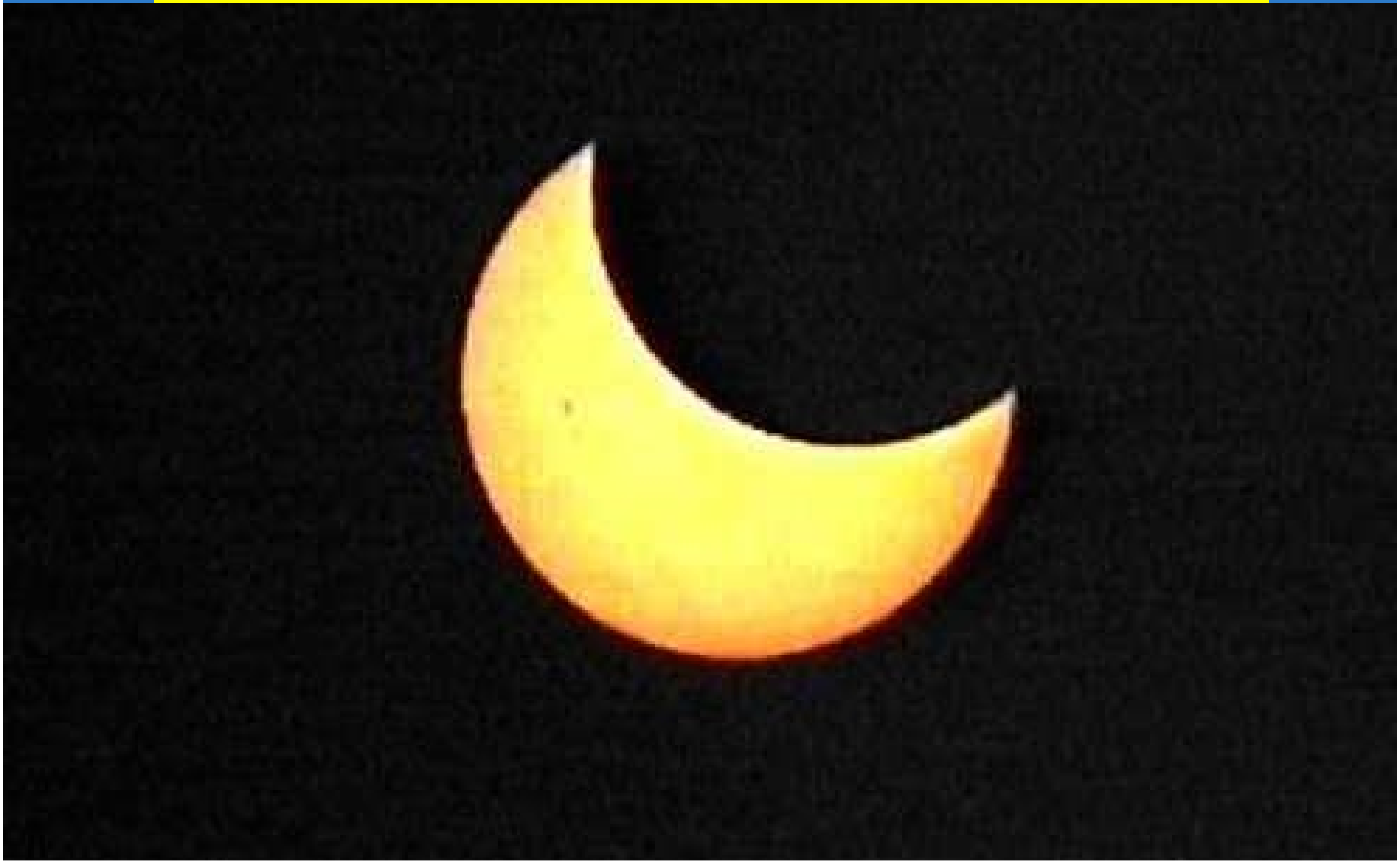


FIGURE 2.5

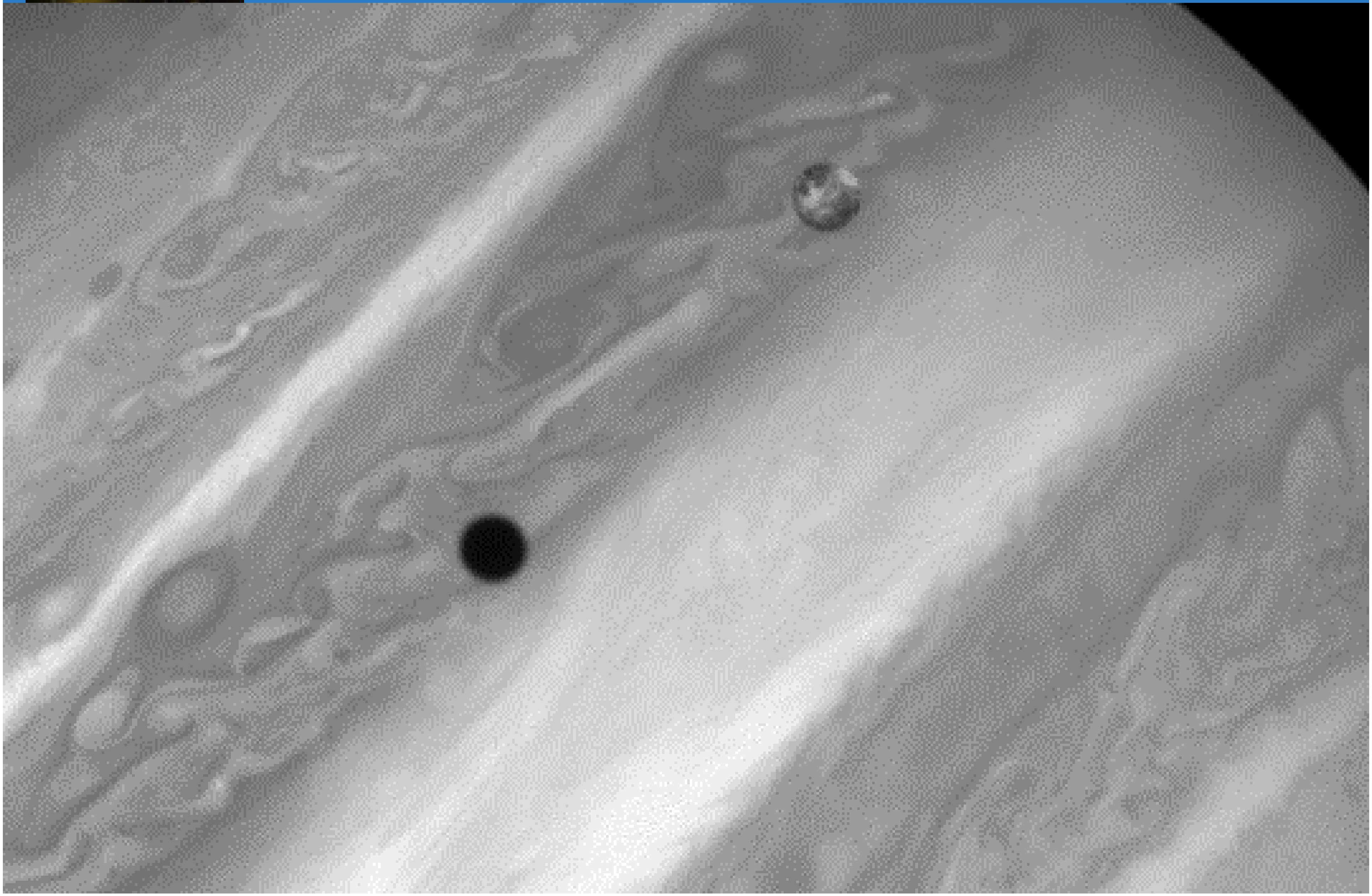
The umbra and penumbra of the moon projected on the earth, in exaggerated scale—the umbra is only about 200 km wide, which explains why total solar eclipses are rare at any given location.

Partial solar eclipse




Eclipse in Venezuela, Feb 26, 1998.
Blend of short and longer exposures
(1/60+1 sec.). 400mm+2x doubler.
Copyright John Sanford 1998.

Eclipse of Jupiter by Io



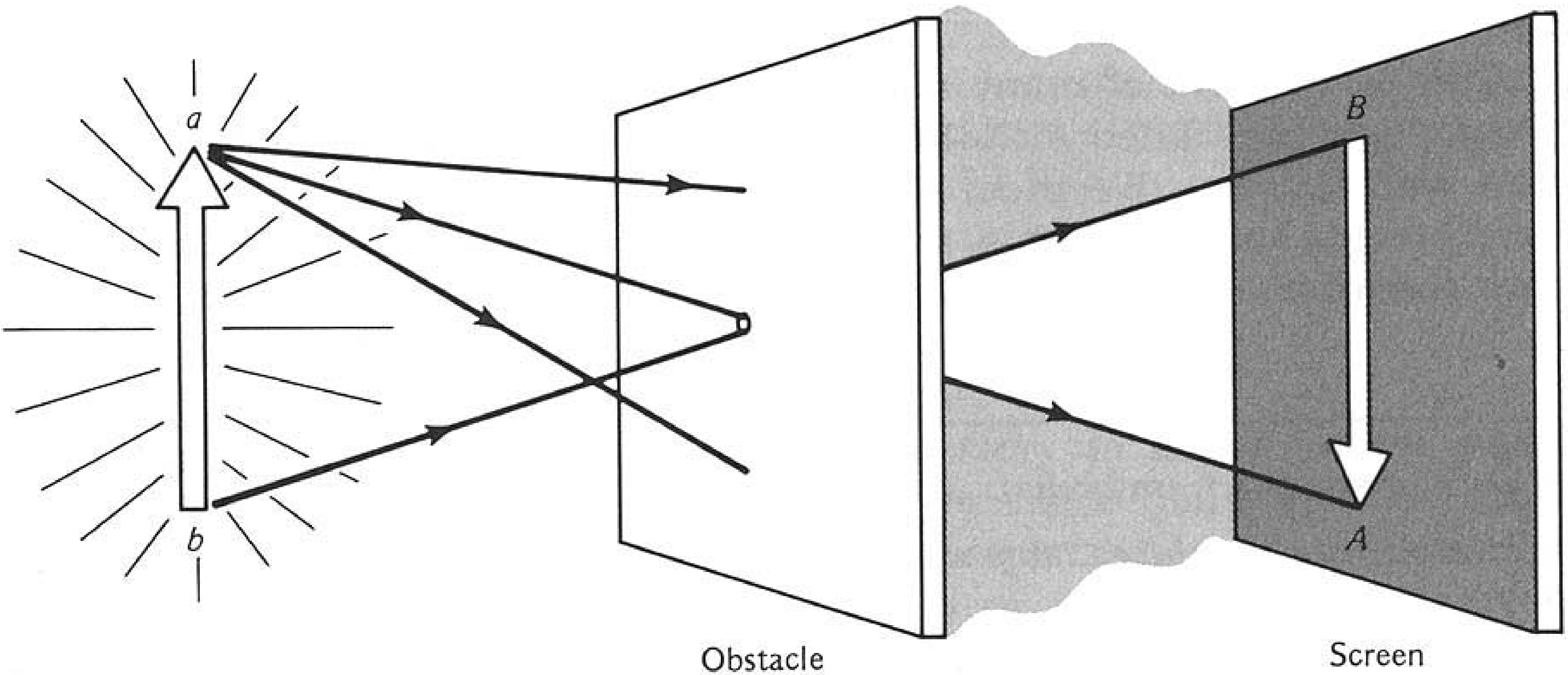
Total Solar Eclipse

- Total solar eclipse above Mauna Kea, Hawaii in 1991
- Observatories in background

Principle of pinhole camera

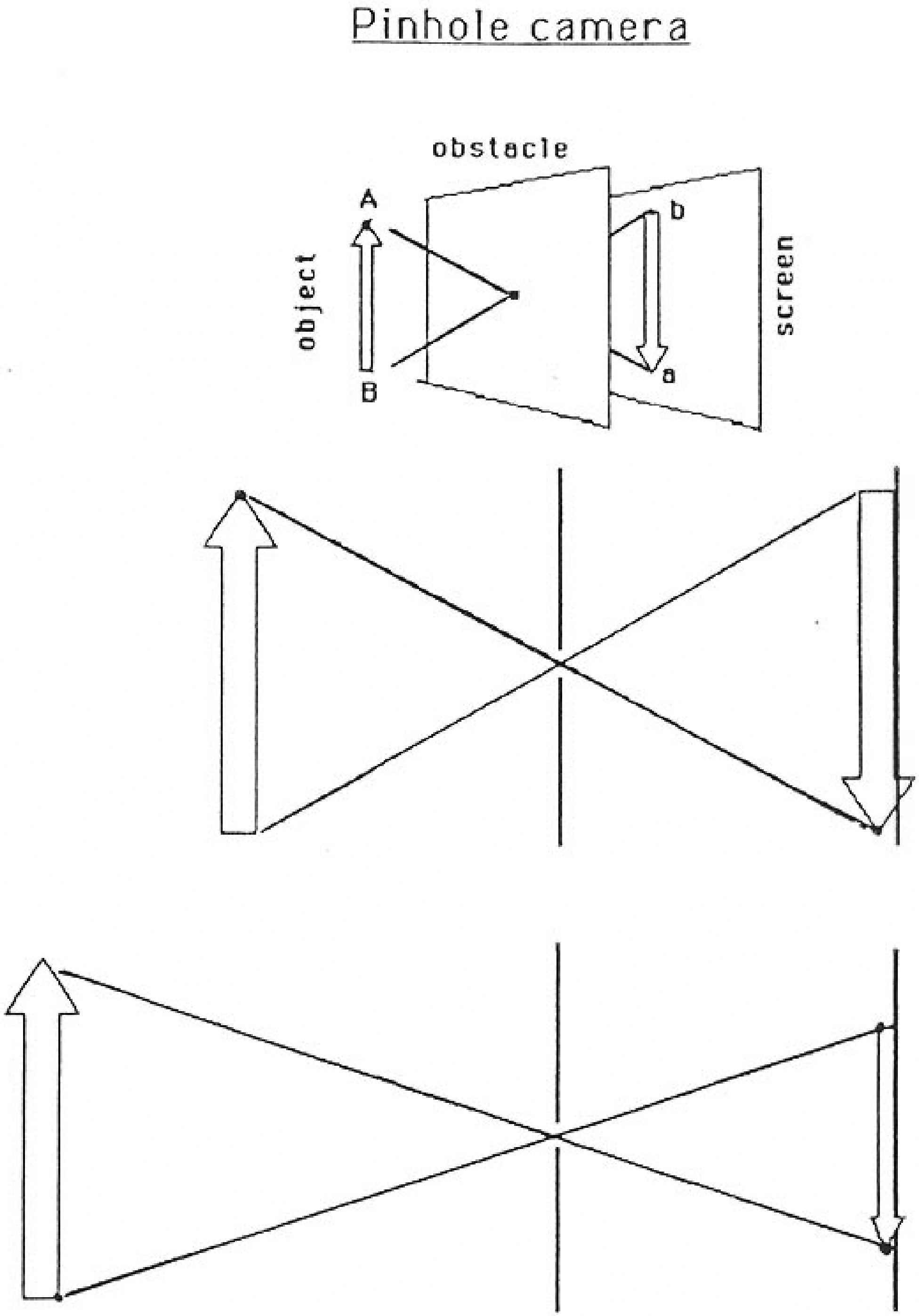
FIGURE 2.6

A pinhole forms an inverted image.



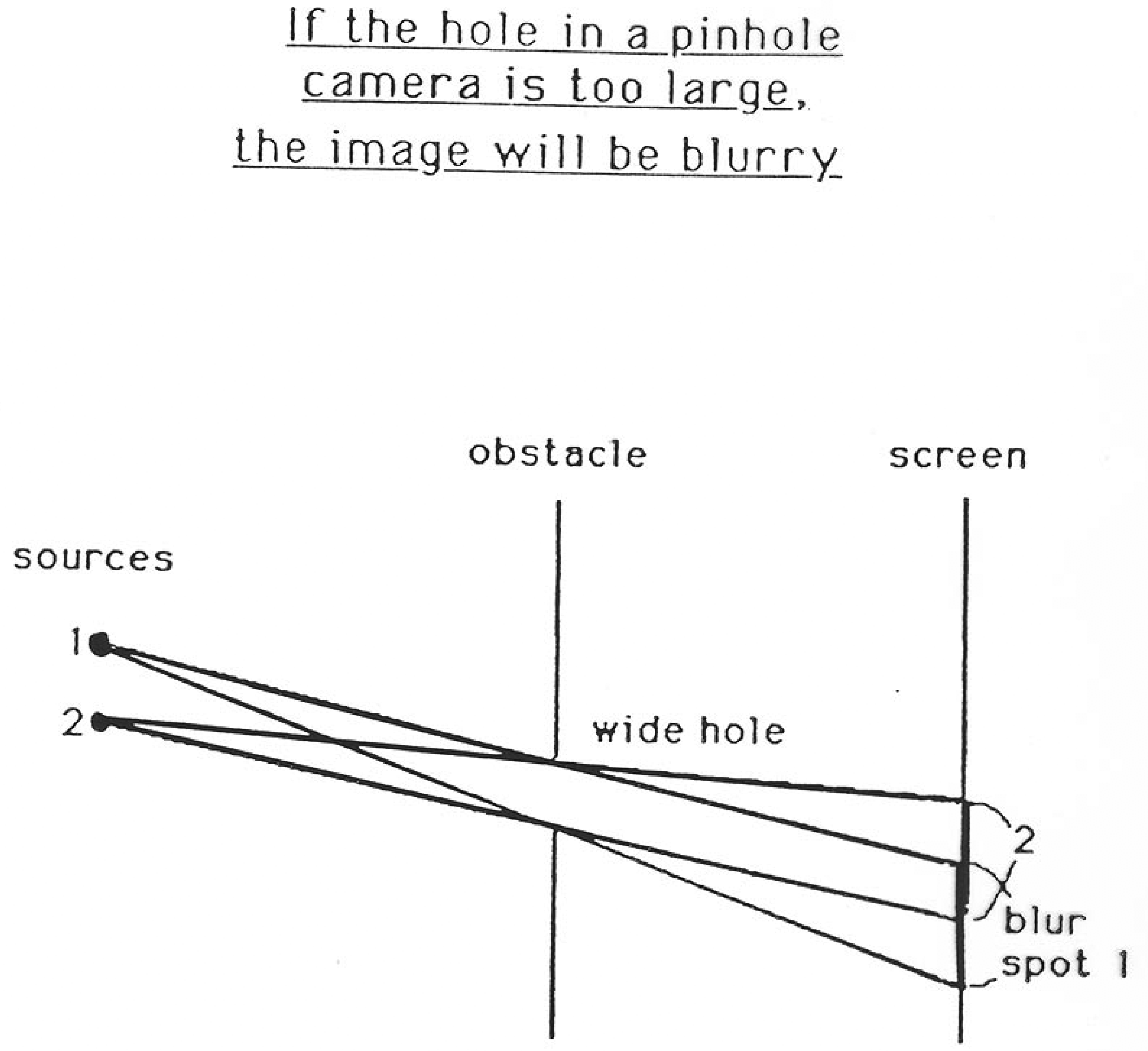
Effect of distance on pinhole image size

- An object further away makes a smaller image



Effect of large hole on pinhole image

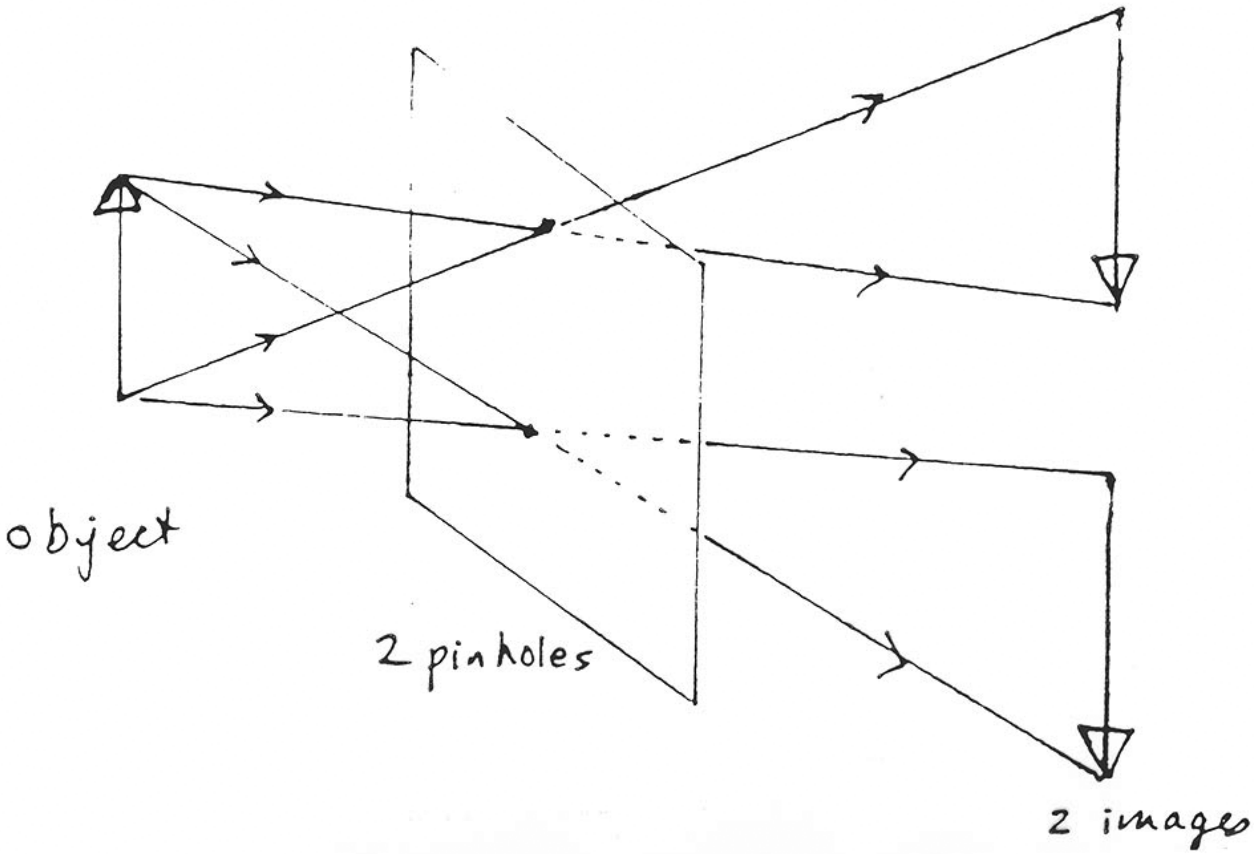
- **Large hole increases the blurriness of image**



Multiple pinholes

- **Each pinhole makes its own image**
- **Multiple pinholes produce multiple images**

If there are two pinholes in the obstacle, there will be two upside down images on the screen



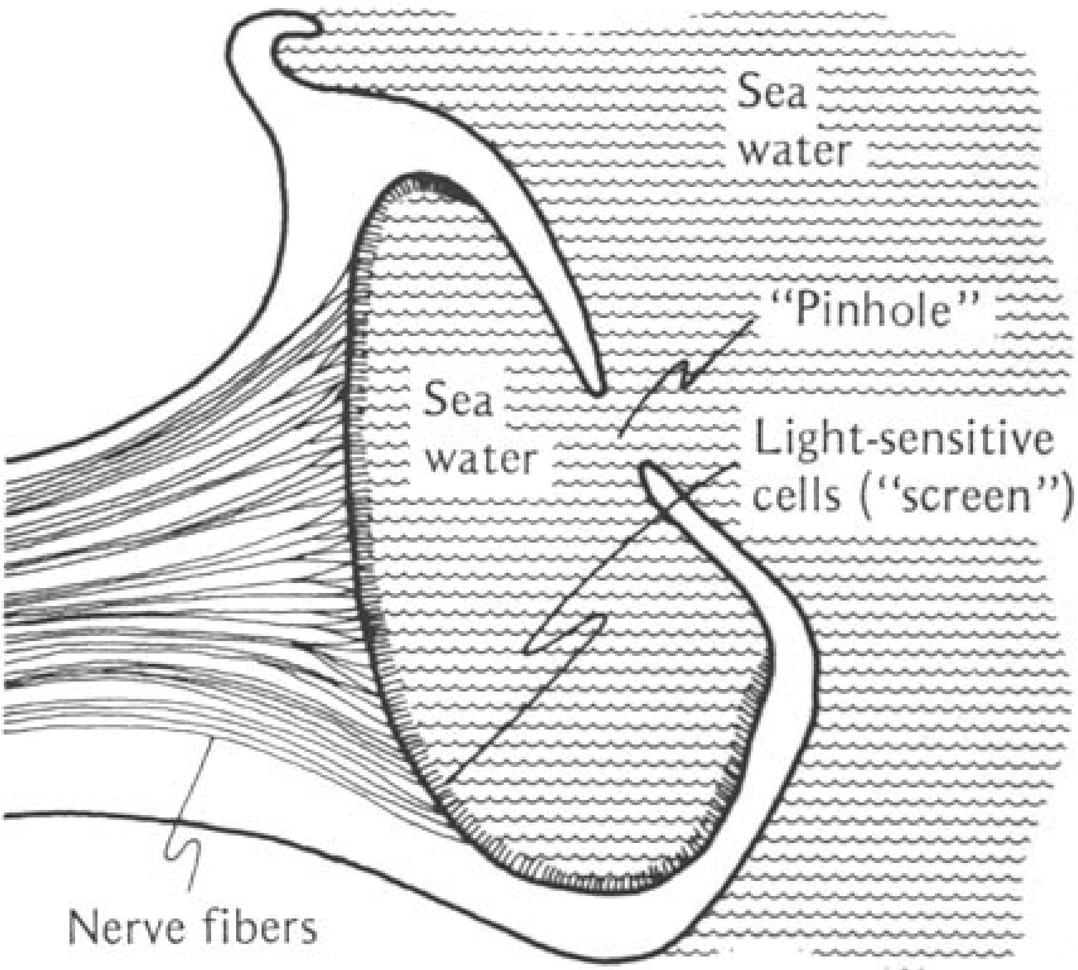


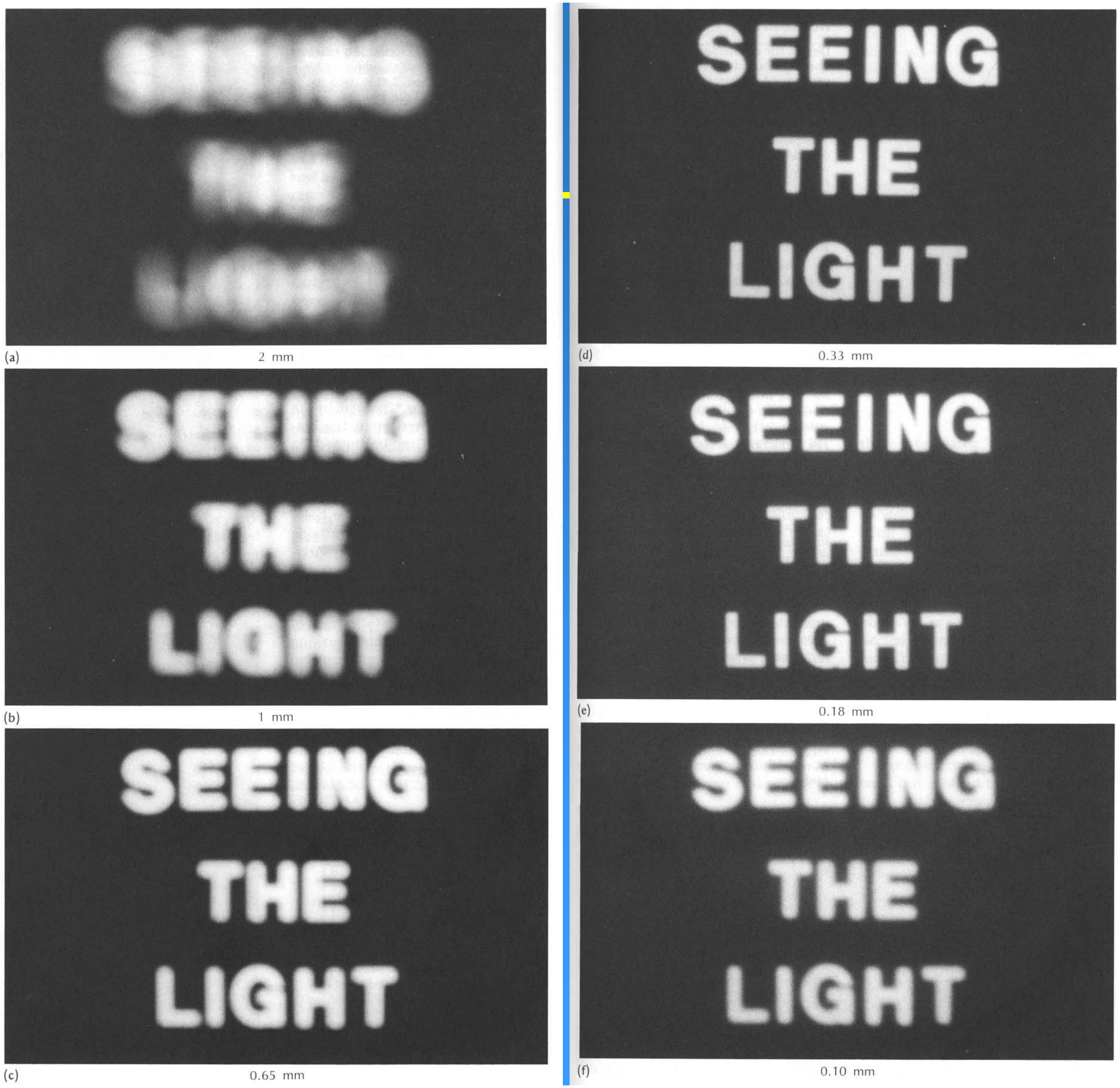
FIGURE 2.9

The pinhole eye of the *Nautilus*.

Optimizing pinholes

- **There is an optimum pinhole size the makes the best mages**
- **Geometric optics**
  - – Larger holes make blurrier images
  - – Smaller holes should make sharper images (but less light)
  - – Blur for distant sources ~ D
- **Physical optics (wave theory)**
  - – Aperture diffraction causes blurring
    - Angular blur = λ/D
      - λ is the wavelength of light
      - D is the hole diameter
    - Linear blur is angular blur x distance to screen

- 2.0 mm
- 1.0 mm
- 0.65 mm
- 0.33 mm
- 0.18 mm
- 0.10 mm

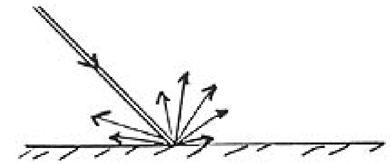


Scattering of light

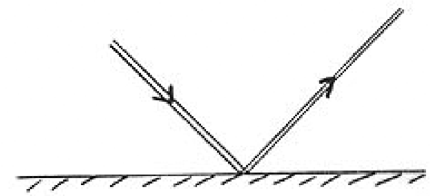
- Four different kinds of scattering

Four categories of objects based on how light the the objects reaches our eyes

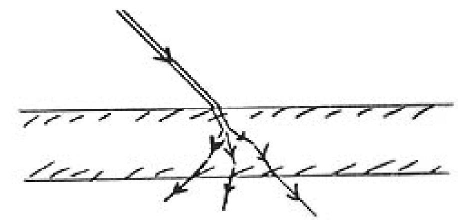
a) non metallic opaque objects



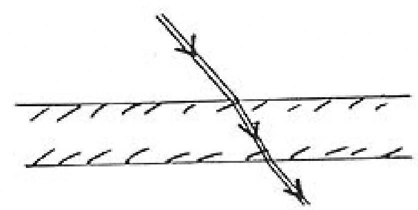
b) metallic objects "specular reflection"



c) translucent objects



d) transparent objects "specular transmission"



Radar

- With radar an antenna sends out a blip of electromagnetic radiation with $f = 10^9$ Hz. This corresponds to a wavelength of

$$\lambda = c/f = 30\text{cm}$$

- Radar reflects off of some surfaces, and the travel time of the wave gives the distance to the object. Hence

$$d = cT/2$$

- so for a delay of 1millisecond, we get d = 150 km.
- Some objects reflect poorly and thus cannot be seen very well or very far away.
- Stealth aircraft are designed to scatter little radar, and to scatter it in directions other than back to the radiation source. This means they have small cross sectional areas, they absorb radar, and they (try to) have surfaces that are not perpendicular to the radar source.

Echolocation in animals

- Some animals generate bursts of sound that is reflected off of objects, thus giving the animal information about the size, shape, and distance of the object.

  speed of sound in air 300m/s

  speed of sound in water 1500m/s

- **bats** use frequencies 30kHz to 120kHz with chirps up to 100/sec

  using $\lambda f = v$ we get $\lambda = = 2.5$mm, they can detect thin wires

- **Odontocetes** (toothed whales, porpoises) generate chirps up to 200kHz

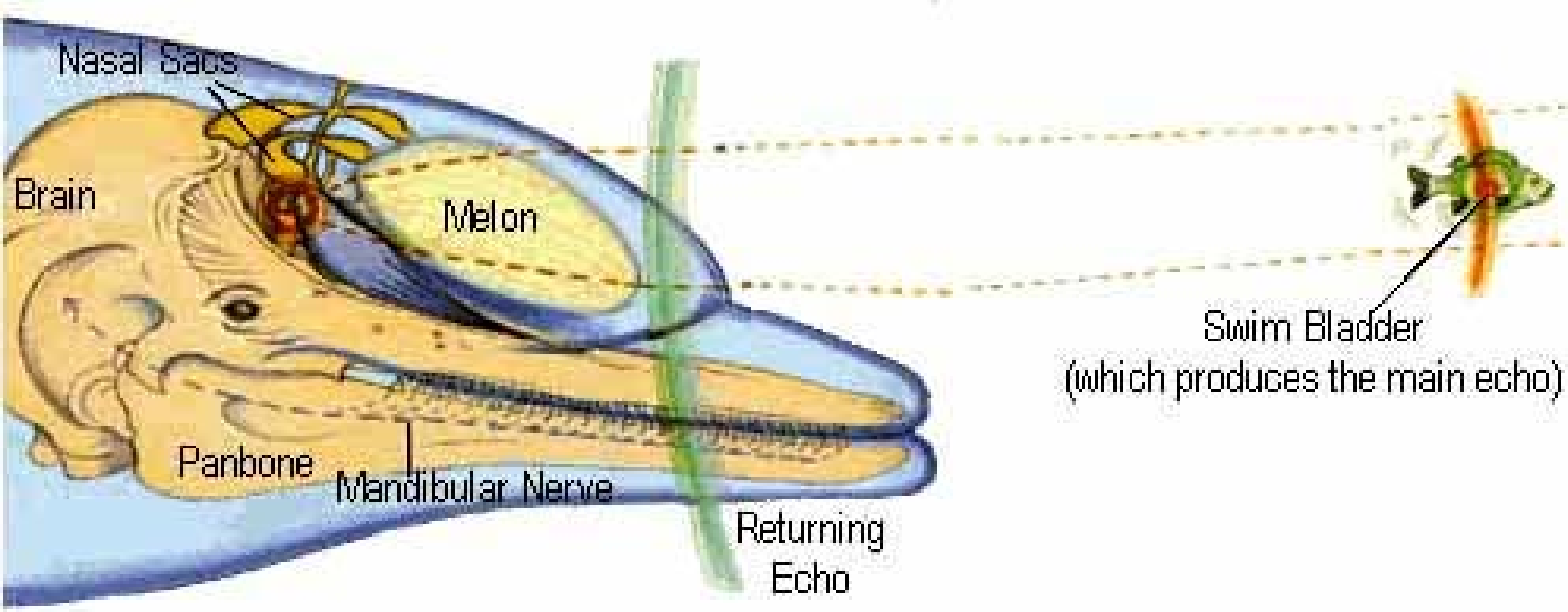
  using $\lambda f = v$ we get $\lambda = = 7.5$mm, they can also detect wires

- Other cetaceans just listen, they dont generate sounds for purposes of echolocaton
- **insectivores** (shrews) use frequencies up to 10-30 kHz

  using $\lambda f = v$ we get $\lambda = = 10$mm

- **birds** (swifts, oilbirds) use frequencies 1-6 kHz

  using $\lambda f = v$ we get $\lambda = = 50$mm



Nasal Sacs
Brain
Melon
Swim Bladder
(which produces the main echo)
Panbone
Mandibular Nerve
Returning
Echo

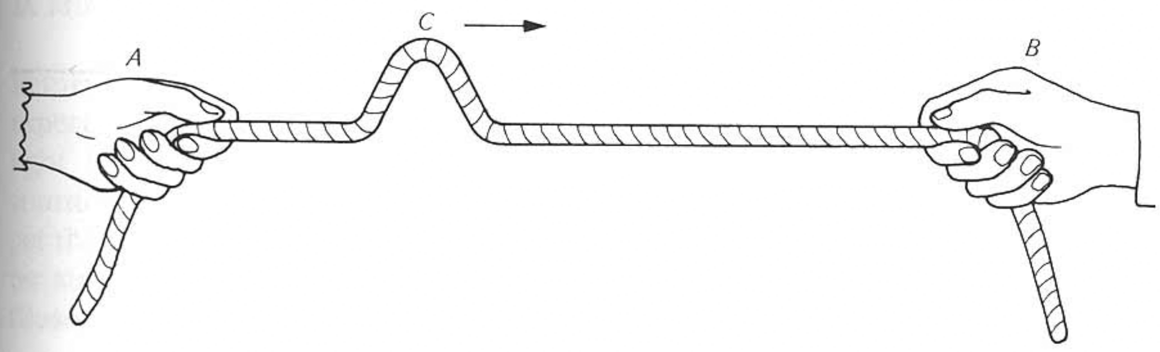
Sonar

- ships, submarines use sound chirps to locate each other, nearby objects, the ocean bottom, by sensing the return echo.
- Fisherman locate schools of fish this way
- some automatic cameras use echolocation to determine the distance to the central object in the field of view.

- **Reflection from hard surfaces requires cancellation of wave at surface**

FIGURE 2.13

The lady, A, keeping her distance, has started a wave propagating toward B.



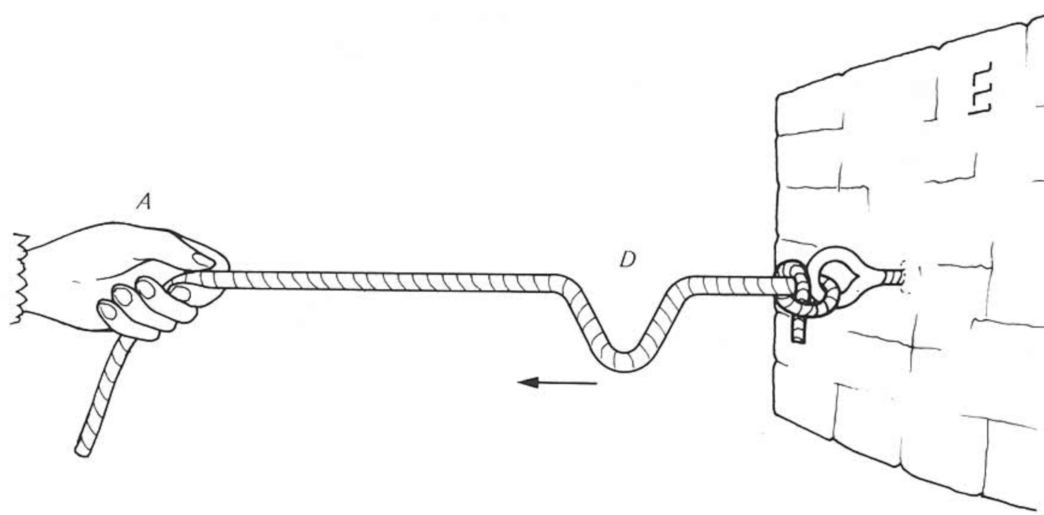


FIGURE 2.14

B, stonewalling the lady's gesture, refused to let his hand be shaken. Consequently, an upside-down wave returns to A.

Ionosphere-reflection

- **Long wavelength radiation is reflected from ionosphere (for light whose frequency is below the plasma frequency**
  - Free charges wiggle to prevent the electric field from being transmitted
- **Same principle for reflections from metals**
  - If free electrons can wiggle as fast as the frequency of light, they will prevent the electric field

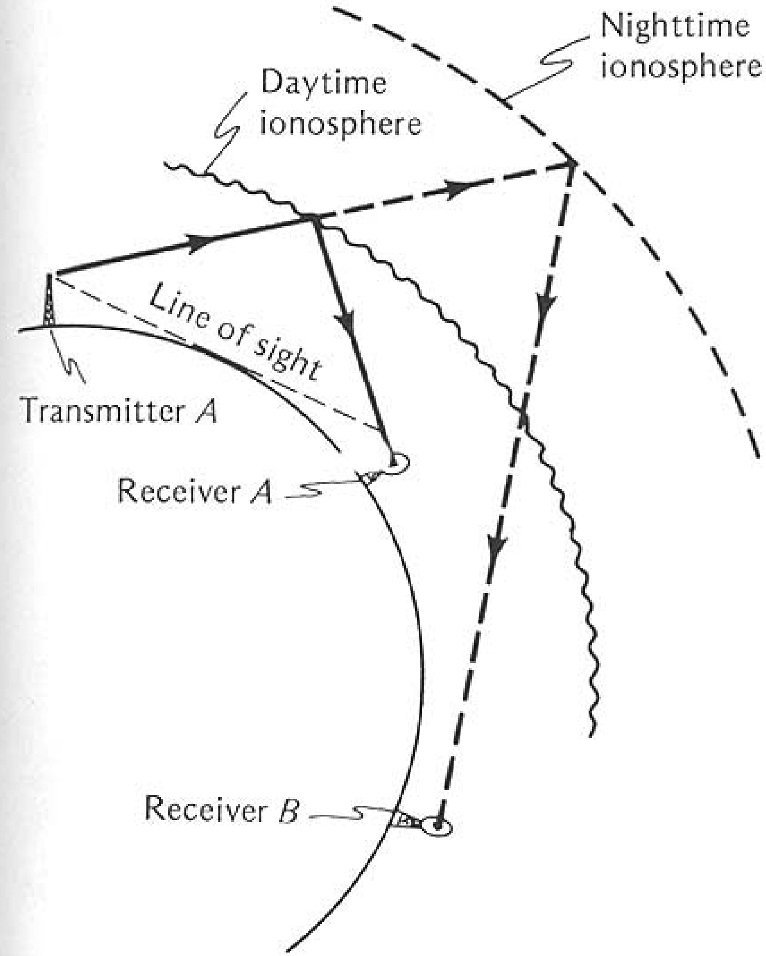


FIGURE 2.15

Reflection of radio signals from the ionosphere makes distant reception possible. The ionosphere rises at night, increasing the range of reception. (Exaggerated for clarity.)

- **Structure of typical mirror**
  - Glass in front
  - Mirror in back

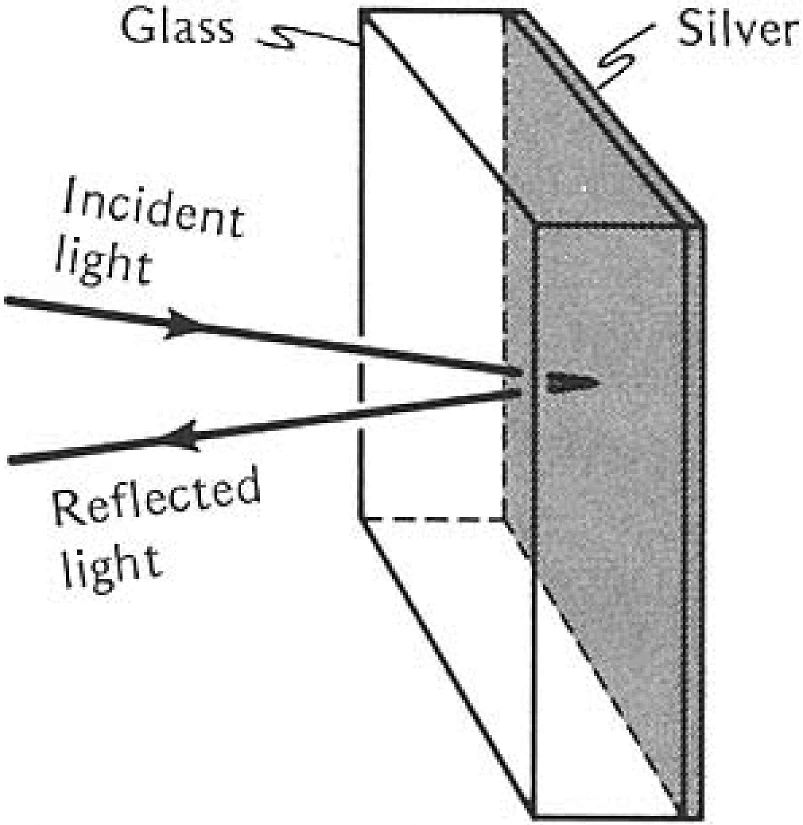
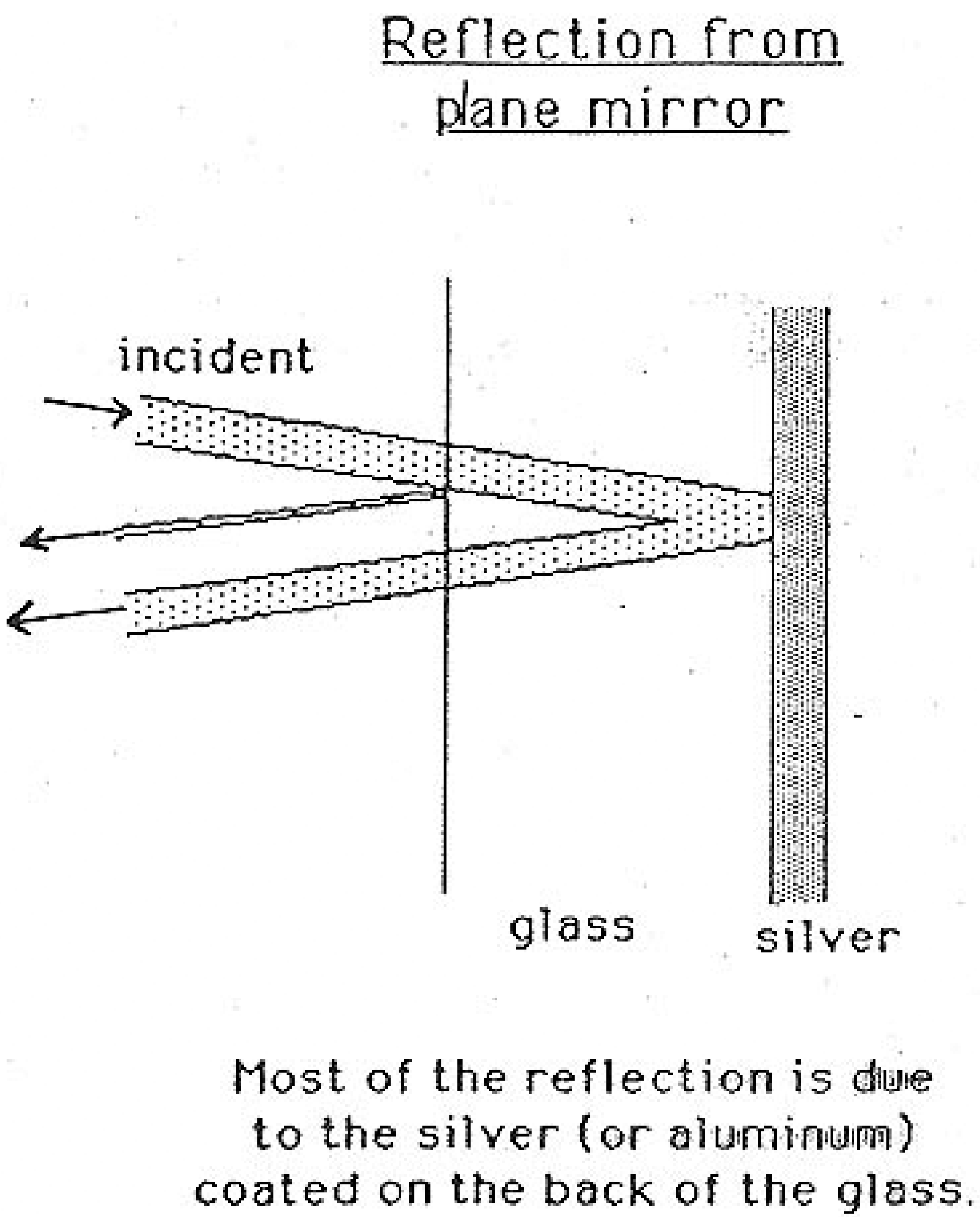


FIGURE 2.16

An ordinary mirror consists of a piece of glass, coated on its back surface with a layer of silver.

Reflection from back surface mirror



Partial reflection-transmission

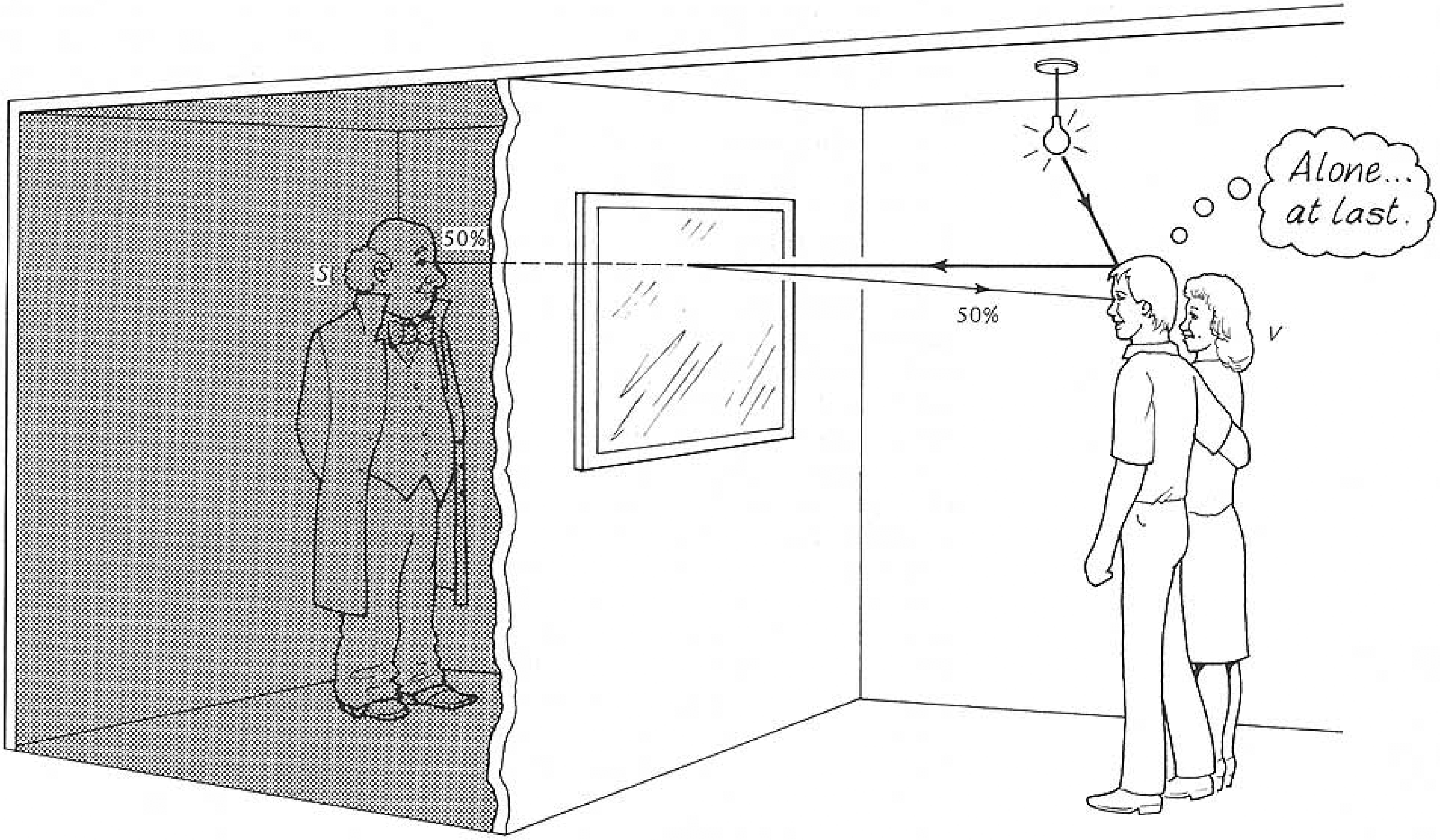
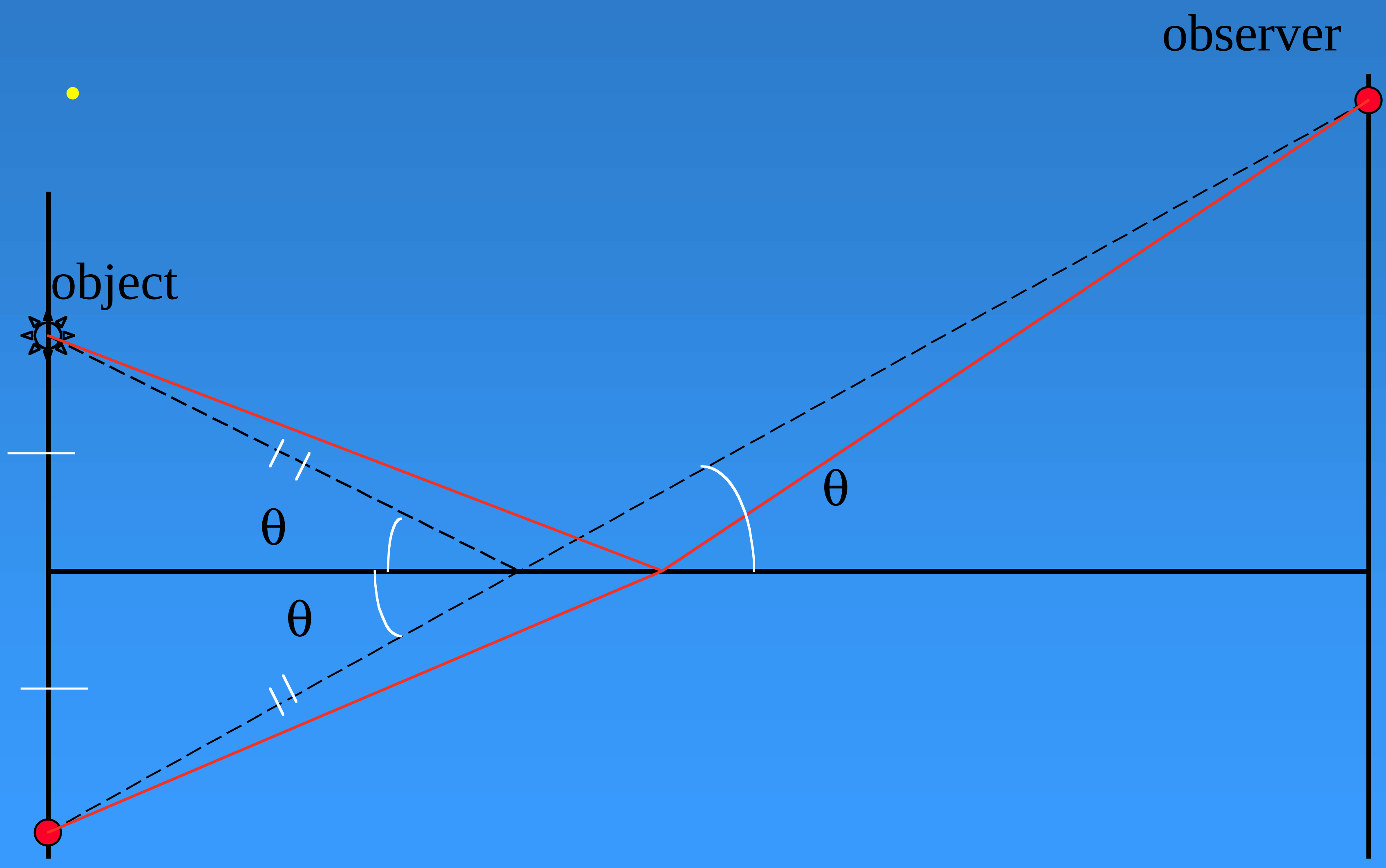


FIGURE 2.17

Illuminated innocents become visible victims of spookish spy behind harmless half-silvered mirror.

Reflection and least time



Virtual image (location is independent of observer location)

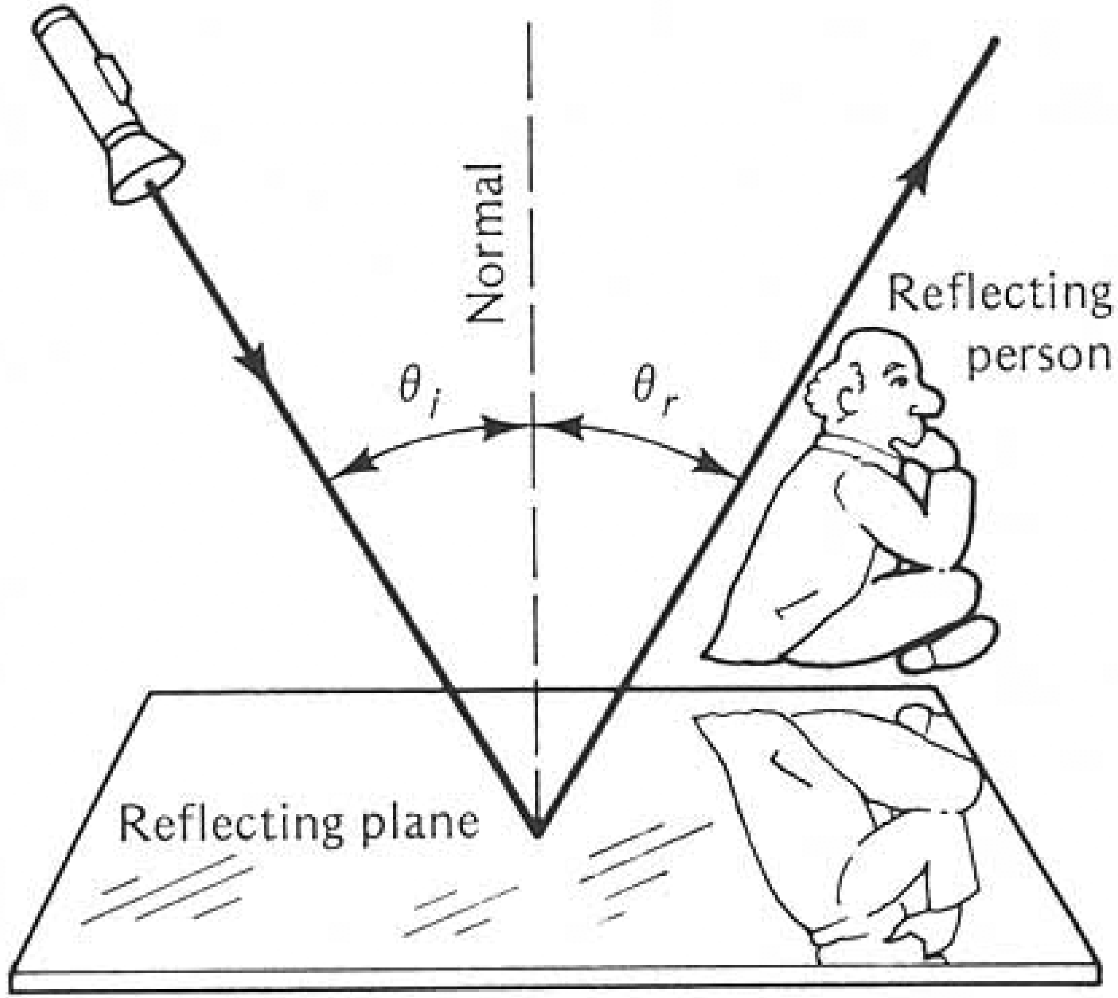


FIGURE 2.18

The law of reflection: $\theta_r = \theta_i$.

- **Virtual images**

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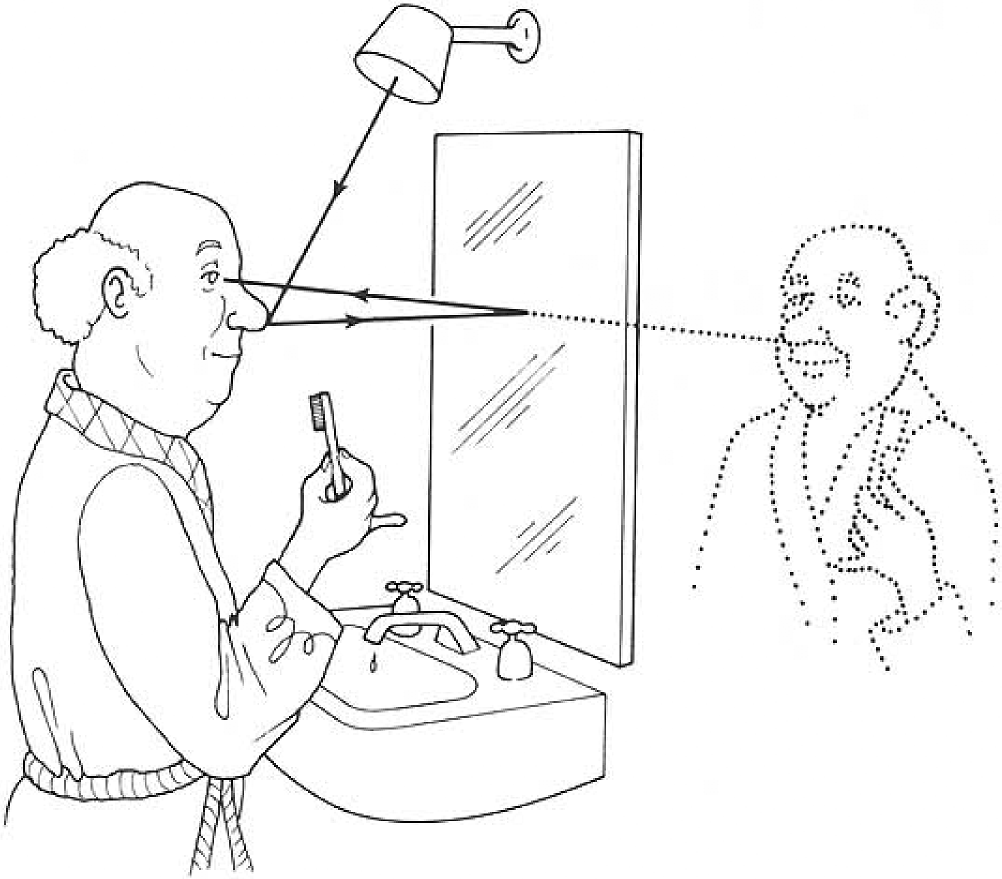
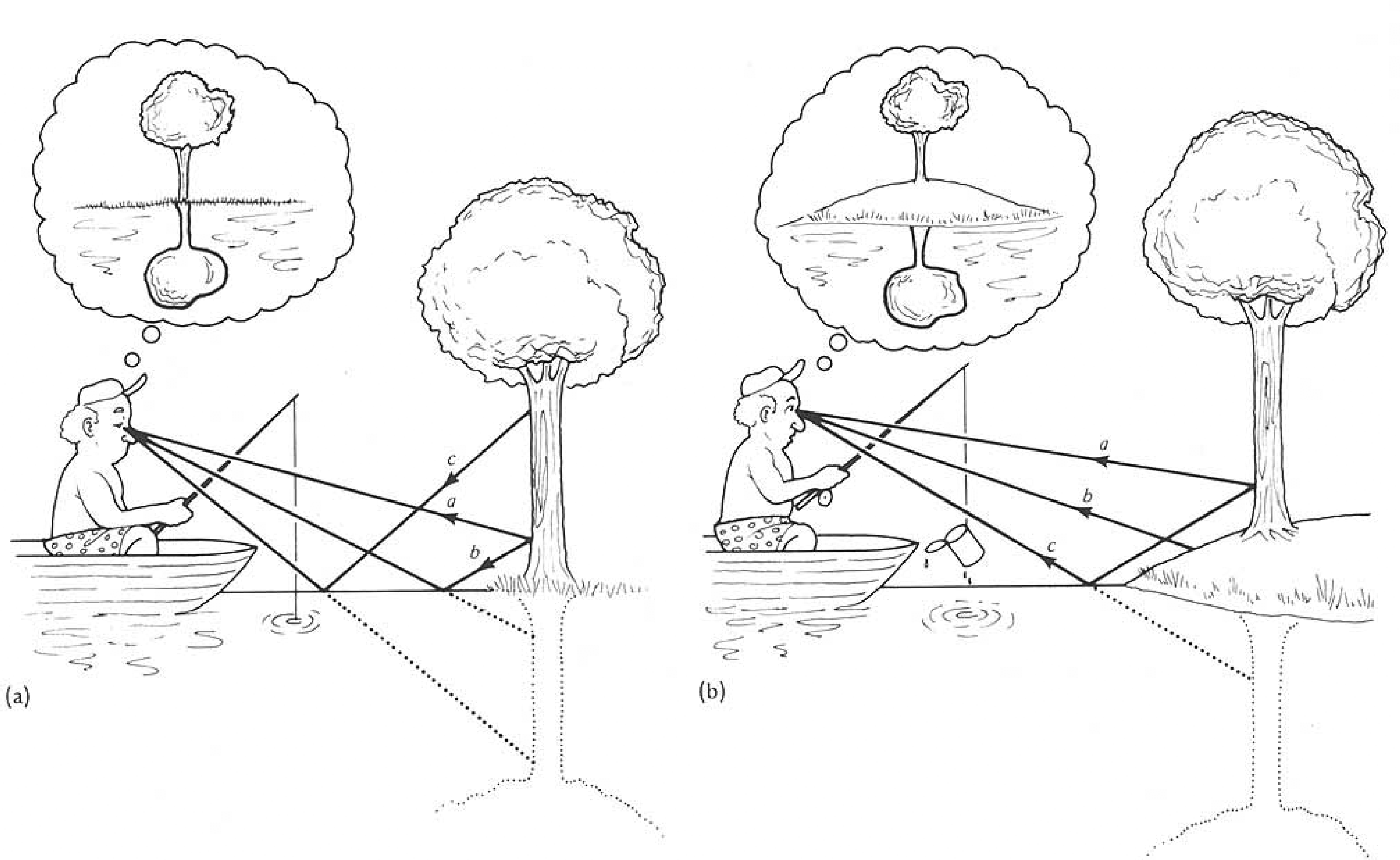
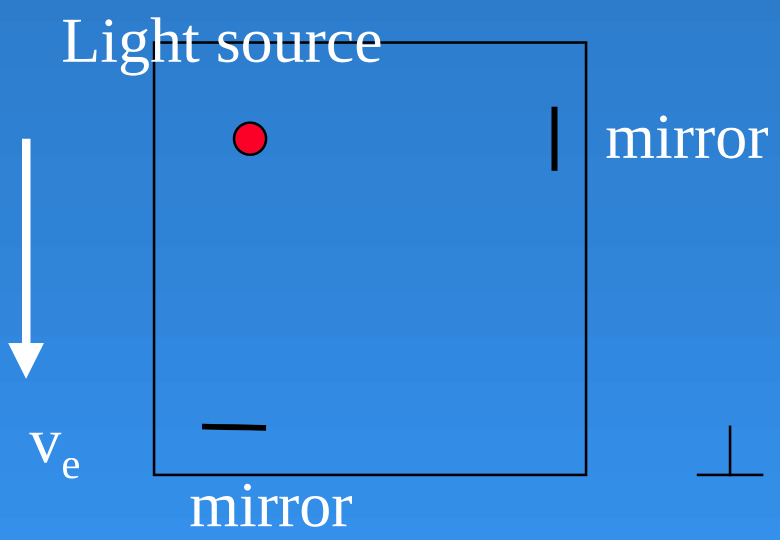
FIGURE 2.19 (below)

The reflected ray does not originate where the eye thinks it came from. The light scattered from the observer's nose (the object) really takes a sharply bent path to his eye, since it is reflected by the mirror. But the observer's brain interprets the light as if it had come in a straight line from a part of the image behind the mirror. This is because the reflected ray comes from the same direction *as if* it came from an object behind the mirror: the image, which is as far from the mirror as the object, but on the other side.




c
a
b
(a)
a
b
c
(b)

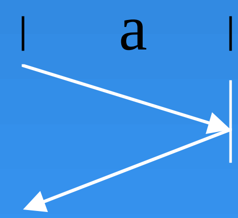
Measuring our speed through the Ether



Michelson-Morley Expt 1887

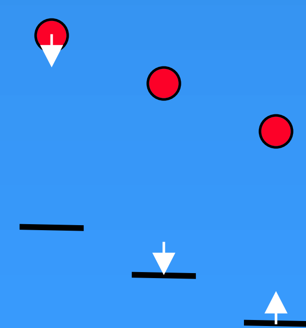
v_e = our speed through the ether
c = speed of light
a = distant to mirrors

⊥ path



$$t_{\perp} = \frac{2a}{c}\frac{1}{\sqrt{1-\frac{v_e^{\,2}}{c^2}}}$$

|| path



$$t_{C} = \frac{2a}{c}\left(\frac{1}{1-\frac{v_e^2}{c^2}}\right)$$

Measuring our speed through the Ether

- Conclusion

$$\frac{t_{\perp}}{t_C} = \sqrt{1 - \frac{v_e^2}{c^2}}$$

- MM measured no difference! (implies $v_e = 0$)
- In fact the uncertainty in their measurements was far less than the speed of the earth around the sun, thus the assumption of earth moving through a stationary was incorrect. Thus the ether idea was not supported experimentally.
- Einstein's theory of special relativity successfully explained this measurement