Physics 6C

Cameras and the Human Eye
CAMERAS

A typical camera uses a converging lens to focus a real (inverted) image onto photographic film (or in a digital camera the image is on a CCD chip).

Light goes through the aperture, and the **EXPOSURE** is jointly proportional to the **Intensity** of the light, the **Area** of the aperture, and the **Time** it is open.

Thus for a given object, if the diameter of the opening is doubled, the time should be $\frac{1}{4}$ as long to give the same exposure. You need this idea for the homework.
Example: Camera A has a lens with an aperture diameter of 8.0mm. It photographs an object using the correct exposure time of 1/30 seconds.

What exposure time should be used with camera B, which has a lens with an aperture diameter of 23.1mm?
Example: Camera A has a lens with an aperture diameter of 8.0mm. It photographs an object using the correct exposure time of 1/30 seconds.

What exposure time should be used with camera B, which has a lens with an aperture diameter of 23.1mm?

We want the total exposure (amount of light energy reaching the film) to be the same in both cases. Since exposure is proportional to time and aperture AREA, we need a smaller amount of time for the larger lens.
Example: Camera A has a lens with an aperture diameter of 8.0mm. It photographs an object using the correct exposure time of 1/30 seconds.

What exposure time should be used with camera B, which has a lens with an aperture diameter of 23.1mm?

We want the total exposure (amount of light energy reaching the film) to be the same in both cases. Since exposure is proportional to time and aperture AREA, we need a smaller amount of time for the larger lens.

We can set up a formula:

\[(\text{area})_A \cdot (\text{time})_A = (\text{area})_B \cdot (\text{time})_B\]
Example: Camera A has a lens with an aperture diameter of 8.0mm. It photographs an object using the correct exposure time of 1/30 seconds.

What exposure time should be used with camera B, which has a lens with an aperture diameter of 23.1mm?

We want the total exposure (amount of light energy reaching the film) to be the same in both cases. Since exposure is proportional to time and aperture AREA, we need a smaller amount of time for the larger lens.

We can set up a formula:

\[
\text{(area)}_A \cdot \text{(time)}_A = \text{(area)}_B \cdot \text{(time)}_B
\]

\[
\text{(time)}_B = \frac{\text{(area)}_A}{\text{(area)}_B} \cdot \text{(time)}_A
\]

\[
\text{(time)}_B = \frac{(\text{diam}_A)^2}{(\text{diam}_B)^2} \cdot \text{(time)}_A
\]

\[
\text{(time)}_B = \frac{(8.0\text{mm})^2}{(23.1\text{mm})^2} \cdot \left(\frac{1}{30} \text{ sec}\right)
\]

\[
\text{(time)}_B = 0.004 \text{ sec}
\]

Here I have spelled out all the details of the proportionality. You can save several steps if you understand that area is proportional to the square of the diameter.
Ideally, the lens of the eye focuses the light rays from an object on the retina at the back of the eyeball.

The lens is somewhat flexible, and its focal length can be adjusted by contracting or relaxing the muscles around the lens. This is called accomodation.

The two most common vision problems involve the curvature of the eye’s lens. When the lens cannot adjust enough, the light will focus in front of or behind the retina, creating a blurry image.
The Human Eye

Myopia (nearsightedness)

- Even when fully relaxed, the lens is too curved (i.e. the light is bent too much).
- If the object is far away, the image formed by the lens is in front of the retina.
- The FAR POINT is the farthest distance that can be seen clearly without correction.
- To correct, the light is intercepted by a diverging lens before it gets to the eye.

The diagram shows a distant object and a myopic eye. The diverging lens forms a virtual image at the far point. It is this virtual image that the eye “sees”, and an image is formed on the retina, where it can be properly interpreted by the brain.
The Human Eye

Hyperopia (farsightedness)

- The lens will not curve enough to focus on very close objects.
- If the object is too close, the image formed by the lens is behind the retina.
- The **NEAR POINT** is the closest distance that can be seen clearly without correction.
- To correct, the light is intercepted by a converging lens before it gets to the eye.

Everybody has a near point – try to find yours:

Focus on your finger, and move it closer and closer until you just barely can’t see your fingerprint clearly. This is your near point.

The diagram shows a very close object and a hyperopic eye. The converging lens forms a virtual image at the near point. It is this virtual image that the eye “sees”, and an image is formed on the retina, where it can be properly interpreted by the brain.
We need to define one term – lens **POWER**.

The power of a lens (units are called DIOPTERS) is just the reciprocal of the focal length, **in meters**. Thus a lens with a power of +0.5 diopters will be a converging lens with focal length 2 meters. If you need a formula, here it is:

\[
\text{Lens Power} = \frac{1}{f}
\]

Make sure the focal length is in meters.
Here’s an example: Doctor Bob needs glasses. He is both myopic and hyperopic, so he will require bifocals. His range of clear vision is from 35cm to 85cm. Anything outside that range seems a bit blurry to him. What prescription(s) will the optometrist give him?

Assume that Bob would like to be able to focus on objects as close as 20 cm, and as far away as the weather will allow (objects at infinity).
Here’s an example: Doctor Bob needs glasses. He is both myopic and hyperopic, so he will require bifocals. His range of clear vision is from 35cm to 85cm. Anything outside that range seems a bit blurry to him. What prescription(s) will the optometrist give him?

Assume that Bob would like to be able to focus on objects as close as 20 cm, and as far away as the weather will allow (objects at infinity).

First let’s deal with the myopia. The problem is that anything farther than 85cm looks blurry. So ideally Bob would like to look at something that is very far away (object distance = ∞) and his corrective lenses will form an image at 85cm so that his eye can focus on it.
Here’s an example: Doctor Bob needs glasses. He is both myopic and hyperopic, so he will require bifocals. His range of clear vision is from 35cm to 85cm. Anything outside that range seems a bit blurry to him. What prescription(s) will the optometrist give him?

Assume that Bob would like to be able to focus on objects as close as 20 cm, and as far away as the weather will allow (objects at infinity).

First let’s deal with the myopia. The problem is that anything farther than 85cm looks blurry. So ideally Bob would like to look at something that is very far away (object distance = ∞) and his corrective lenses will form an image at 85cm so that his eye can focus on it.

We can use our standard formula for this:

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]
Here’s an example: Doctor Bob needs glasses. He is both myopic and hyperopic, so he will require bifocals. His range of clear vision is from 35cm to 85cm. Anything outside that range seems a bit blurry to him. What prescription(s) will the optometrist give him?

Assume that Bob would like to be able to focus on objects as close as 20 cm, and as far away as the weather will allow (objects at infinity).

First let’s deal with the myopia. The problem is that anything farther than 85cm looks blurry. So ideally Bob would like to look at something that is very far away (object distance = $\infty$) and his corrective lenses will form an image at 85cm so that his eye can focus on it.

We can use our standard formula for this:

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]

\[
\frac{1}{f} = \frac{1}{\infty} + \frac{1}{-0.85m}
\]

\[
f = -0.85m
\]

\[
\text{Power} = -1.18 \text{ Diopters}
\]

Notice how the image at infinity gives a focal length equal to the near point distance.

Also note the image distance – it is negative.

It is a virtual image – it will always be negative.
Here’s an example: Doctor Bob needs glasses. He is both myopic and hyperopic, so he will require bifocals. His range of clear vision is from 35cm to 85cm. Anything outside that range seems a bit blurry to him. What prescription(s) will the optometrist give him?

Assume that Bob would like to be able to focus on objects as close as 20 cm, and as far away as the weather will allow (objects at infinity).

First let’s deal with the myopia. The problem is that anything farther than 85cm looks blurry. So ideally Bob would like to look at something that is very far away (object distance = $\infty$) and his corrective lenses will form an image at 85cm so that his eye can focus on it.

We can use our standard formula for this:

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]

\[
\frac{1}{f} = \frac{1}{\infty} - \frac{1}{-0.85m}
\]

\[
f = -0.85m
\]

Power = $-1.18$ Diopters

Notice how the image at infinity gives a focal length equal to the near point distance.

Also note the image distance – it is negative.

It is a virtual image – it will always be negative.

Now for the hyperopia. Anything closer than 35cm looks blurry. He should be able to have an object at 20cm, and his glasses will form an image at his near point.

Here is the calculation:
Here’s an example: Doctor Bob needs glasses. He is both myopic and hyperopic, so he will require bifocals. His range of clear vision is from 35cm to 85cm. Anything outside that range seems a bit blurry to him. What prescription(s) will the optometrist give him?

Assume that Bob would like to be able to focus on objects as close as 20 cm, and as far away as the weather will allow (objects at infinity).

First let’s deal with the myopia. The problem is that anything farther than 85cm looks blurry. So ideally Bob would like to look at something that is very far away (object distance = ∞) and his corrective lenses will form an image at 85cm so that his eye can focus on it.

We can use our standard formula for this:

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]

**Notice how the image at infinity gives a focal length equal to the near point distance.**

**Also note the image distance – it is negative.**

**It is a virtual image – it will always be negative.**

Now for the hyperopia. Anything closer than 35cm looks blurry. He should be able to have an object at 20cm, and his glasses will form an image at his near point.

Here is the calculation:

\[
\frac{1}{f} = \frac{1}{0.20m} + \frac{1}{-0.35m} \Rightarrow f = +0.47m
\]

**Again note the image distance – it is negative.**

**It is a virtual image – it will always be negative.**
The Magnifying Glass

The closest that a person can focus on an object is called the Near Point (N). If the object is brought closer, it will seem bigger, but look blurry.

The purpose of a magnifying glass is to be able to bring the object closer to the eye, but still be able to see a clear image of it.

The typical situation is shown below in figure (b). The object is placed at the focal point of the magnifier, which forms a virtual image of the object at infinity \((d_i=\infty)\).

**Angular Magnification, \(M=\theta'/\theta\).**

Using the small angle approximation \(\tan\theta \approx \theta\) we can find a formula for the typical case:

\[ M = \frac{N}{f} \]

The magnification can be made even better if the object is brought a bit closer to the eye, so that the image is at the near point of the magnifier.

In this case the formula is:

\[ M = 1 + \frac{N}{f} \]
The Compound Microscope

In a compound microscope the object to be viewed is placed just outside the focal point of the objective. The resulting enlarged image is at the focal point of the eyepiece, which is basically a magnifying glass, which produces a large image at infinity for the viewer.

The angular magnification of the microscope is found by multiplying the magnifications of the individual lenses:

\[ M_{\text{total}} = m_{\text{objective}} \cdot M_{\text{eyepiece}} = -\frac{d_i \cdot N}{f_{\text{objective}} \cdot f_{\text{eyepiece}}} \]
The Telescope

Here is the diagram for a typical telescope. The light from a distant object forms an image at the focal point of the objective lens, which is made to coincide with the focal point of the eyepiece, which then forms an image at infinity for the viewer to look at.

The overall magnification turns out to be the ratio of the focal lengths:

$$M_{\text{total}} = \frac{f_{\text{objective}}}{f_{\text{eyepiece}}}$$