Announcements 1/28/10

Share lenses (every other person), handle only by plastic holder

Problem session and more mechanics review tonight 7:30 – 9:30 SC 128

E&M test: I know many of you have not previously studied this material; just answer questions as best you can, don't spend too much time

Reading for Tuesday: Wolfson 20.1 and 20.2. (It's short!) On Tuesday we will also wrap up discussing angular magnification.

Key ideas from last time:

Image formation with converging lenses

Converging lenses focus light by refraction in focal plane

Converging lenses can form either real or virtual image depending on object location;

$s_o > f$ → real image

$s_o < f$ → virtual image

How do we find this out?

Principal rays with lenses:

(1) Ray parallel to axis refracts through focal point

(2) Ray through focal point refracts parallel to axis

(3) Ray through center of lens is not deflected

$$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o} \qquad \text{and} \qquad \frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

Key properties of images:

real/virtual

size

upright/inverted

location

Most important application

Human vision: eye has a lens with adjustable f, fixed distance from lens to retina (s_i)

real image must form on retina

Lens has vitreous humor on one side, air on the other:

$$\frac{n_1}{f_1} = \frac{n_2}{f_2} = \frac{n_1}{s_o} + \frac{n_2}{s_i} \qquad \text{object in 1, image in 2}$$

J.S.

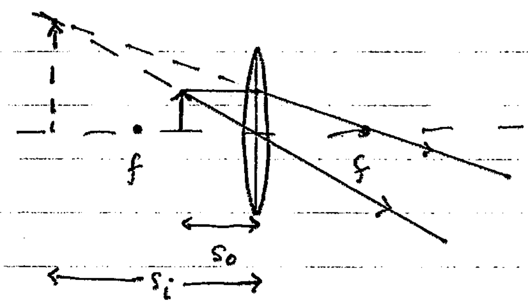
1/28/10 BRING COMPUTER W/LENS APPLETS LOADED

Today:

(1) Images with multiple lenses
Bottom line: image formed by 1^{st} lens serves as object for 2^{nd}
(2) Human vision correction

How do we use a magnifying glass? (Convex/converging lens)
Place object inside f of converging lens → enlarged, upright, virtual image

[How do we know? Don't memorize!
ray diagram
AND/OR lens eq: $s_o < f \rightarrow$ negative s_i
(means a virtual image)



Eye's lens then takes these rays and forms a real image on the retina

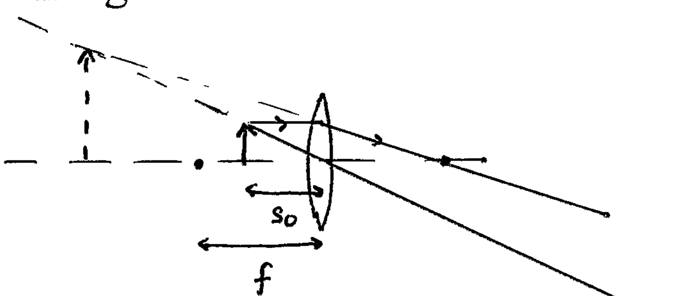
$\boxed{\text{Example problem}}$: bug + mag. glass

Your eye then takes this image and focuses it: (see Images with Two Lenses, Virtual image from 1^{st} lens)
$\boxed{\text{Next problem}}$ Emphasize image from #1 → object for #2 lens
Show rays on ~~[illegible]~~ figure already drawn

(How does your eye do this? Rays to your eye travel exactly as if they came from the virtual image.)

Problems and questions, Physics 4L 28 January 2010

You are outdoors using a magnifying glass to examine an interesting insect on a sunny day. You notice that if you hold a piece of paper 15.0 cm underneath the magnifying glass and let the sun's light fall on the magnifying glass, it makes a bright spot. Where should you hold the lens to form a 3x magnified image of the insect?



Goal: find s_o in terms of what we know

$M = 3$ tells us upright image

($M \equiv \frac{h_i}{h_o}$ so h_i must be ⊕)

Ray diagram tells us s_i ⊖

Also $M = -\frac{s_i}{s_o} = 3 \Rightarrow s_i = -3s_o$

focal length given in problem as 15.0 cm (rays from distant source focus to a point at the focal point)

Use lens equation:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \Rightarrow \frac{1}{15.0\text{ cm}} = \frac{1}{s_o} - \frac{1}{3s_o} = \frac{2}{3s_o}$$

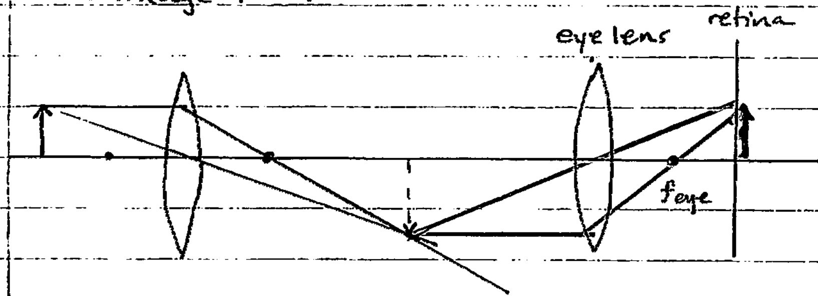
$$\Rightarrow s_o = \frac{(15.0\text{ cm})(2)}{(3)} = 10.0\text{ cm}$$

So we want to hold the lens 10.0 cm from the insect

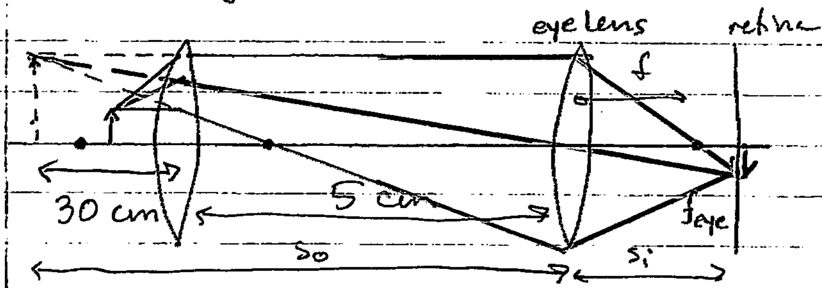
Also note $s_i = -30.0$ cm $(= -3s_o)$

Images with two lenses

Real image from 1st lens:



Virtual image from 1st lens:



Rays coming into eye's lens travel exactly as if they were coming from image

$$\frac{n_2}{f_2} = \frac{n_1}{s_o} + \frac{n_2}{s_i}$$

$s_i = 2.30\text{ cm}$

$s_o = 30.0\text{ cm} + 5.0\text{ cm} = 35.0\text{ cm}$

$n_2 = 1.34$

$n_1 = 1.00$

Substitute, solve

$\Rightarrow f_2 = 2.19\text{ cm}$

You are viewing an insect with 3x magnification with your magnifying glass as in the previous problem. If the magnifying glass is 5.0 cm from your eye, and your retina is 23.0 mm from your eye's lens, what is the focal length of your eye's lens inside your eye? (The eye's contents have $n_{eye} = 1.34$.)

See previous page for diagram with distances labeled

We found in 1st problem that the image distance for 1st lens is -30 cm

So image formed by 1st lens is 30.0 cm + 5.0 cm = 35.0 cm from eye's lens

To find f_{eye}, use generalized lens eq:

$$\frac{n_2}{f_2} = \frac{n_1}{s_o} + \frac{n_2}{s_i}$$

s_i = distance from eye lens to retina = 2.30 cm

s_o = 35.0 cm

n_1 = air index = 1.00

$n_2 = n_{eye} = 1.34$

$$\frac{1.34}{f_2} = \frac{1.00}{35.0\text{ cm}} + \frac{1.34}{2.34\text{ cm}} = 0.611/\text{cm}$$

$$\rightarrow f_2 = \frac{1.34}{0.611/\text{cm}} = 2.19\text{ cm}$$

What if you want to look at a real image?
See Images with two lenses, real image from 1st

Must also consider range of adjustment of eye's lens:

Normal human vision

- Eye's lens can adjust focal length over a limited range
  Normal range allows focusing on objects from
  25 cm to distant

$\boxed{\text{CT}}$ Why can't see page
Real image forms on side of lens closest to eye
Image will be less than 25 cm from eye!

How does f change from near objects to distant?

$\boxed{\text{CT}}$ Going from nearby object to distant object
To keep image on retina, f must ~~decrease~~ increase:

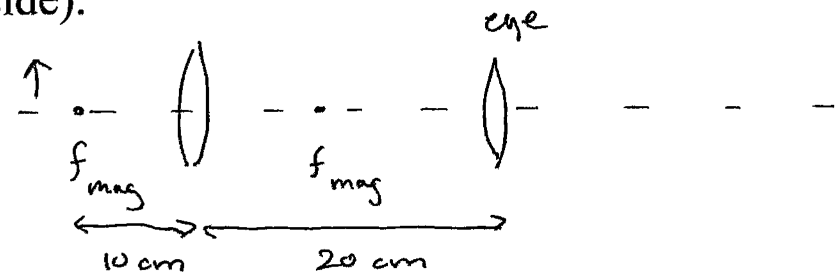
$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$ As s_o increases, f must also increase with s_i fixed

Increasing $f \Leftrightarrow$ flatter lens

ILLUSTRATE W/APPLET

Very distant objects $\Rightarrow$ $s_i = f$ so normal eye has retina located at longest f that eye can achieve, to see distant objects
closer objects are viewed with shorter f

You hold a 10 cm focal length lens 12 cm from your page of Physics 4L notes. Explain why you can't see anything through the lens if you hold your head 20 cm from the lens (on the other side).



When focused on a nearby object, the focal length of your eye's lens is *f*. To focus on a distant object, the focal length must

1. increase.
2. decrease.

$$\frac{1}{f} = \frac{1}{S_o} + \frac{1}{S_i}$$

S_o increasing

S_i fixed

f must increase

(lens gets flatter)

Myopia

Nearsighted person has a mismatch between maximum f and size of eyeball — can focus on nearby objects but not on distant objects

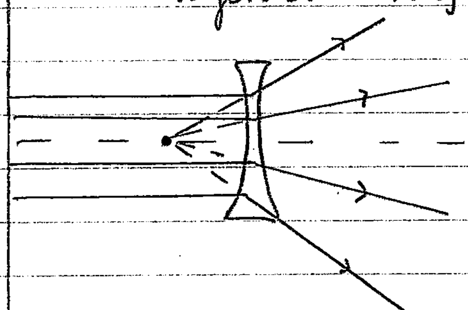
$\boxed{\text{CT}}$ too long/too short?

Too long — image of dist object falls @ f
image of nearer object is behind f

(Use applet to show)

To correct: want to bring the object nearer.
If can't bring the object nearer, use a lens that makes an image that is nearer than the object — Diverging lens

Diverging (concave) lens: spread rays out instead of bringing together — rays refract so that they appear to be coming from a virtual focus



f is $\ominus$ (means rays don't really go there)

Placing a diverging lens in front of the eye makes ~~focuses~~ ~~creates~~ parallel rays ~~an image~~ ~~of distant objects~~ appear to come from virtual focal plane

Distant objects → ∥ rays
⇒ image of dist objects forms in focal plane

$\boxed{\text{Problem}}$: lens for nearsighted person

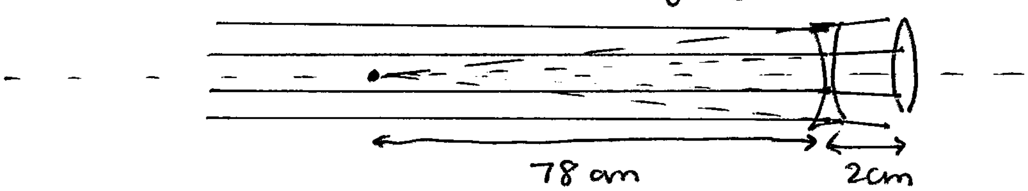
Define lens power $\equiv \frac{1}{f}$ with f in m (NEGATIVE for div lens)

Is the retina in a nearsighted person too close to the lens or too far from the lens?

1. Too close.
2. Too far.

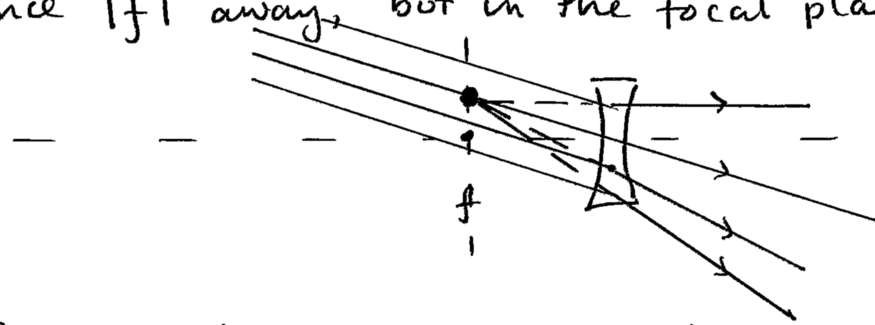
Erik Smith (Physics 4L Jedi/SA) cannot see clearly beyond 80 cm. Prescribe a lens power that will allow him to see distant objects clearly.

We need a lens that will form images of distant objects 80 cm from his eyes. Assume his glasses are 2 cm from his eyes, so we need lenses to form images of distant objects 78 cm in front of the lens: want diverging lens with
$f = -78$ cm
(negative sign shows diverging lens)

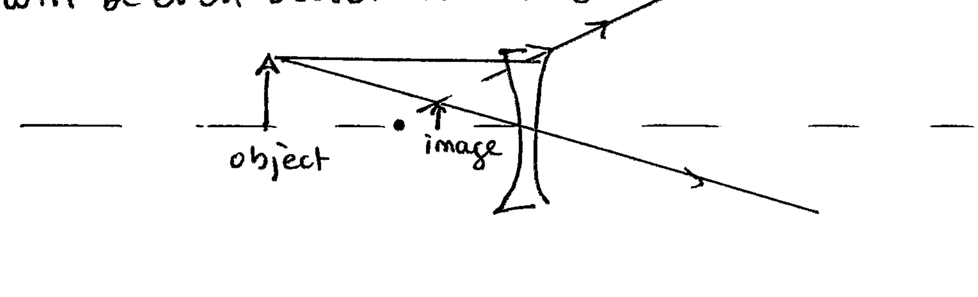


Rays from a distant object straight ahead will be refracted from lens to appear to come from a point at the virtual focus.

Rays that come from a distant object above the axis also refract to appear to come from a point a distance $|f|$ away, but in the focal plane (off-axis):



If the object is not distant, image will be closer to lens than the focal plane, so image will be even closer than 80 cm:

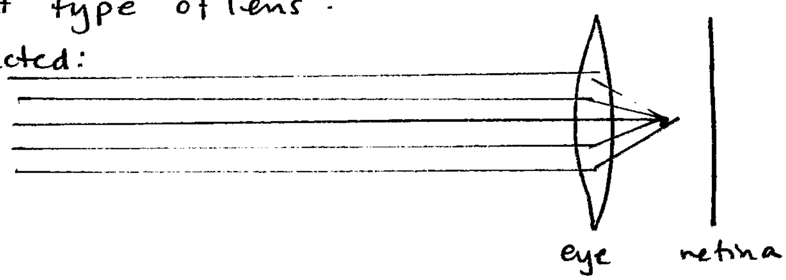


Problem: nearsighted person cannot focus on objects past 80 cm

Goal: find lens that will create an image of distant objects that is 80 cm in front of wearer's eyes

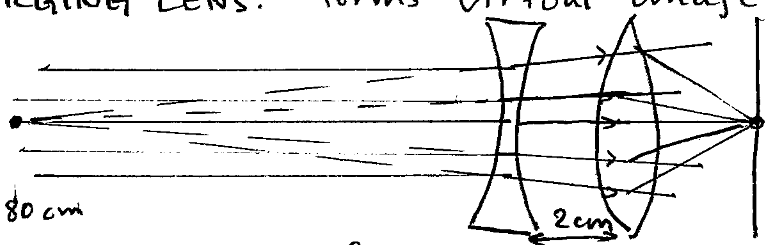
What type of lens?

Uncorrected:



How can we reconfigure these rays so they appear to be coming from 80 cm from eye?

DIVERGING LENS: forms virtual image of ∥ rays @ focal pt



(Draw rays only as far as eye's lens!)

Eye's lens can then focus these rays properly onto retina

Lens with $f = -78$ cm is needed if lens 2 cm in front of eye

Define

$$\text{Power} = \frac{1}{f \text{ in meters}} = -\frac{1}{0.78\text{ m}} = -1.28 \text{ diopters}$$

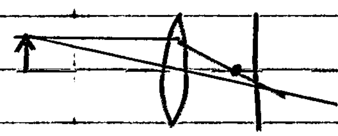
(power in diopters requires f in meters)

Farsightedness (hyperopia)

Can focus on distant objects, but cannot focus on nearby objects because lens cannot reach a short enough focal length

$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$ Fixed $s_i \Rightarrow$ small s_o requires small f

Image falls behind retina



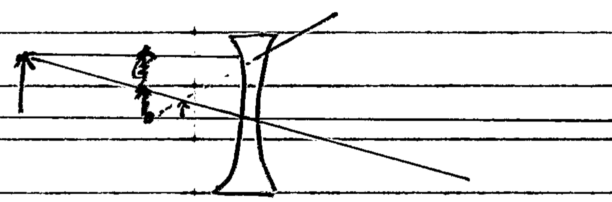
Need to place a lens in front of eye that creates an image farther away from the eye (and upright)

What kind of image, real or virtual? virtual (to be upright)

What kind of lens? either type can create virtual image

$\boxed{\text{CT}}$ BUT only conv → image that is farther away

See what happens w/diverging lens:



anywhere you put the object this will be ~~true b/c rays spread out~~

Or, lens eq:

$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$ ~~$\frac{1}{f}$ is negative, so~~

~~ALWAYS have s_i less than s_o for diverging lens~~

For diverging lens, f negative : write as $-\frac{1}{|f|}$

$\Rightarrow -\frac{1}{|f|} - \frac{1}{s_o} = \frac{1}{s_i}$ ~~means s_i is negative always (virtual)~~

AND ~~$|s_i|$ is less than s_o~~

$\frac{1}{|f|} + \frac{1}{s_o} = -\frac{1}{s_i}$

So image is always closer to the lens w/a diverging lens

$\boxed{\text{Does not work}}$

Converging lens → virtual image farther away (magnifying glass)

Microscope

Wolfson figure confusing - handout is clearer

Microscope has 2 lenses

(1) Objective lens produces highly magnified real image

Use a very short focal length

To get very enlarged real, where do we want object?

just outside focus:

then $\frac{1}{f} - \frac{1}{s_o} = \frac{1}{s_i}$ is very small, (+)

then $s_i \gg s_o \Rightarrow |M|$ large

s_i (+) $\Rightarrow$ real image

(2) Eyepiece lens used like a magnifying glass -

locate it so real image from objective is

just inside its focal length

→ enlarged virtual image where you can see it

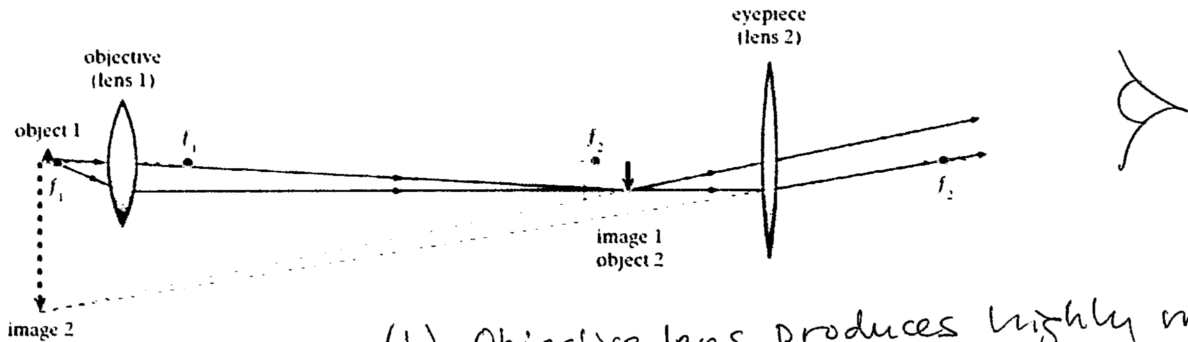
Biggest mag if virtual image is at your

near point - will discuss Thes.

Sample problem on page: ~~we'll do Monday if time permits~~

you can try out, we'll do ~~Mon~~ Thesday if time

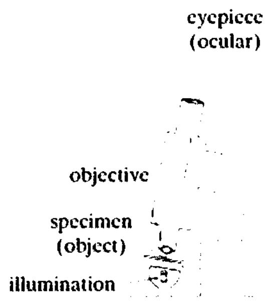
Microscope and angular magnification figures (Mazur, *Principles and Practice of Physics*)



(1) Objective lens produces highly magnified real image of small object

max mag $\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \Rightarrow \frac{1}{f} - \frac{1}{s_o} = \frac{1}{s_i}$

if $f \lessapprox s_o$ then s_i very large



(2) Eyepiece lens placed to be used like a mag. glass — real image 1 is just <u>inside</u> focus of eyepiece lens

Position so that image 2 is ≈ 25 cm from observer's eye

Microscope problem:

The objective lens of a microscope has focal length 3.00 mm and the eyepiece has focal length 40.0 mm. If the image formed by the objective lens is 20.0 cm from the objective, what is the "working distance" of the microscope (distance from objective lens to object when microscope is in focus)?