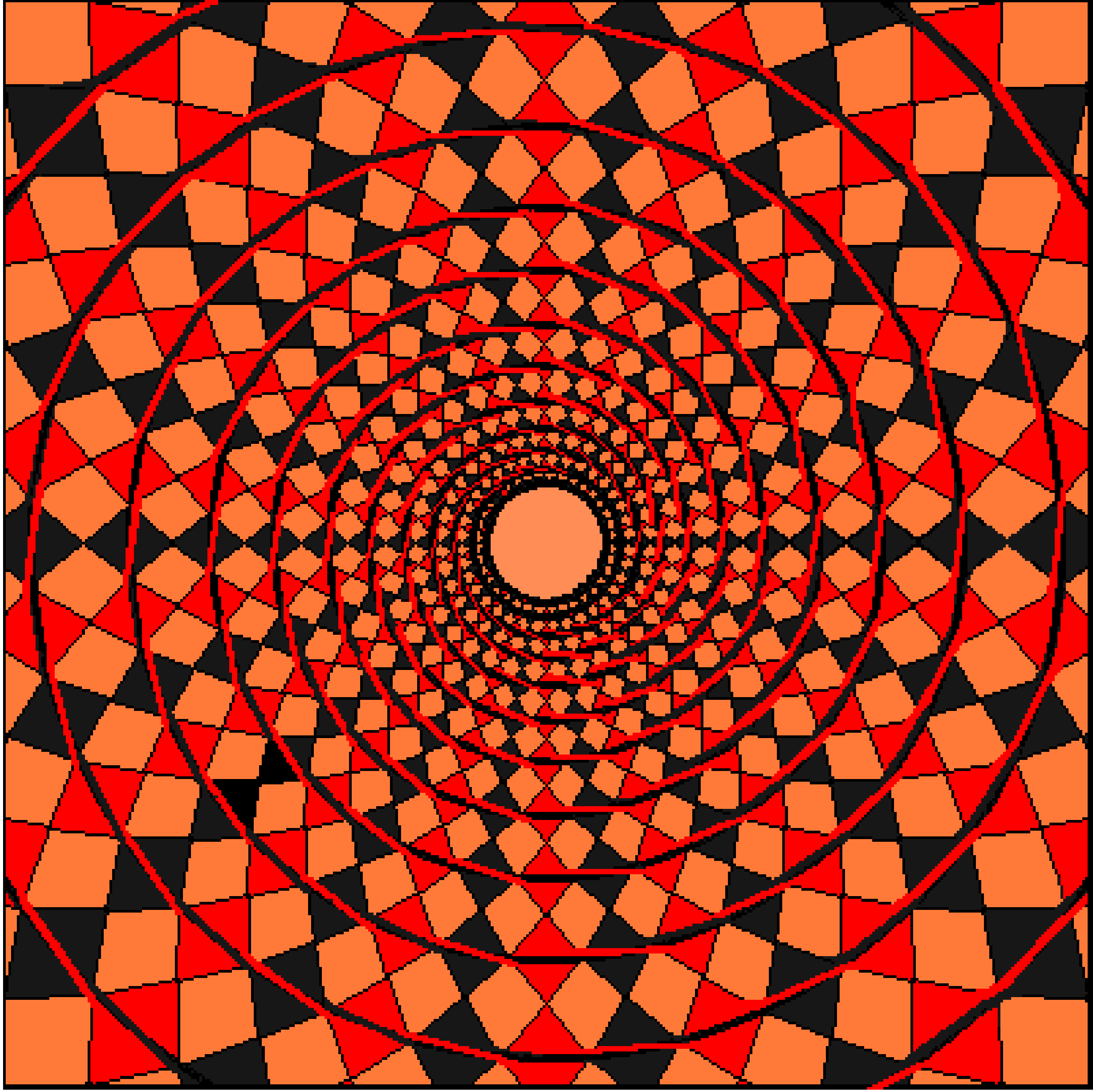
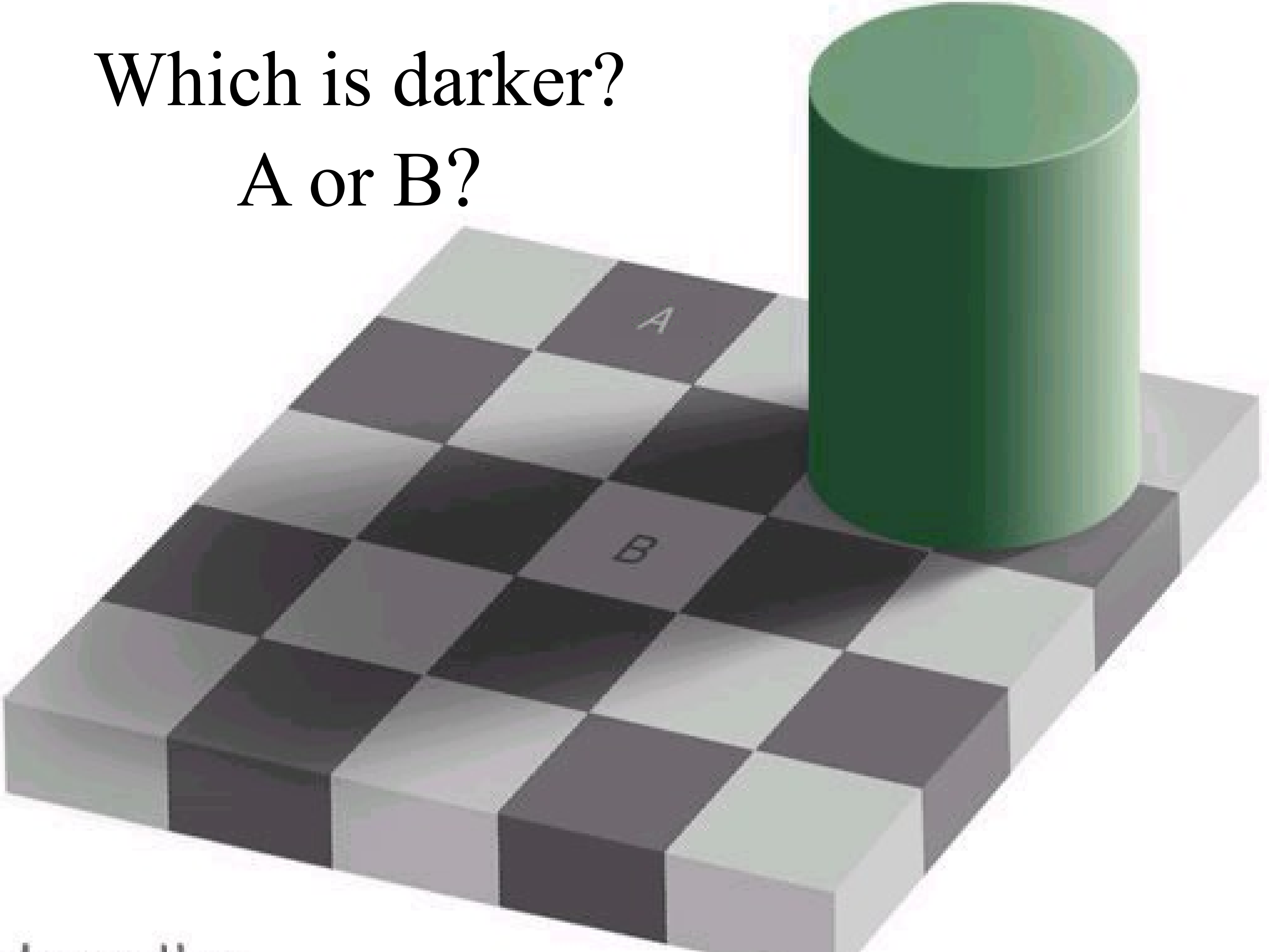
Optics

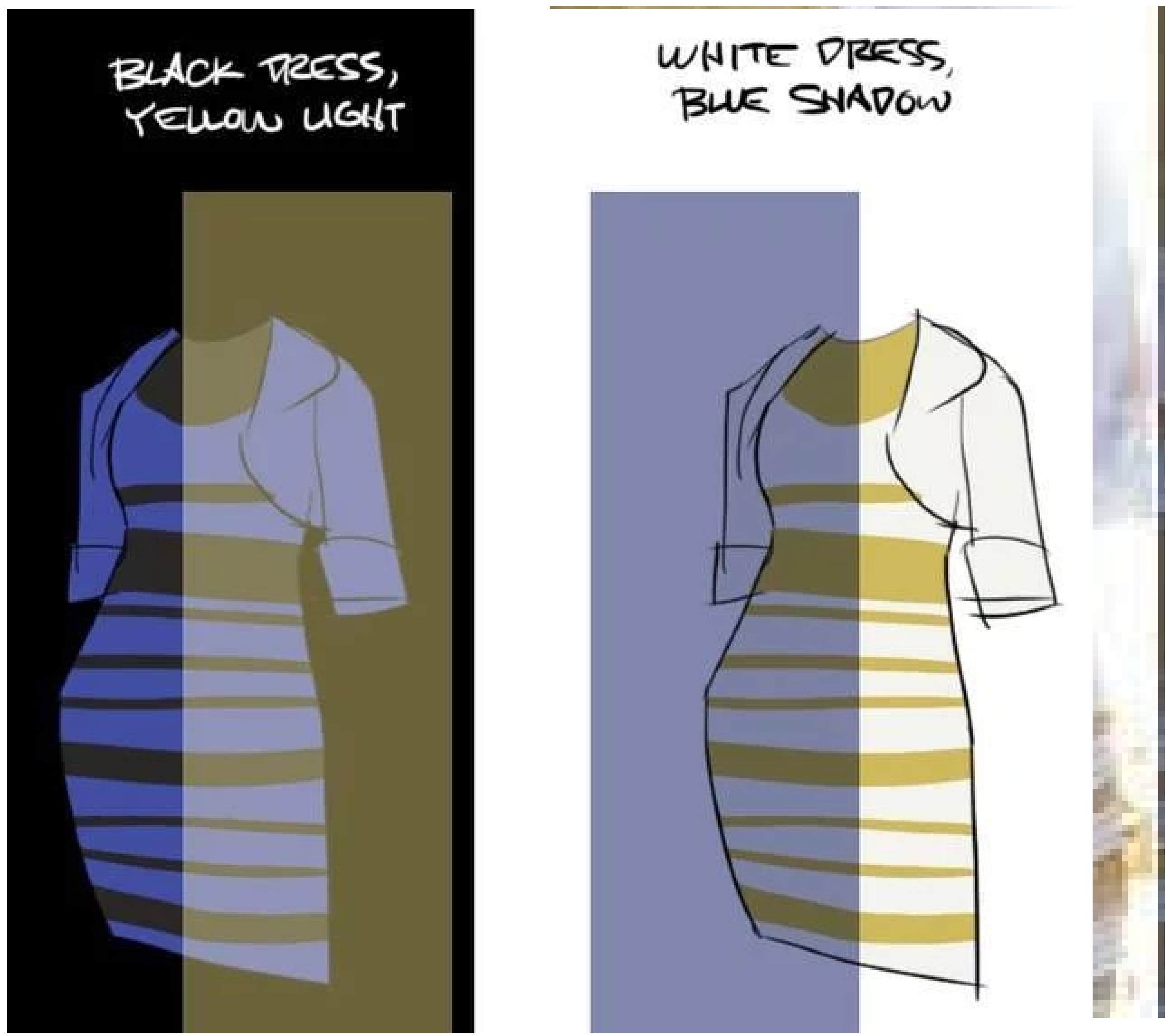
Circles
or
Spiral?

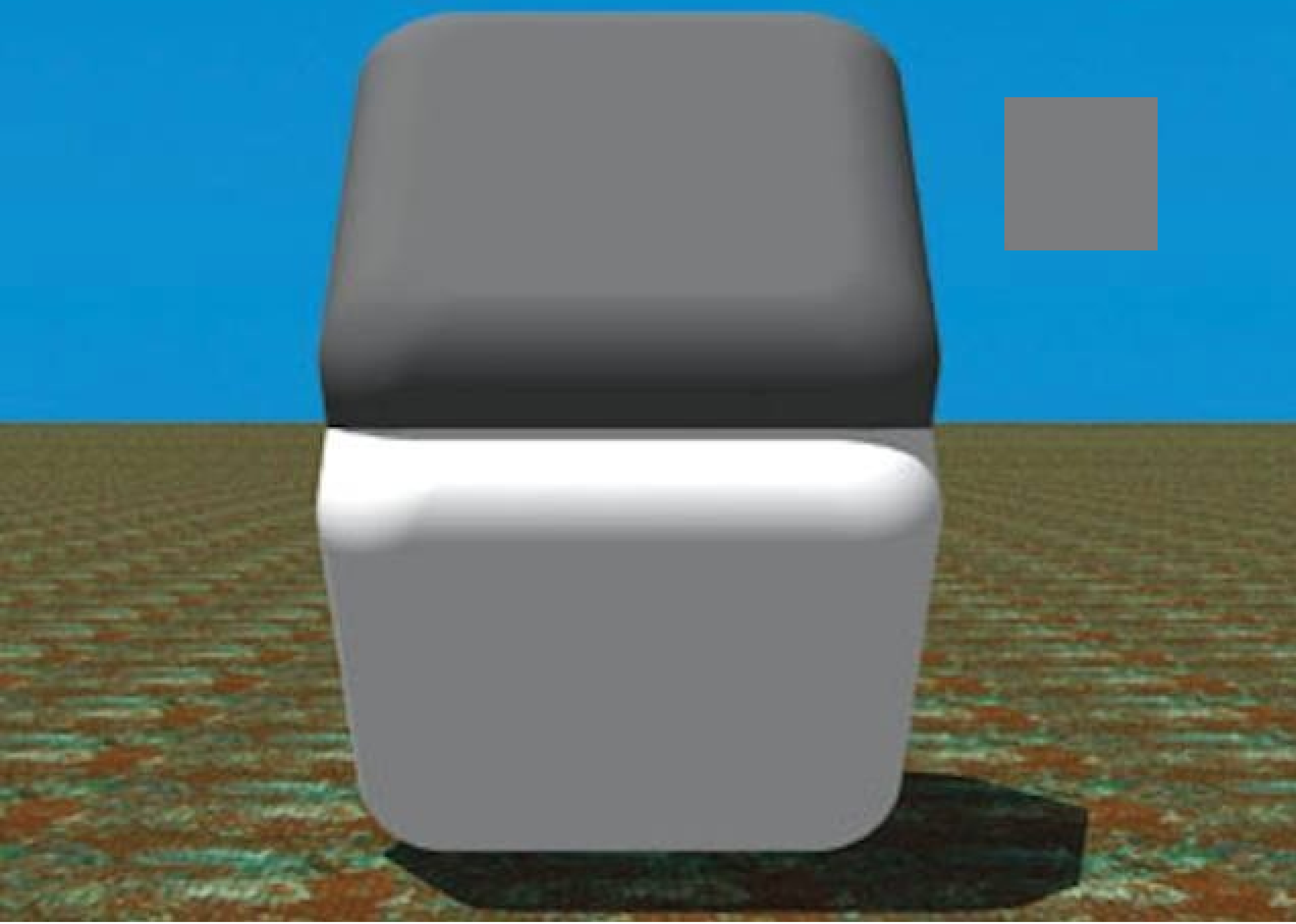


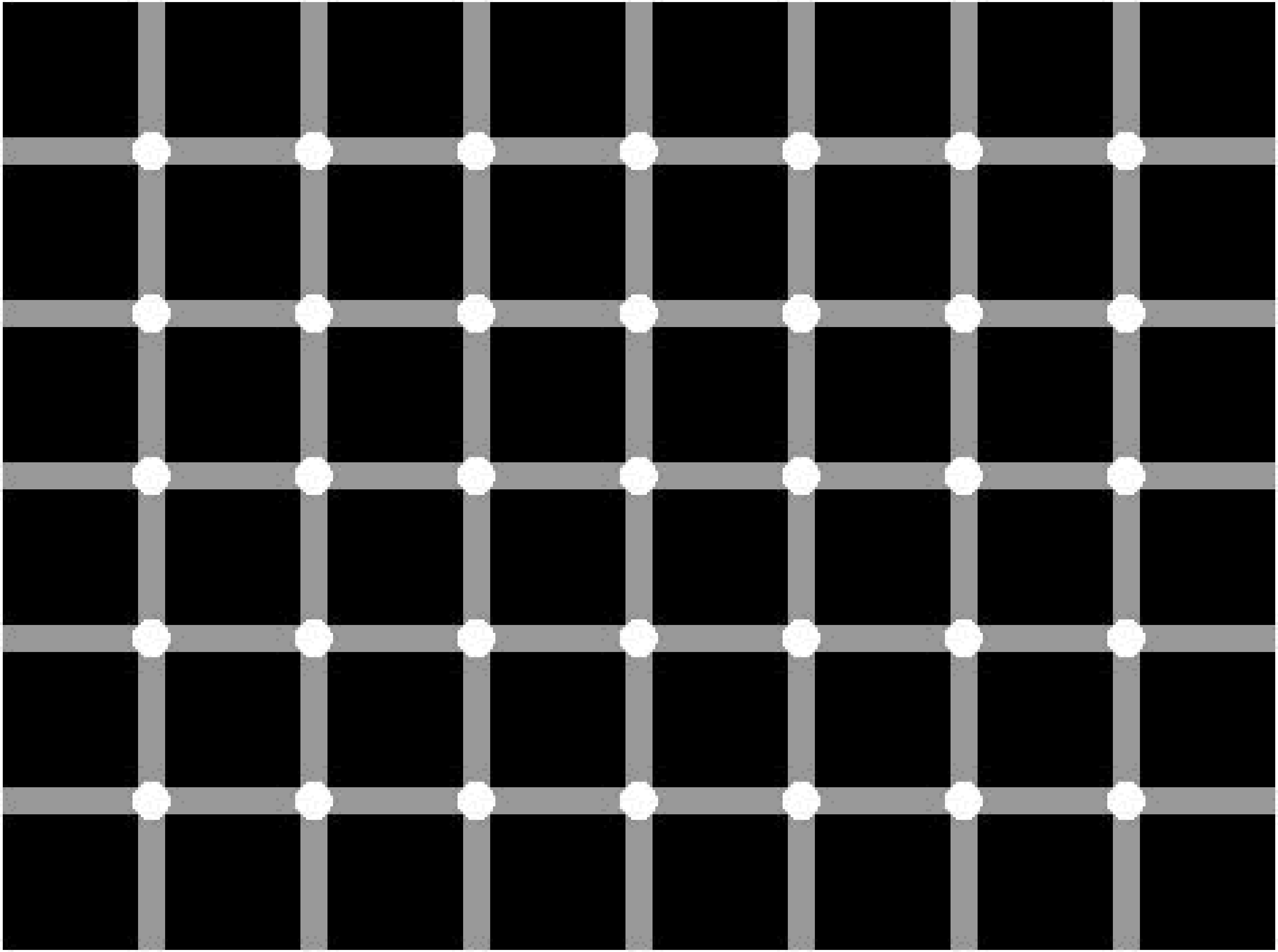
Which is darker?
A or B?

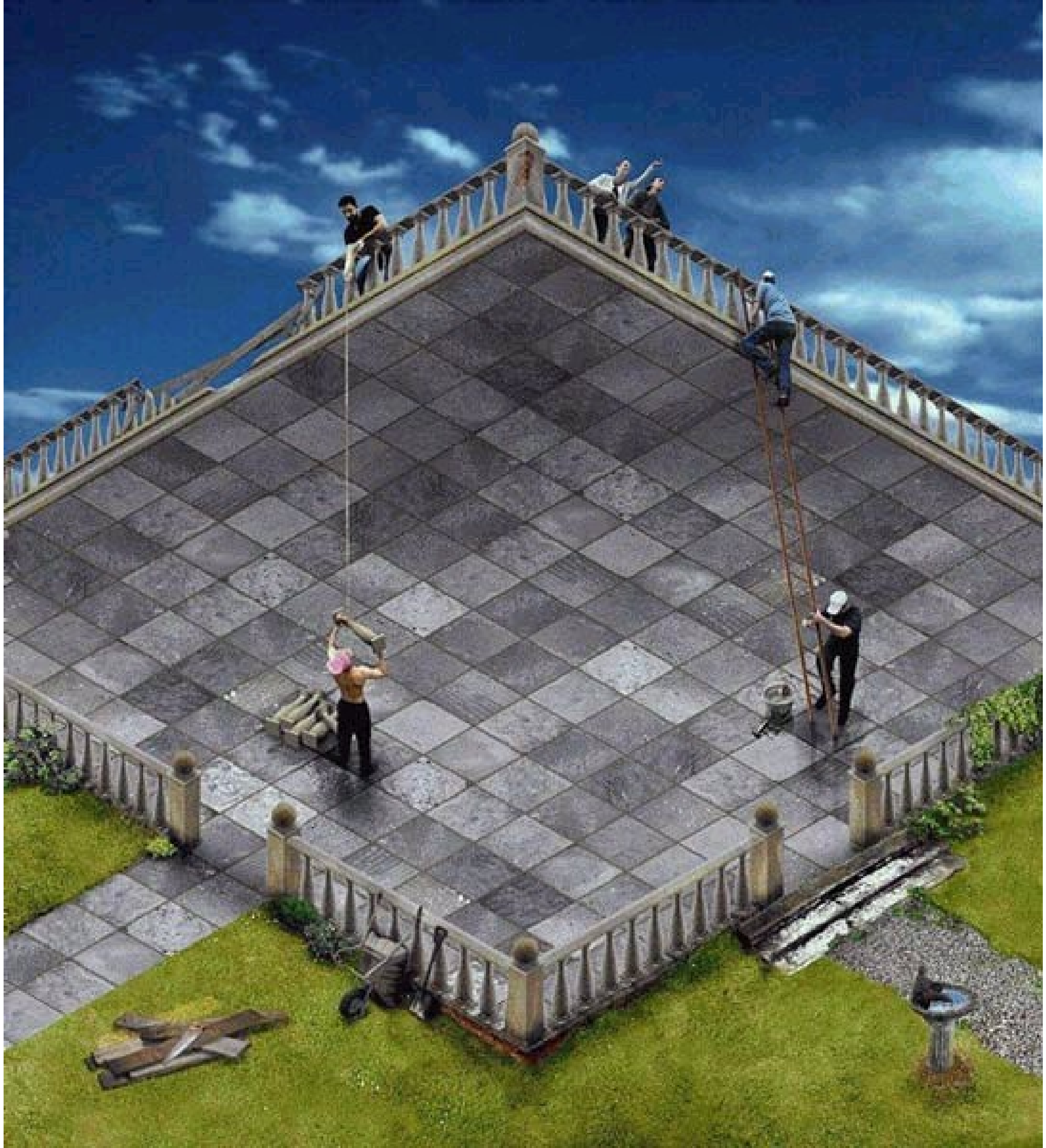


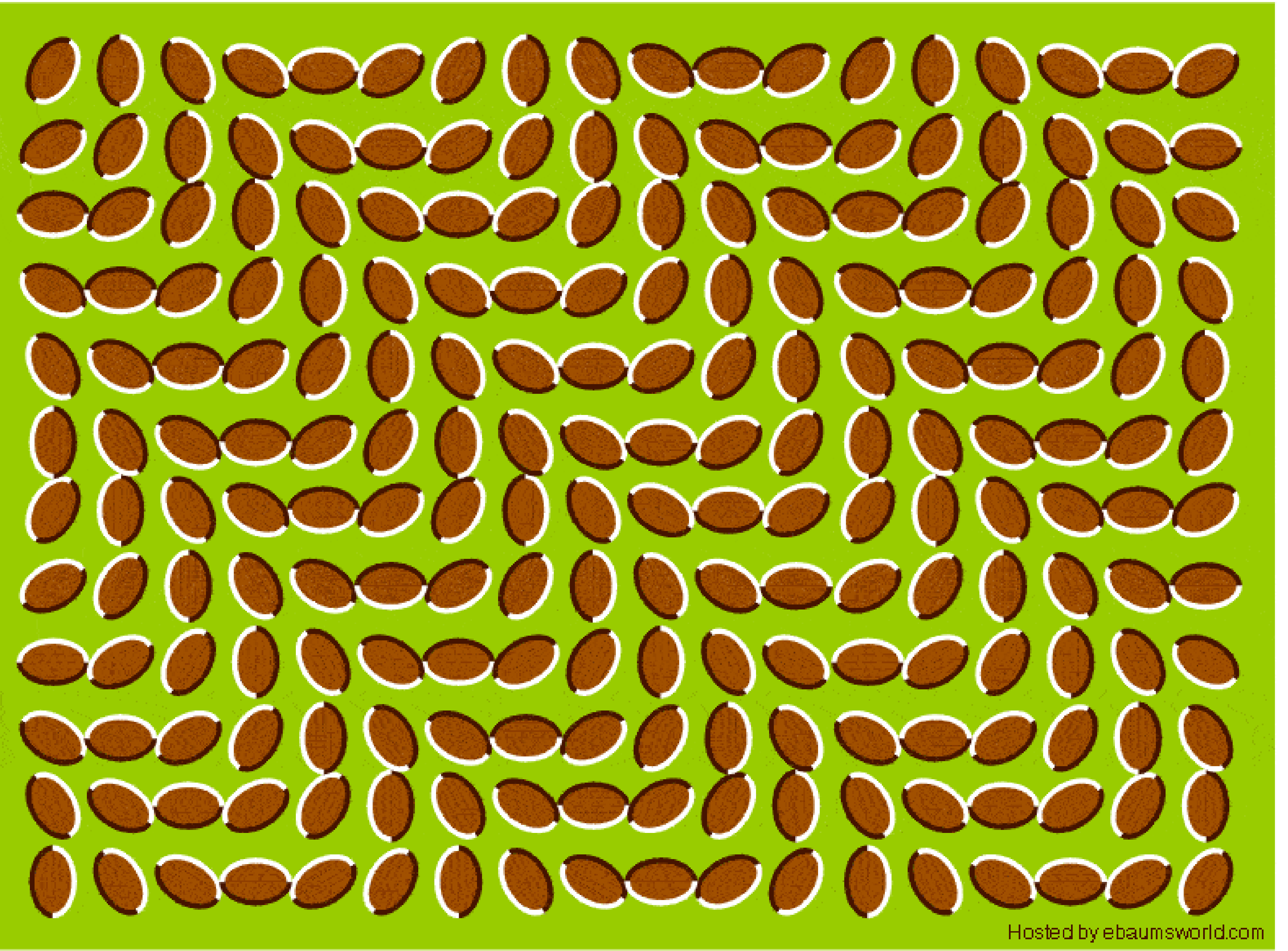
What color is the dress?










Hosted by ebaumsworld.com

Look at the chart and say the COLOR not the word

YELLOW BLUE ORANGE
BLACK RED GREEN
PURPLE YELLOW RED
ORANGE GREEN BLACK
BLUE RED PURPLE
GREEN BLUE ORANGE

Left - Right Conflict

Your right brain tries to say the color but your left brain insists on reading the word

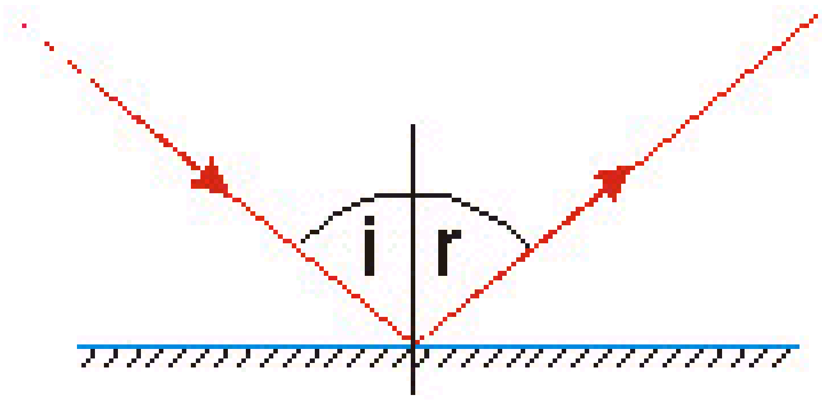
Confused yet?

Ray Diagrams

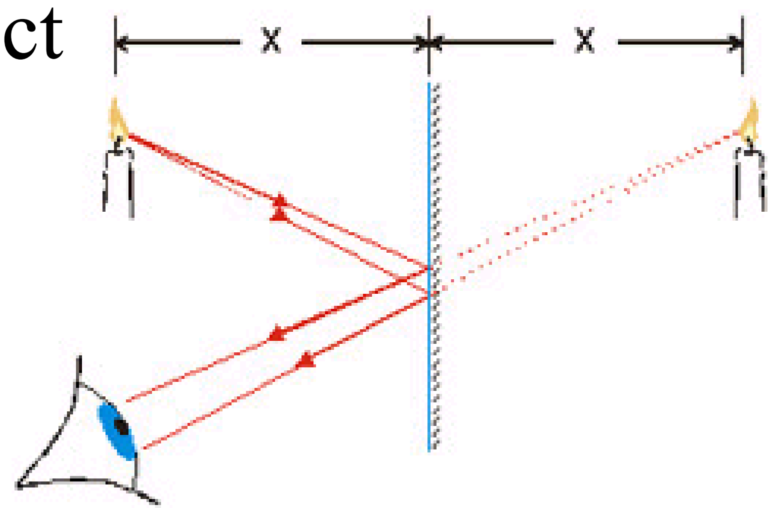
- Everybody loves Ray diagrams!

Law of Reflection

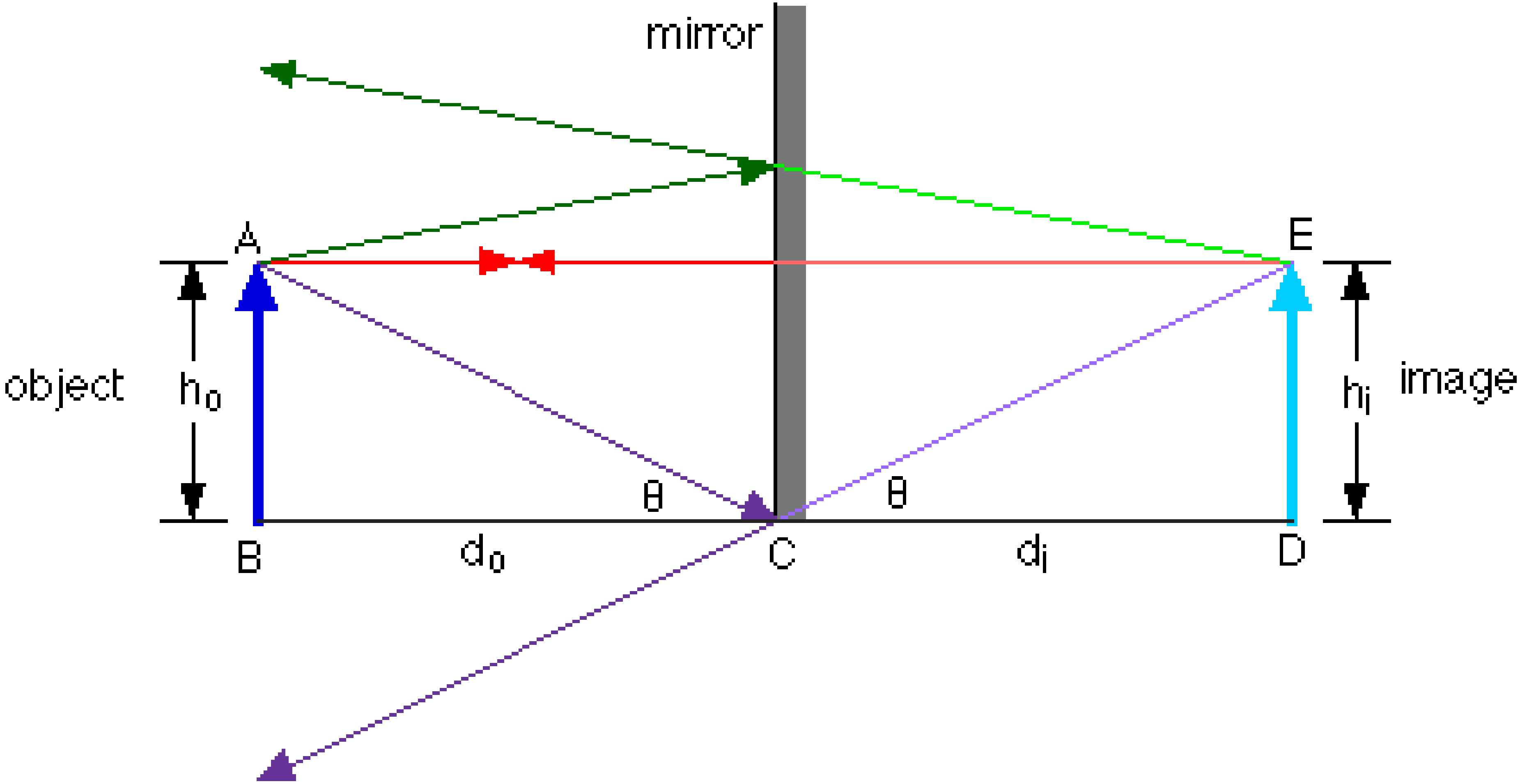
- Incident angle = Reflected angle



- We can use this to draw ray diagrams and locate the image of an object

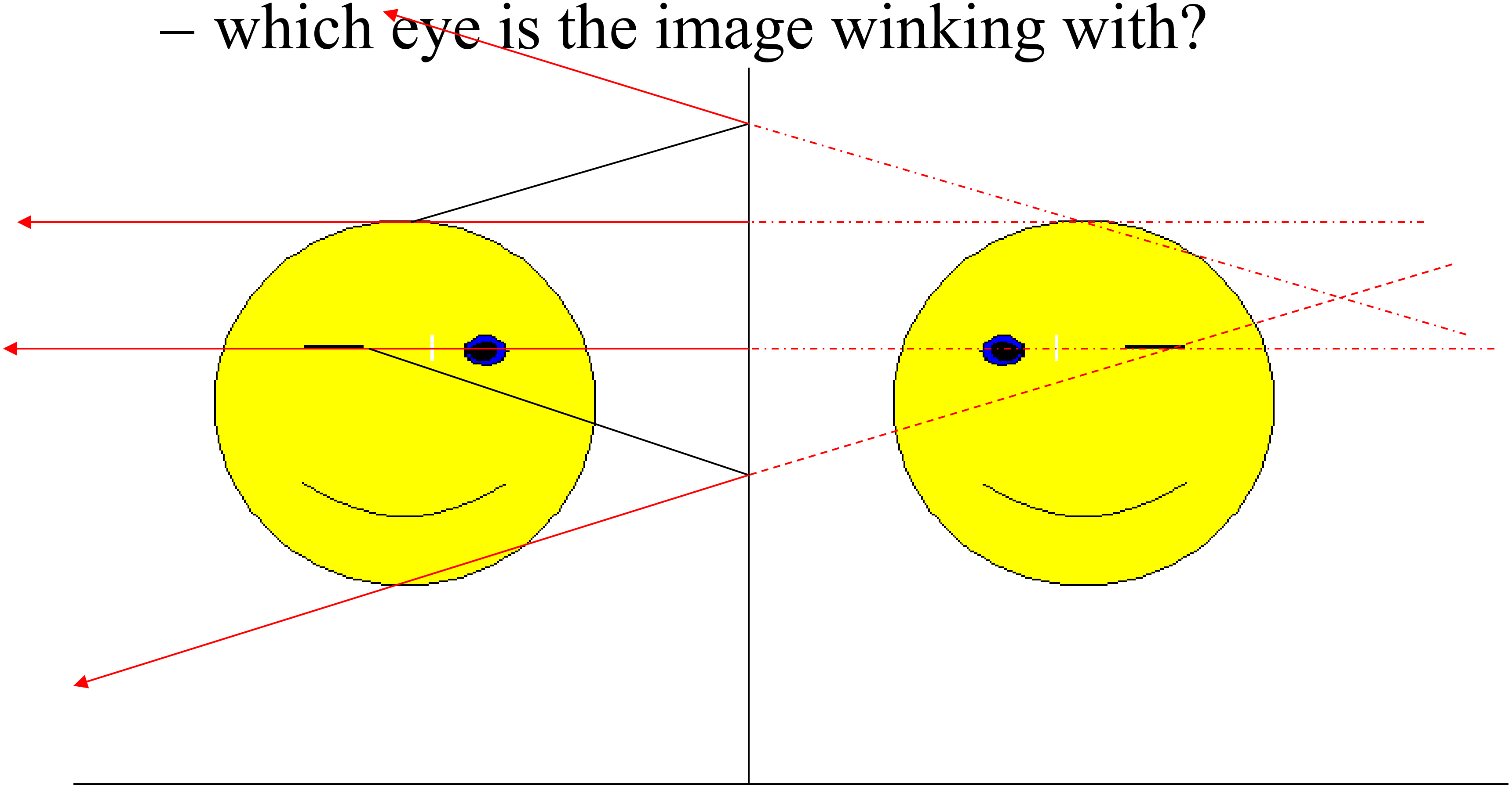


- The image can be located by tracing reflected rays back to where they seem to come from



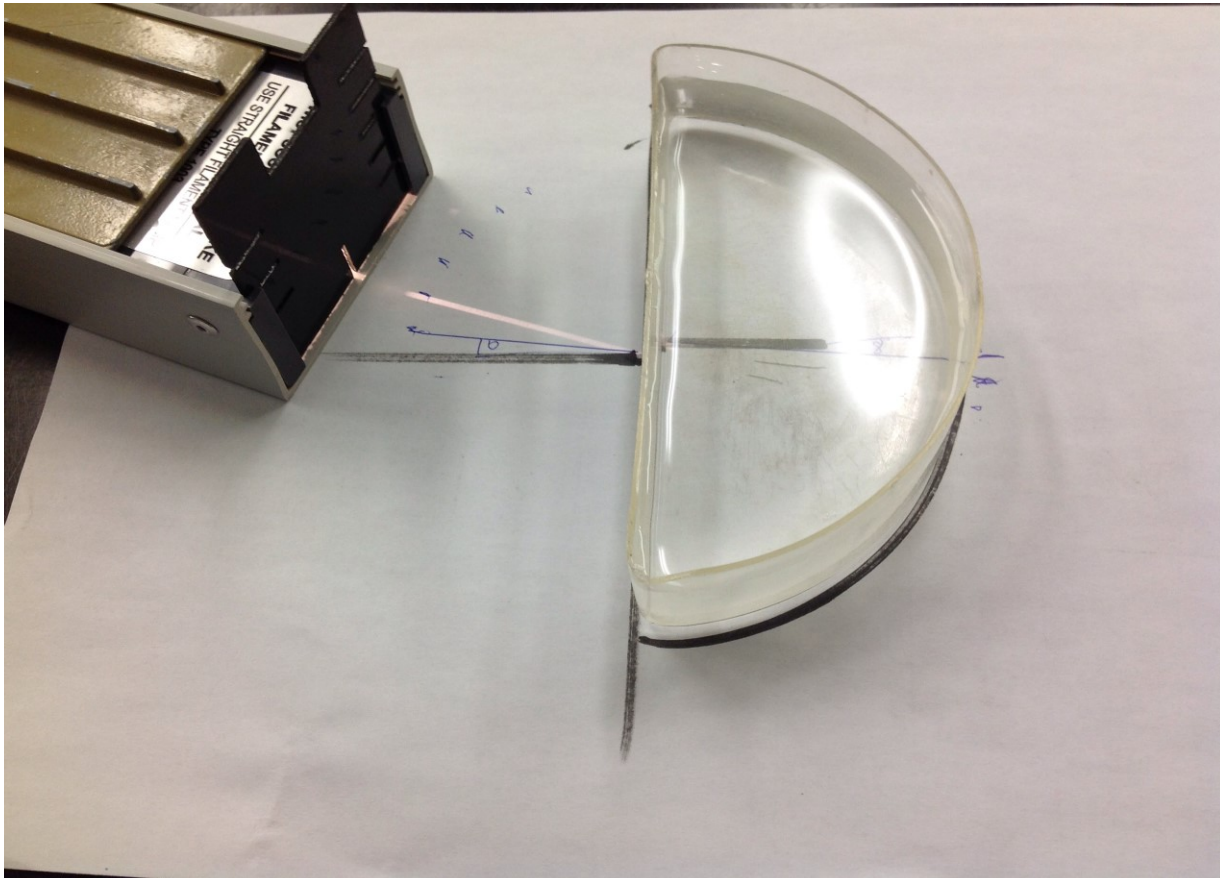
  – virtual

- Ex 1: use a ray diagram to locate the image
  - which eye is the image winking with?

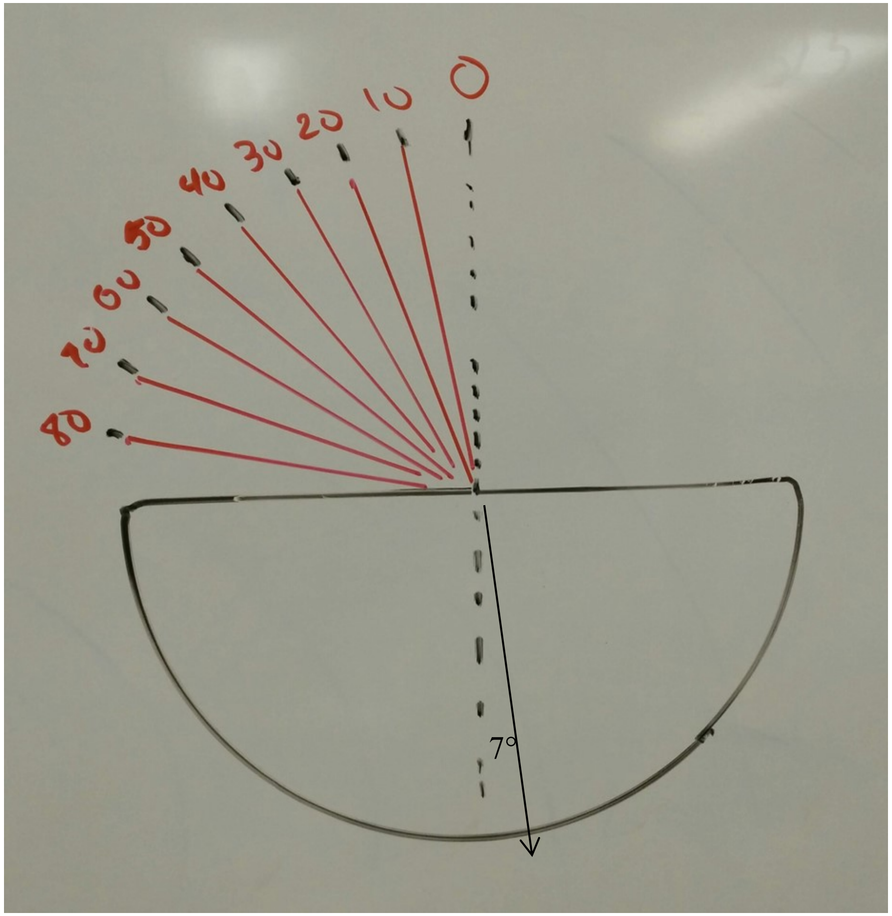


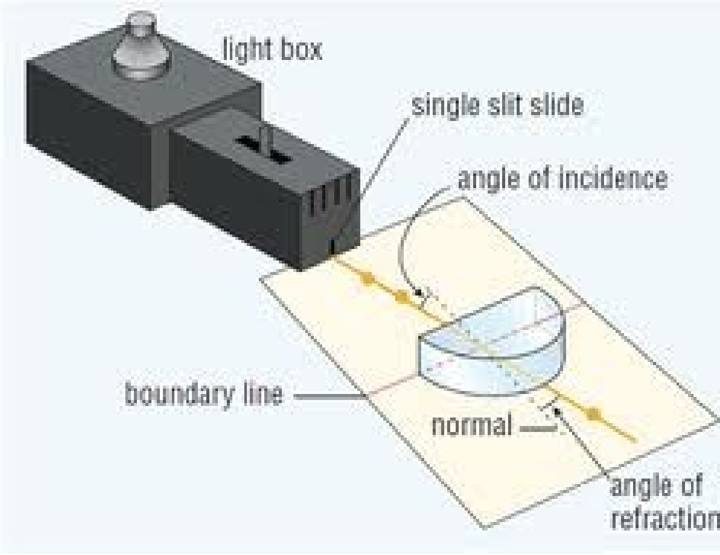
Exercises

- P. 214 #2,5,6
- Lab p. 215: only water!



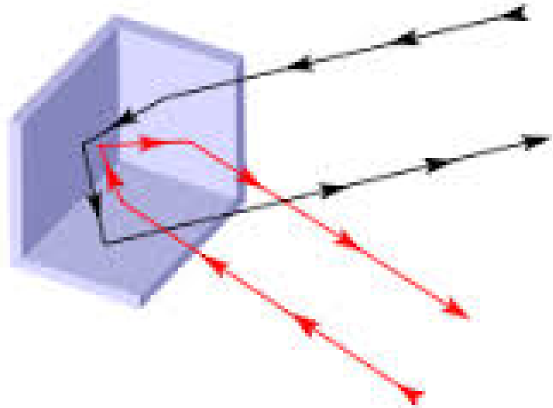
Snell's Law: Lab p. 215

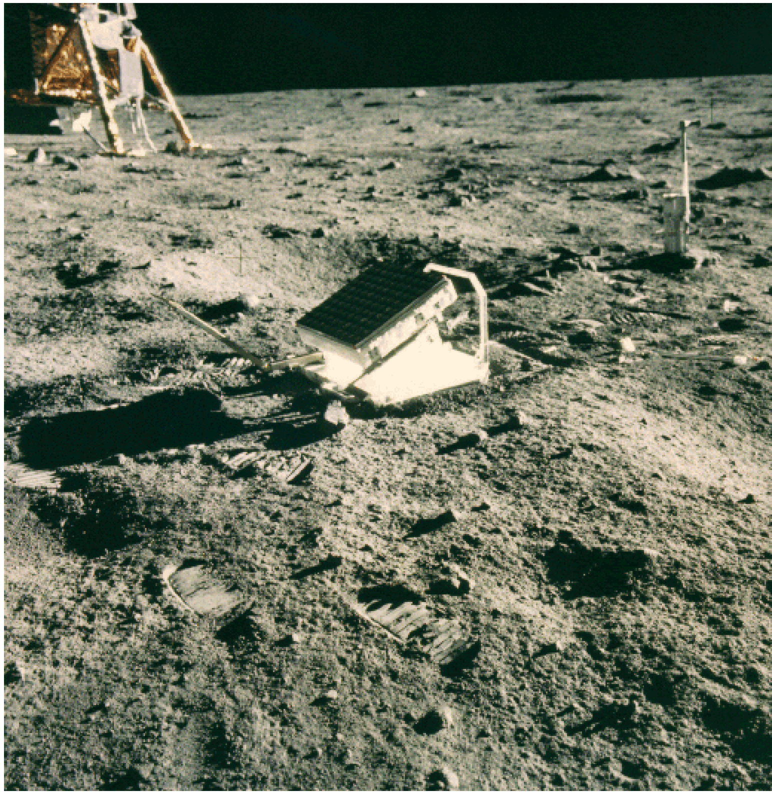




Retroreflector on the moon!

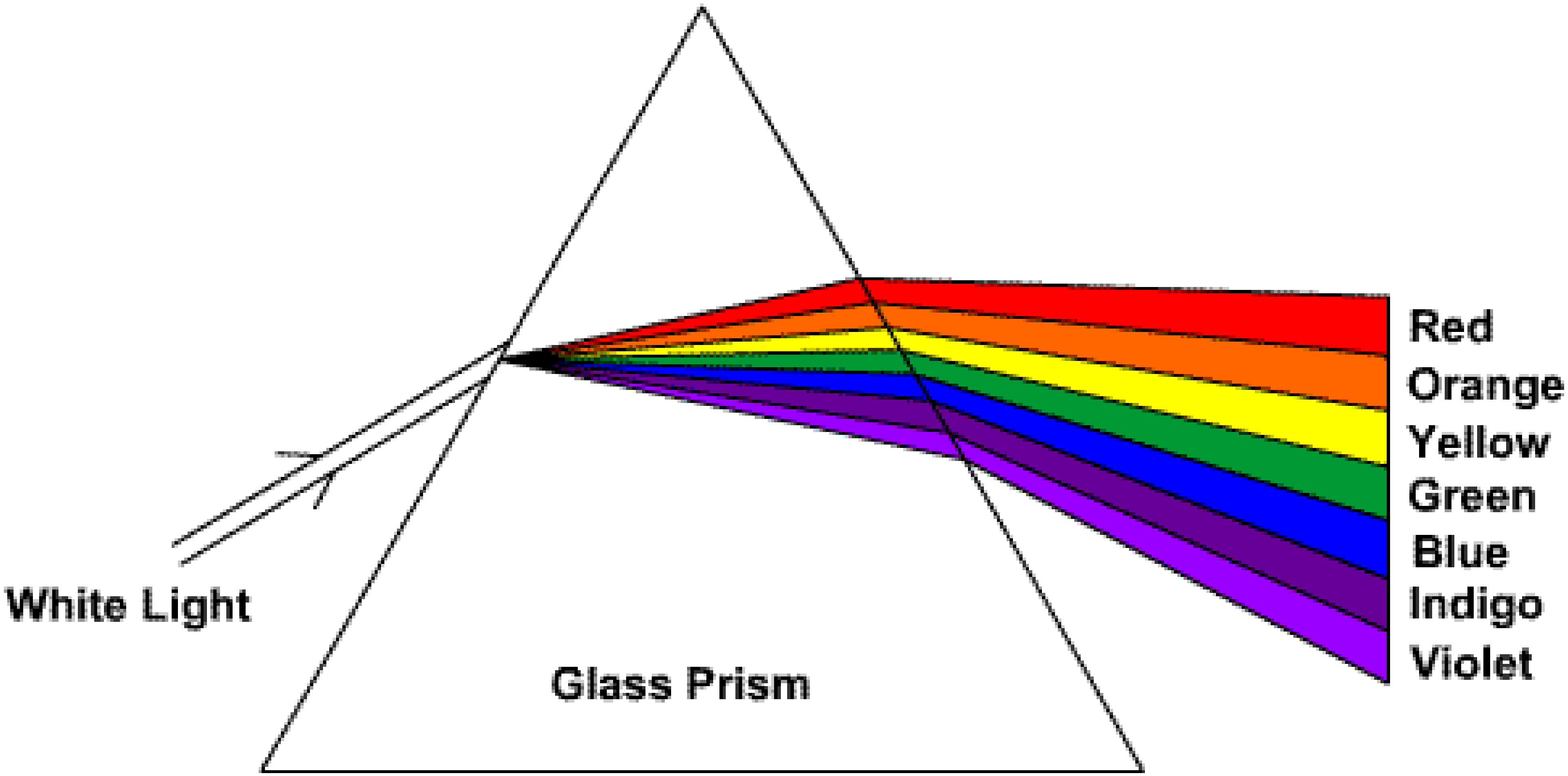
- Three right angles should cause the “laser” to bounce back directly





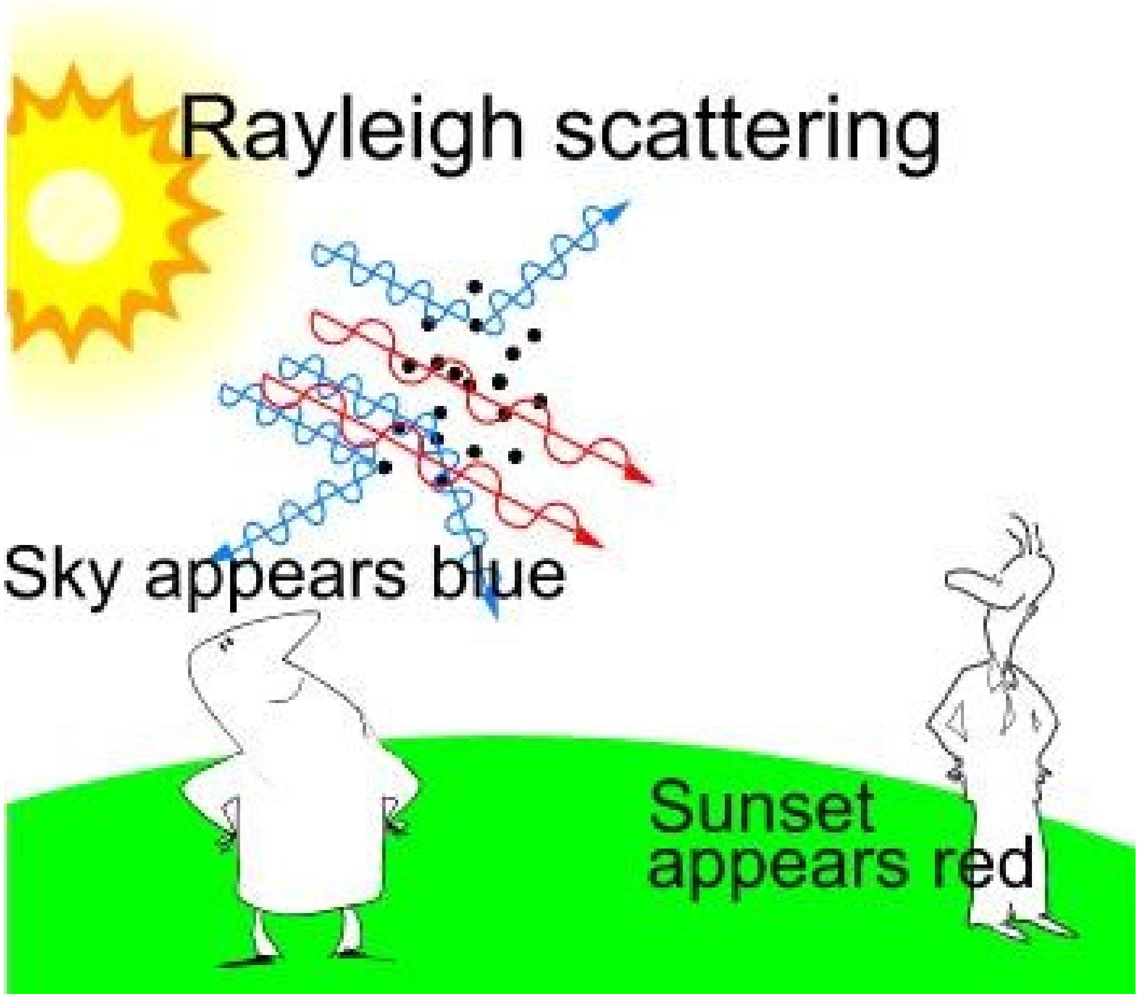
Dispersion

- Different wavelengths refract more



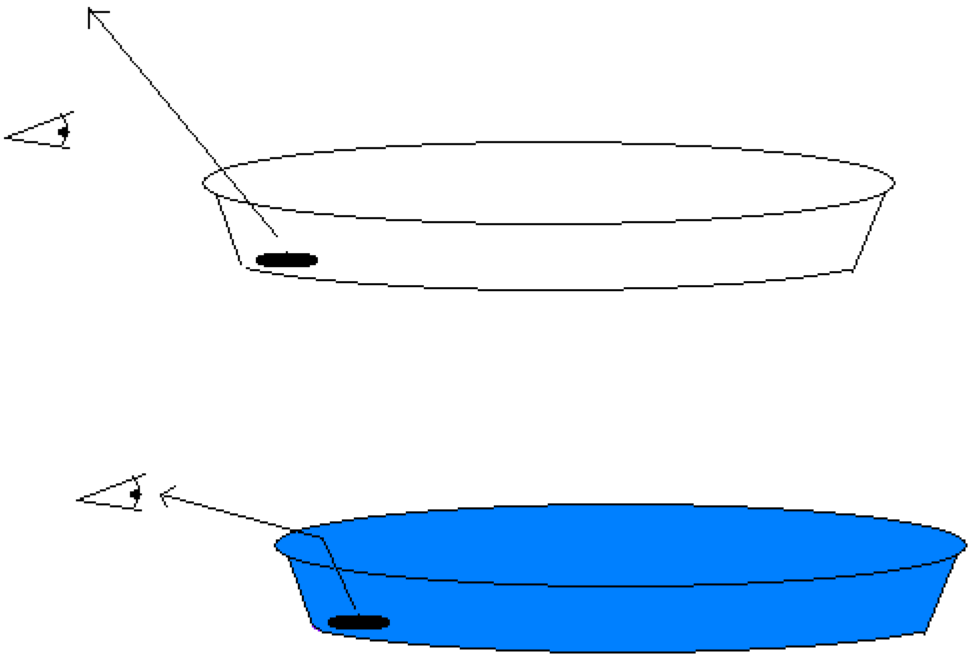
Scattering

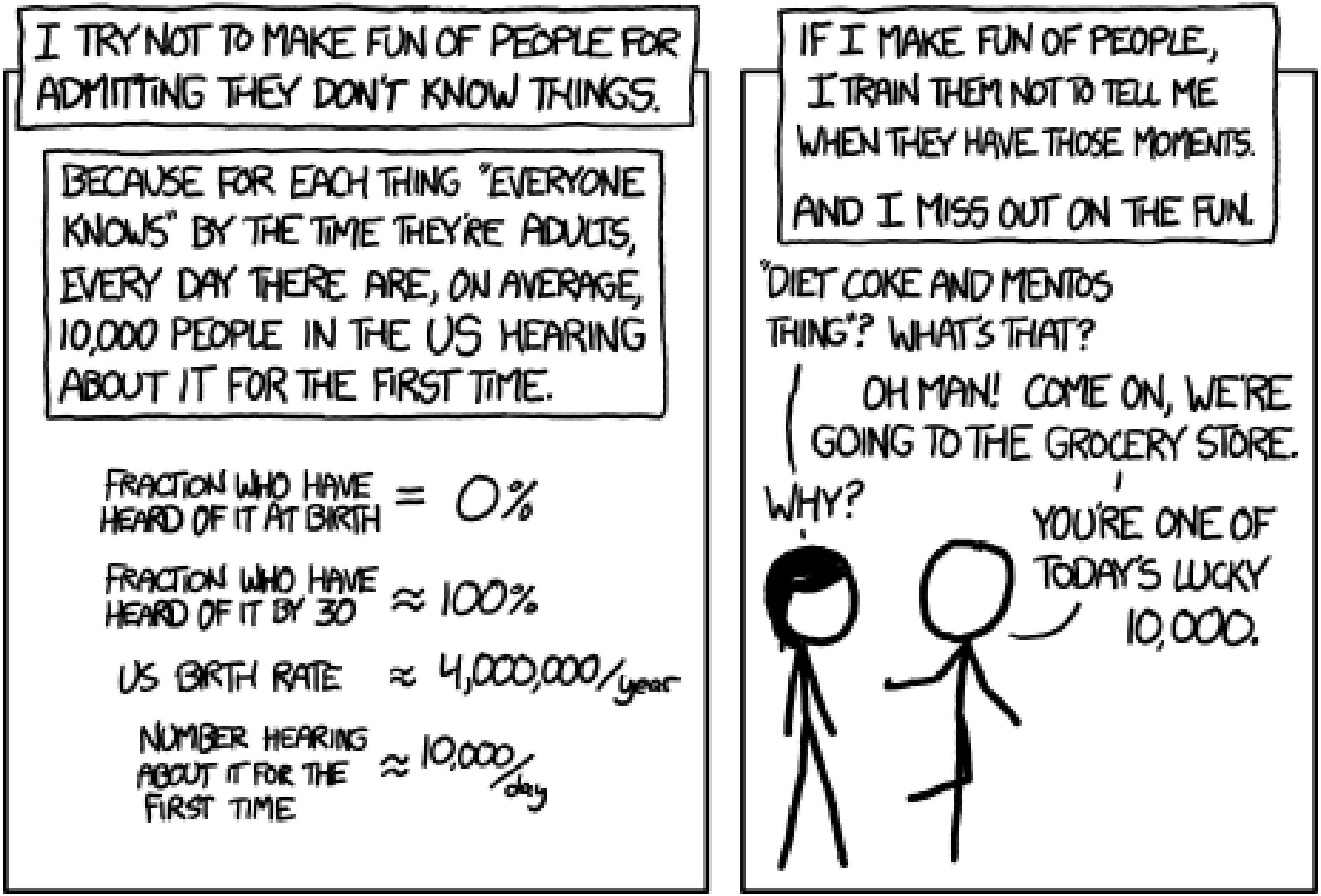
- Why is the sky blue?



Refraction of Light

The amazing "reappearing penny"

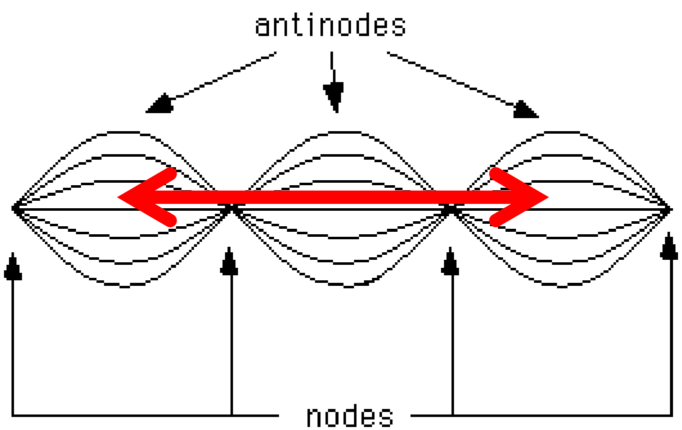




I TRY NOT TO MAKE FUN OF PEOPLE FOR ADMITTING THEY DON'T KNOW THINGS.
BECAUSE FOR EACH THING "EVERYONE KNOWS" BY THE TIME THEY'RE ADULTS, EVERY DAY THERE ARE, ON AVERAGE, 10,000 PEOPLE IN THE US HEARING ABOUT IT FOR THE FIRST TIME.
FRACTION WHO HAVE HEARD OF IT AT BIRTH = 0%
FRACTION WHO HAVE HEARD OF IT BY 30 ≈ 100%
US BIRTH RATE ≈ 4,000,000/year
NUMBER HEARING ABOUT IT FOR THE FIRST TIME ≈ 10,000/day
IF I MAKE FUN OF PEOPLE, I TRAIN THEM NOT TO TELL ME WHEN THEY HAVE THOSE MOMENTS.
AND I MISS OUT ON THE FUN.
"DIET COKE AND MENTOS THING"? WHAT'S THAT?
OH MAN! COME ON, WE'RE GOING TO THE GROCERY STORE.
WHY?
YOU'RE ONE OF TODAY'S LUCKY 10,000.

Chocolate Lab

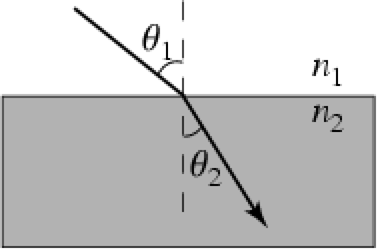
- According to the microwave, the frequency is 2450 MHz
- The distance between melt spots will be half the wavelength
- Ex: 7 cm between antinodes



$$c = f\lambda$$

$$c = 2450 \times 10^{6} (0.14m)$$

$$c = 3.4 \times 10^{8} \, m/s$$



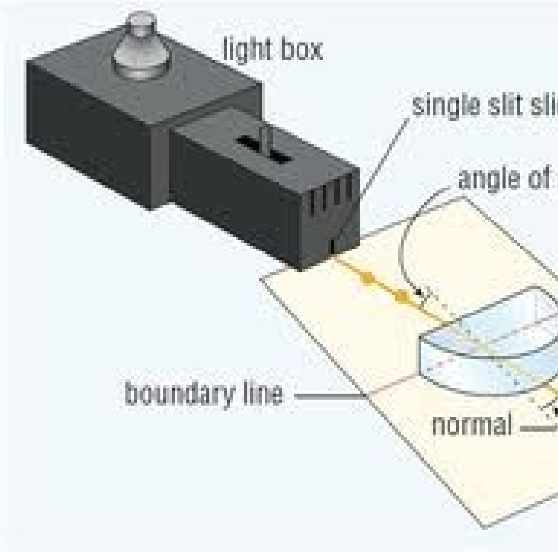
Refraction of light

- When light enters a slower medium, rays are bent towards the normal
- The greater the difference in speed, the more rays are bent:
- The speed ratio in the medium is written as “n”
- This is also called the index of refraction, and can be calculated as:

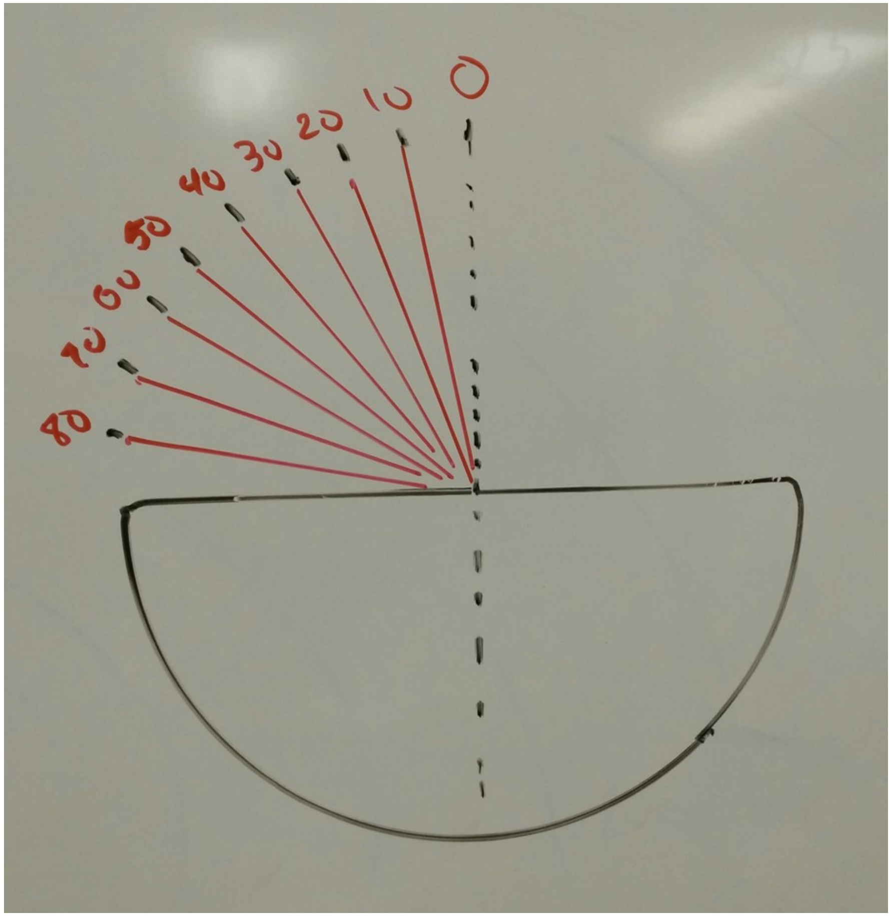
$$n = \frac{c_0}{c}$$

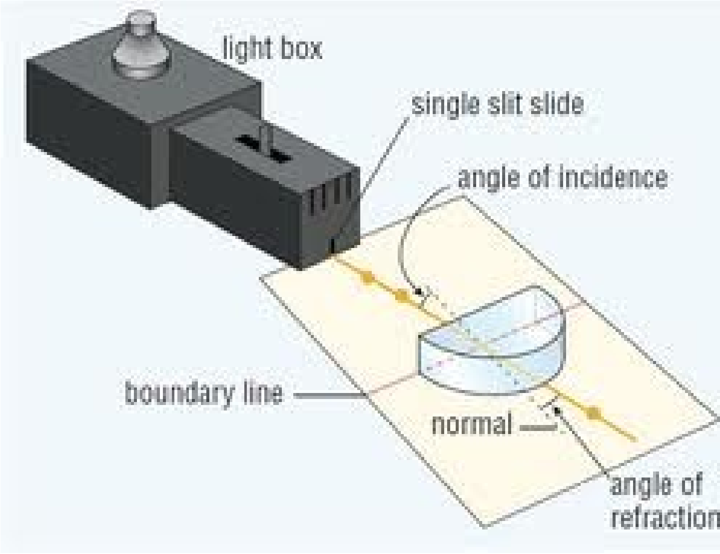
Snell's Law: Lab p. 215 G1

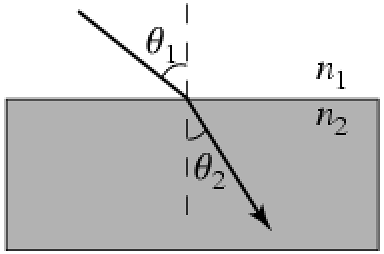
- Trace out dish, measure center, draw normal, premeasure incident angles
- Then fill dish half full and measure refracted angles
- Graph $\sin\theta_i$ vs $\sin\theta_r$: find the slope
- No Questions
- Conclusion: include slope, improvements



Snell's Law: Lab p. 215







Snell's Law

- When light enters a slower medium, rays are bent towards the normal
- The greater the difference in speed, the more rays are bent:

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

- Recall n can be calculated as:

$$n = \frac{c_0}{c}$$

Snell

Come listen and learn, I've a story I tell

I sing of the genius of Willebrord Snell

A mathematician who lived long ago

In the Netherlands where the Rhine river does flow

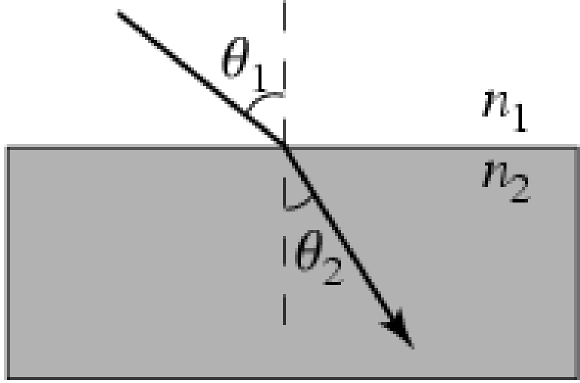
He set for his mind occupations of worth

Improved navigation and measured the Earth!

He gave us the sine law, that wonderful guy

And he made more precise calculation of pi!

Singin' $n_1 \sin\theta_1$ (hey hey hey) = $n_2 \sin\theta_2$, hip hooray!



His greatest feat came in Sixteen Twenty-one

When optics as science was really begun!

While flashes of lightning illumined his page

He wrote down Snell's law, his great gift to the age!

So if you wear glasses or like to fry ants

Be grateful your lenses were not made by chance!

Astronomers hail him with each new-found star!

Microscopists toast him from each sleazy bar!

Singin' $n_1 \sin\theta_1$ (hey hey hey) = $n_2 \sin\theta_2$, hip hooray!

Now some credit Harriot, others Descartes

Both studied refraction, and both were real smart.

But we prefer Willebrord van Roijen Snell

He laid down the law, and he did it darn well!

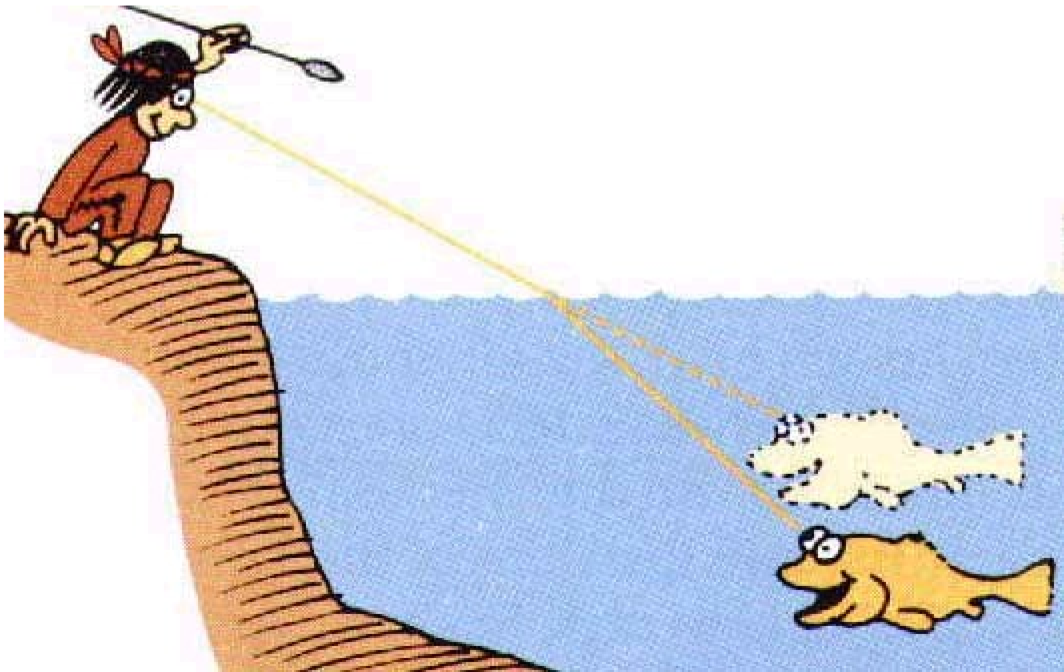
Singin' $n_1 \sin\theta_1$ (hey hey hey) = $n_2 \sin\theta_2$, hip hooray!

Where do you aim the spear?

- Given that the hunter observes the light exiting the water at an angle of 35°, can we calculate to find the actual position of the fish?

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

$$\sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1}$$



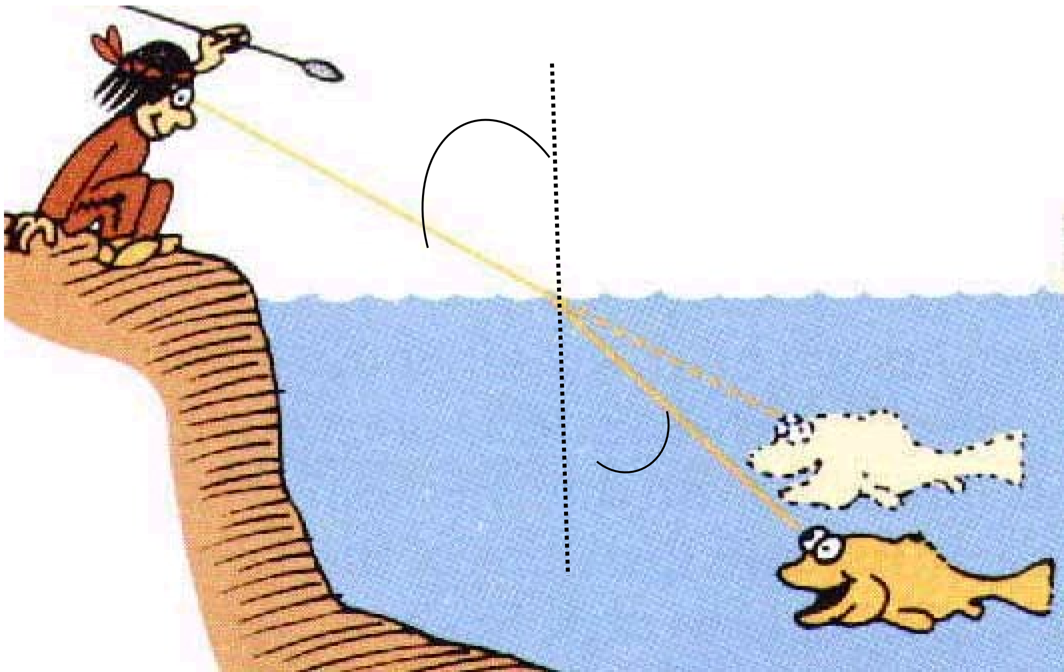
Where do you aim the spear?

$$\sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1}$$

$$\theta_1 = \sin^{-1}\left(\frac{1\sin 35}{1.33}\right)$$

$$\theta_1 = \sin^{-1}\left(\frac{n_2 \sin\theta_2}{n_1}\right)$$

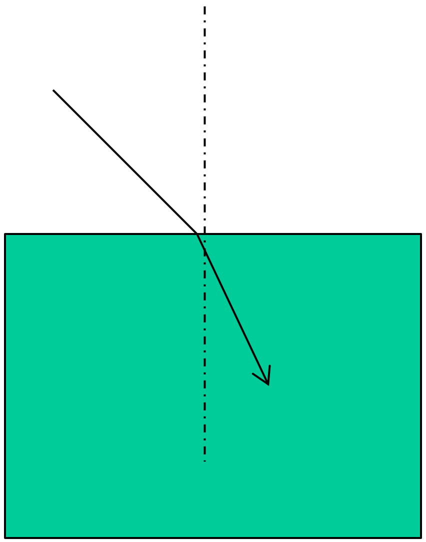
$$\theta_1 = 26°$$



Finish labs, hand them in

Exercises p. 218 #1-4

Ex: find n



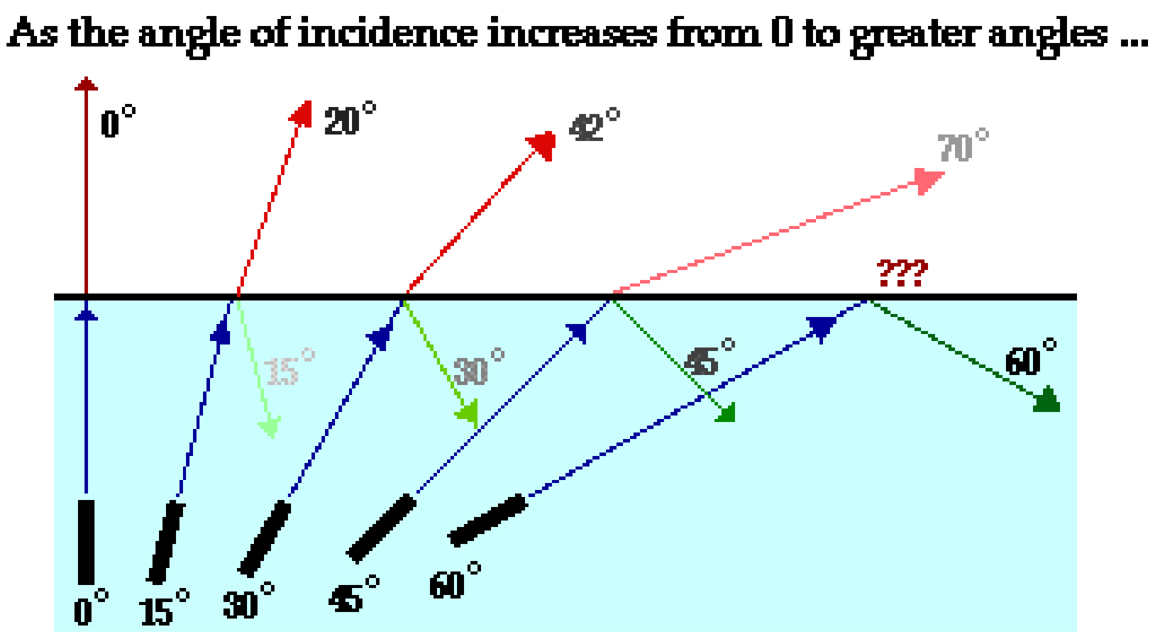
- Light encountering a block of glass at 18.5 degrees goes in at 12 degrees find the index of refraction for this glass

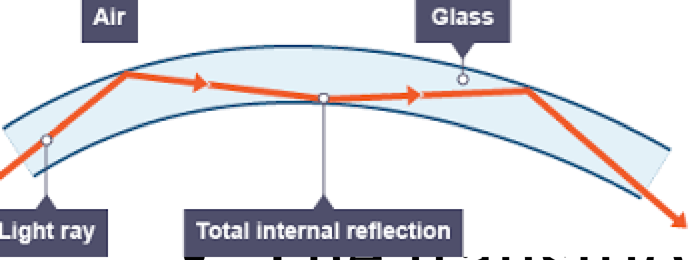
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2} \qquad n_2 = \frac{1.00029 \sin 18.5^\circ}{\sin 12^\circ}$$

Total Internal Reflection

- What happens as we increase the angle of incidence for light going into a less optically dense medium?
- The refracted ray gets bent further and further from the normal.





ritical An

- The transition point between refraction and reflection is for a refraction angle of 90°
- Solving Snell's law for critical angle gives:

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

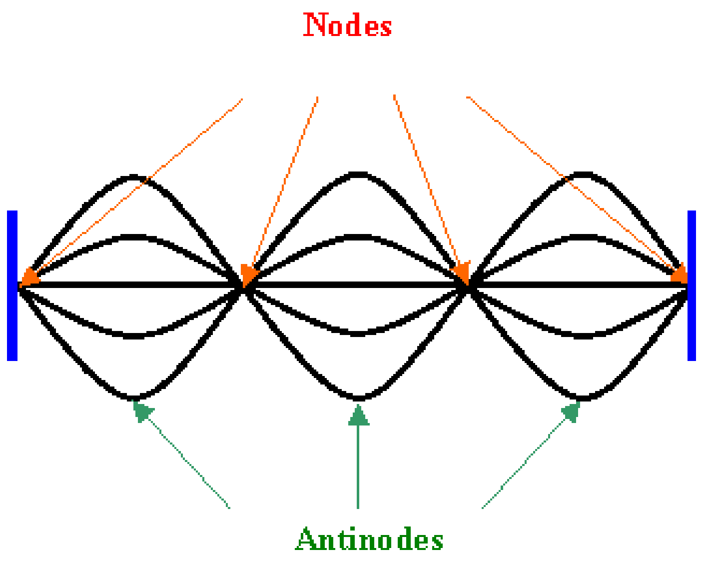
$$n_1 \sin\theta_1 = n_2$$

$$\sin\theta_1 = \frac{n_2}{n_1} \qquad \theta c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$\theta c = \sin^{-1}\left(\frac{1}{1.5}\right) \qquad \theta c = 42^\circ$$

Microwave speed of light

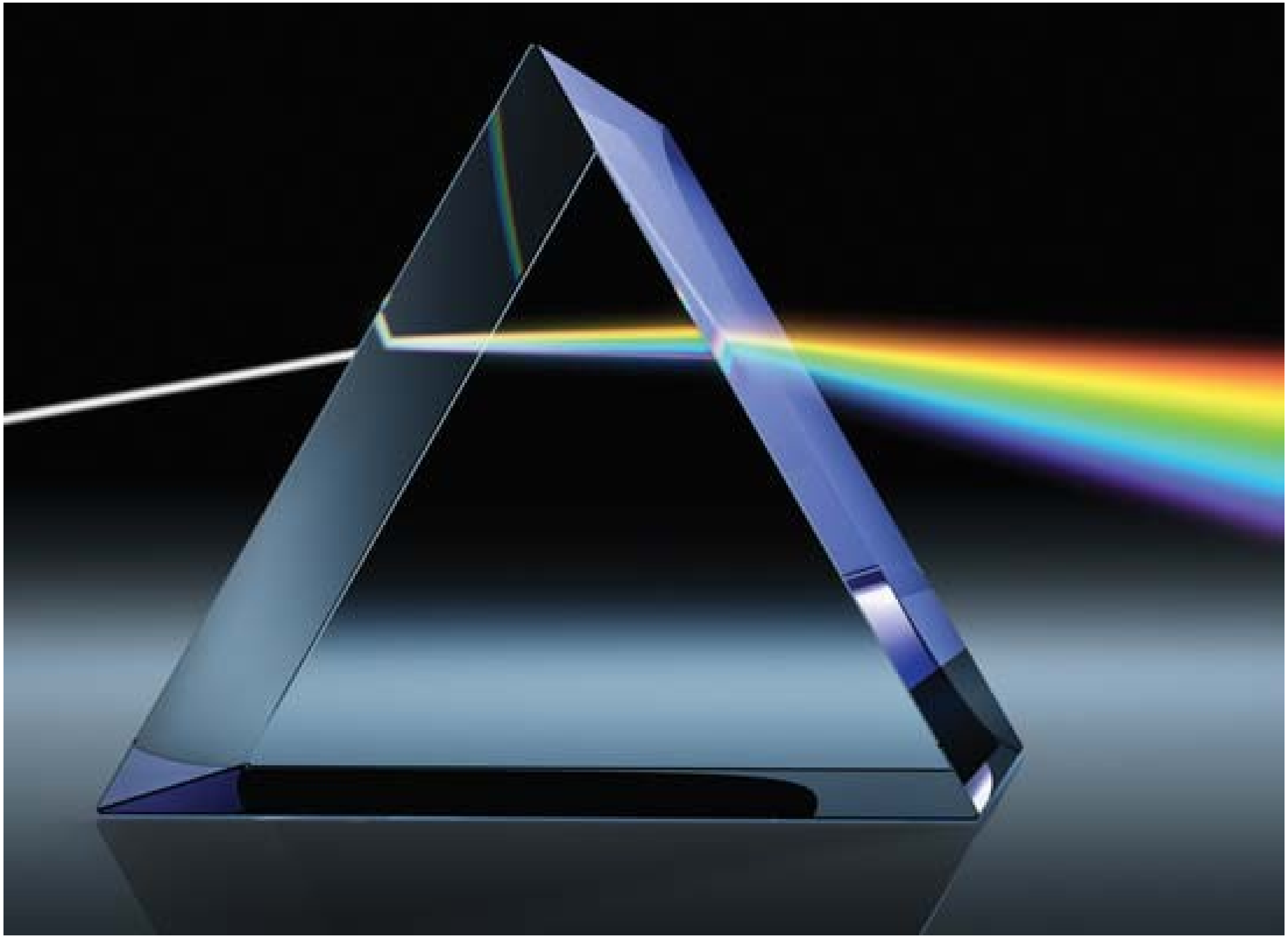
- Measure the distance between two antinodes of this standing wave
- Double this to get wavelength
- Use the wave equation to find



Speed of light?

- v1=3.43E8 m/s
- v2=1.35E8 m/s
- v3=3.06E8 m/s
- v4=2.57E8 m/s
- v5=3.68E8 m/s
- v(ave)=2.82E8 m/s

Which color refracts more?



Exercises p. 221 #1-7

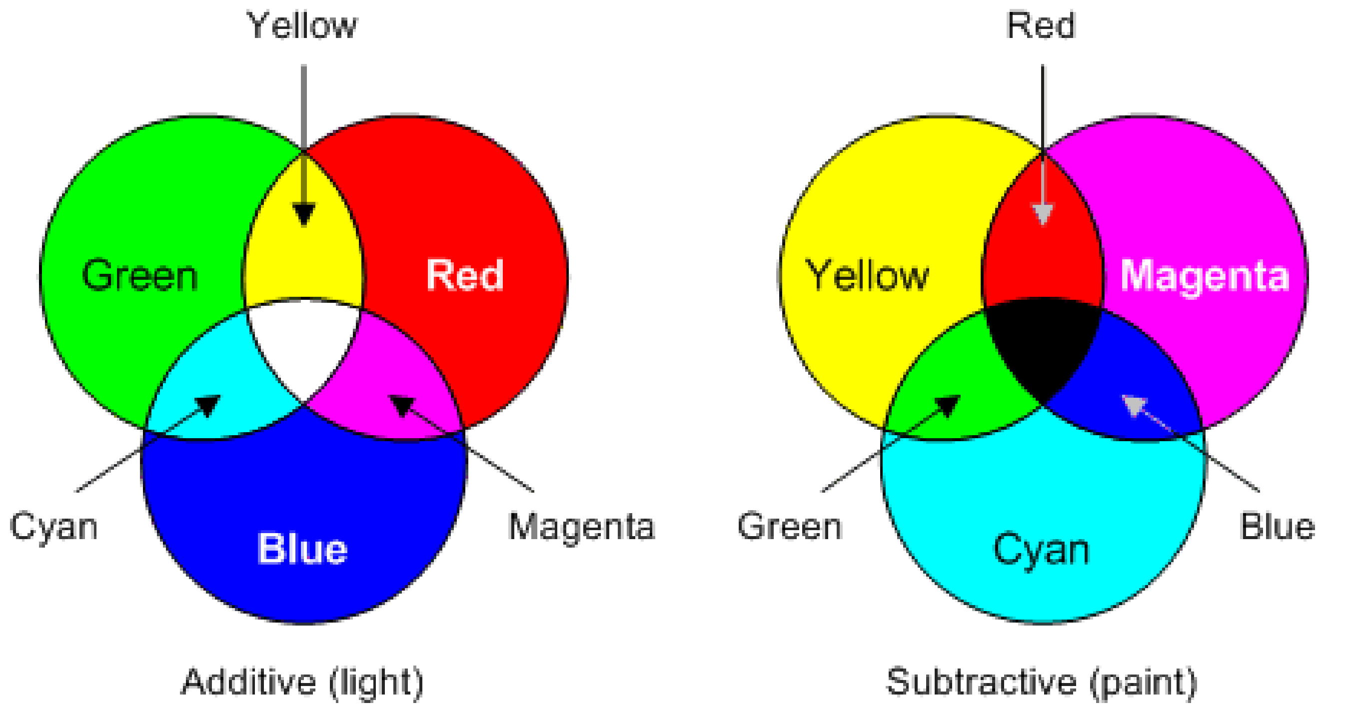
Optics quiz tomorrow:

3 MC: do you know the difference between diffraction, refraction, reflection? 1 WR: Snell’s Law question

Dispersion

- Different wavelengths are refracted different amounts so we get:

Primary colors



Additive and subtractive color combinations

Scattering

- Blue light is scattered by the atmosphere so the sky looks blue, sunsets look red

Exercises p. 221 #1-4

Start p. 237 Test Yourself!

Quiz tomorrow

Waves/optics Test 15th

Final Exam 25th on Everything!!!!!!!!!!

Yes Shelby: Everything.

Spectroscopy Activity

- Do diagrams for the spectra of:

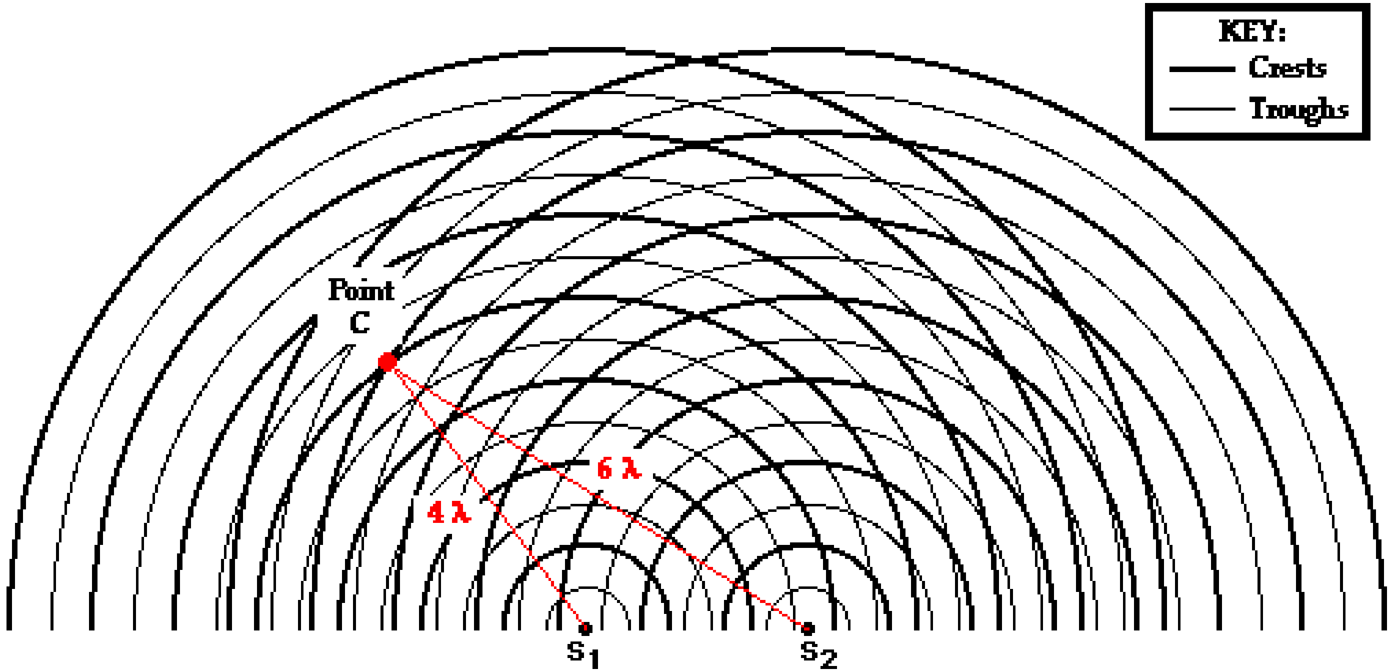
  Incandescent light
  Fluorescent light
  Nitrogen gas
  Argon gas
  "LASER" light

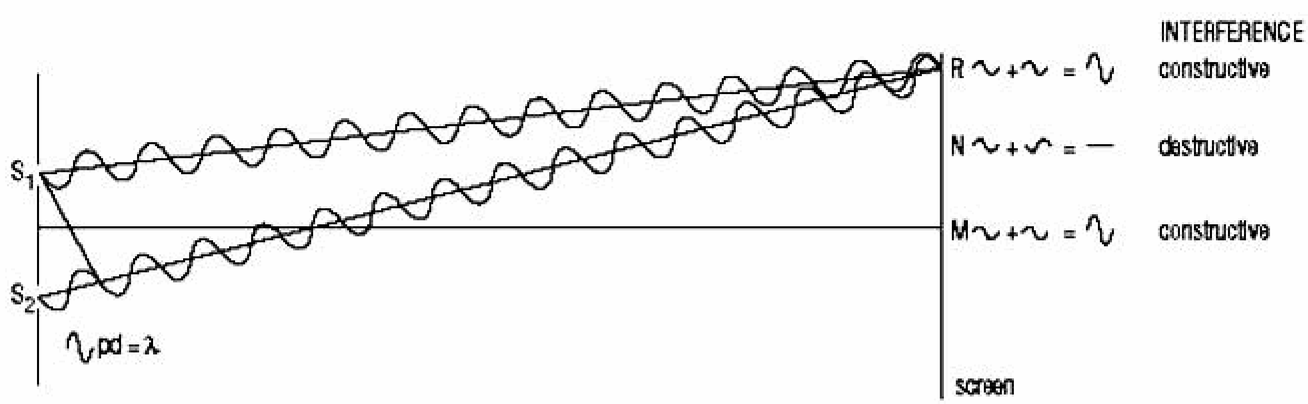
- Then continue review questIons!

Test Yourself p. 237

- Choose 5 Chapter Review Page 274
- Open book Quizzam tomorrow
- Start Modern Physics next week
- Final Exam Jan 23

Path difference





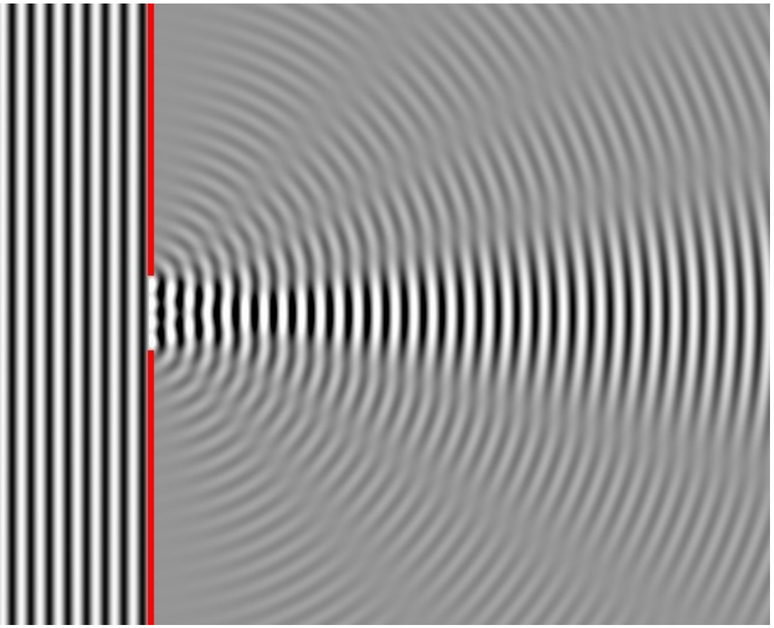
Path difference

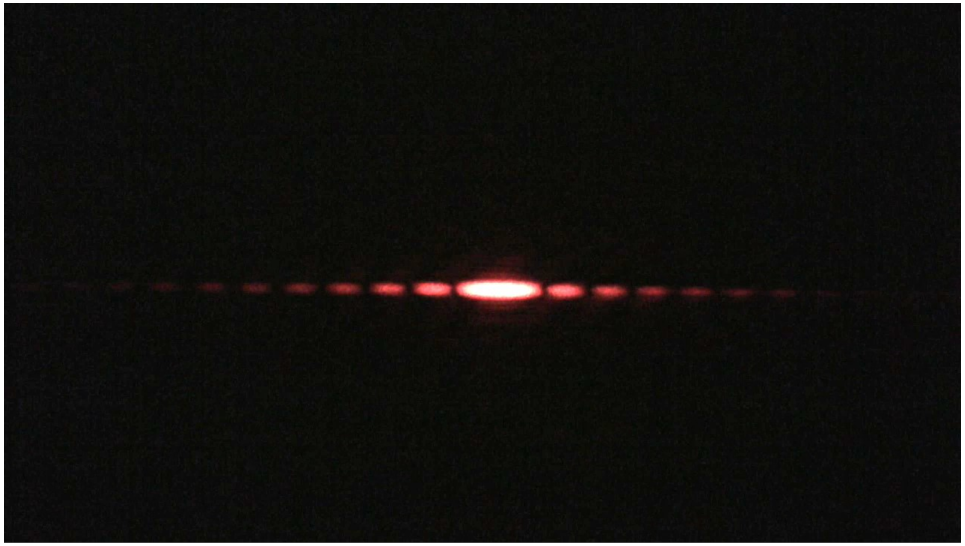
- If waves travel a path difference of one wavelength (or any multiple n) we get constructive interference
- Ex: find the path difference for these speakers to get maximum sound intensity of A

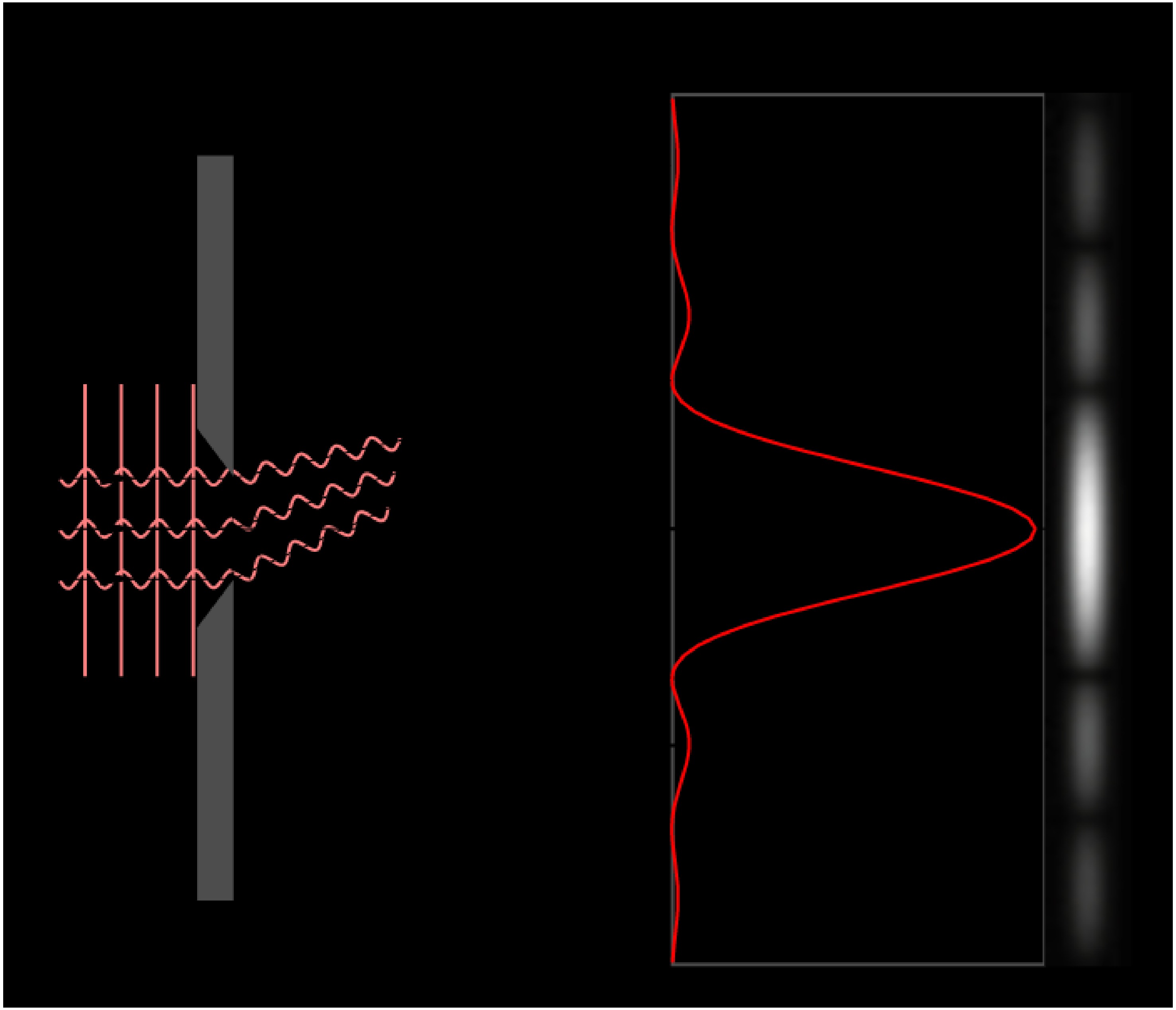
$$v = f\lambda \qquad \lambda = \frac{v}{f} = \frac{330}{440} \quad 0.75m$$

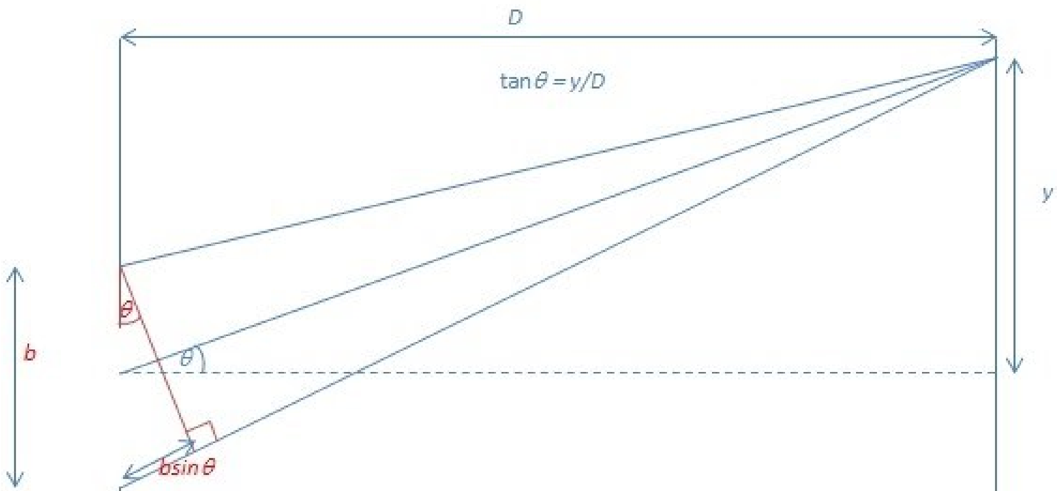
Single slit diffraction

- We find the waves with wavelength λ don't just spread out, they reach a minimum at angle θ after passing through a thin slit of width b









When $b \sin\theta = n\lambda$, then a minimum is achieved

The small angle approximation allows $\sin\theta = \tan\theta = \theta$

Making this approximation allows us to write

$b\theta = n\lambda$, and thus...

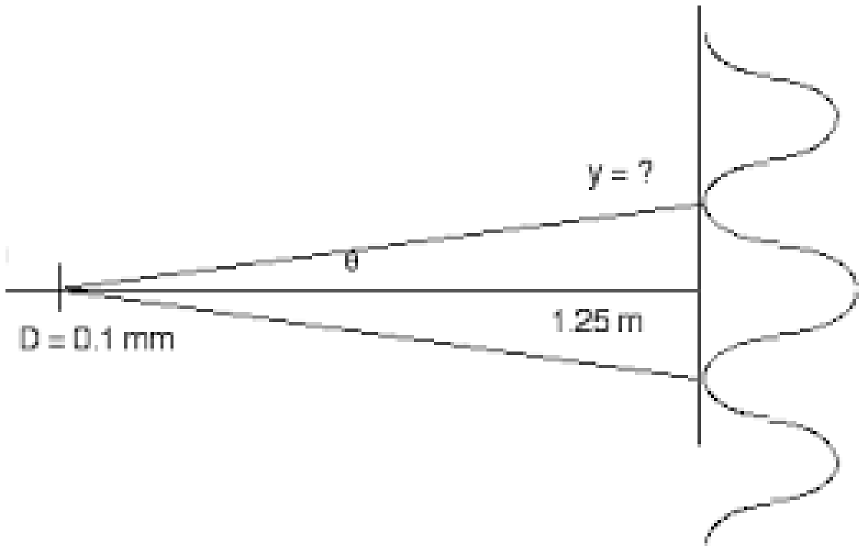
$\theta = \dfrac{\lambda}{b}$ *for the first order minimum.*

A note for calculations:

The small angle approximation allows $\sin\theta = \tan\theta = \theta$*, and thus we can rewrite the first equation as* $\theta = y/D$*. This allows* θ *to be determined from simple linear measurements from experimental apparatus.*

- Ex 1: find the angle for the first diffraction minimum for a red laser passing through a 0.3 mm slit

$$\theta = \frac{\lambda}{b} = \frac{700\times10^{-9}}{0.0003m} = 0.0023rad$$



Ex 2: find the width of the central maximum of violet light passing through a 0.1 mm slit shining on a screen 1.25 m away

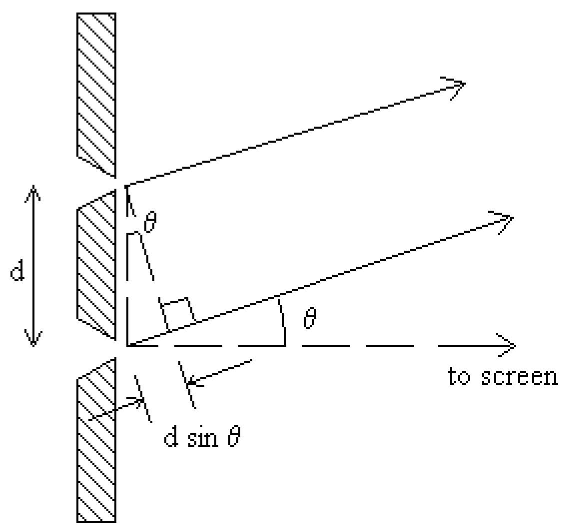
$$\theta = \frac{\lambda}{b} = \frac{400 \times 10^{-9}}{0.0001m} = 0.004rad$$

$$s = r\theta = 1.25m(0.004rad) = 0.005m$$

$$w = 2(0.005m) = 1cm$$

Double slit or Diffraction Grating

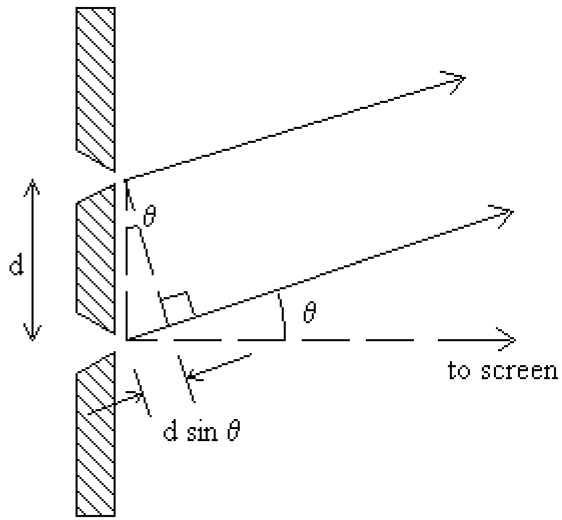
- For constructive interference we want a path difference of one wavelength, or any multiple



$$n\lambda = d\sin\theta$$

- Ex: find the angle from the central maximum to the next, for 600 rulings per mm, and 680 nm light

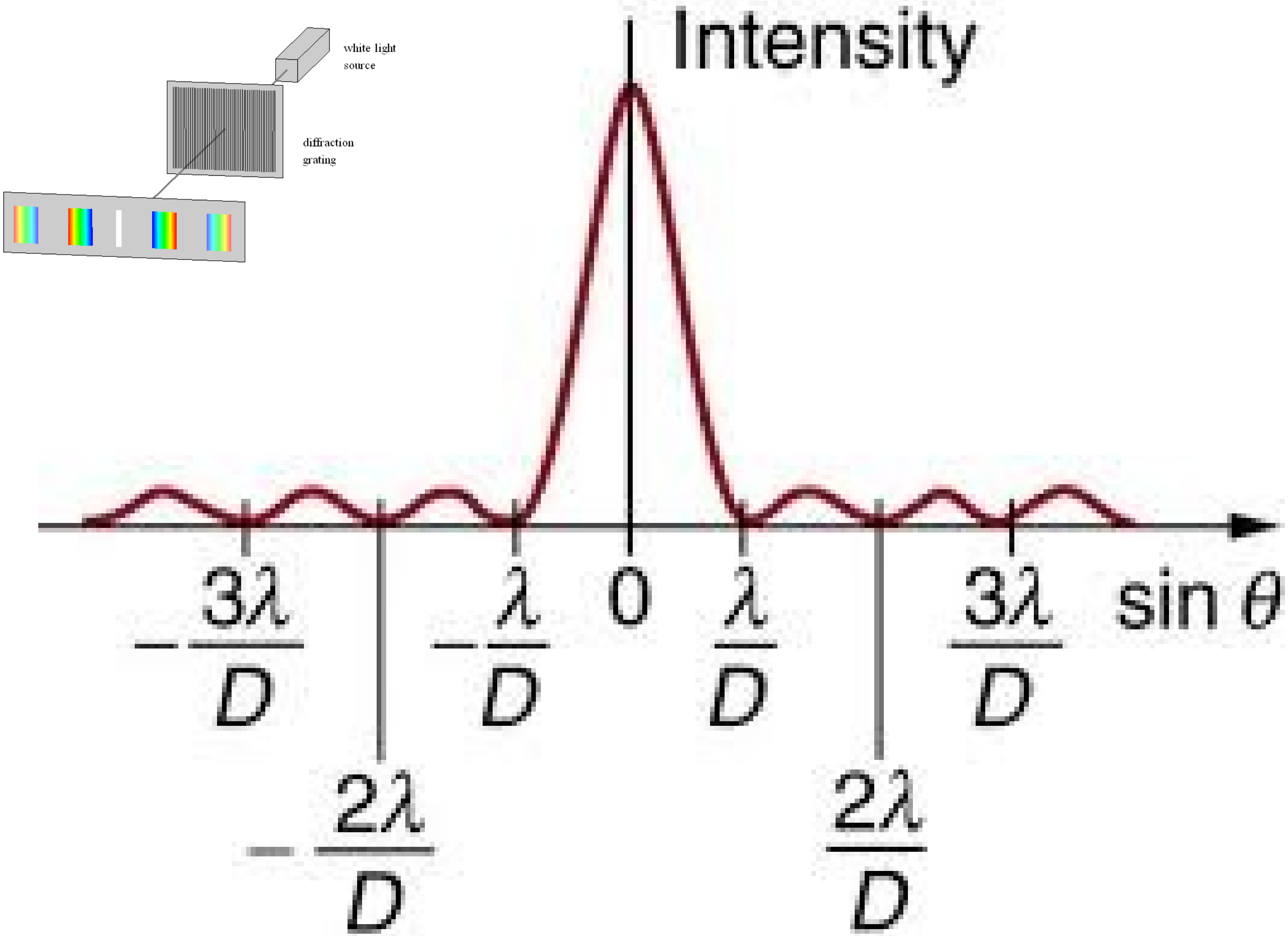
- Ex: find the angle from the central maximum (n=0) to the next (n=1)



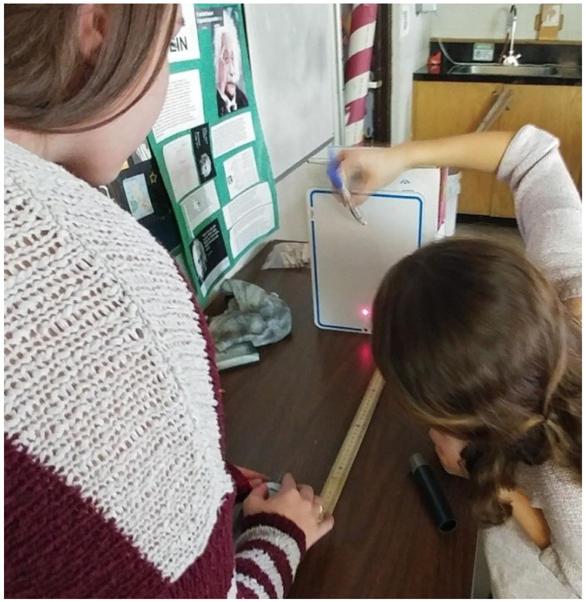
$$\theta = \sin^{-1}\left(\frac{n\lambda}{d}\right)$$

$$\theta = \sin^{-1}\left(\frac{(1)680\times10^{-9}}{0.001/600}\right)$$

$$\theta = 0.42^{rad} = 24°$$


white light source
diffraction grating
Intensity
sin θ
0
−3λ/D
−2λ/D
−λ/D
λ/D
2λ/D
3λ/D

- Ex: find the spacing of the lines in your diffraction grating



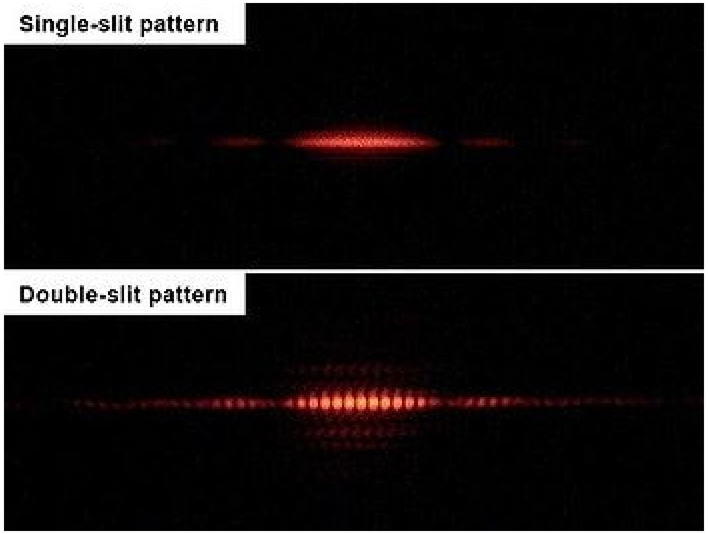
$$n\lambda = d\sin\theta$$

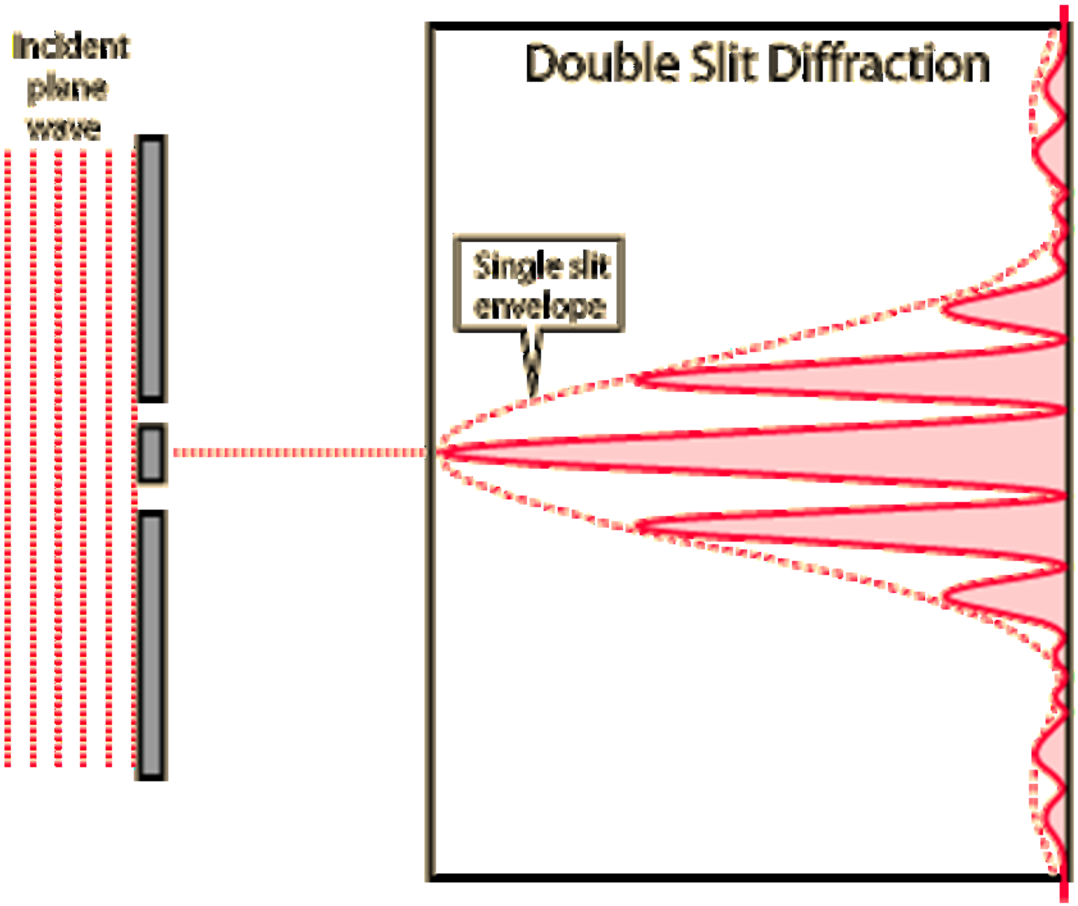
$$d = \frac{n\lambda}{\sin\theta}$$

$$d = \frac{(1)680\times10^{-9}}{\sin 21} \qquad = 1.9\,\mu m$$

Single or double or both?

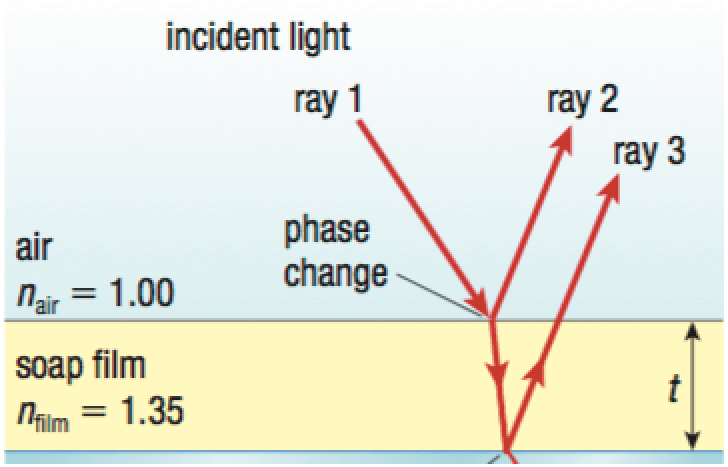
- If each slit has a significant width, we get both!





Thin film interference

- For film thickness d, index of refraction n. Assuming one phase change for reflection off the surface we get constructive interference for:

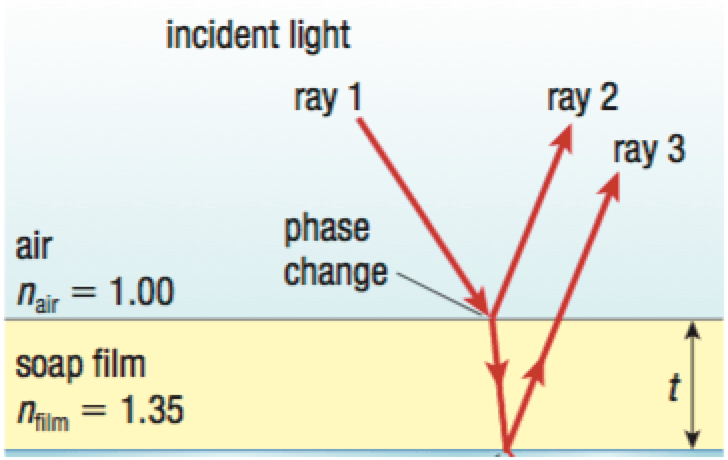


$$2dn = \left(m + \frac{1}{2}\right)\lambda$$

$$d = \frac{\lambda}{4n} = \frac{650nm}{4(1.43)} = 114nm$$

- Ex: find the thickness of a film with n=1.43 when 650nm light gives constructive interference

- For thin film interference, we get destructive interference for :

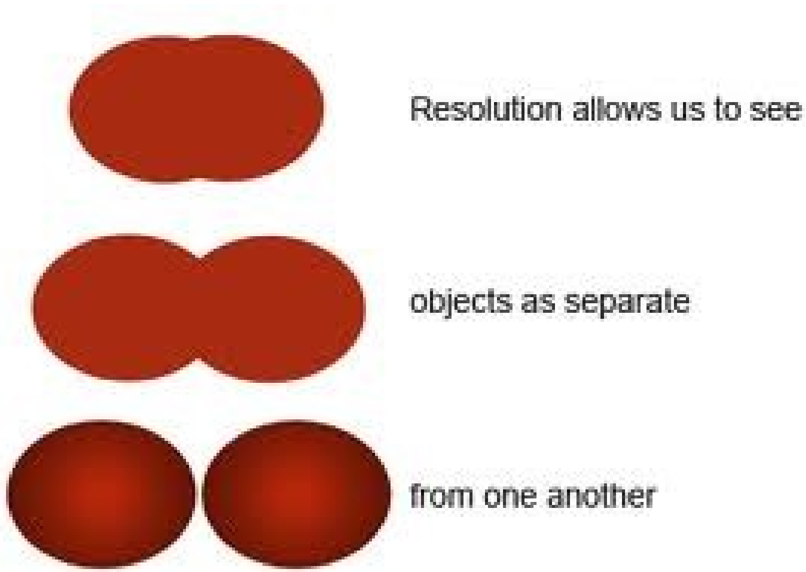


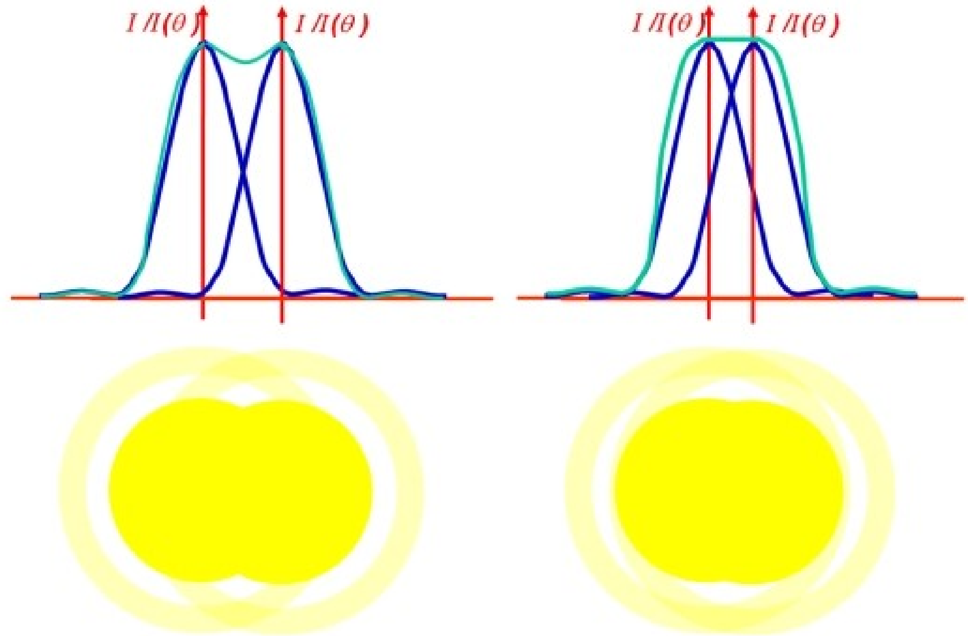
$$2dn = m\lambda$$

$$d = \frac{\lambda}{2n} = \frac{440nm}{2(1.55)} = 142nm$$

- Ex: find the thickness of an n=1.55 film with "no reflection" for 440nm light

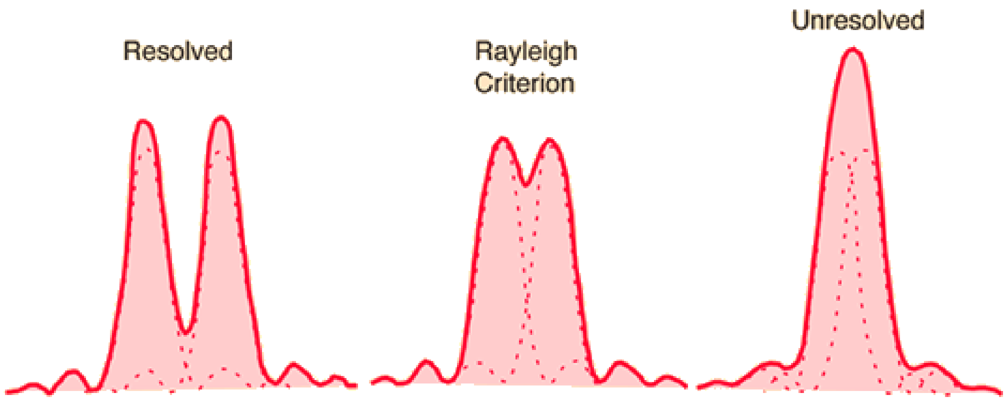
Resolution


Resolution allows us to see
objects as separate
from one another



Rayleigh criterion

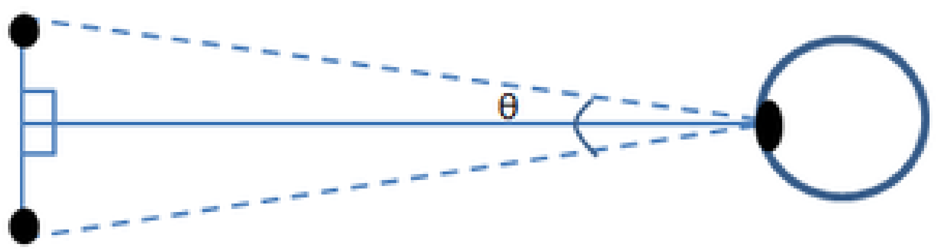
- The three possibilities are well resolved, not resolved or just resolved
- The Rayleigh criterion applies to just resolved:



Rayleigh criterion

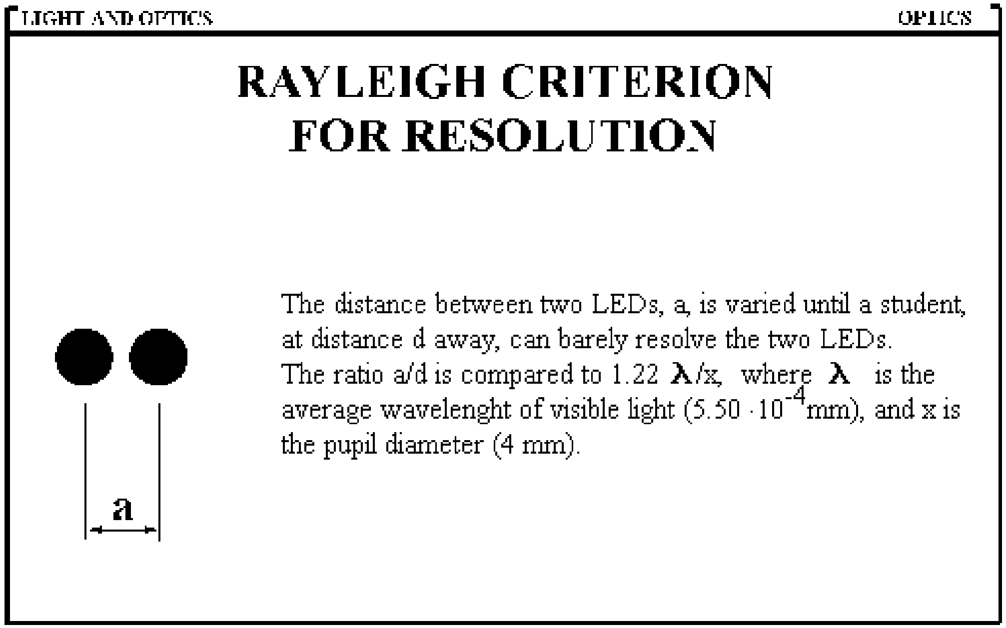
$$\theta = 1.22\frac{\lambda}{b}$$

λ is the wavelength of incident light, b is the aperture diameter and θ is the critical angle. Below is a diagram of what the critical angle is:



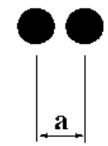
The critical angle is thus the angle at which the two sources can just be resolved.

Ex: find a for d=17m



$$\theta = 1.22\frac{\lambda}{b} = 1.22\frac{550\times10^{-9}}{0.004} = 1.68\times10^{-4}$$

FOR RESOLUTION



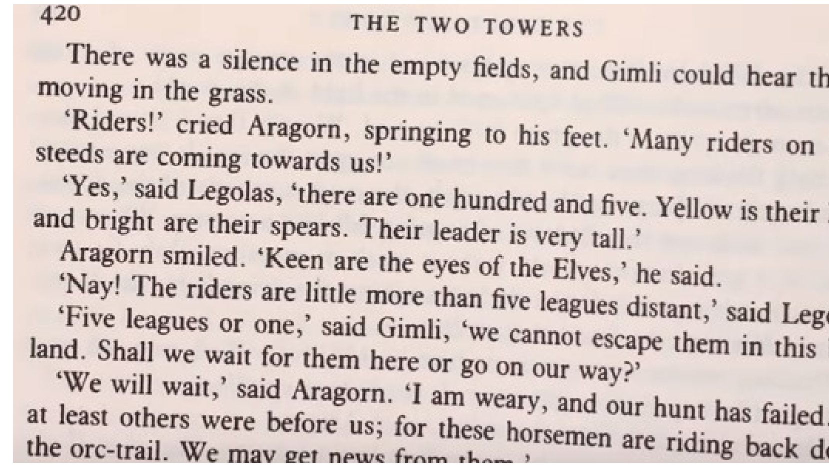
The distance between two LEDs, a, is varied
at distance d away, can barely resolve the tw
The ratio a/d is compared to 1.22 λ/x, whe
average wavelenght of visible light (5.50 ·10
the pupil diameter (4 mm).

Ex: find a for d=17m

$$s = r\theta = 17\times 1.68\times 10^{-4} = 2.9mm$$

Ex: find b for Legolas to resolve 10cm detail from 24 km

$$\theta = \frac{s}{r} = \frac{0.1}{24000} = 4.2\times10^{-6}$$


420 THE TWO TOWERS

There was a silence in the empty fields, and Gimli could hear th
moving in the grass.

'Riders!' cried Aragorn, springing to his feet. 'Many riders on
steeds are coming towards us!'

'Yes,' said Legolas, 'there are one hundred and five. Yellow is their
and bright are their spears. Their leader is very tall.'

Aragorn smiled. 'Keen are the eyes of the Elves,' he said.

'Nay! The riders are little more than five leagues distant,' said Leg

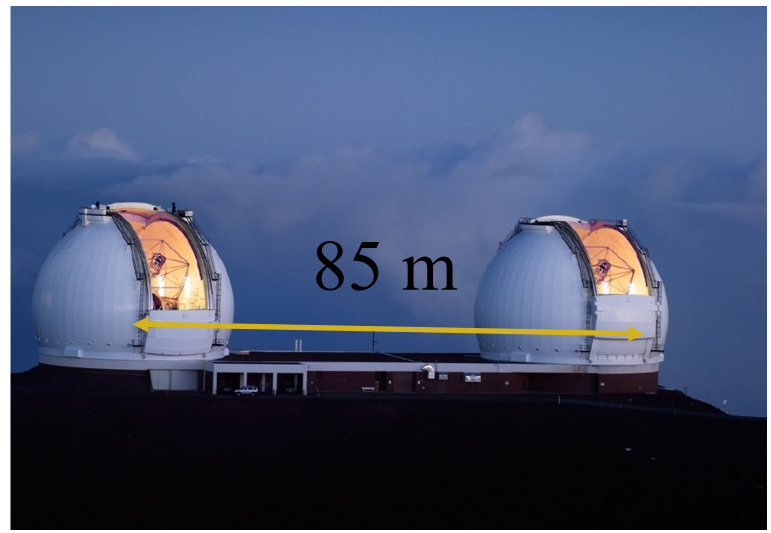
'Five leagues or one,' said Gimli, 'we cannot escape them in this
land. Shall we wait for them here or go on our way?'

'We will wait,' said Aragorn. 'I am weary, and our hunt has failed.
at least others were before us; for these horsemen are riding back d
the orc-trail. We may get news from them.'

$$\theta = 1.22\frac{\lambda}{b} \qquad b = 1.22\frac{\lambda}{\theta}$$

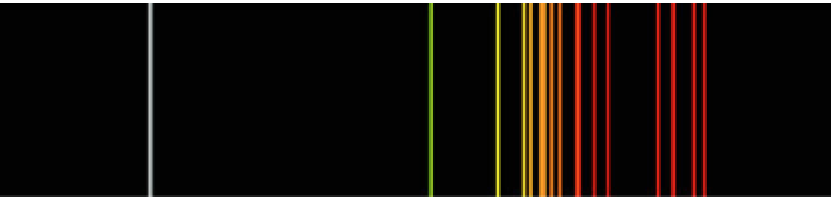
$$= 1.22\frac{550\times10^{-9}}{4.2\times10^{-6}} = 0.16m!$$

Ex: find the critical angle for Keck at 500nm



$$\theta = 1.22\frac{\lambda}{b}$$

$$\theta = 1.22\frac{500\times10^{-9}}{85} = 7.2\times10^{-9}\,rad$$



Resolvance R

A diffraction grating with N slits can resolve spectral lines that are apart Δλ where m is the order of diffraction

$$R = \frac{\lambda}{\Delta\lambda} = mN$$

Example: a) what is the resolvance necessary to resolve two lines in the sodium spectrum with wavelengths 589.00 and 589.59nm?

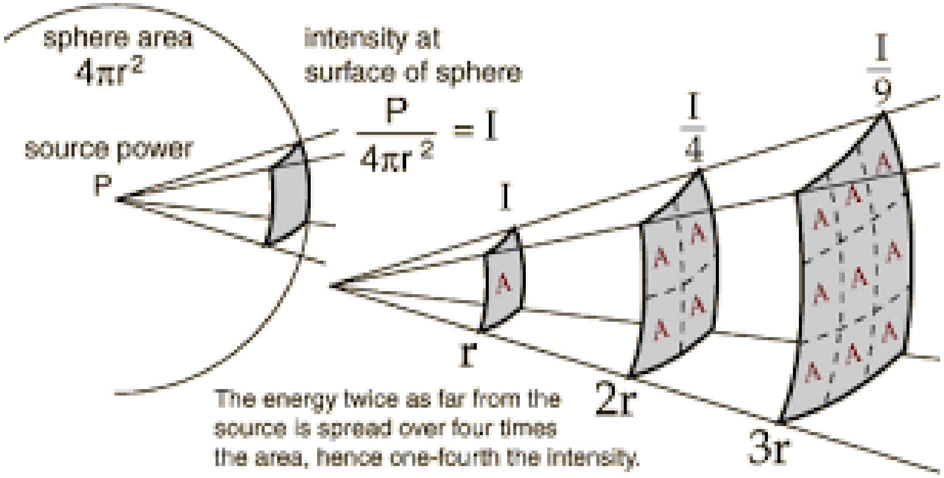
Example: b) how many diffraction lines are necessary to resolve these for second order spectrum?

$$R = \frac{\Delta\lambda}{\lambda} = mN$$

$$N = \frac{R}{m} = \frac{999}{2} = 500 lines$$

Intensity

BRACE YOURSELF
INTENSITY IS COMING
memegenerator.net



sphere area
4πr²
source power
P
intensity at
surface of sphere
P / 4πr² = I
I
I/4
I/9
A
r
2r
3r
The energy twice as far from the
source is spread over four times
the area, hence one-fourth the intensity.

Intensity

- This is related to brightness of light, or loudness of sound
- Measured as Watts per square meter
- Intensity is proportional to:

$$I \alpha A^{2} \qquad I \alpha x^{-2}$$

- Ex: The total power output of the Sun is 386 YottaWatts. What is the intensity here?

- Ex: The total power output of the Sun is 386 septillion Watts. What is the intensity here?

$$I = W \cdot m^{-2}$$

$$I = \frac{385 \cdot 10^{24} W}{4\pi \left(1.5 \times 10^{11} m\right)^2}$$

$$I = 1360 W \cdot m^{-2}$$

- Ex: Mars is 1.524 AU from the Sun. What is the Intensity there?

$$I \alpha x^{-2}$$

$$I_M = I_E (1.524)^{-2}$$

$$I = 1361 W \cdot m^{-2} / 2.32$$

$$I = 590 W \cdot m^{-2}$$

- Ex: Sheldon turns up his amplifier to get thrice the sound amplitude from his speaker. By what factor has the sound intensity changed??

$$I \alpha A^2$$

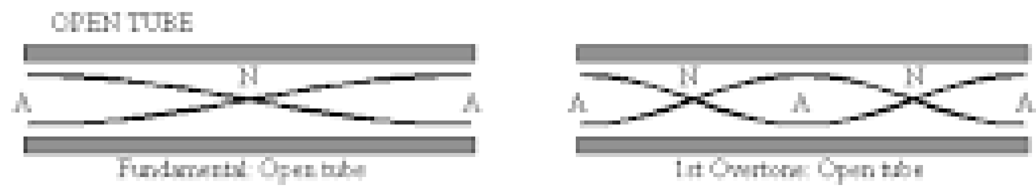
$$I_2 = I_1 3^2$$

$$I_2 = 9I_1$$

Standing waves

- What is the fundamental (1^{st} harmonic) frequency for a 52 cm long open tube?

$$v = f\lambda$$



$$f = \frac{v}{\lambda} = \frac{320}{1.04} = 308Hz$$

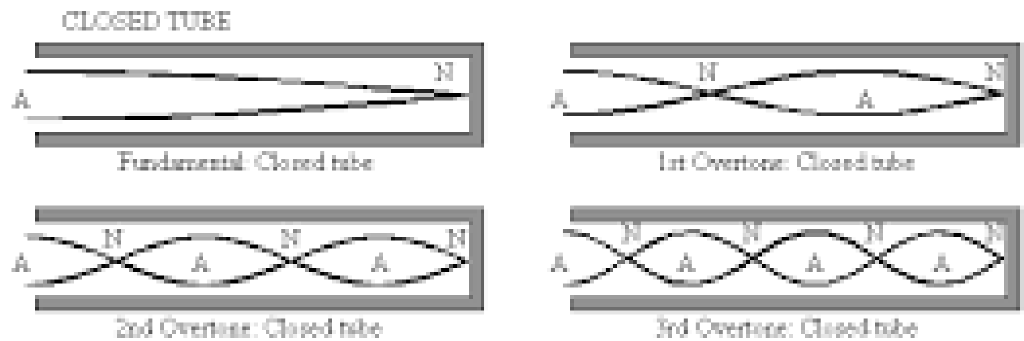
- 2^{nd} harmonic?

$$f = \frac{v}{\lambda} = \frac{320}{0.52} = 616Hz$$

Closed at one end?

- What is the frequency for the 3rd harmonic for this pipe with a length of 1.5m?

$$\frac{5\lambda}{4} = L$$



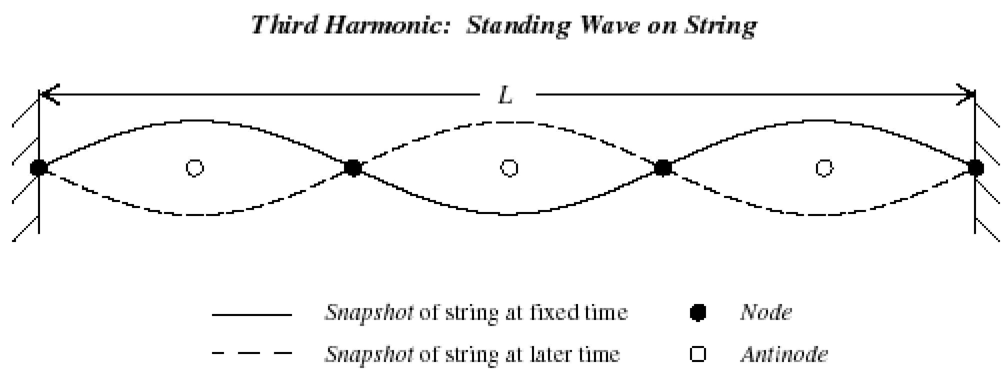
$$\lambda = \frac{4}{5}L = \frac{4}{5}1.5m = 1.2m$$

$$f = \frac{v}{\lambda} = \frac{315}{1.2} = 267\,Hz$$

Ex: Guitar string

- What is the wavelength for the 3rd harmonic for this guitar string with a length of 0.75 m?

$$\frac{3\lambda}{2} = L$$

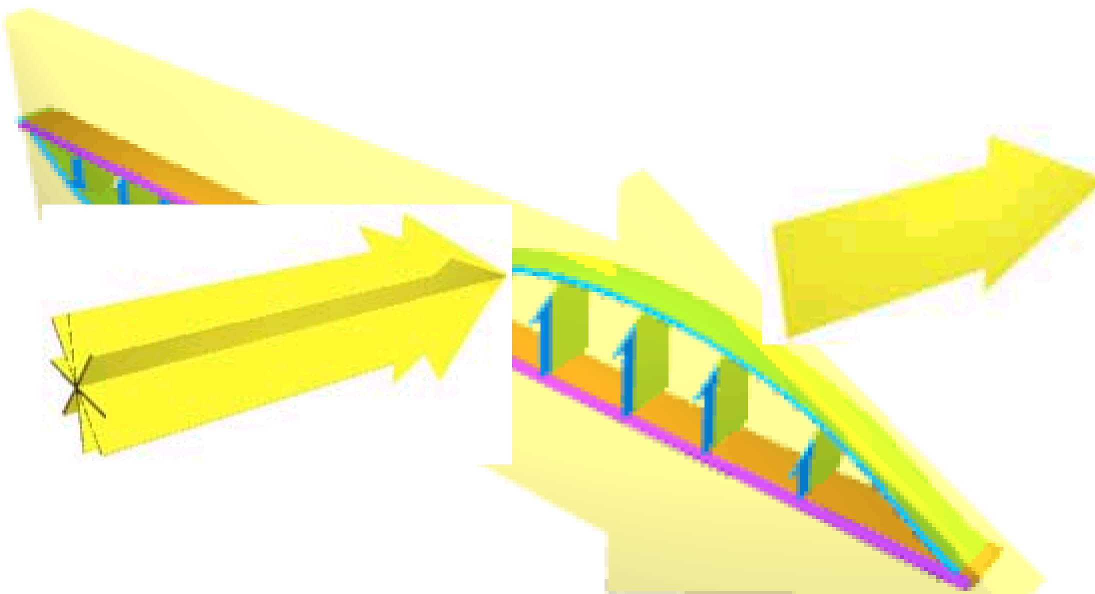


$$\lambda = \frac{2}{3}L = \frac{2}{3}0.75m = 0.50m$$

Polarization

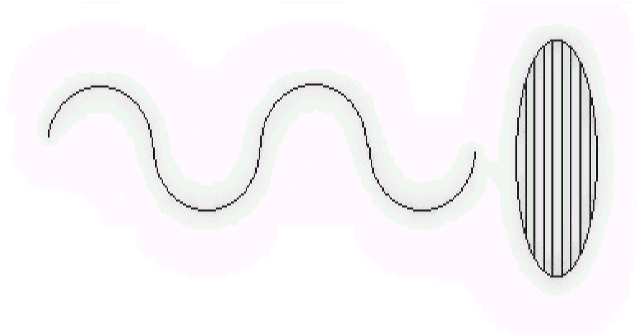
Direction of oscillation

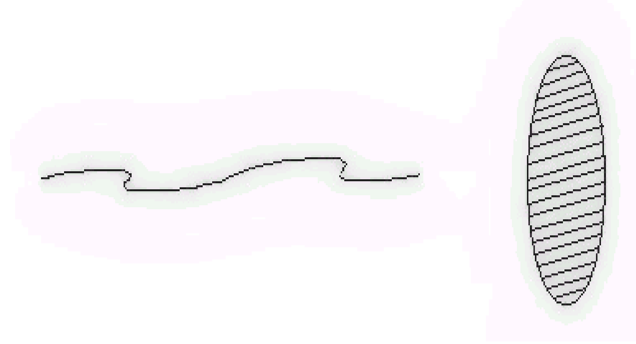
- Since E and M fields are vectors, E-M waves have a direction of oscillation as well as a direction of motion



Polarizating Filters

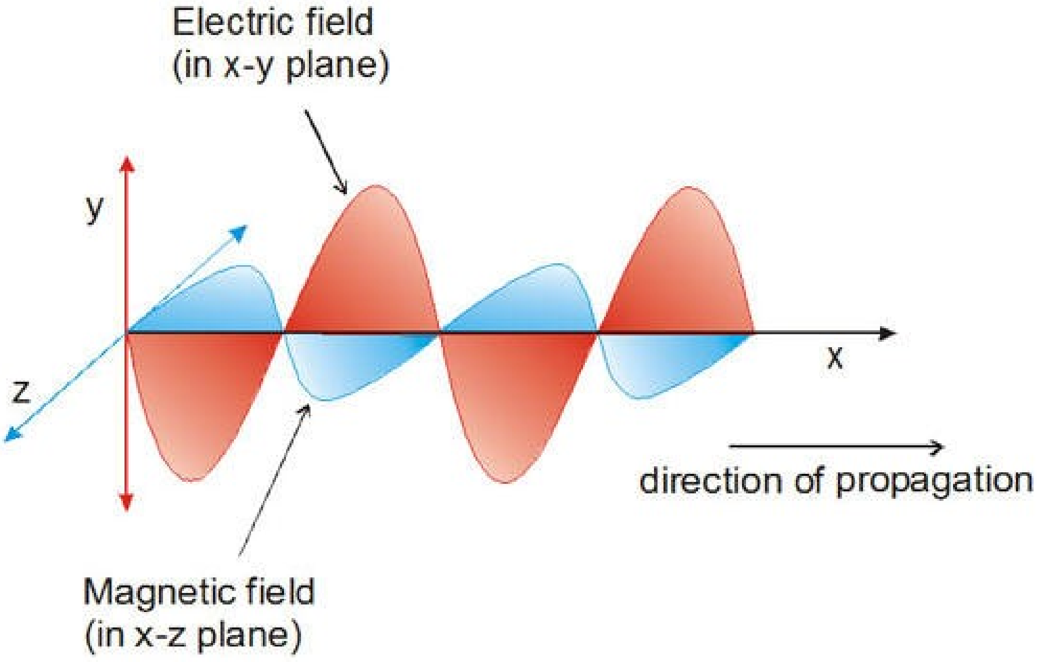
- We can allow only light polarized in a particular direction
- When unpolarized light passes through a filter, its intensity is reduced by 50%





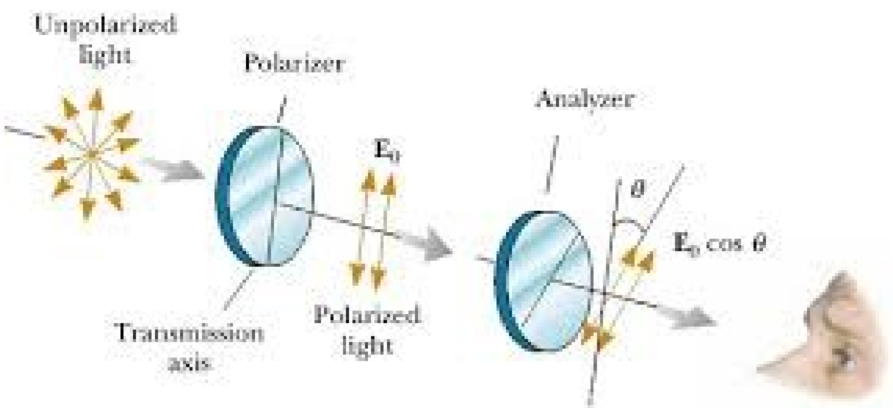
Polarizating Filters

- We define polarization as the direction of the electric field oscillation



Malus' Law

The intensity of light passing through a filter with its axis at an angle θ from the polarization direction is:



$$I = I_0 cos^2\theta$$

Ex: find the intensity

- **Unpolarized light passes through two polarizing filters oriented 60 degrees relative to each other:**

$$I = I_0 cos^2 \theta$$

$$I = 0.5 \times I_0 (\cos 60)^2$$

$$I = \frac{1}{2} \times I_0 \left(\frac{1}{2}\right)^2 \quad I = \frac{1}{8} I_0$$

p. 146 #30

p. 148 #31

Start Review p. 149

IA Research Question done this week!?

final waves review

- Test Yourself p. 178 q's1-7, m.c. 1-5