Light and Telescopes
Light
The Electromagnetic Spectrum

- **Wavelength (meters)**
  - Shorter: $10^{-12}$ to $10^{-10}$
  - Longer: $10^0$ to $10^2$

- **Frequency (hertz)**
  - Higher: $10^{20}$ to $10^{18}$
  - Lower: $10^6$ to $10^4$

- **Energy (electron-volts)**
  - $10^6$ to $10^2$

- **Sources of wavelength**
  - Hydrogen atom
  - Protein
  - Bacterium
  - Animal cell
  - Pinhead
  - Baseball
  - Football field

- **Sources of frequency**
  - Radioactive elements
  - X-ray machines
  - Light bulb
  - People
  - Radar
  - Microwave oven
  - Radio transmitter

- **Cosmic sources**
  - Gamma ray burst
  - Black hole accretion disk
  - Sun's chromosphere
  - Sun
  - Planets, star-forming clouds
  - Cosmic microwave background
  - Radio galaxy
If you could line up electrons, they would wriggle up and down as light passes by, demonstrating that light is a wave.

Wavelength is the distance between adjacent peaks of the electric (and magnetic) field.

... while frequency is the number of times each second that the electric (and magnetic) field vibrates up and down (or side to side) at any point.

All light travels with speed $c = 300,000 \text{ km/s}$.

Light can affect both electrically charged particles and magnets, so we say that light is an electromagnetic wave.
Light as a Wave

- Wavelength: 1 cm, Frequency: 30 GHz
- Wavelength: 0.5 cm, Frequency: 60 GHz
- Wavelength: 0.25 cm, Frequency: 120 GHz

Longer wavelength means lower frequency.
Shorter wavelength means higher frequency.
THE ELECTRO MAGNETIC SPECTRUM

Wavelength (metres)

Radio $10^3$, Microwave $10^{-2}$, Infrared $10^{-5}$, Visible $10^{-6}$, Ultraviolet $10^{-8}$, X-Ray $10^{-10}$, Gamma Ray $10^{-12}$

Frequency (Hz)

$10^4$, $10^8$, $10^{12}$, $10^{15}$, $10^{16}$, $10^{18}$, $10^{20}$
Thermal Radiation

The graph shows the relative intensity per square meter of surface as a function of wavelength (nm). Different curves represent various temperature bodies:

- **15,000 K star**
- **the Sun (5,800 K)**
- **3,000 K star**
- **310 K human**

The visible light spectrum is indicated by a vertical line. The graph also distinguishes between ultraviolet and infrared regions.
Thermal Radiation

Stefan-Boltzmann Law

\[ L \approx \sigma T^4 \]

Wien’s Law

\[ \lambda_{\text{max}} \cdot T = 2.9 \times 10^6 \text{(nm} \cdot K) \]
Continuous Spectrum

![Graph showing the continuous spectrum with different temperatures for stars and a human, indicating ultraviolet and infrared regions.

The graph displays the relative intensity per square meter of surface as a function of wavelength (nm) for 15,000 K star, the Sun (5,800 K), 3,000 K star, and 310 K human. The spectrum is color-coded with a legend ranging from ultraviolet (400nm) to infrared (700nm).]
How light and matter interact

- **Emission** – matter transmits some of its energy to a photon
- **Absorption** – a photon transmits its energy to matter
- **Transmission** – some matter allows light to pass though
- **Reflection/Scattering** – light bounces off matter and travels in a different direction
Atoms

The nucleus is nearly 100,000 times smaller than the atom but contains nearly all of its mass.

Ten million atoms could fit end to end across this dot.

Atom: Electrons are “smeared out” in a cloud around the nucleus.

Nucleus: Contains positively charged protons (red) and neutral neutrons (gray).

$10^{-10}$ meter
atomic number = number of protons
atomic mass number = number of protons + neutrons
(A neutral atom has the same number of electrons as protons.)

Hydrogen (\(^1\)H):
- atomic number = 1
- atomic mass number = 1
  (1 electron)

Helium (\(^4\)He):
- atomic number = 2
- atomic mass number = 4
  (2 electrons)

Carbon (\(^{12}\)C):
- atomic number = 6
- atomic mass number = 12
  (6 electrons)

Different isotopes of a given element contain the same number of protons, but different numbers of neutrons.

Isotopes of Carbon:
- carbon-12: \(^{12}\)C (6 protons + 6 neutrons)
- carbon-13: \(^{13}\)C (6 protons + 7 neutrons)
- carbon-14: \(^{14}\)C (6 protons + 8 neutrons)
Atomic Energy Levels

Energy (eV)

- 0.5  third excited state
- 1    second excited state
- 2    first excited state
- 3
- 4    ground state
Continuous Spectrum

The diagram illustrates the relative intensity per square meter of surface area as a function of wavelength (nm) for different objects. The x-axis represents wavelength in nanometers (nm), ranging from $10^1$ to $10^5$. The y-axis represents intensity, ranging from $10^0$ to $10^8$. The diagram includes curves for different temperatures:

- **15,000 K star**
- **the Sun (5,800 K)**
- **3,000 K star**
- **310 K human**

The diagram also highlights the ultraviolet and infrared regions. The visible spectrum is indicated by a rainbow-colored band, ranging from 400nm to 700nm.
Absorption Spectrum

Energy (eV)

- 4
- 3
- 2
- 1
- 0.5

ground state
first excited state
second excited state
third excited state

Hδ 410 nm
Hγ 434 nm
Hβ 486 nm
Hα 656 nm
Absorption Spectrum

Energy (eV)

- 0.5
- 1
- 2
- 3
- 4

ground state

first excited state
second excited state
third excited state

Hα
656 nm

Hβ
486 nm

Hγ
434 nm

Hδ
410 nm
Emission Spectrum

Energy (eV)

- 4
- 3
- 2
- 1
- 0.5

ground state

first excited state

second excited state

third excited state

Hδ  410 nm
Hγ  434 nm
Hβ  486 nm
Hα  656 nm
Doppler Shift

**train stationary**

- The pitch this person hears...

**train moving to right**

- Behind the train, sound waves stretch to longer wavelength (lower frequency and pitch).
- In front of the train, sound waves bunch up to shorter wavelength (higher frequency and pitch).

**a** The whistle sounds the same no matter where we stand near a stationary train.

**b** For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.
Doppler Shift

The light source is moving to the right.

- The light source is moving away from this person so the light appears redder (longer wavelength).
- The light source is moving toward this person so the light appears bluer (shorter wavelength).

Laboratory spectrum

- Lines at rest wavelengths.

Object 1

- Lines redshifted: Object moving away from us.

Object 2

- Greater redshift: Object moving away faster than Object 1.

Object 3

- Lines blueshifted: Object moving toward us.

Object 4

- Greater blueshift: Object moving toward us faster than Object 3.

We get the same basic effect from a moving light source (although the shifts are usually too small to notice by eye).
Telescopes
Collecting Area

Area = \pi r^2

Area = \pi (2r)^2 = 4 \pi r^2
Angular Resolution

\[ \theta = 1.22 \frac{\lambda}{D} \]
Refracting Telescope
Reflecting Telescope

Cassegrain System
Telescopes through the Spectrum
Radio Telescope
X-ray Telescope
Difficulties with Observing

• Light pollution

• Atmospheric Turbulence

• Atmospheric Absorption

• Can be solved by going to space, adaptive optics, more powerful equipment and other clever techniques