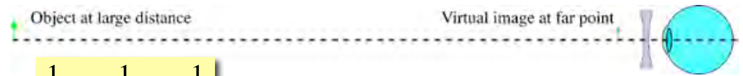
Physics for Scientists & Engineers 2

Spring Semester 2005

Lecture 40

Review

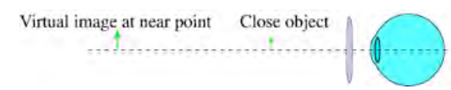
- To correct near-sightedness, a corrective lens (a diverging lens) must form a virtual, upright image at the far point, d_{far}, in front of the lens of an object located at infinity as shown below



$$\frac{1}{\infty}+\frac{1}{-d_{far}}=\frac{1}{f}$$

- To correct far-sightedness, a corrective lens (a converging lens) must produce a virtual, upright image of the newspaper at the near point, d_{near}, of the person's vision as shown below

$$\frac{1}{0.25\text{ m}}+\frac{1}{-d_{near}}=\frac{1}{f}$$

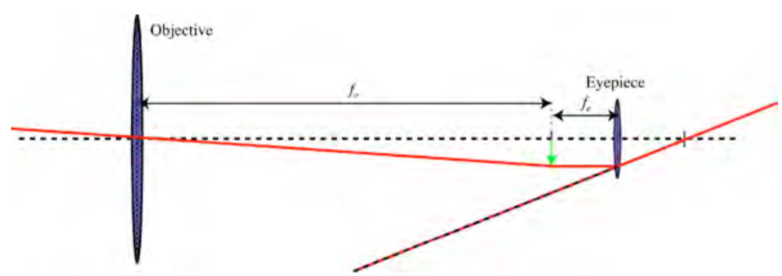


The Telescope

- Like the microscope, telescopes come in many forms
- First we will discuss the refracting telescope and then we will delve into the reflecting telescope
- The refracting telescope consists of two lenses
  - the objective lens and the eyepiece
- In our example we represent the telescope using two thin lenses
- However, an actual refracting telescope will use more sophisticated lenses
- The objective lens forms a real image of the distance object at distance f_o
- The eyepiece is placed so that the image formed by the objective is a distance f_e from the eyepiece
- The eyepiece forms a virtual, magnified image of the image formed by the objective
- Because the object to be viewed is at a large distance, the incoming light rays can be thought of as being parallel
- The eyepiece forms a virtual image at infinity, again producing parallel rays

Geometry of the Telescope

- In the drawing of the geometry of a refracting telescope below, the parallel light rays from the object are depicted by a single ray
- A red-black dashed line depicts the parallel light rays forming the virtual image



Magnification of a Telescope

- The magnification of the telescope is defined as the angle observed in the eyepiece, θ_e, divided by the angle subtended by the object being viewed, θ_o

$$m_\theta = -\frac{\theta_e}{\theta_o} = -\frac{f_o}{f_e}$$

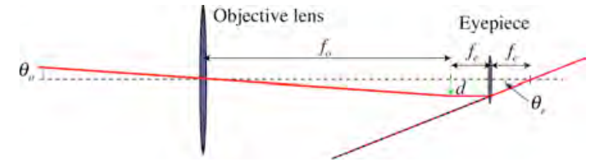
- Because the telescope deals with objects at large distances, we cannot calculate the magnification of the telescope using the lens law
- For example, one might try to express the magnification of the objective lens using the lens equation

$$m = -\frac{d_i}{d_o} = -\frac{d_i}{\infty} = 0 \text{ (bad)}$$

- We can get the angular magnification from the geometric drawing on the next slide

Calculation of Magnification of Telescope

- Let's calculate the angular magnification of a refracting telescope



- The angle θ_o is the angle subtended by a distant object

$$\theta_o \approx \tan\theta_o = \frac{d}{f_o}$$

- The angle θ_e is the apparent angle seen in the eyepiece

$$\theta_e \approx \tan\theta_e = \frac{d}{f_e}$$

- The magnification is

$$\frac{\theta_e}{\theta_o} = \frac{d / f_e}{d / f_o} = \frac{f_o}{f_e} \quad \Rightarrow \quad m_\theta = -\frac{f_o}{f_e} \quad \text{(inverted)}$$

Example: Refracting Telescope

- The world's largest refracting telescope was completed in 1897 and installed in Williams Bay, Wisconsin (between Chicago and Milwaukee). It had an objective lens of diameter 40 inches (1.0 m) with a focal length of 62 feet (19 m). What should the focal length of the eyepiece be to give a magnification of 250?

The 40 inch refracting telescope at Yerkes Observatory

$$f_o = 19 \text{ m} \qquad |m| = 250$$

$$|m| = \frac{f_o}{f_e}$$

$$f_e = \frac{f_o}{|m|} = \frac{19 \text{ m}}{250} = 0.076 \text{ m} = 7.6 \text{ cm}$$

Problems with Refracting Telescopes

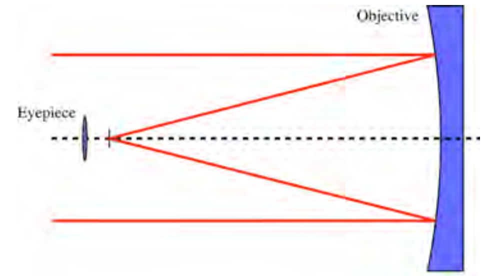
- The objective lens of a refracting telescope is large and heavy
  - The 40 inch refractor at Yerkes weighed 500 pounds
- Supporting a large glass lens was difficult
  - Must be supported by its edges
- Constructing the large glass lens was difficult
- The glass lens was thick and absorbed light
- A glass lens has chromatic aberration
  - Different focal lengths for different colors
- The solution was to replace the objective lens with a mirror

The Reflecting Telescope

- Most large astronomical telescopes are reflecting telescopes with the objective lens being replaced with a concave mirror
- Large mirrors are easier to fabricate and position than large lenses
- The eyepiece is still a lens
- Various types of reflecting telescopes have been developed
- We will discuss three examples of the geometries of reflecting telescope
  - Reflector
  - Newtonian
  - Cassegrain

Basic Reflecting Telescope

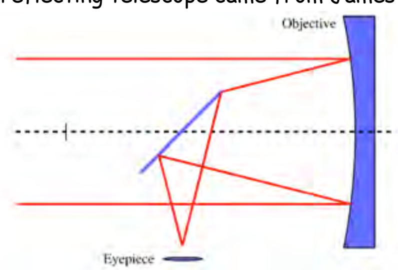
- Basic reflector



- Replace the objective lens with a parabolic mirror
- This design is impractical because the observer must be in the line of the incident light

Newtonian Reflecting Telescope

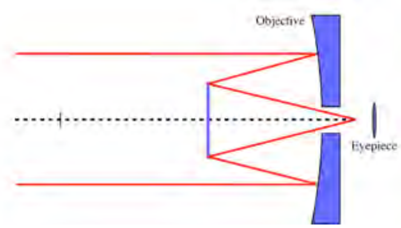
- In 1670 Newton presented his design for a reflecting telescope to the Royal Society
  - The idea for a reflecting telescope came from James Gregory



- Newton solved the observer problem by placing a small mirror that reflect the light out to an eyepiece
- This mirror is small compared with the objective mirror and causes only a small loss of light from the image

Cassegrain Geometry for Reflecting Telescope

- A further improvement on the geometry of the reflecting telescope is the Cassegrain geometry (named for the French sculptor Sieur Guillaume Cassegrain) first proposed in 1672



- Here a small mirror is used to reflect the image through a hole in the center of the objective mirror
- This design and many improvements this basic idea are the basis of modern astronomical telescopes

The Hubble Space Telescope

- The Hubble Space Telescope (HST) was deployed April 25, 1990 from the Space Shuttle mission STS-31
- The HST orbits the Earth 590 km above the surface of the Earth, far above the atmosphere that disturbs the images gathered by ground based telescopes
- The HST is a Ritchey-Chrétien reflecting telescope arranged in a Cassegrain geometry

- This type of telescope uses a concave hyperbolic objective mirror rather than a spherical mirror and a convex hyperbolic secondary mirror
- This arrangement gives the HST a wide field of view and eliminates spherical aberration
- The objective mirror is 2.40 m in diameter and has an effective focal length of 57.6 m

Hubble Corrected

- The original HST objective mirror was produced with a flaw caused by a defective testing instrument
- In December 1993, Space Shuttle Service Mission 1 (STS-61) deployed the COSTAR package that corrected the flaw in the objective mirror and allowed the HST to begin a spectactular career
- The two images of the galaxy M100 shown in demonstrate the image quality of the HST before and after the installation of COSTAR

The James Webb Space Telescope

- The planned replacement for the HST is the James Webb Space Telescope (JWST)
- This project is planned for launch in the year 2010. The objective mirror for the JWST will be 6.5 m in diameter composed of 36 mirror segments
- The JWST will view in the infrared, which allows more distant object because infrared light is less attenuated by interstellar dust
- An artist's conception of the JWST is shown to the right