**Light** is the form of electromagnetic radiation that our eyes respond to.

Isaac Newton was the first to show that sunlight was actually composed of many different colors.

He used a **prism**, which spread the light out into a **spectrum**.

Ole Romer was the first person to determine that light traveled at a finite speed (1675).

---

We now know that the speed of light (c) is $3.0 \times 10^8$ m/s (186,000 miles/second).

**Christiaan Huygens** (mid-1600's) felt that light traveled in waves-- Newton thought that light was a particle.

**Thomas Young** (1801) showed that light was definitely a wave.

Different colors are simply light of different wavelengths.

---

**James Clerk Maxwell** showed that light was a wave that had both electrical and magnetic properties.

The term **electromagnetic radiation** is now used for light.

In 1905, **Albert Einstein** showed that light is definitely made of particles.

He called the particles **photons**.

Different colors are photons of different energy.

---

The **electromagnetic spectrum** contains all wavelengths of electromagnetic radiation, from radio to gamma rays.

Visible light is just a small slice of the spectrum.

---

1800 - **William Herschel** discovers **infrared radiation**.

1888 - **Heinrich Hertz** discovers **radio waves**.

1895 - **Wilhelm Röntgen** discovers **x-rays**.

Many other wavelengths of light have since been discovered.

The earth's atmosphere is transparent to some of these wavelengths and opaque to others.
When light passes from one substance (medium) to another, its speed changes.

This change of speed usually means that the light's direction also changes (refraction).

The light is refracted toward the denser medium.

**Lenses** use this property in order to bend light toward an appropriate direction.

Lenses are usually shaped so that parallel light rays are all bent toward a common point called the **focal point**.

Only parallel rays focus to a point (stars, etc).

Objects that are not points (planets, moon) do not produce parallel rays and so they do not focus to a point-- instead, they form an image which has a real size.

Refracting telescopes (**refractors**) are composed of two parts:

1) **Objective lens** gathers light and brings it to a focus at the focal point (focal plane) to form an image.

2) **Eyepiece (ocular)** magnifies the image formed by the objective and makes the light rays parallel again so that they can be focused by your eye.

\[
\text{Mag} = \frac{\text{focal length objective}}{\text{focal length eyepiece}}
\]

Recommended maximum magnification is about 50x per inch:

- 2x (4.5 x 50) = 120x
- 20x (60 x 50) = 600x
- 30x (40 x 50) = 1200x
Refractors have some disadvantages:

1) **Spherical aberration** occurs if the lens is spherical in shape (it should be a parabola).

   Spherical lenses do not bring all light to focus at a single point, instead, they focus to a circle.

2) **Chromatic aberration** occurs when different colors do not focus to the same point.

   In the old days, telescopes were made very long (f/15 or more) in order to minimize the effects of chromatic aberration.

Modern objectives, called **achromats**, use *two* different types of glass whose aberrations cancel out.

Very expensive objectives, called **apochromats**, use *three* different types of glass.

3) Lenses **sag** under their own weight, since they can be supported only along their edges.

   This limits the maximum size that a refractor can be— the largest is 40 inches (1-meter) across.

4) Glass is **opaque** to certain wavelengths of light.

5) Since the light must pass through the glass, the glass must be of high optical quality (no bubbles).

   The lens in a large refractor is also very thick, absorbing a lot of the light that passes through it.

   Some of the light is also reflected away from the front of the glass and does not even enter the lens.

   Modern lenses have anti-reflective coating to help counteract this.

Isaac Newton invented a type of telescope that used curved mirrors instead of lenses— this got him admitted to the Royal Society.

A curved mirror focuses light by **reflection**.
All colors are reflected equally so there is no chromatic aberration.

Spherical aberration still exists if the mirror is shaped like a sphere.

Shorter mirrors (<f/8) should be parabolic—longer focal lengths can be left spherical.

The main difference with a mirror is that the image forms in front of the objective, not behind it.

Newton placed a small secondary mirror at the front of his telescope to reflect the light out to the side so that it could be seen.

Otherwise, the observer's head is in the way.

Newtonians are the most cost-effective type of telescope, but they are not convenient in large sizes.

The eyepiece is a long way from the ground if the telescope is very large—and also, any instruments hang on the side and make the telescope unbalanced.

**Cassegrain telescopes** are a type of reflector that uses a curved mirror to reflect light back down the tube and out through a hole in the main mirror.

Cassegrains provide a long focal length in a short tube.

**Catadioptric telescopes** use a combination of lenses and mirrors.

**Advantages of a reflector:**

1) Since the light does not go through the glass, it doesn't have to be perfect—only its surface has to be perfect.

2) A mirror is supported all across its back so it can be made very large.

**Disadvantages of a reflector:**

1) The secondary mirror blocks some of the light.

2) The mirror must be shaped like a parabola in most designs.

A spherical mirror can be used if a corrector lens or mirror is used.

Large, modern mirrors are made by **spin-casting** in a rotating furnace.
The Purpose of a Telescope (in order)

1) **Gather light** - this is the most important thing that a telescope does since most objects in space are very faint.
   
   Depends on the objective's area, which goes up as the square of the diameter.

2) **Resolve fine detail** in objects.
   
   Depends on the objective's diameter.

3) **Magnify** an object.
   
   Depends on the telescope's focal length.
   
   Focal length (telescope)/focal length eyepiece
   
   This is the least important thing that a telescope does.

The earth's atmosphere causes many problems for ground-based telescopes.

The air is in constant motion and causes stars to **twinkle**, which smears out their images.

Telescopes in space, such as Hubble, do not suffer from these problems, although ground-based telescopes are finally overcoming them.

It is now possible to get high quality images from ground-based telescopes.

1) **Active Optics** - mirrors are repositioned to keep the target centered.

2) **Adaptive Optics** - the actual shape of the mirror is changed constantly to cancel out atmospheric distortions.

**Light pollution** is now causing major problems for ground-based astronomy.

It is caused by misdirected artificial light.

The **Hubble Space Telescope** was designed in order to avoid many of the problems of earth-based telescopes.

It was launched in 1990, but was soon found to have **spherical aberration** in its main mirror.

This was corrected with special lenses.

By combining the light from several widely spaced telescopes, it is possible to get the resolution of a larger instrument.

**Data Collection:**

1) **Naked Eye** - no longer used by professionals, still used by many amateurs.

2) **Film** - no longer used by most professionals, still used by a few amateurs.

3) **CCD’s (charge-coupled device)** - like a digital camera. Used by most professionals and many amateurs.

4) **Photodetector photometers (PEP)**
   - one pixel
   - bright stars

**How CCDs Work**

Sep 9-11:26 AM
Radio astronomy began in the 1930's when Karl Jansky discovered radio signals coming from space.

Radio telescopes are usually similar to optical telescopes, but are larger (radio waves are longer).

Interferometry is often used (VLA, VLBA, etc.).

There are also numerous orbiting telescopes that operate at other wavelengths (x-rays, gamma rays, etc).

Hubble is a visible light telescope (some UV).

Its replacement, the James Webb Telescope, will operate in the infrared.

Hubble is in a near-earth orbit and is servicable, the JWT will be farther away and not reachable.
Attachments

- Refraction Applet
- About Lenses
- TextBook
- Newtonian Telescope
- Refractor Telescope
- Cassegrain Telescope
- Large Mirror
- Spin Casting
- Light Pollution
- Professional Telescopes
- Herschel's Experiment