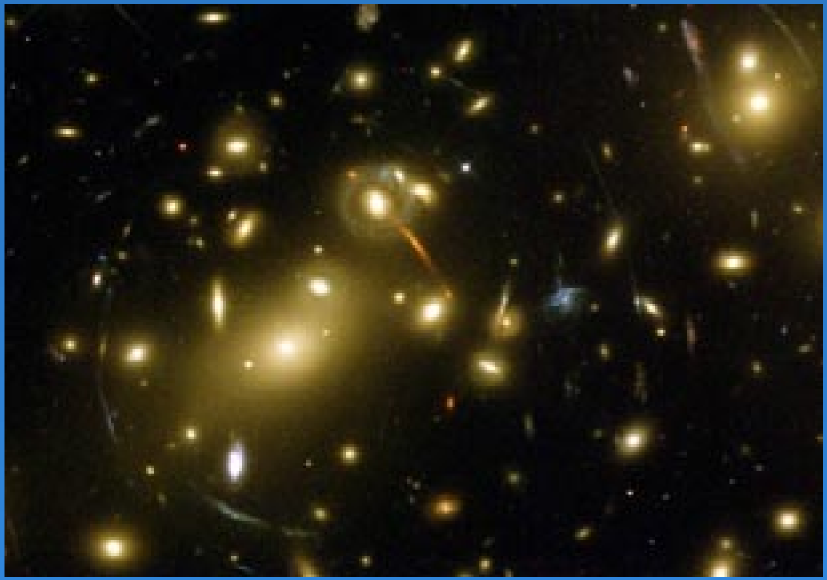
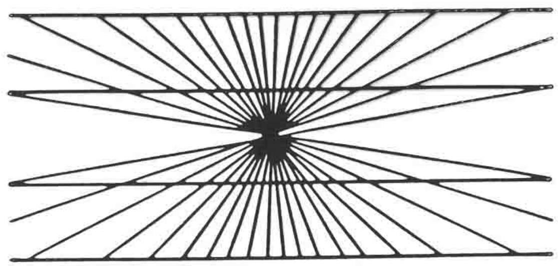


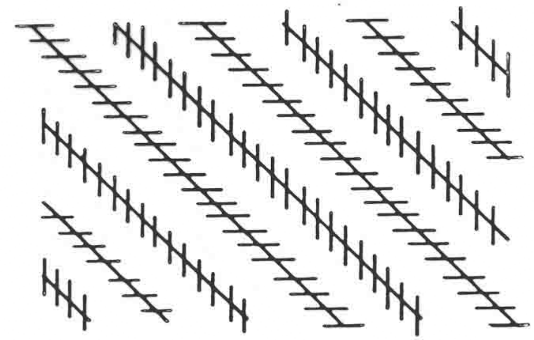
Astronomy 80 B: Light

Lecture 2: Basic Properties of Light

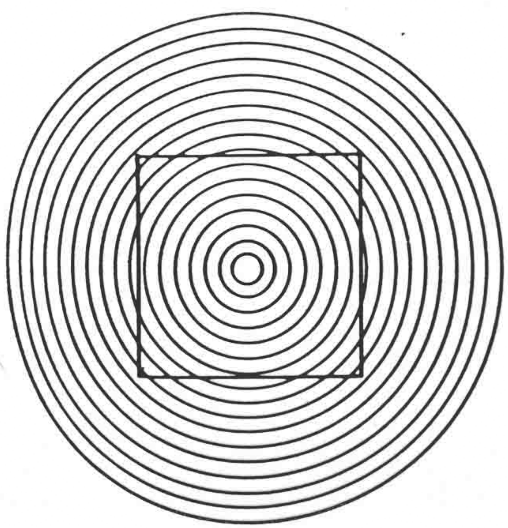
3 April 2003

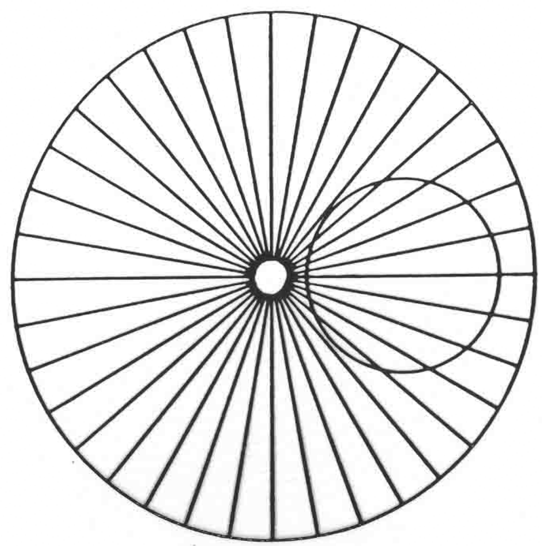
Jerry Nelson



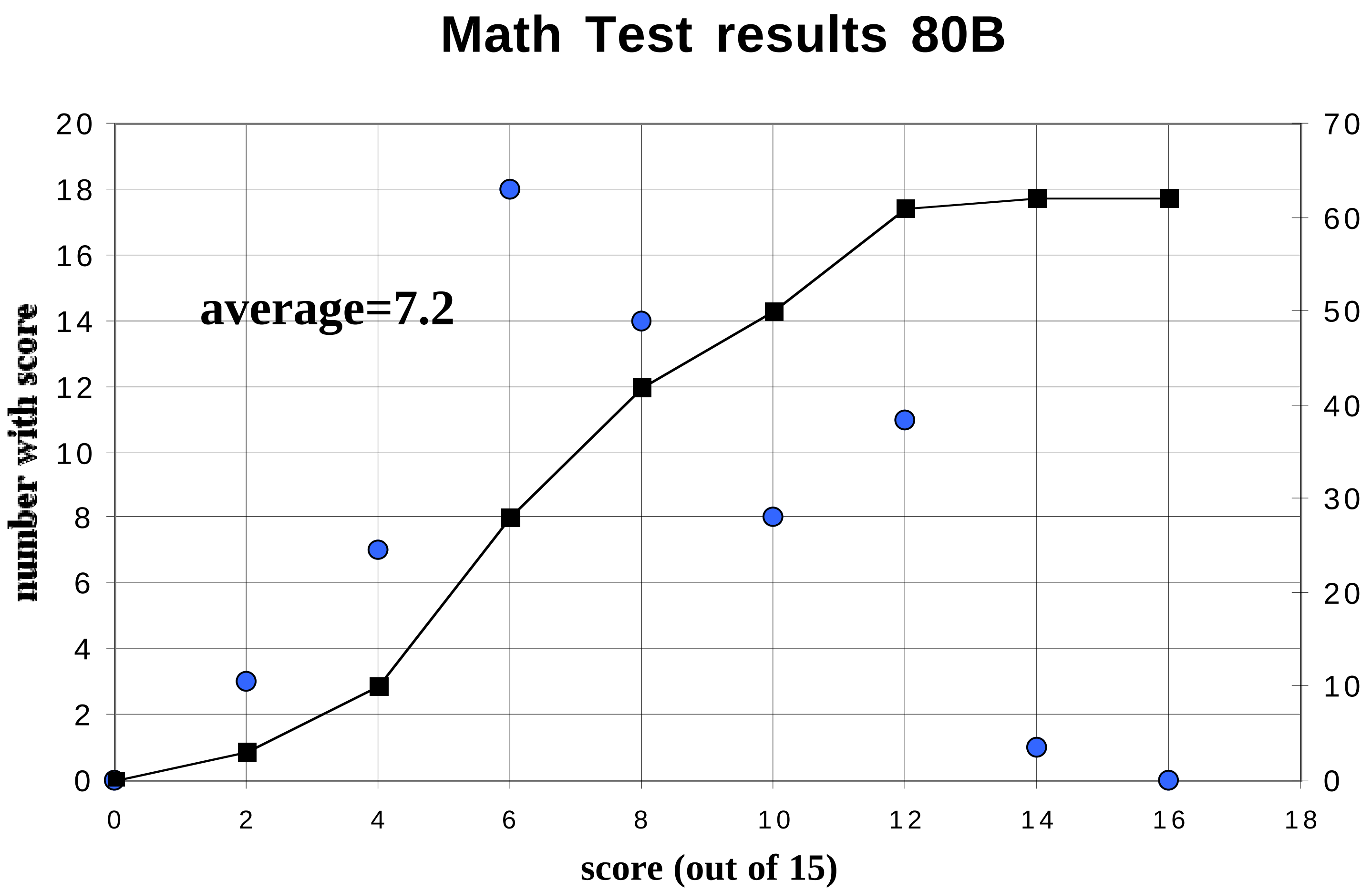


Other well-known illusions are said to have in common test lines that appear to bend away from the inducing lines that cross them.





Math Assessment



Best Grades on Math Test

- Hallock Lillian 10
- HEALY DANIEL 10
- LOLL CHRISTOPHER 11
- MANZI MIKE 11
- PONCE MICHAEL 11
- RUCKER CLINTON 11
- SEMANA CHRISTOPHER 11
- ZEE Peter 11
- MCCLELLAND COLLEEN 12
- MCVEY CHRISTOPHER 12
- SPICKARD GREGORY 12
- WILDMAN NATHAN 12
- WOODRUFF AMANDA 12
- PATEL MIRA 14

Powers of Ten

- Short hand notation for large or small numbers For example
  - For example $1 = 10^0$

$10 = 10^1$

$100 = 10^2$

$1000 = 10^3$

etc

and

$0.1 = 10^{-1}$

$0.01 = 10^{-2}$

$0.001 = 10^{-3}$

etc

Thus

$43{,}000 = 4.3\text{x}10^4$

$0.00341 = 3.41\text{x}10^{-3}$

and

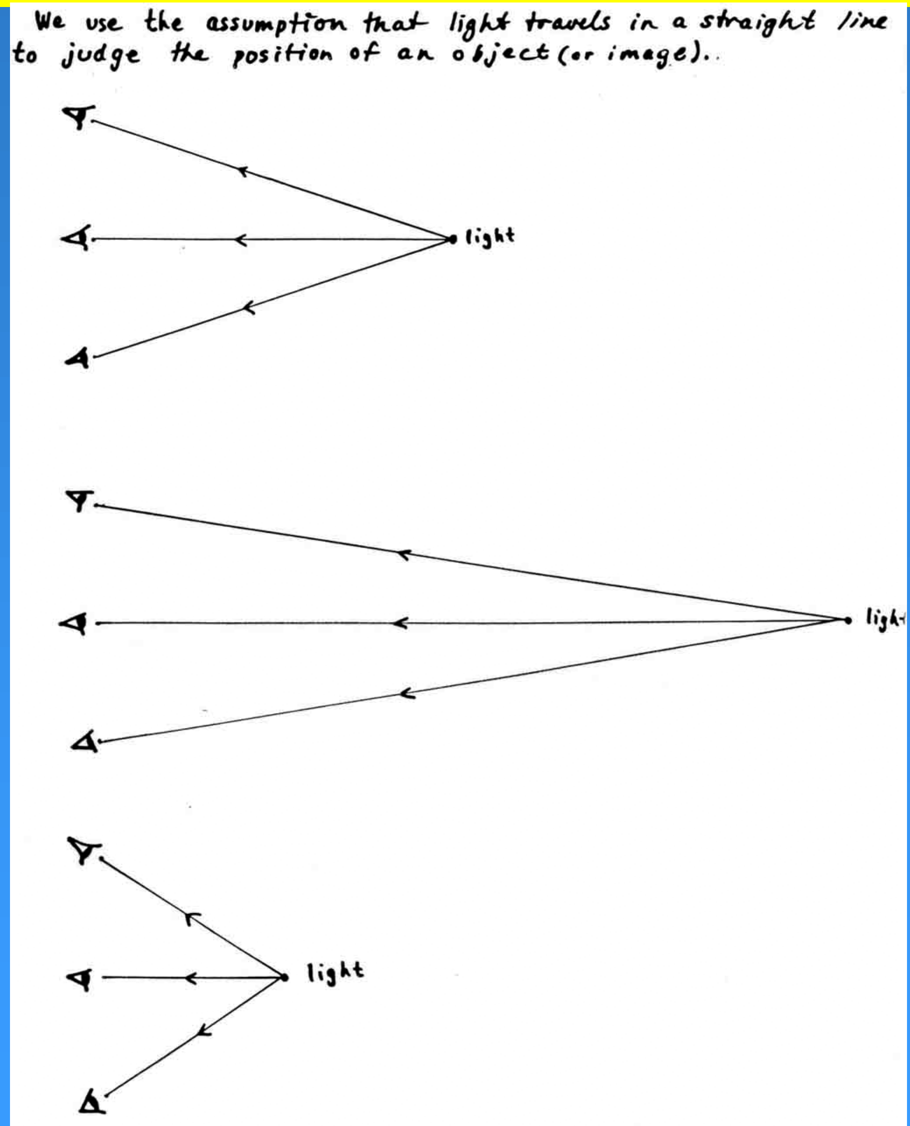
$23{,}000 \text{ x } 0.0020 = 2.3\text{x}10^4 \text{ x } 2.0\text{x}10^{-3} = 4.6\text{x}10^1$

$= 0.8\text{x}10^{8-5} = 0.8\text{x}10^3 = 8\text{x}10^2$

Trigonometry

- **See viewgraph**

Light tends in straight lines



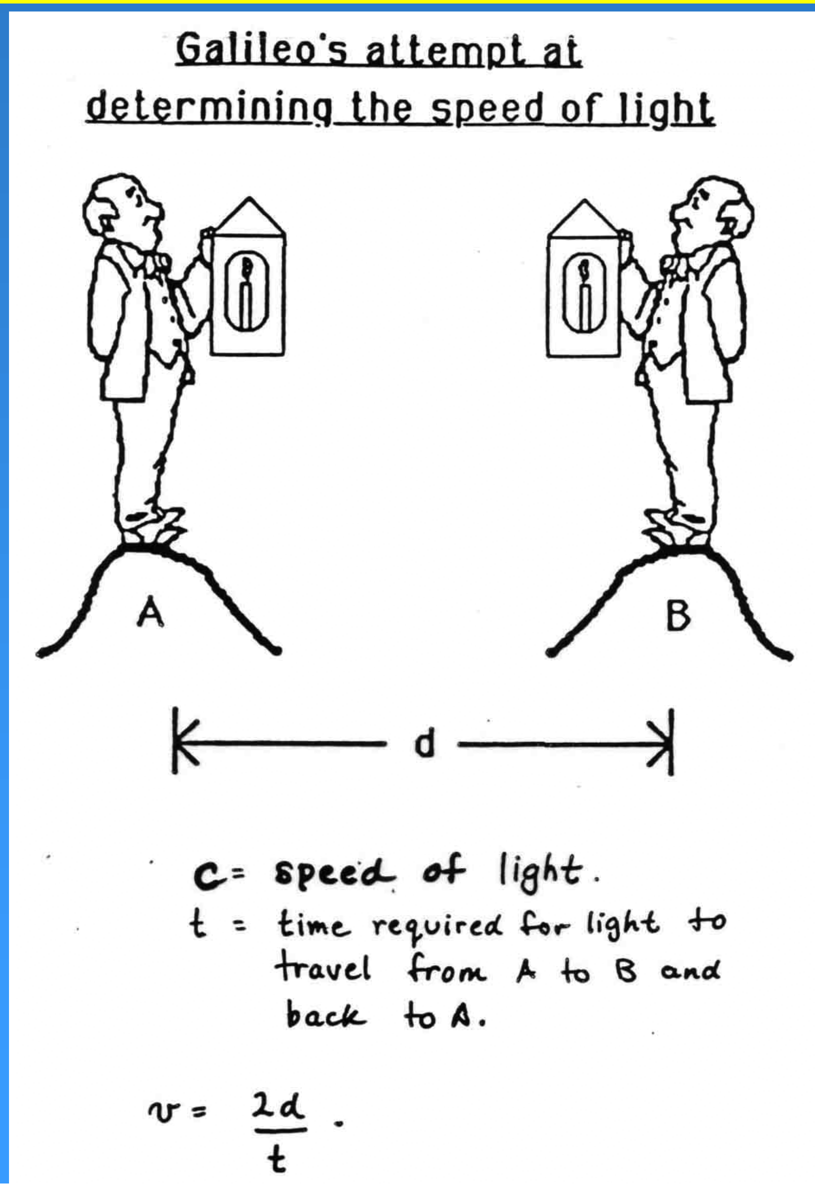
What is the speed of light?

- **Sound propagates through material stuff**
  - Rocks
    - Water
    - Air
    - Etc
  - Sound speed is about 330 m/s (1000ft/s) in air, faster in rocks
  - Experience is that light is much faster than sound
    - Lightning, thunder
    - Distant events seen, then heard
- **Galileo (b. 1564) attempted to measure light speed**
- **Ole Roemer measured it crudely (17th century)**
- **Michelson measured it accurately (late 19th century)**

What is the speed of light-2

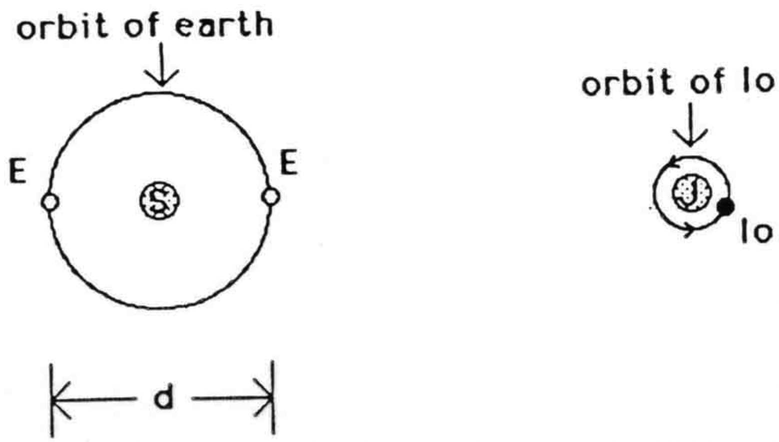
- **What does light propagate through- what is the medium?**
- **Evidence indicates the speed of light is a constant in a vacuum**
  – Independent of the wavelength of light
  – Independent of the speed of the source
  – Independent of the speed of the receiver
  – c = 300,000,000 m/s (186,000 miles/s)
- **This evidence makes the concept of the ether untenable**
- **This dilemma led to the theory of special relativity by Einstein (1905)**

Galileo's attempt to measure the speed of light



Ole Roemer’s determination of the speed of light

Ole Roemer's determination of the speed of light

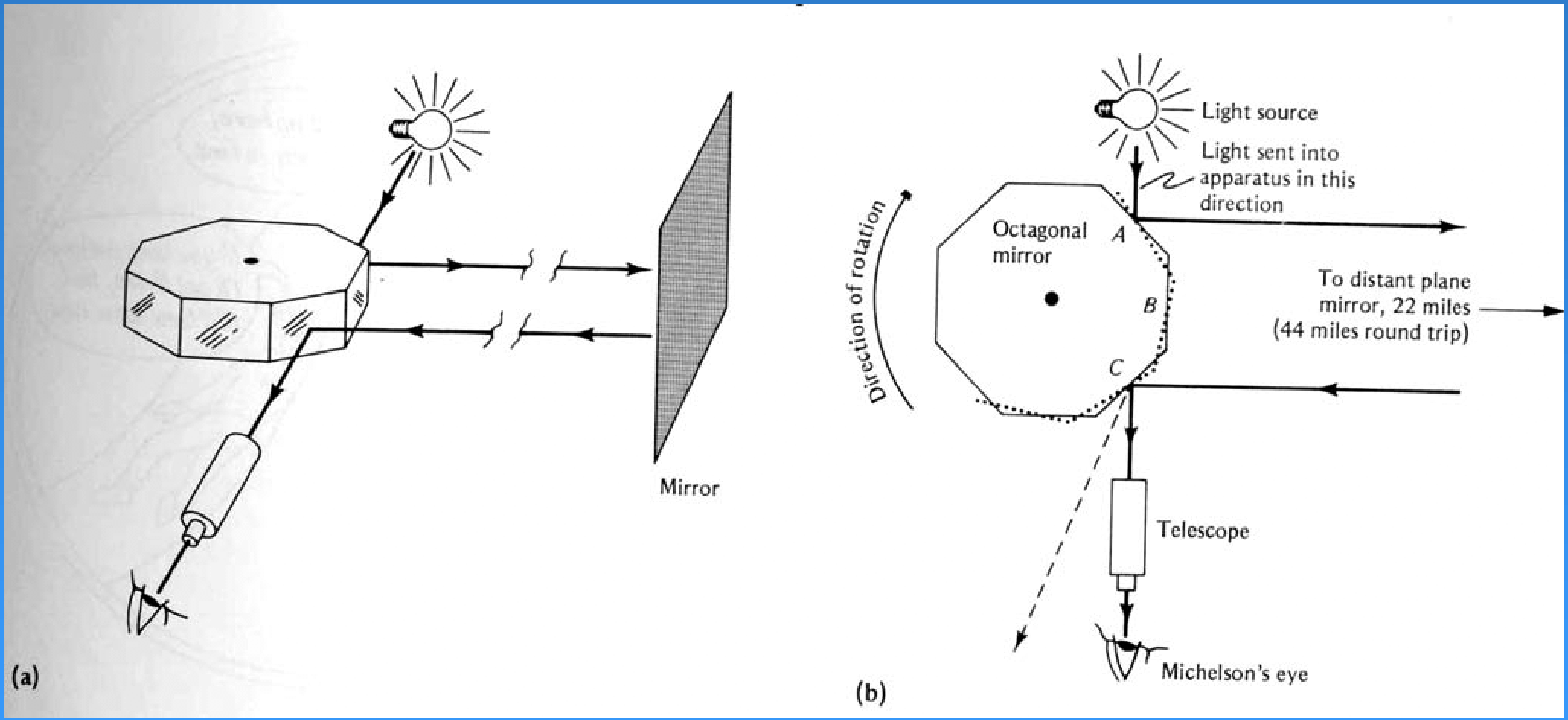


$d = 186{,}000{,}000$ miles

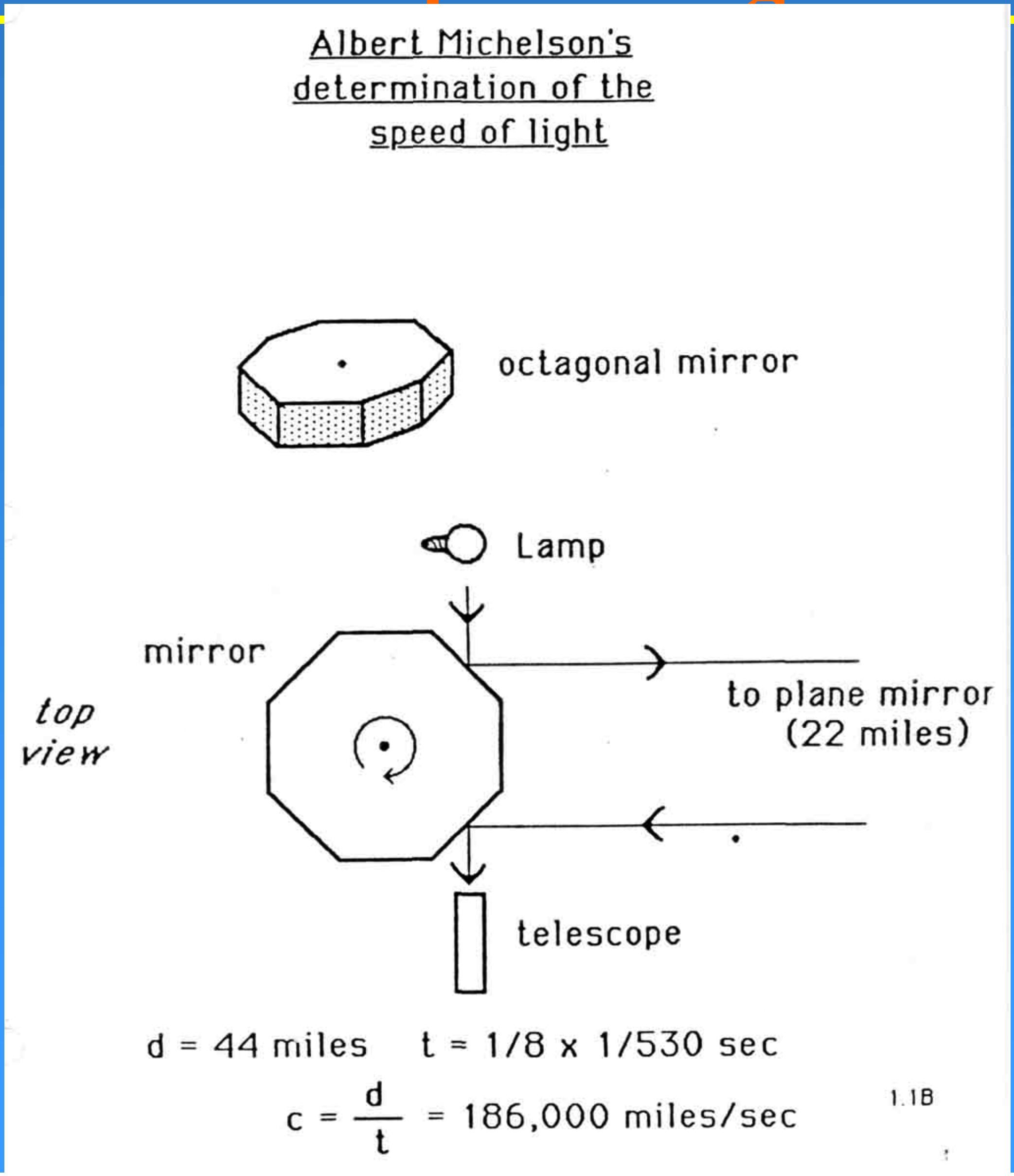
$t = 17$ minutes $= 1000$ sec

so $c = \dfrac{d}{t} = 186{,}000$ miles/sec

Albert Michelson's determination of the speed of light-1



Albert Michelson's determination of the speed of light-2



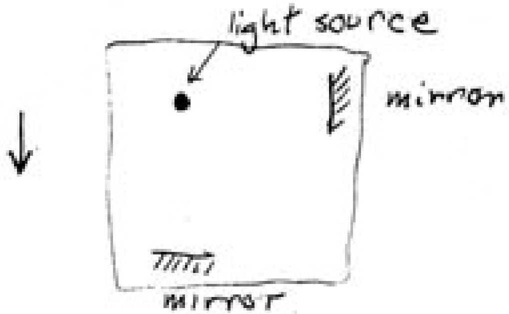
Properties of Light

- Source, object, detector or source, detector
- Straight line propagation
- Finite speed: c=300,000km/s = 186,000 miles/sec
- Needs no medium, but can also travel through transparent medium
- Carries energy
- Carries momentum
- polarization

Measuring our speed through the ether

Michelson-Morley experiment

1887

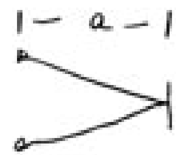


let v_e = our speed through aether

c = speed of light

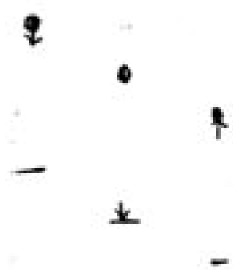
a = distance to mirrors

$\perp$ path



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

$\parallel$ path



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

so

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

Where does light come from

- **Charged particles are responsible for producing light**
  - positive (protons)
  - negative (electrons)
- **A charged particle has an electric field around it**
- **A moving charged particle makes a changing electric field and a changing magnetic field.**
- **If the charged particle oscillates, these field oscillate.**
- **These changing fields propagate (move) and are called electromagnetic waves**
- **These waves move at a fixed speed v = c**
- **These waves are also called electromagnetic radiation or light**

How is light detected?

- Electromagnetic waves may cause charged particles to move and to oscillate
- When a charge is part of a resonant system the response can be enlarged when the frequency of the electromagnetic oscillation matches the natural resonant frequency of the system
- (A simple resonant system is a child’s swing)
- Such oscillations can cause chemical reactions
- Such oscillations can be amplified electronically to produce large signals

Ideas of Light

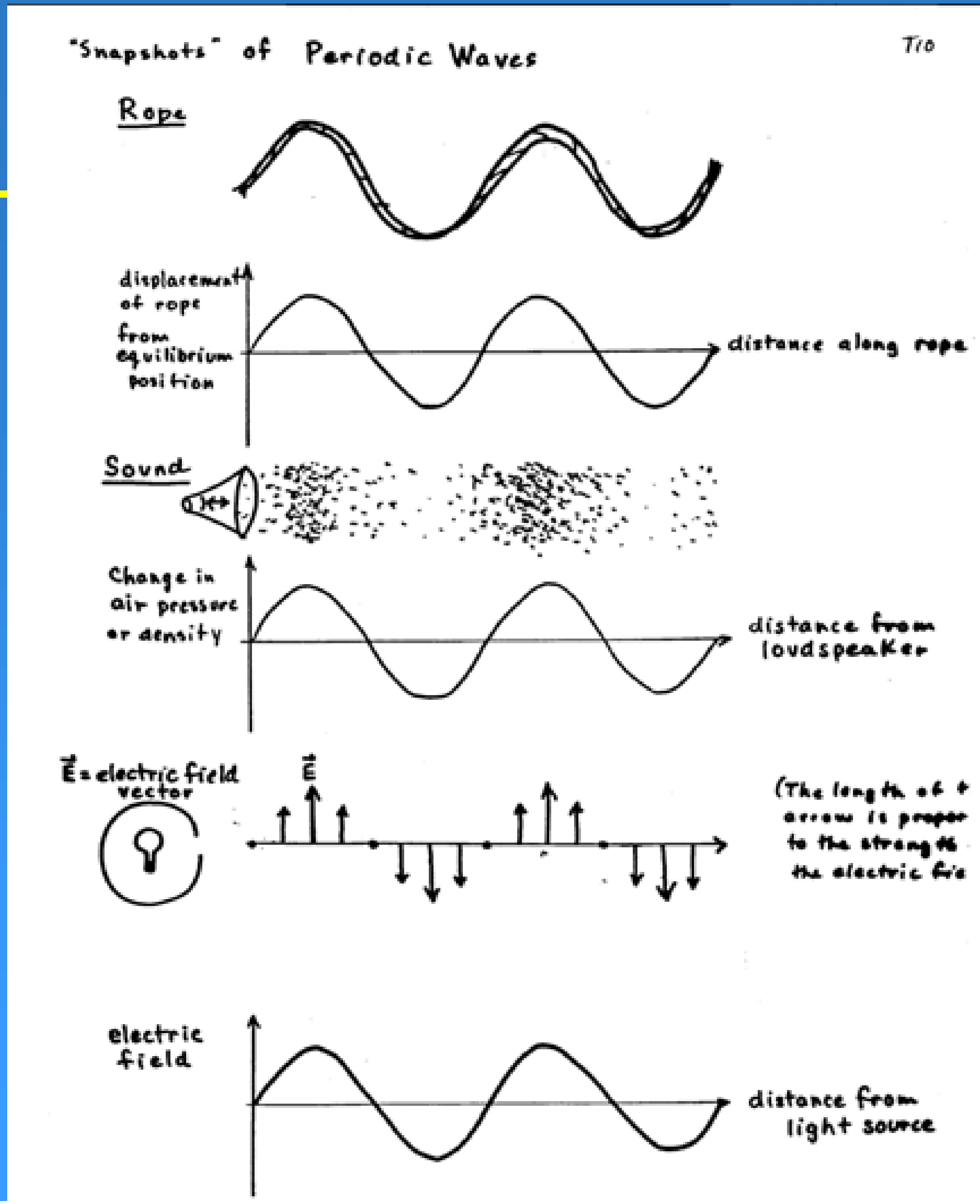
- **Particle model of light**
  - Newton was strong proponent, also Descartes
  - light goes in straight lines
  - principle of least distance
  - principle of least time
  - law of reflection
  - law of refraction (required speed of light to increase in materials)
  - no polarization

Ideas of Light-2

- **Wave model of light**
  - – idea is that a wave is a traveling disturbance
  - – water waves
  - – sound waves, traffic waves, football game waves
  - – waves in solids (jello, ropes, earthquakes, etc)
  - – fiction of "ether" often invoked to support light waves
  - – explains interference and diffraction and polarization
  - – Does not explain discrete detection of photons

Ideas of Light-3

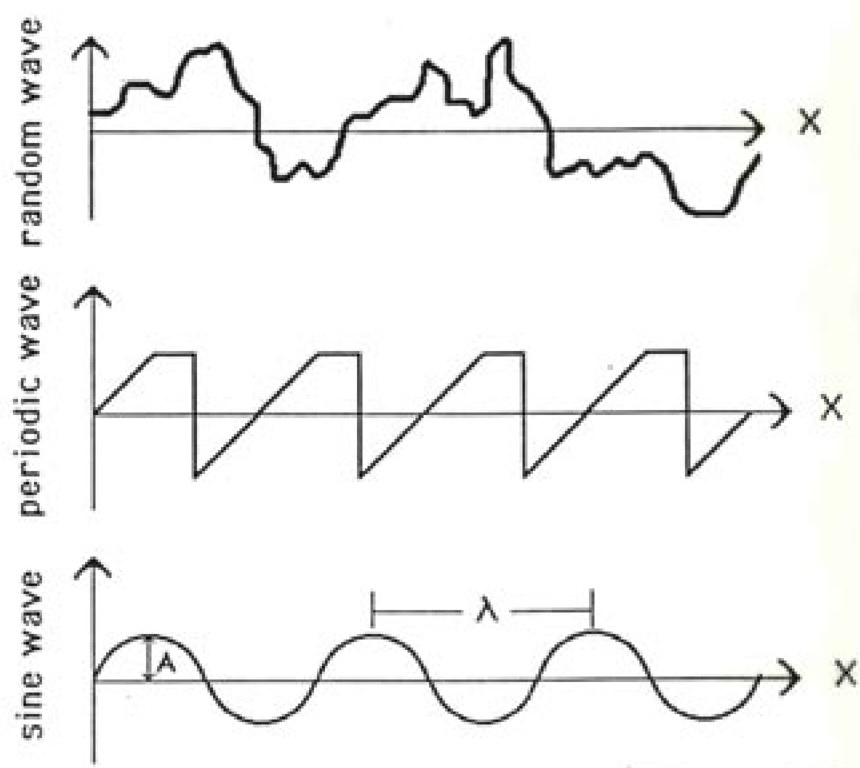
- **Modern model of light**
  - Quantum electrodynamics (QED) very complete but subtle model
  - has many wave characteristics
  - shaking electric charge causes undulations in electric field
  - has particle characteristics
  - photoelectric effect
  - light carries specific amount of energy (photons)
  - Wants to get to destination as quickly as possible (principle of least time)
  - Non deterministic theory: express results as probabilities
- **no known violations to its predictions**



"Snapshots" of Periodic Waves
T10
Rope
displacement of rope from equilibrium position
distance along rope
Sound
Change in air pressure or density
distance from loudspeaker
E = electric field vector
E
(The length of the arrow is proper to the strength the electric fie
electric field
distance from light source

$c = \lambda f$

"Snapshots" of sample waves



$f = \nu = 1/\tau$

A = amplitude

λ = wavelength [meters]

ν = frequency [Hz, osc/sec, 1/sec]

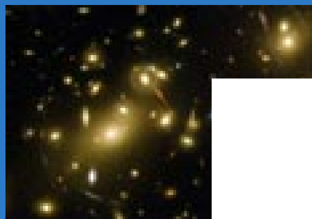
τ = period [sec]

v = velocity [m/s, miles/s]

$v = \lambda \nu$

1.3

$d = vt$, $v = \frac{d}{t} = \frac{\lambda}{\tau} = \lambda f = \lambda \nu$



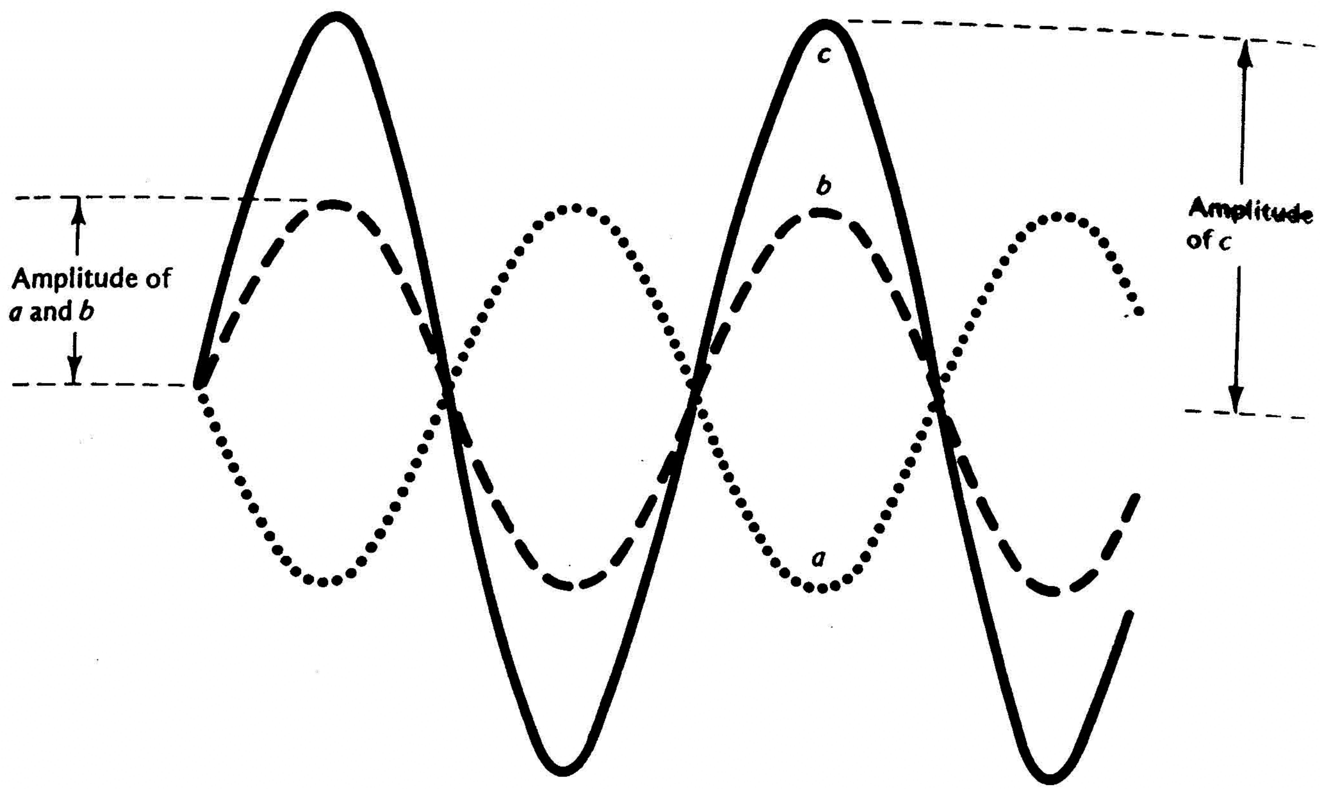
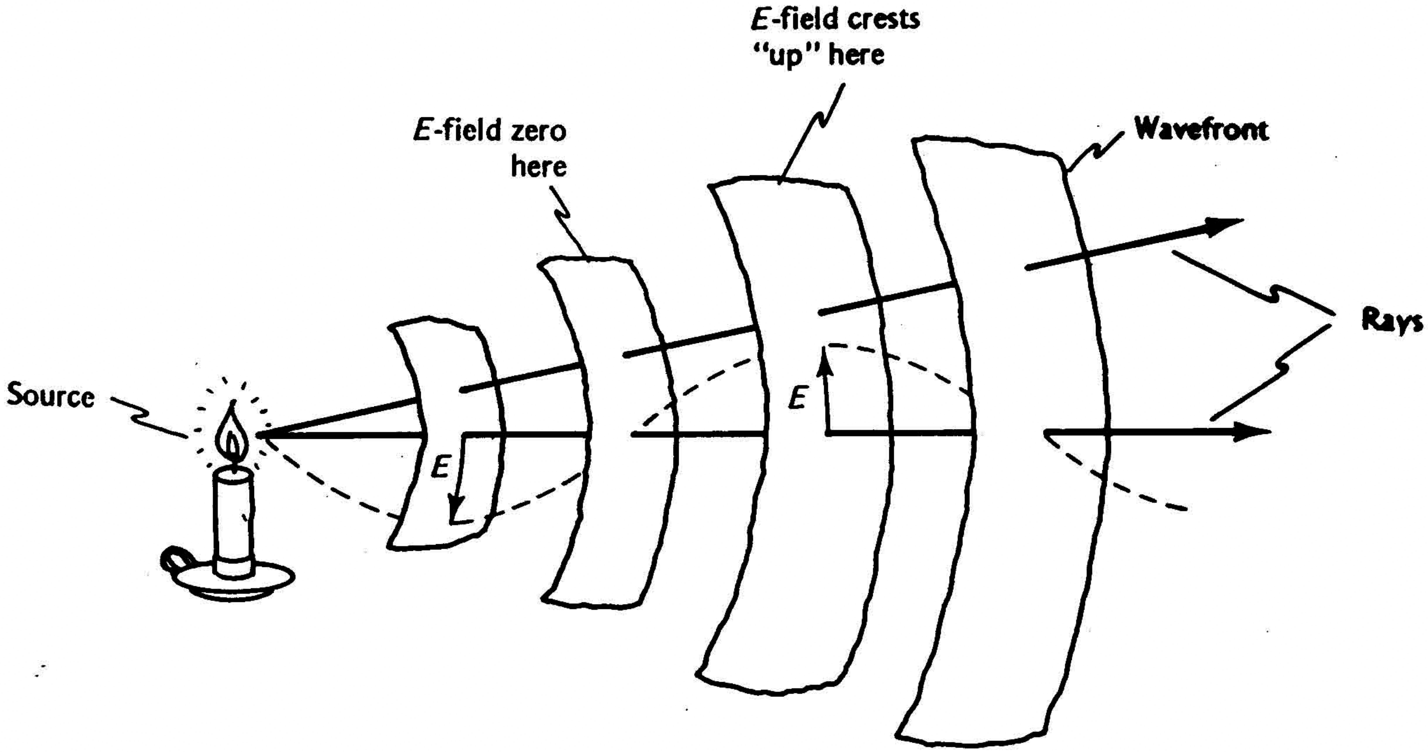


FIGURE 1.16

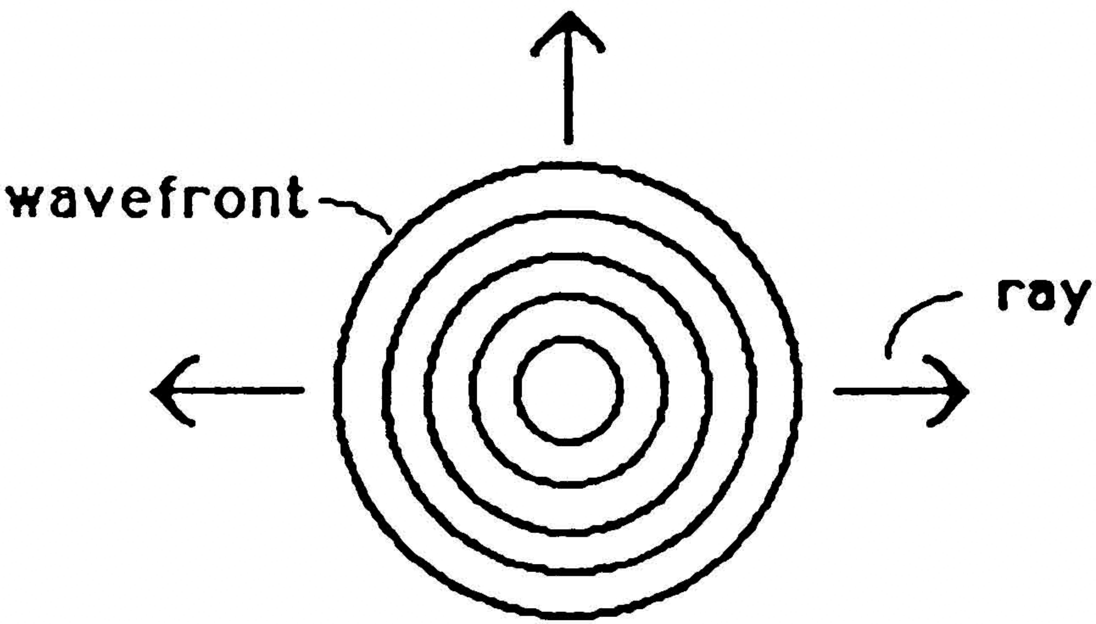
Three waves of different amplitudes and phases.

FIGURE 1.17

A snapshot of a wave traveling away from a small source showing the wavefronts. The rays are also marked. (Real candlelight is unpolarized.)

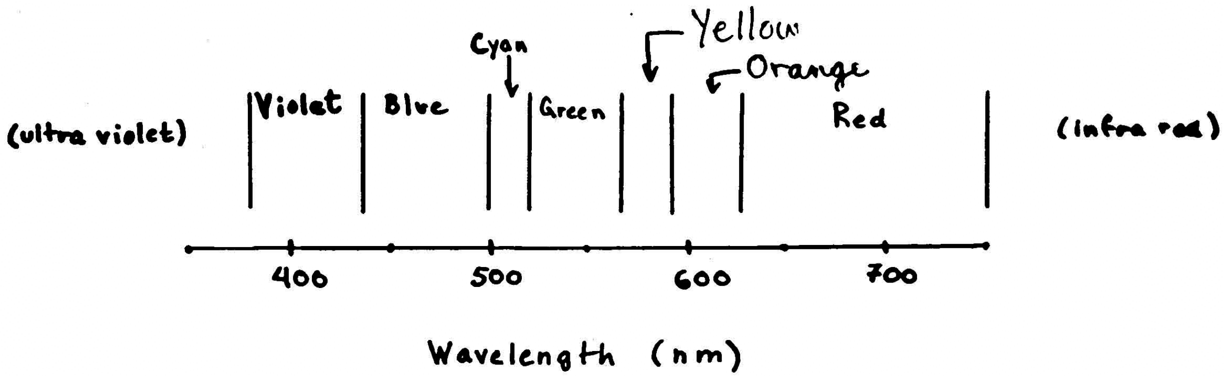


Wavefronts and rays

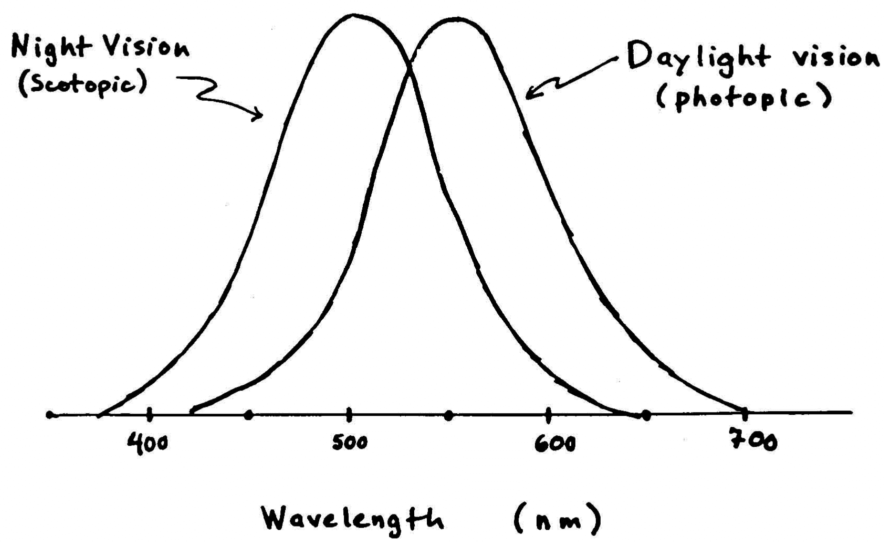


T13

Visible Light



Relative Sensitivity Curves for Daylight and Night Vision



Wave Nature of Light

- **Waves in general**
  - Have a wavelength λ
  - Have a frequency f
  - Have a speed c

  - fλ = c
- **This is true for sound waves, water waves, light waves**
  - Examples:
  - Visible light has λ = 500 nm, so f = c/λ = 3x108m/s / 500x10-9 m = 6x1014/s = 6x1014 Hz

  - FM radio has f = 100 MHz = 1x108 Hz
  - Or λ = c/f = 3x108m/s / 1x108/s = 3m wavelength

Brief History of Understanding of Light, color, optics, vision

Date	Person	Contribution
Classical		
250 BC	Euclid Greek mathematician	law of rectilinear propagation law of reflection
100 BC	Hero Greek scientist	principle of shortest path law of reflection
100-170	Claudius Ptolemy Greek astronomer	approx. law of refraction additive color mixing
965-1039	Alhazen Middle East scientist	sources illuminate objects optics of eye camera obscura

Brief History of Understanding of Light, color, optics, vision-2

- **Date Person Contribution**
- **Middle Ages and Renaissance:**
  - 1266?-1337 Giotto — emphasis on realism stimulate
    Florentine painter — an interest in perspective and optics
  - 1401-1428? Masaccio — perspective painter
    Italian
  - 1377?-1446 Brunelleschi — perspective painter, architect
    Italian
  - 1495-1575 Francesco Maurolico — recognized role of lens in eye
    Benedictine monk — for causing rays to converge
  - 1452-1519 Leonardo da Vinci — pinhole camera
    Italian painter
  - 1564-1642 Galileo Galilei — telescope, speed of light
    Italian scientist

Brief History of Understanding of Light, color, optics, vision-3

- **Date Person Contribution**
- **Middle Ages and Renaissance:**

Date	Person	Contribution
1571-1630	Johannes Kepler German astronomer	approx. law of refraction theory of lenses
1591-1626	Willebrord Snell Dutch mathematician	measured law of refraction
1596-1650	Rene Descartes French philosopher	law of refraction particle model
1601-1655	Pierre de Fermat French	principle of least time particle model
1642-1727	Isaac Newton English scientist	particle model, color, refraction, interference
1644-1710	Olaf Römer Danish astronomer	speed of light measurement

Brief History of Understanding of Light, color, optics, vision-4

- **Date Person Contribution**
- **Wave nature of Light**
  - 1618-1663 Francesco Grimaldi — wave theory of light
    Italian scientist
  - 1635-1703 Robert Hooke — wave theory of light
    English physicist
  - 1629-1695 Christian Huygens — wave theory of light
    Dutch physicist
  - 1773-1829 Thomas Young — interference
    English physicist
  - 1788-1827 Augustin Fresnel — diffraction
    French physicist
  - 1787-1826 Joseph von Fraunhofer — diffraction
    German physicist

Brief History of Understanding of Light, color, optics, vision-5

- **Date** **Person** **Contribution**
- **Wave nature of Light and modern theory**

Date	Person	Contribution
1821-1894	Hermann Helmholtz German physiologist	wave theory, color mixing physiological optics
1831-1879	James Clerk Maxwell Scottish physicist	science of colorimetry first color photograph theory of electromagnetism
1858-1947	Max Planck German physicist	proposed electromagnetic energy is quantized
1879-1955	Albert Einstein German physicist (US citizen >1940)	deduced that energy of photon is proportional to its frequency
1918-1988	Richard Feynman	Quantum electrodynamics

Sources of Light

- **Black bodies**
  - Stars
  - the Sun
  - molten lava
  - blast furnaces
  - the moon?
  - the blue sky?
- **Chemical combustion**
  - wood fire
  - candles
  - alcohol fire
  - blowtorch
  - gas mantle lantern

Sources of Light-2

- **Electrical sources**
  - lightning
  - incandescent lights (tungsten filament)
  - carbon arc
  - discharge lamps (mercury vapor, sodium)
  - fluorescent lights (mercury vapor + phosphor coating)
  - high intensity discharge lamps (high pressure)
  - lasers
  - phosphors from TV set (electron bombardment)
- **Biological**
  - fireflies
  - some fish