Mastering Physics Assignment 3

Chapters 21, 22
due Friday, Feb 29 at 11 pm

Week of February 18 - 22

Midterm Break

Week of February 25 - 29

Tutorial and Test 2: Chapters 19, 20, 21

Thursday, March 6, 7-9 pm

Midterm Test, chapters 18-22, 24, 25

Chapter 24: Electromagnetic Waves

- The nature of electromagnetic waves
- Speed of light, $c = 3 \times 10^8$ m/s in vacuum

- **Omit sections 3, 4, 5, 6** (energy carried by em waves, Doppler effect, polarization of light)

Chapter 25: Reflection of Light

- Wavefronts and rays
- Reflection of light, formation of image in a plane mirror

- **Omit sections 4, 5, 6** (spherical mirrors, mirror equation)

The nature of electromagnetic waves

Electromagnetic waves:

- radio waves
- infrared
- visible light
- ultraviolet
- x-rays, gamma rays

Long wavelength, low frequency

↓

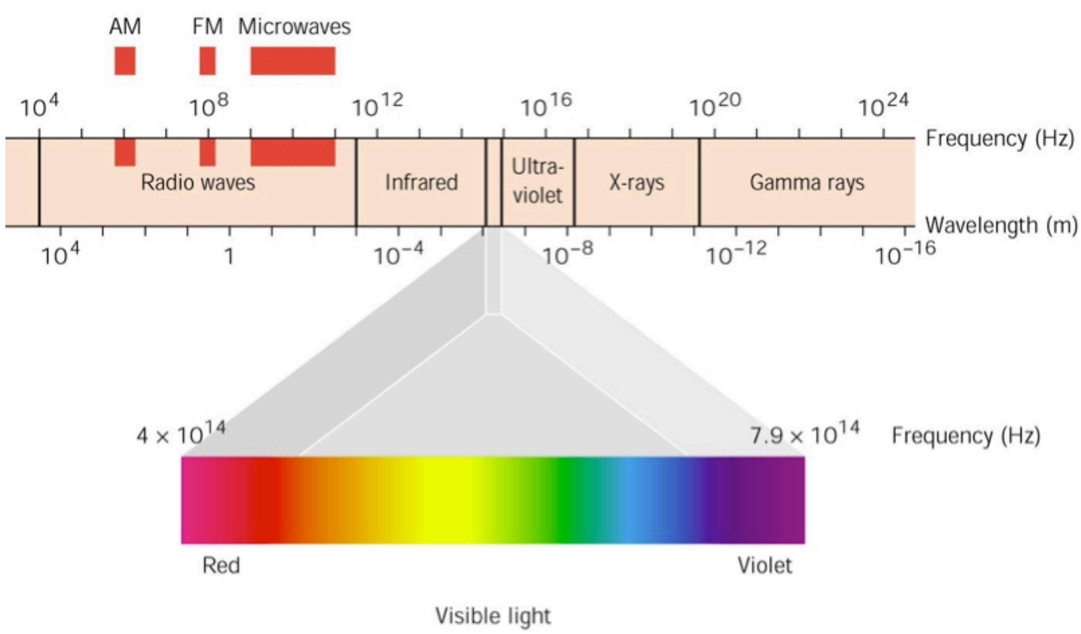
Short wavelength, high frequency

All travel at the speed of light, c = 3×10^8 m/s, differ only in wavelength and frequency.

Can travel through vacuum (starlight is visible).

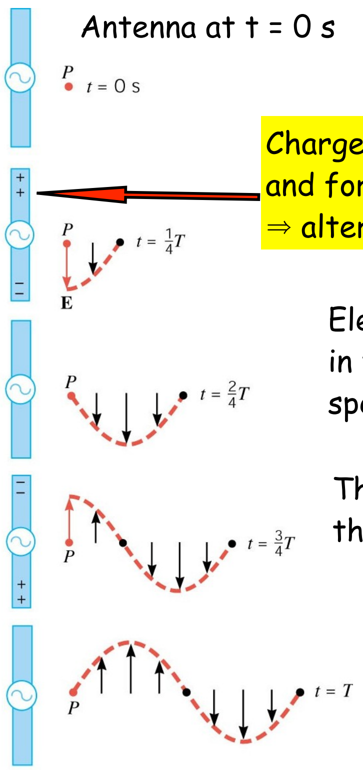
Contain both electric and magnetic fields oscillating at right angles to the direction of the wave and at right angles to each other ("transverse waves")

The spectrum of electromagnetic radiation



Generation of radio waves – electric component

Antenna at t = 0 s



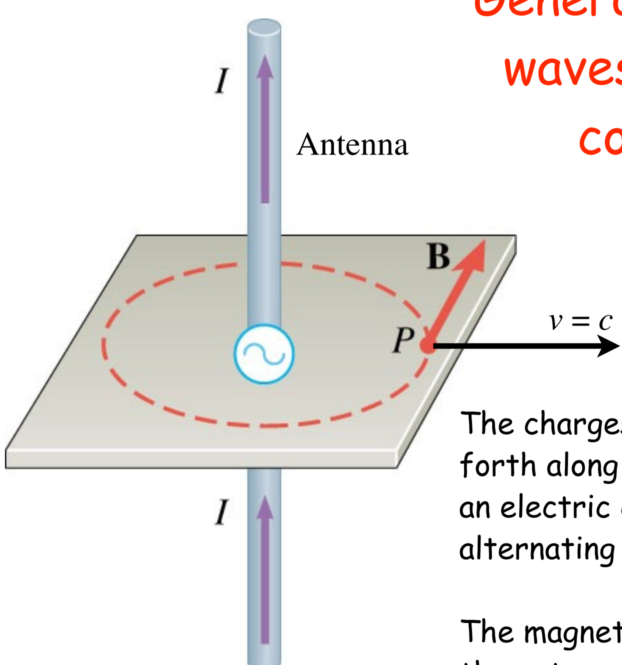
Charges oscillate back and forth along antenna
⇒ alternating current

Electric field produced by separation of charges in the antenna propagates away from antenna at speed of light.

The electric field is parallel with the antenna – the wave is "polarized" parallel to the antenna.

An electromagnetic wave results, travelling to the right:
v = c = 3×10^8 m/s

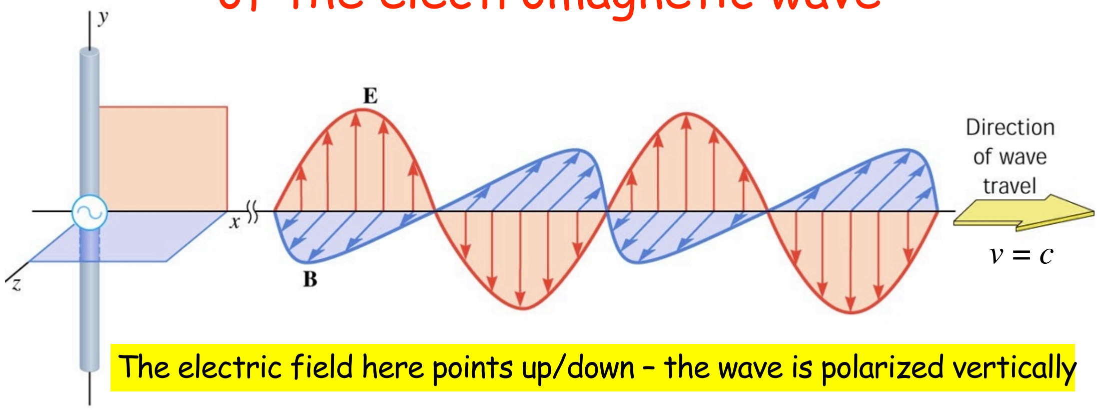
Generation of radio waves – magnetic component



The charges that oscillate back and forth along the antenna also constitute an electric current that generates an alternating magnetic field.

The magnetic field is at right angles to the antenna and at right angles to the electric field.

The electric and magnetic components of the electromagnetic wave



The electric field here points up/down – the wave is polarized vertically

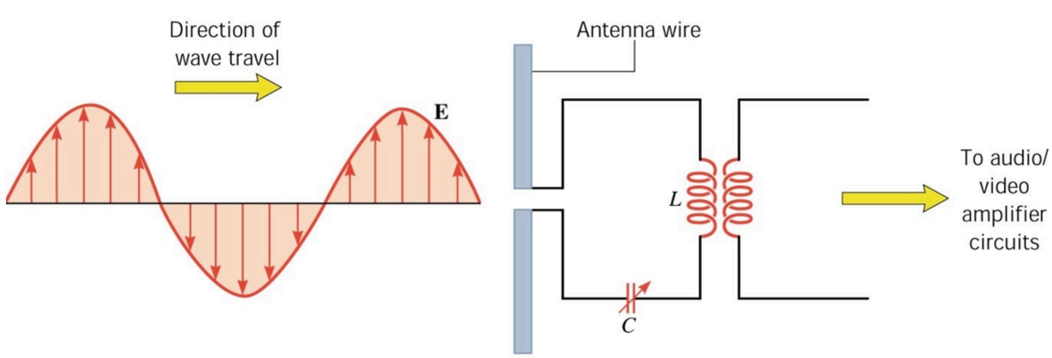
The electric and magnetic fields are perpendicular to one another and to the direction of travel of the electromagnetic wave.

All other electromagnetic waves (light, x-rays, etc) are of the same nature, but wavelength is too short to be generated with an antenna. Those waves originate in the atom, or the atomic nucleus.

Receiving a radio wave – electric field

The electric field of the wave interacts with charges in the antenna that is oriented parallel with the electric field of the wave.

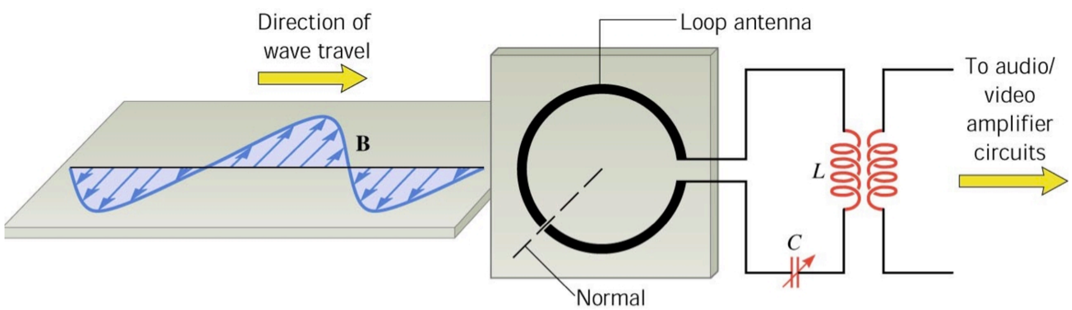
The electric field moves charges up and down in the antenna, that is, it produces a current that can be detected and amplified by a circuit tuned to the frequency of the wave.



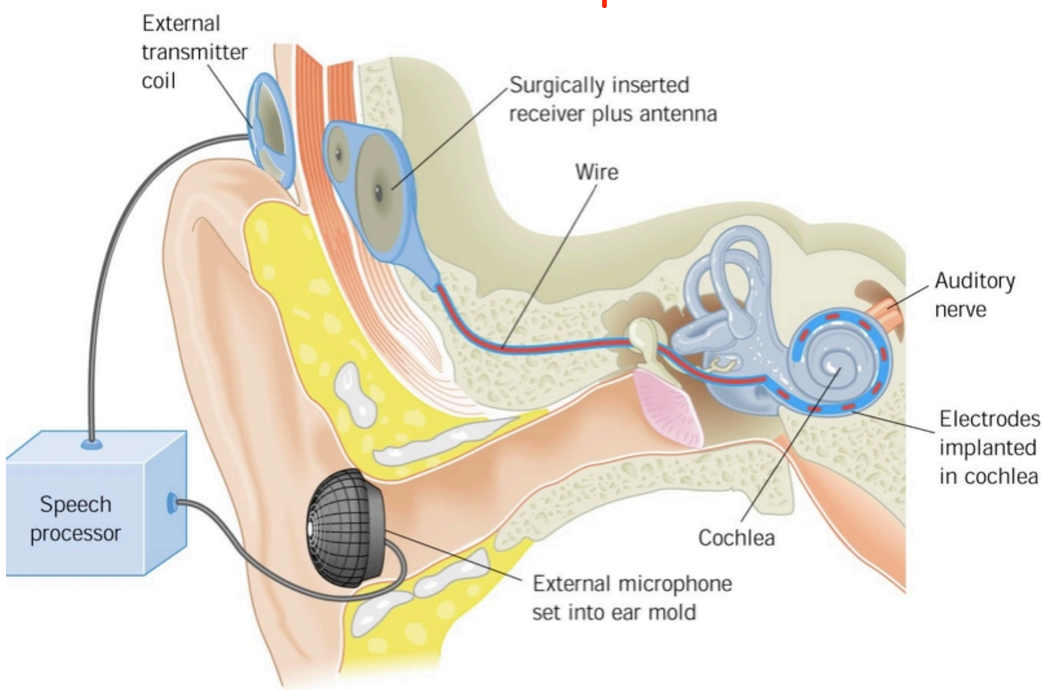
Receiving a radio wave – magnetic field

The magnetic field of the wave produces an alternating magnetic flux in the loop antenna, which generates a current in the loop.

The loop should be perpendicular to the magnetic field of the wave.

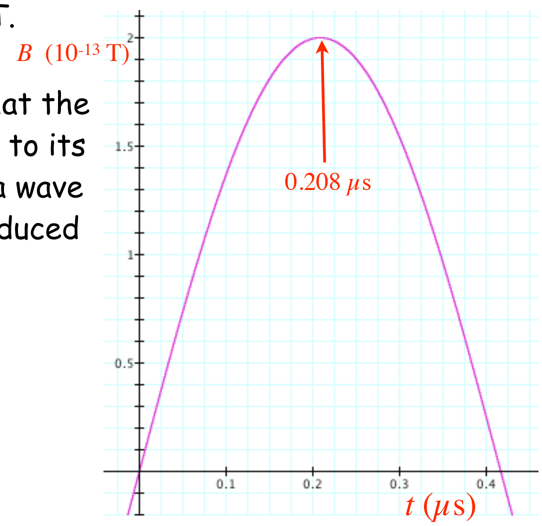


Cochlear implant



Prob. 24.6: A flat coil of wire of radius 0.25 m and 450 turns is used as a receiving antenna.

The transmitted radio wave has a frequency of 1.2 MHz. The magnetic field of the wave is parallel to the normal to the coil and has a maximum value of 2×10^{-13} T.

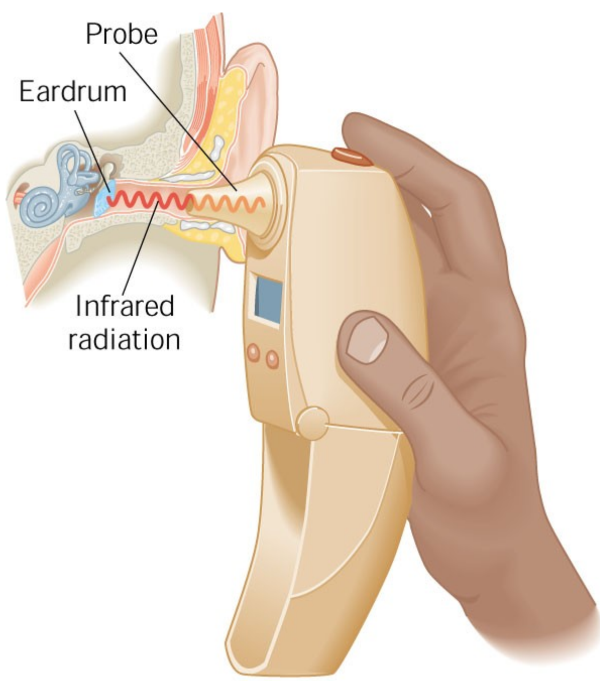


Use Faraday's law and the fact that the magnetic field changes from zero to its maximum value in one quarter of a wave period to find the average emf induced in the antenna during this time.

Period, T = 1/1.2 μs

$$V = \frac{\Delta\Phi}{\Delta t} = NA\frac{\Delta B}{\Delta t}$$

Pyroelectric thermometer



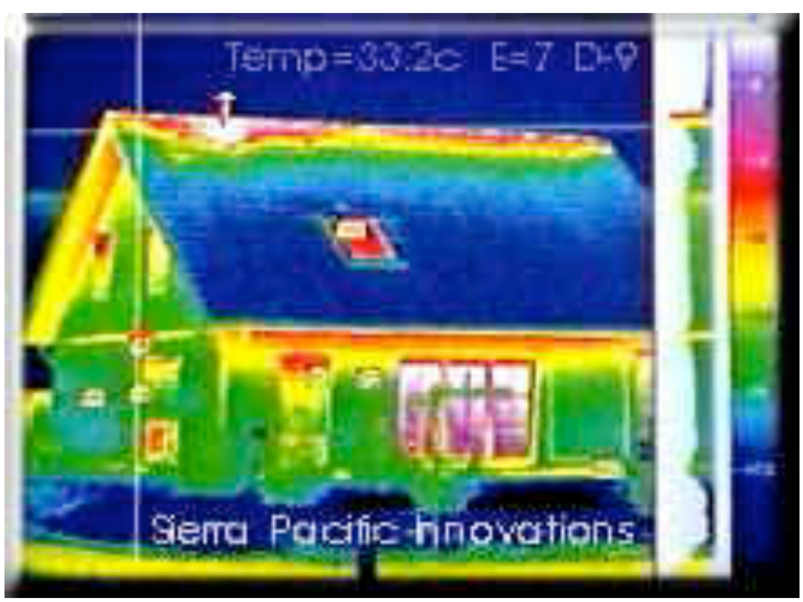
Everything emits electromagnetic radiation, the intensity and colour depending on temperature.

Measure the temperature of the inner ear from the infrared radiation it emits.

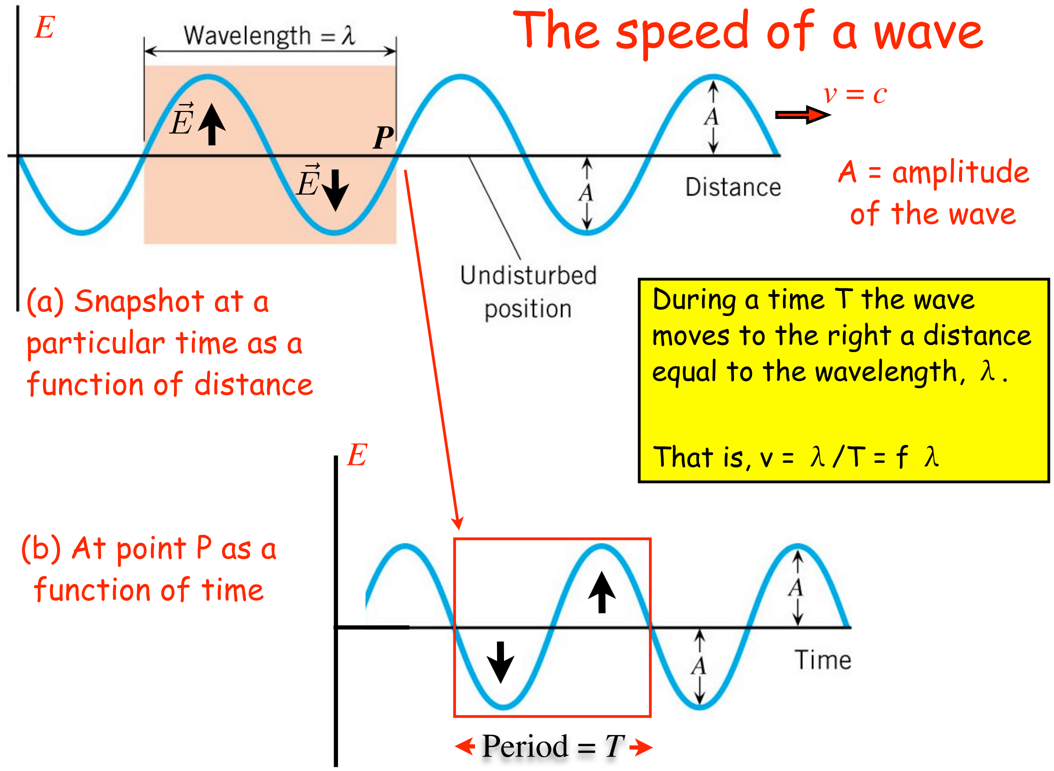
The sensor is warmed by infrared radiation from the interior of the ear, changing the sensor's resistance, which is measured and converted to a temperature.

Night vision goggles detect the infrared radiated by warm objects (eg people, animals, poorly insulated buildings).

Infrared detection of heat leaks from a building



The speed of a wave



During a time T the wave moves to the right a distance equal to the wavelength, λ.

That is, $v = \lambda / T = f\,\lambda$

Prob. 24.41/7: Some of the x-rays produced in an x-ray machine have a wavelength of 2.1 nm. What is their frequency?

$c = f\lambda$,

so

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{2.1 \times 10^{-9} \text{ m}} = 1.42 \times 10^{17} \text{ Hz}$$

Prob. 24.12: Two radio waves of different frequency are used in the operation of a cellular telephone, one to receive, the other to transmit.

If the cell tower transmits at a wavelength of 0.34339 m and the phone at 0.36205 m, find the the difference in frequency between the two waves.
(Use $c = 2.9979 \times 10^8$ m/s).

$c = f\lambda$, so $f = c/\lambda$

$f_1 = c$ / (0.34339 m) = 873.031 MHz
$f_2 = c$ / (0.36205 m) = 828.035 MHz

Difference = 44.996 MHz

Prob. 24.11: "Rabbit ear" TV antennas used to be common. They consisted of a pair of metal rods adjusted in length to one quarter of a wavelength of an electromagnetic wave of frequency 60 MHz.

How long was each rod?

$$c = f\lambda, \text{ so } \lambda = \frac{c}{f} = \frac{3 \times 10^8}{60 \times 10^6} = 5 \text{ m}$$

So rods were 5/4 = 1.25 m long.

Prob. 24.3/43: In astronomy, distances are often expressed in light years, the distance light travels in one year.

Alpha Centauri, the closest star to earth, is 4.3 light years away. Express this distance in metres.

1 light year (LY) = $ct = (3 \times 10^8 \text{ m/s}) \times (365 \times 24 \times 3600 \text{ s}) = 9.5 \times 10^{15}$ m

$L = 4.3 \times (9.5 \times 10^{15} \text{ m}) = 4.1 \times 10^{16}$ m

Prob. 24.-/1: The distance from the earth to the moon can be determined from the time it takes a laser beam to travel from the earth to the moon and back. If the round trip can be measured to an accuracy of 0.1 ns, what is the corresponding error in the earth-moon distance?

Summary of Chapter 24

- Light (and x-rays, gamma-rays, radio waves, infrared, ultraviolet...) is an electromagnetic wave

- Electromagnetic waves travel at speed $c = 3 \times 10^8$ m/s in vacuum

- The relation between speed, wavelength and frequency is:

  $c = f\lambda$

PHYS 1030 Term Test

Thursday, March 6, 7-9 pm

Chapters 18-22, 24, 25
20 multiple choice questions
Formula sheet provided

Seating is by family name

From	To	Room
A	Gill	200 Armes
Gils	Lee	201 Armes
Leg	P	204 Armes
Q	Z	208 Armes

Mastering Physics Assignment 3

Chapters 21, 22
due Friday, Feb 29 at 11 pm

Week of February 25 - 29

Tutorial and Test 2: Chapters 19, 20, 21

Thursday, March 6, 7-9 pm

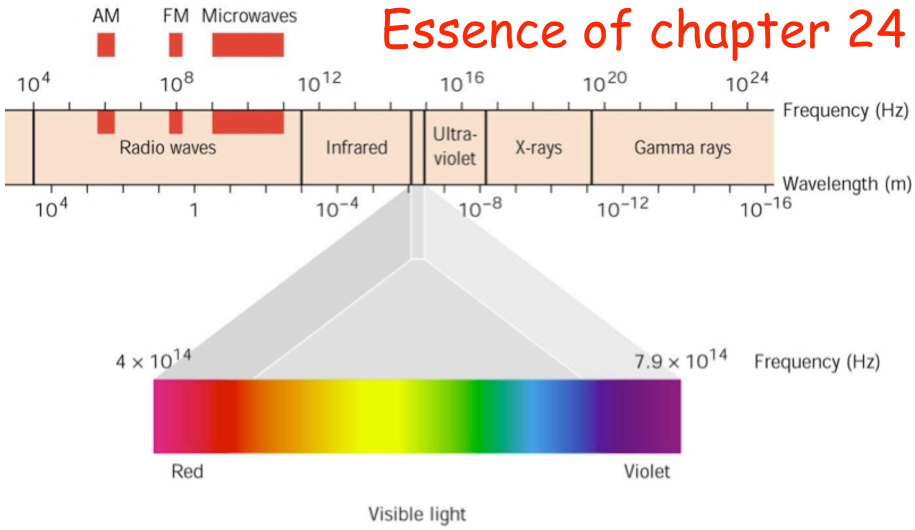
Midterm Test
Chapters 18-22, 24, 25
20 multiple choice questions, formula sheet provided

Review in class on Wednesday, March 5 - email me your questions!

PHYS 1030: the second half

8	M	25	19	Chapter 24, 25	Electromagnetic Waves and Laws of Reflection (omit 24.4, 24.5, 24.6 and 25.4, 25.5, 25.6)	Tutorial and Test 2 (chapters 19, 20, 21)
	W	27	20			
	F	29	21	Chapter 26	Refraction, Lenses & Optical Instruments	
9	M	**Mar 3**	22			Week of TERM TEST NO LAB OR TUTORIAL
	W	5	23		**Review in class - send questions!**	
	Th	6			MIDTERM TEST (7:00 - 9:00 pm)	
	F	7	24	Chapter 27	Interference (omit 27.9)	
10	M	10	25			Experiment 4: Geometrical Optics
	W	12	26			
	F	14	27	Chapter 28	Special Relativity (omit 28.7)	
11	M	17	28			Tutorial and Test 3 (chapters 22, 24, 25, 26)
	W	19	29			
	F	21			**GOOD FRIDAY (no classes)**	
12	M	24	30	Chapter 29	Particles & Waves (omit 29.4)	Experiment 5: Spectroscopy
	W	26	31			
	F	28	32			
13	M	31	33	Chapter 30	Atom (omit 30.5, 30.6)	Tutorial and Test 4 (chapters 27, 28)
	W	**Apr 2**	34			
	F	4	35	Chapter 31	Nucleus & Radioactivity	
14	M	7	36			NO LABS or TUTORIALS
	W	9	37			
	Fr	11	38	Review	**Last day of classes**	

Essence of chapter 24



- Visible light, x-rays, gamma-rays, radio waves, infrared, ultraviolet... are all electromagnetic waves, contain electric and magnetic fields

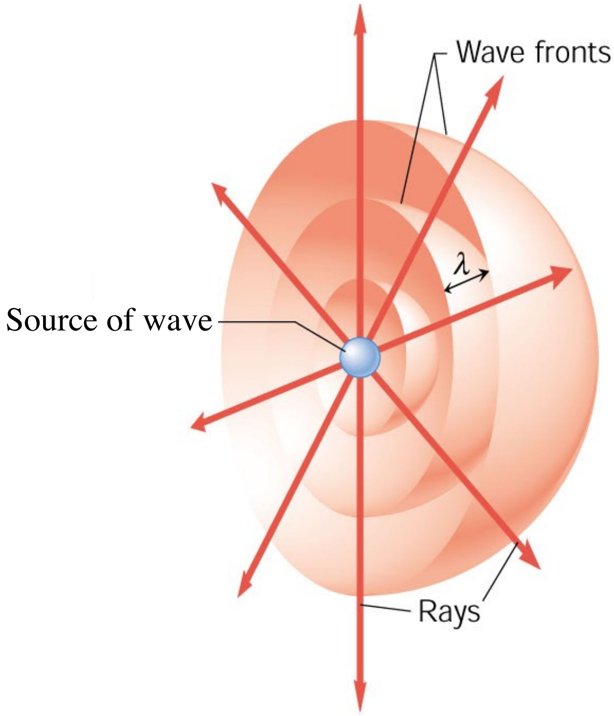
- Electromagnetic waves travel at speed $c = 3 \times 10^8$ m/s in vacuum

- The relation between speed, frequency and wavelength is: $c = f\,\lambda$

Chapter 25: Reflection of Light

- Wavefronts and rays
- Reflection of light, formation of image in a plane mirror
- **Omit sections 4, 5, 6** (spherical mirrors, mirror equation)

Waves originating from a point source



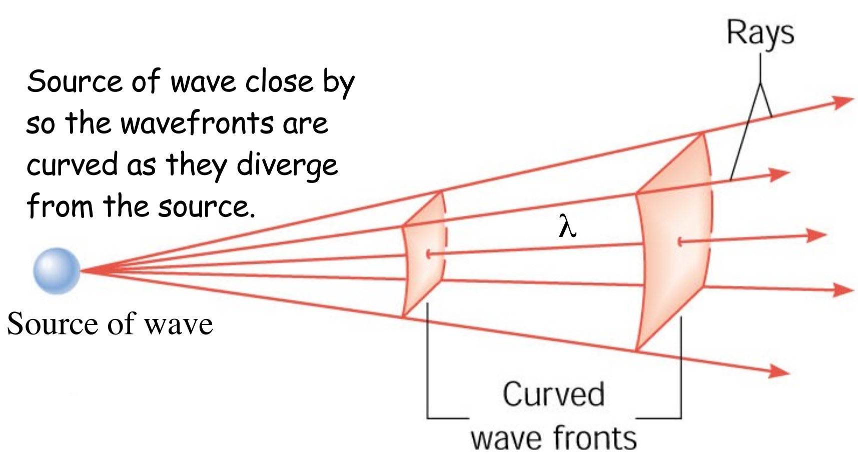
The waves move out from the source, travelling at the same speed in all directions.

The wavefronts are surfaces on which the wave has the same phase. For example, where the electric field of a light wave has its peak value.

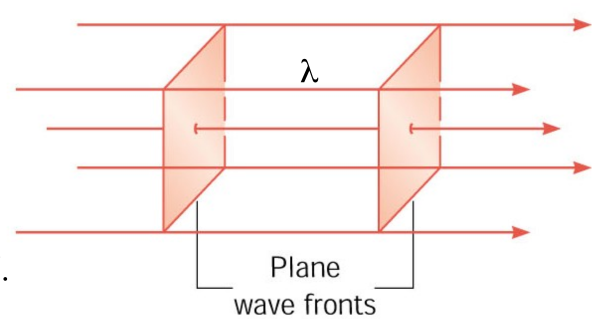
The distance between wavefronts is the wavelength, λ.

The rays travel at right angles to the wavefronts.

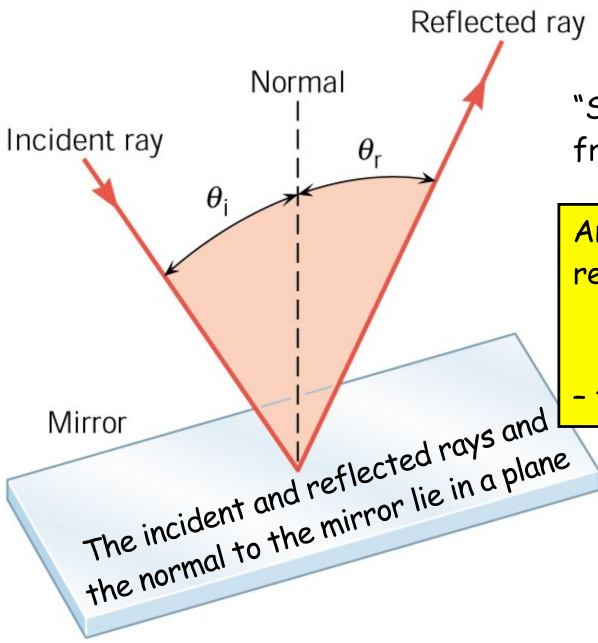
Source of wave close by so the wavefronts are curved as they diverge from the source.



Source of wave far away so that the wavefronts are flat to a good approximation and the rays are parallel – "plane waves".



Specular reflection of light



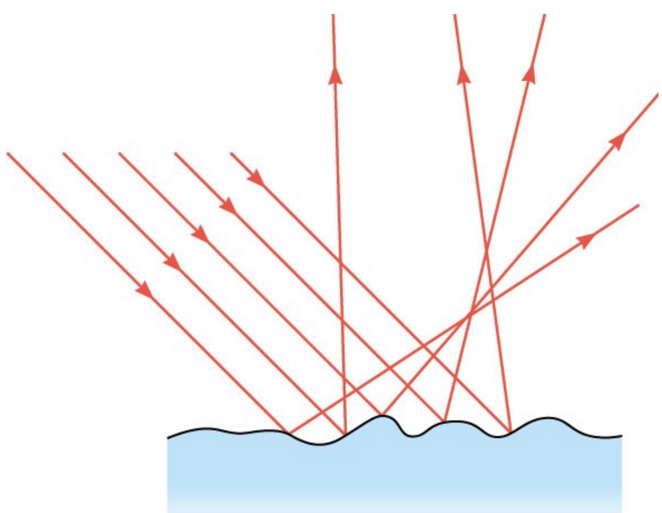
"Specular reflection", as from a mirror.

Angle of incidence = angle of reflection:

$$\theta_i = \theta_r$$

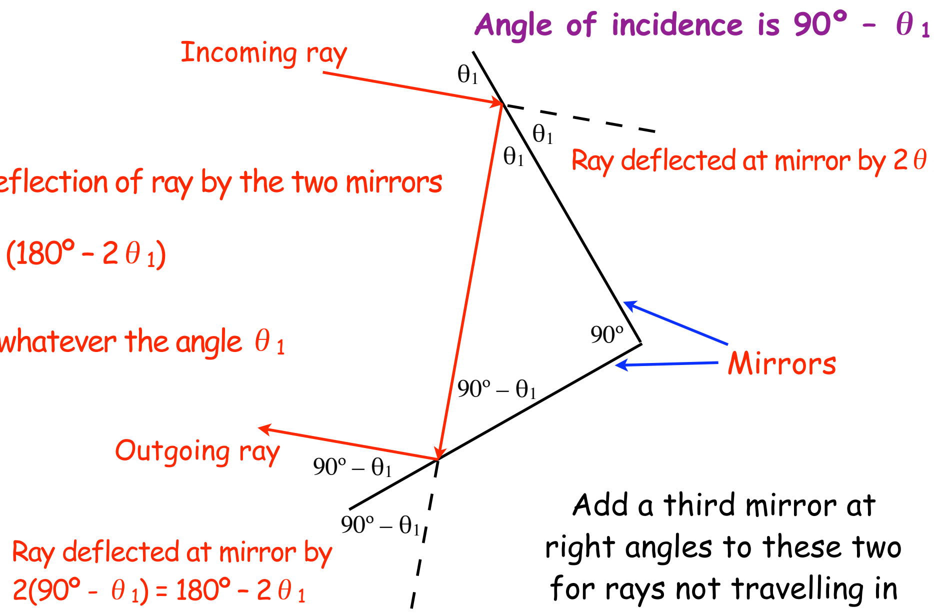
– the law of reflection

Diffuse reflection



The surface is irregular so that, although the law of reflection holds for each ray, the rays are not all reflected in the same direction. Example, reflection of light from paper, or from any surface that is not shiny.

Corner Reflector



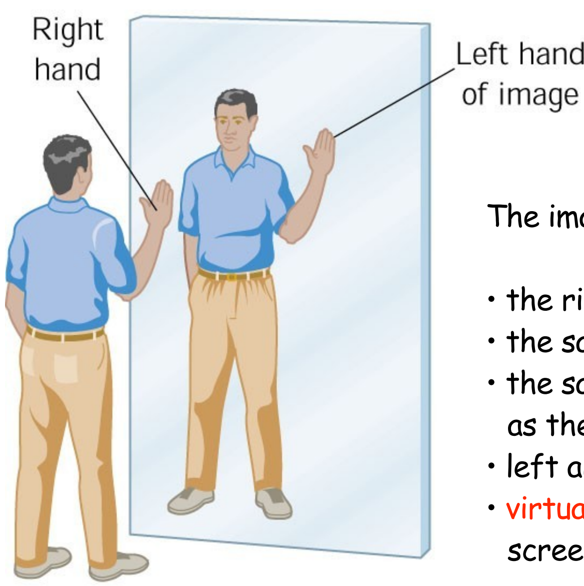
Total deflection of ray by the two mirrors

= 2 θ_1 + (180° – 2 θ_1)

= 180°, whatever the angle θ_1

Add a third mirror at right angles to these two for rays not travelling in the plane of the screen

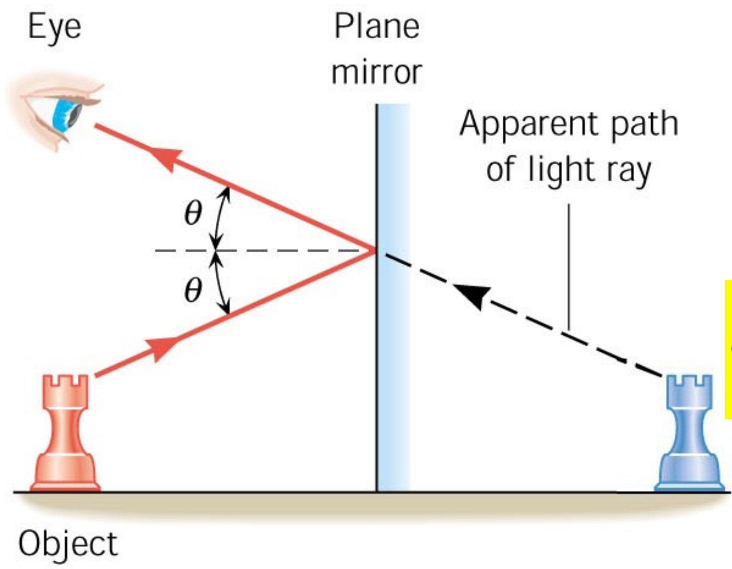
The image formed by a plane mirror



The image is:

- the right way up (upright)
- the same size as the object
- the same distance behind the mirror as the object is in front
- left and right are reversed
- virtual – cannot show the image on a screen

Formation of image by a plane mirror



The **virtual image** – where the light appears to be coming from

Formation of image by a plane mirror

A number of rays from the same point on the object hit the mirror at different angles, are reflected according to the law of reflection and reach the eye.

The light rays appear to come from the "virtual image" which is at the same distance behind the mirror as the object is in front.

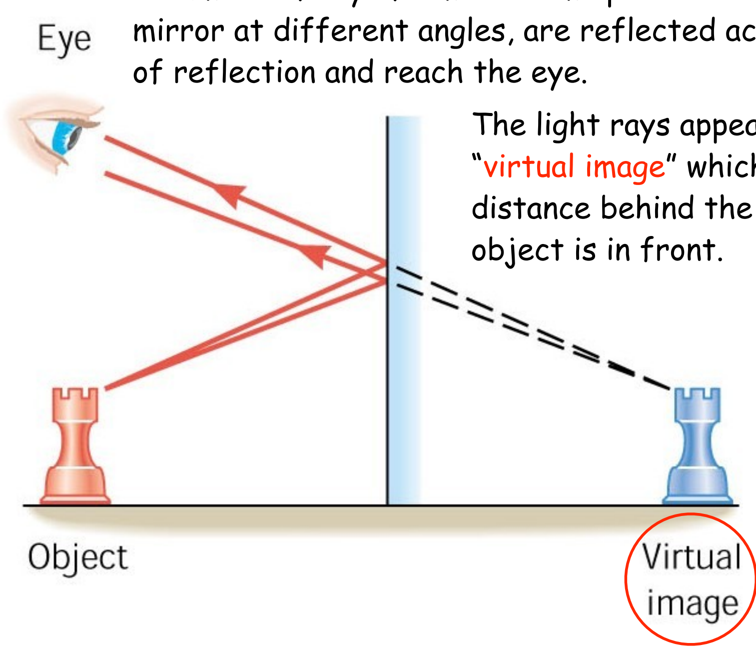
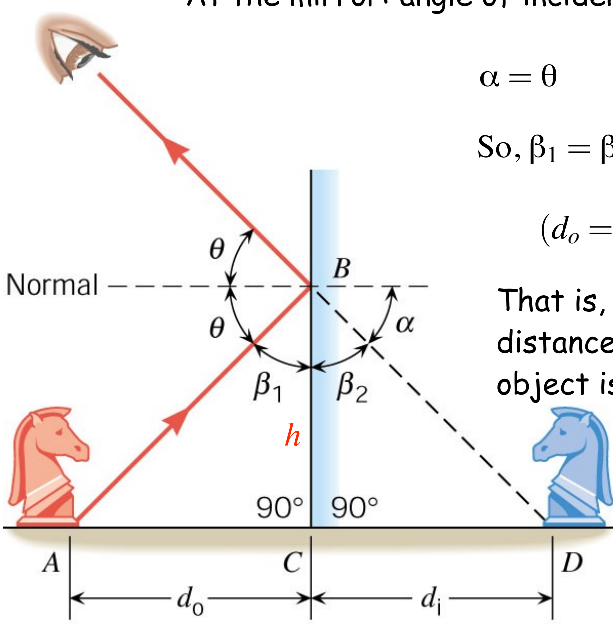


Image distance = object distance

At the mirror: angle of incidence = angle of reflection



$$\alpha = \theta$$

So, $\beta_1 = \beta_2$ and $d_i = d_o$

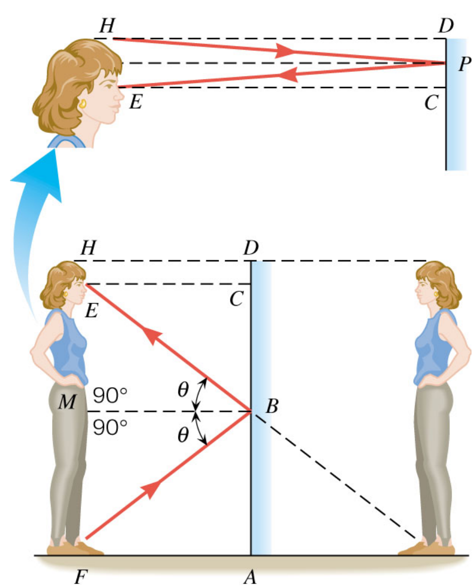
$$(d_o = h\tan\beta_1, \quad d_i = h\tan\beta_2)$$

That is, the image is the same distance behind the mirror as the object is in front of it.

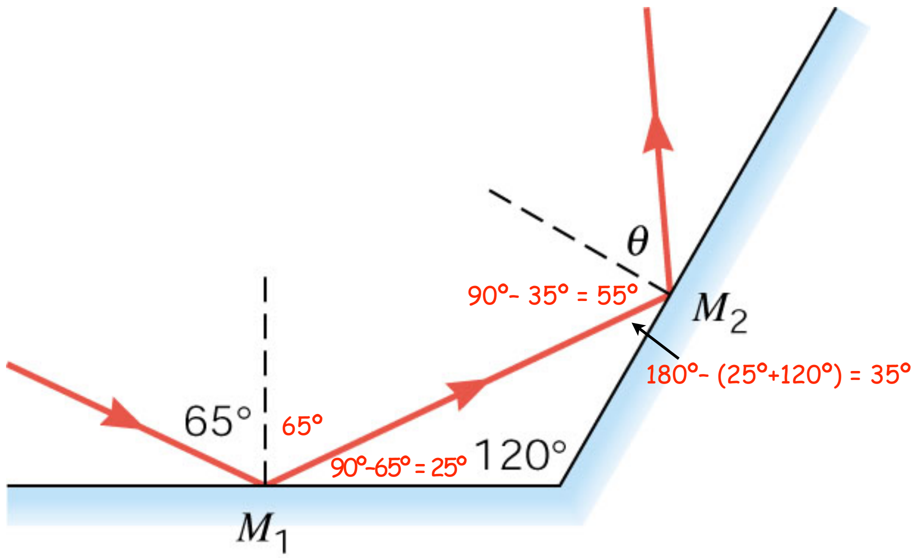
Prob. 25.2: A person whose eyes are 1.7 m above the floor stands in front of a plane mirror. The top of her head is 0.12 m above her eyes.

a) What is the height of the shortest mirror in which she can see her entire image?

b) How far above the floor should the bottom edge of the mirror be placed?



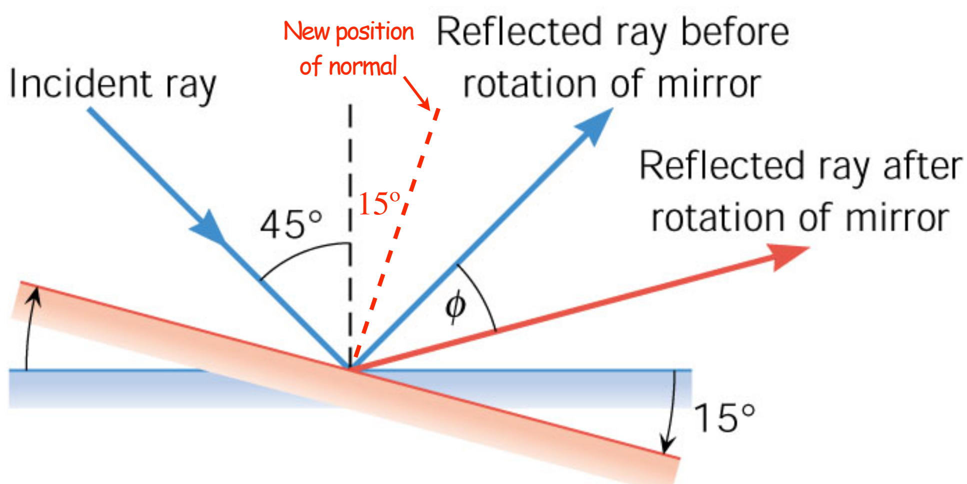
Prob. 25.5/1: What is the angle θ?



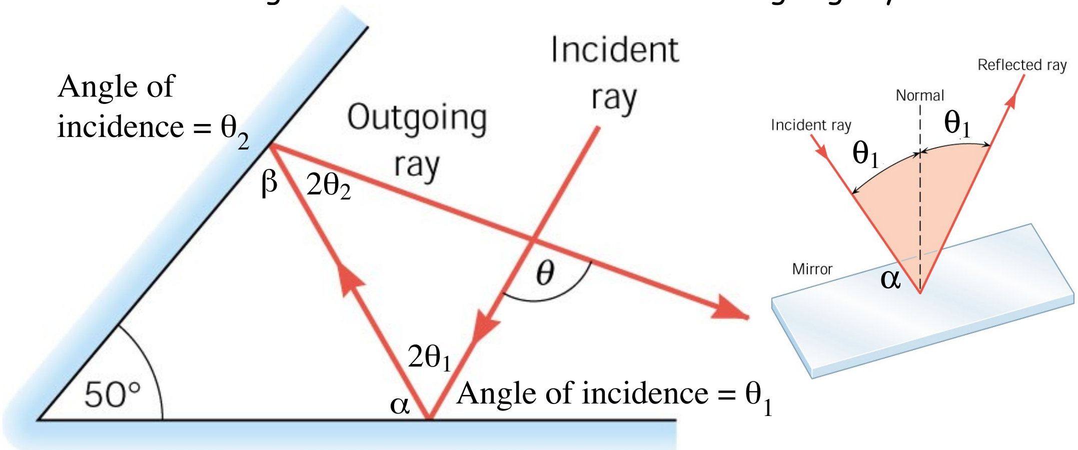
Prob.25.36/8: A ray of light strikes a mirror at 45°. The mirror is then rotated by 15° into the position shown in red, while the incident ray is kept fixed.

a) Through what angle ϕ does the reflected ray rotate?

b) What is the answer if the initial angle of incidence is 60° instead of 45°?



What is the angle θ between the incident and outgoing rays?

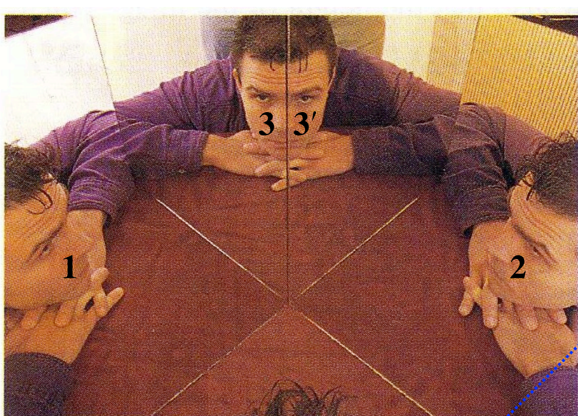


$\alpha+\beta+50^\circ=180^\circ$, so $\alpha+\beta=130^\circ$ $\qquad$ $\theta=2\theta_1+2\theta_2$

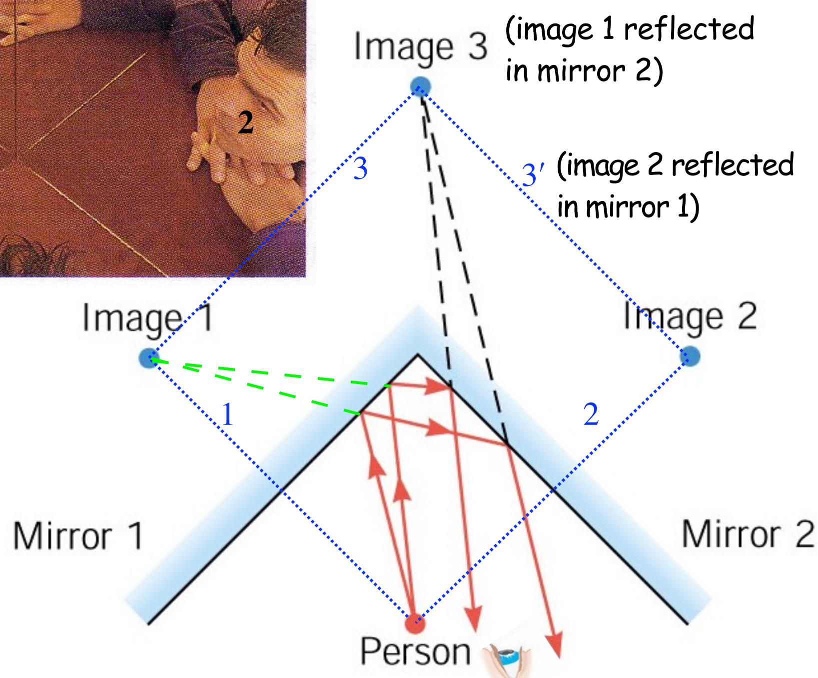
Also, $\alpha+\theta_1=\beta+\theta_2=90^\circ$ $\qquad$ so $(\alpha+\theta_1)+(\beta+\theta_2)=180^\circ$

Therefore, $(\alpha+\beta)+(\theta_1+\theta_2)=180^\circ$

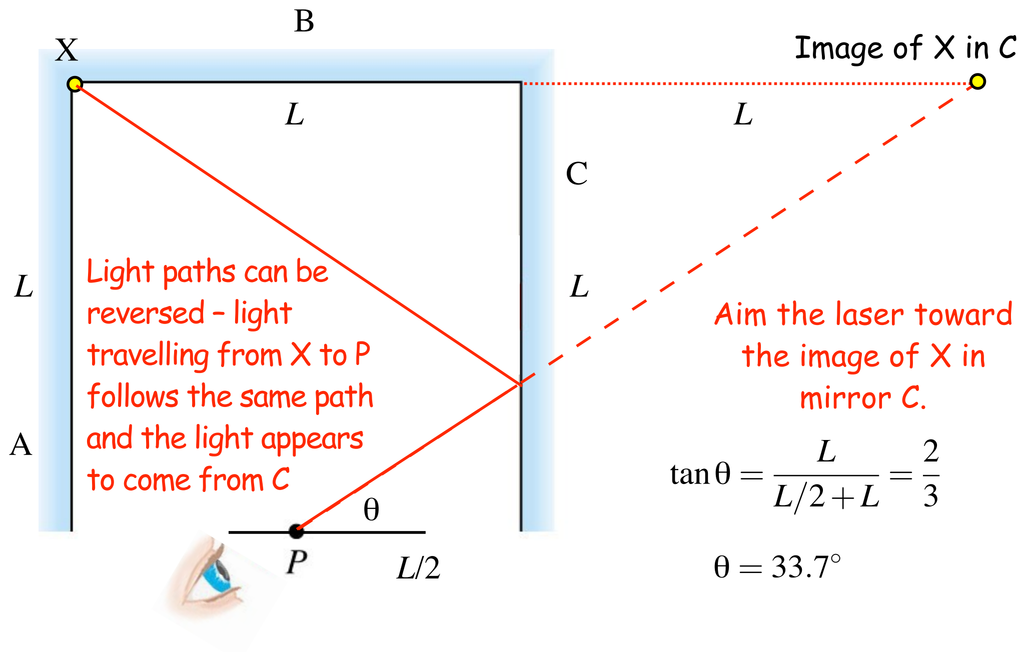
$$130^\circ+\theta/2=180^\circ \quad \rightarrow \quad \theta=100^\circ$$



Multiple reflections



Prob. 25.9: At what angle must the laser be fired from P toward mirror C to hit the upper left corner at X?



Aim the laser toward the image of X in mirror C.

$$\tan\theta = \frac{L}{L/2+L} = \frac{2}{3}$$

$$\theta = 33.7^\circ$$

Summary of Chapter 25

- Specular and diffuse reflectors
- Angle of incidence = angle of reflection
- Formation of an image by a plane mirror – virtual image
- In a plane mirror, the image is the same distance behind the mirror as the object is in front