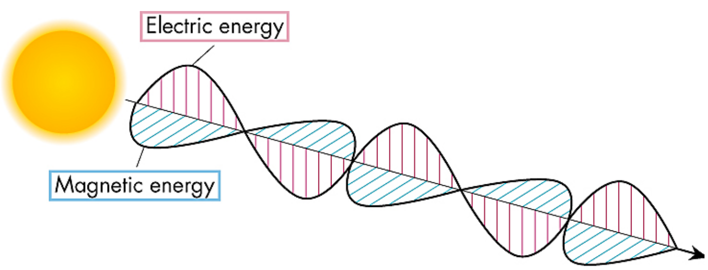
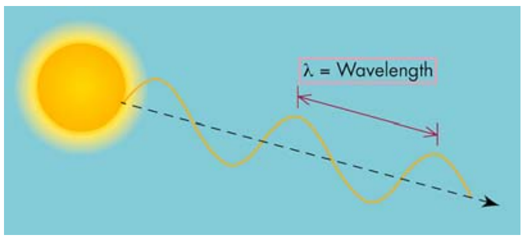
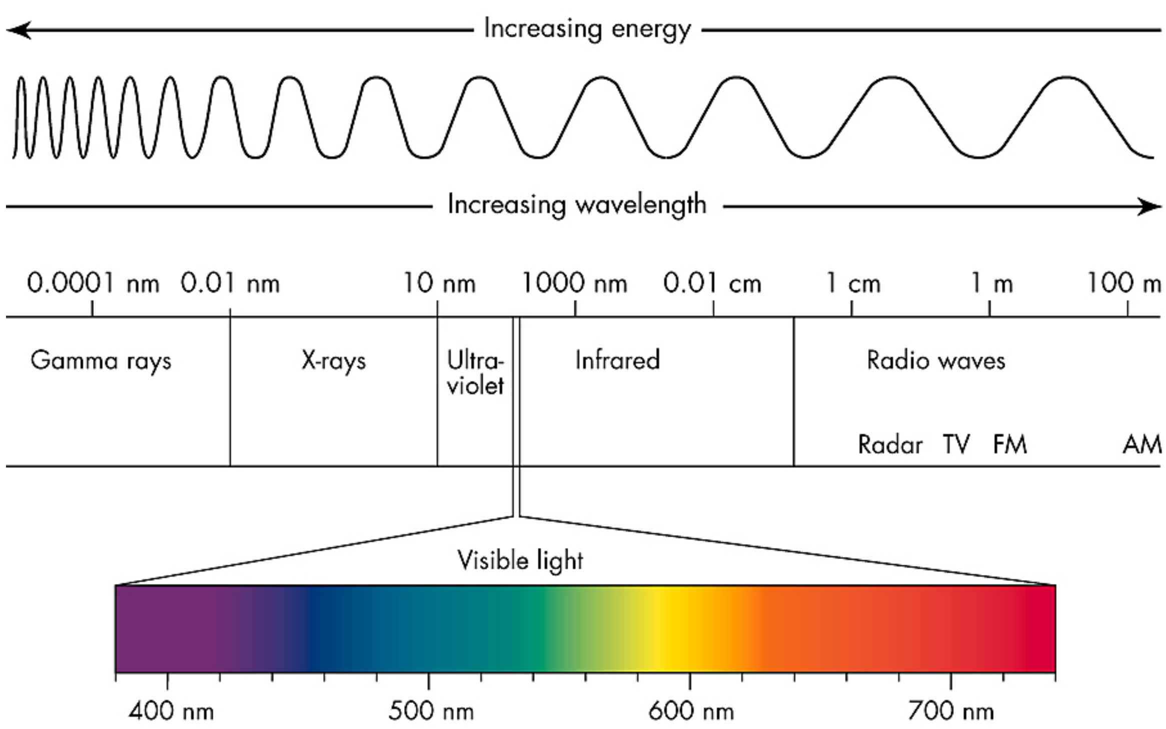
Light, Atoms, the Electromagnetic Spectrum

The Electromagnetic Spectrum/Electromagnetic Waves

- E/M waves are disturbances that travel through space
- Consist of particles and waves
- All e/m waves travel at the speed of light (3×10^8 m/s) in free space, c
- All e/m waves transport energy (electromagnetic energy)
- The relationship between speed, frequency and wavelength in free space: $c = \lambda f$
- The relationship between energy and frequency or wavelength: $E = hf = h\dfrac{c}{\lambda}$
- Note that decreasing wavelengths $\rightarrow$ increasing energy
- Longer wavelengths $\rightarrow$ lower frequency
- E/M waves reflect, refract, scatter, diffract, interfere, and may be polarized





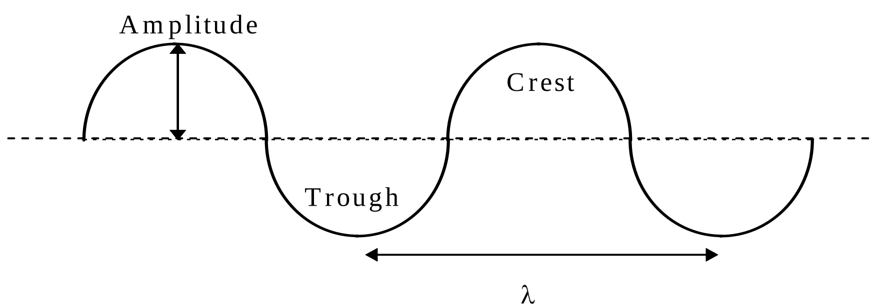


Historical Figures and Their Contributions to Theories of Light

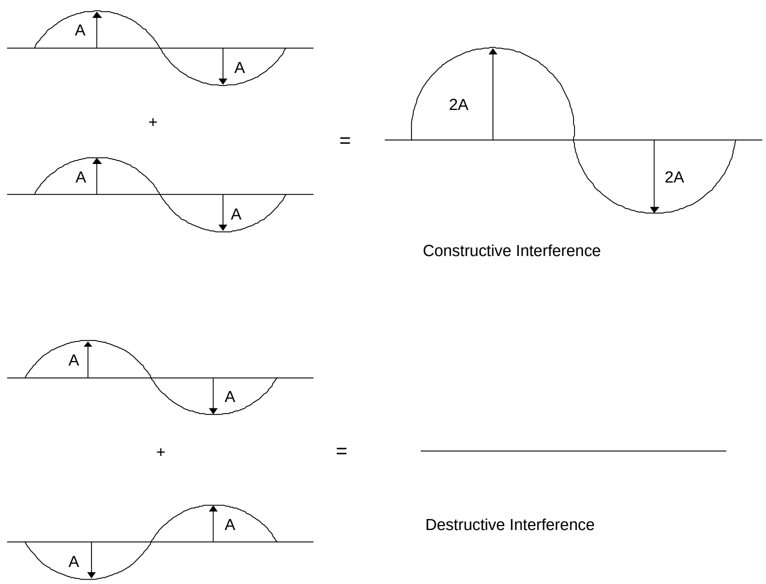
- Newton – corpuscular theory
- Huygens – wave theory
- Young – interference
- Maxwell – E/M equations
- Michaelson & Morley – luminiferous ether
- Einstein – photons

Physical Attributes of Light

- Visible light exists between 400 – 700 nanometers (10^{-9})
- White light consists of all frequencies in the visible range combined
- Wavelength – peak to peak distance
- Amplitude – ½ of the distance from peak to trough
- Frequency – number of oscillations per second

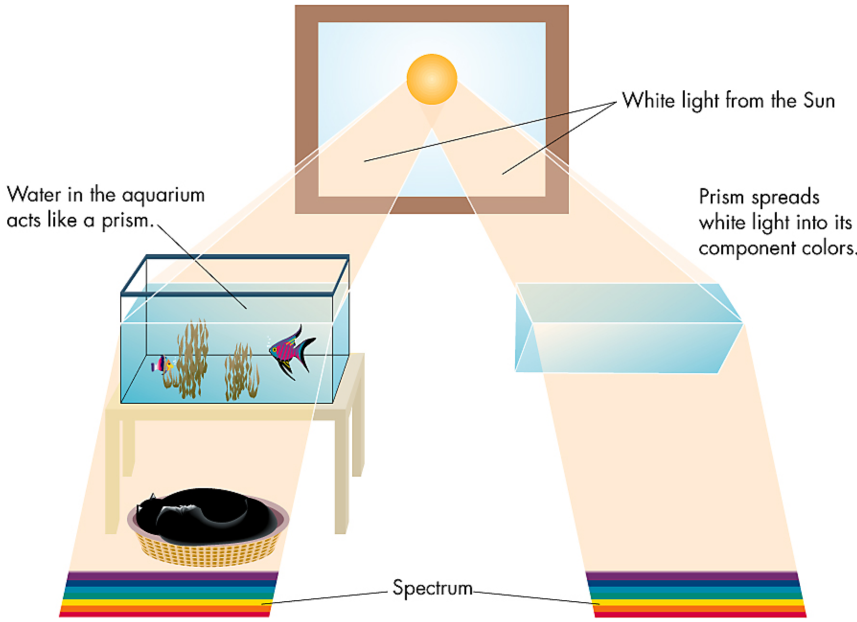


- *interference* - combining e/m waves together in such a manner as to cause constructive (bright) or destructive (dark) patterns to result.



- *diffraction* – bending of light or any e/m waves as they pass through narrow openings or around sharp corners. Explained by *Huygen's Theory* (below).
- *reflection* - a form of scattering that may be described with a simple geometric relationship, i.e. angle of incidence equals angle of reflection (The Law of Reflection).
- *scattering* – what happens, in general, when light or any e/m waves interact with matter.
- *polarization* – orientation of e/m fields in space

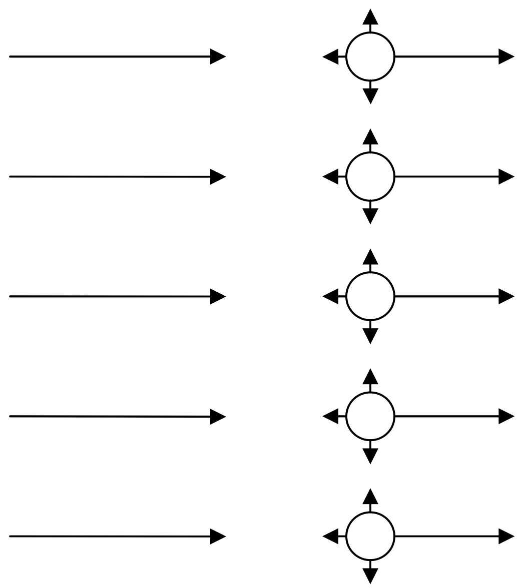
- *refraction* – the change of speed and direction that occurs when light goes from one medium to another. Refraction of white light, which contains all wavelengths from 400 to 700 nanometers results in *dispersion*.



How Light Interacts with Matter

Light is propagated through any dense medium (air, water, etc.) primarily by scattering. When light encounters a change in medium (falls on a surface, for instance) it may be absorbed, scattered or reflected.

Light travels through any dense medium via scattering

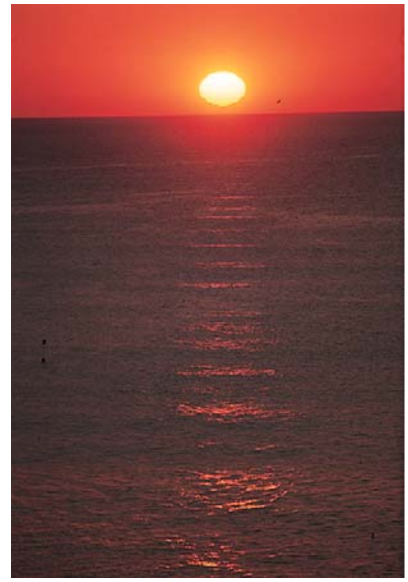


- Christian Huygens was the first to propose that light was a wave.
- Light waves traveling together through space or any dense medium form *wavefronts*.
- Any point on a wavefront is capable of acting as a new source of the wave. This is known as ***Huygens Theory*** and may be used to explain *reflection, refraction, diffraction* and *interference*.

Consider Earth's sky. On a clear day the sky is blue at noon and reddish or yellow near sunrise and sunset. On days when there is a lot of particulate matter in the atmosphere (water vapor, pollutants, etc.) the sky appears milky white.

Can you use Huygen's Theory and your knowledge of visible light to explain this?

Natural Occurrences of Optical Phenomena



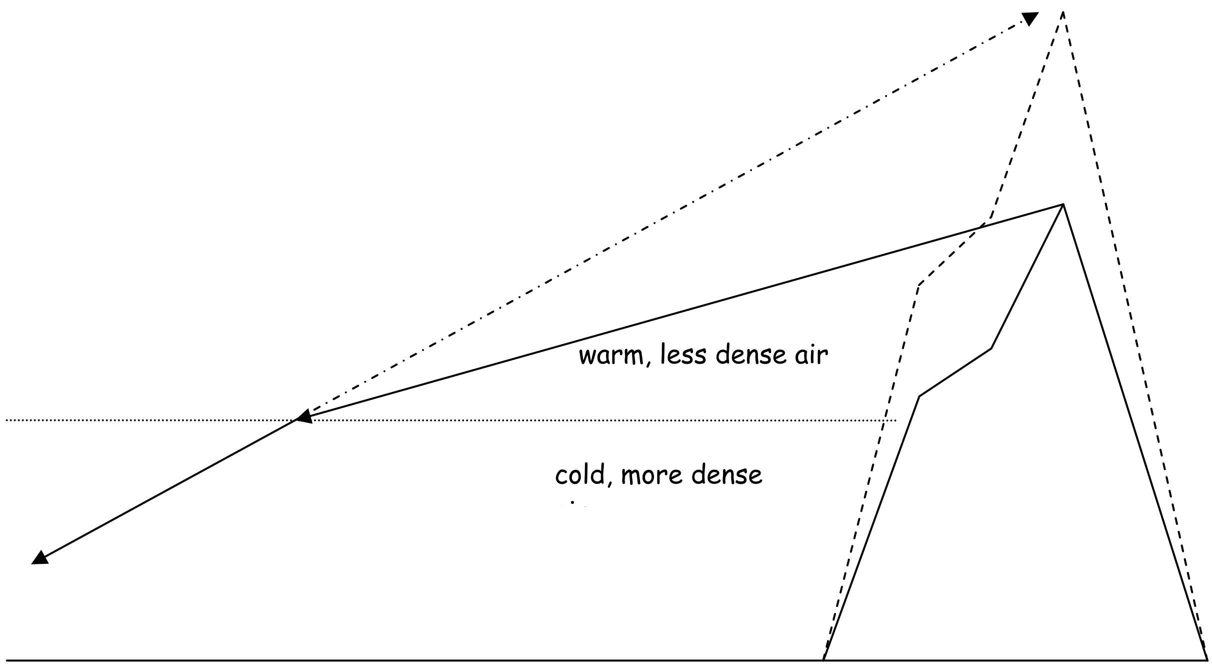
Reflection

- Glitter Path
- Rainbows (total internal reflection)

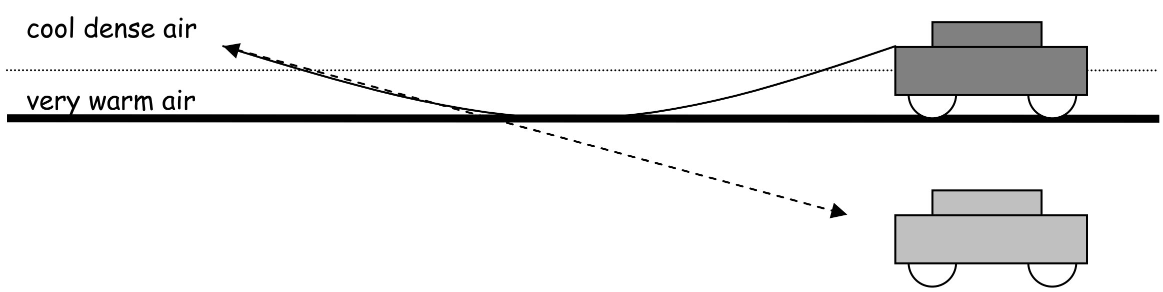
Refraction

- Twilight
- Stars "twinkle"
- Rainbows (dispersion)
- Mirage

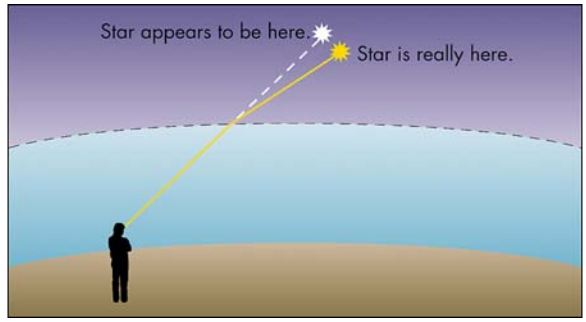
Superior Mirage



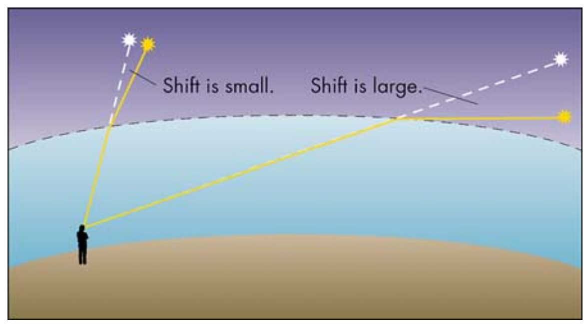
Inferior Mirage



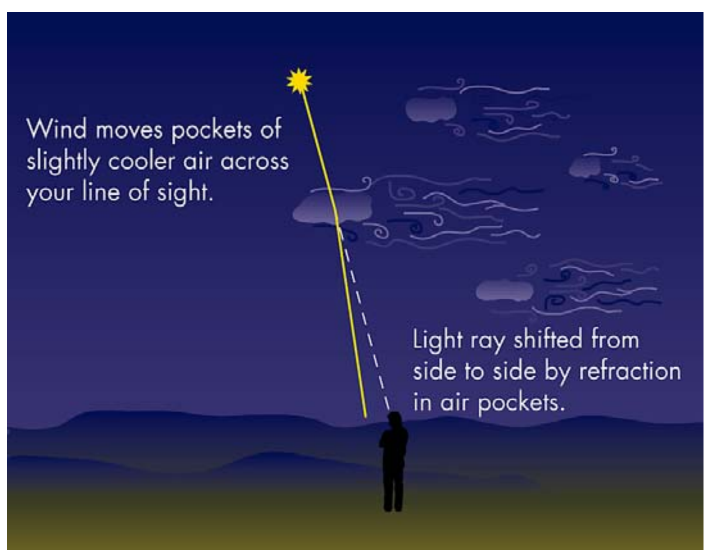
Refractory phenomena



Twilight



The “twinkle” of stars



Diffraction

- Corona
- Glory
- Heiligenschien
- Some Halos

Scattering

- Blue skies
- Red sunsets

Interference

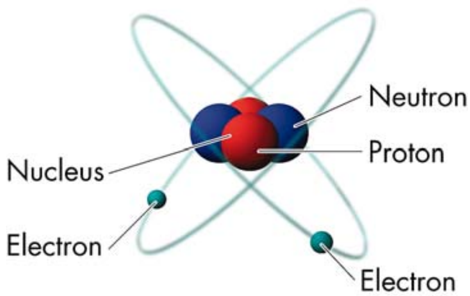
- Supernumerary Arcs (rainbows)

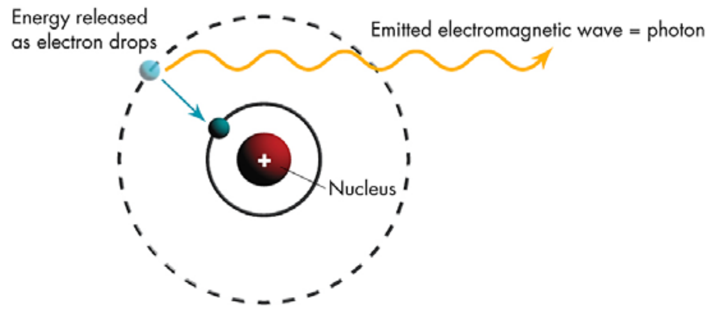
Polarization

- Light at high altitudes is highly polarized
- Reflected light may be highly polarized

Origin of E/M Radiation

Visible, ultraviolet and infrared light originates from electronic transitions in atoms. Gamma rays originate from similar events in the nuclei of atoms. X rays may form in any of several ways but most commonly from the rapid acceleration of atoms. At the other end of the spectrum, radio waves result from the oscillations of large numbers of charged particles.



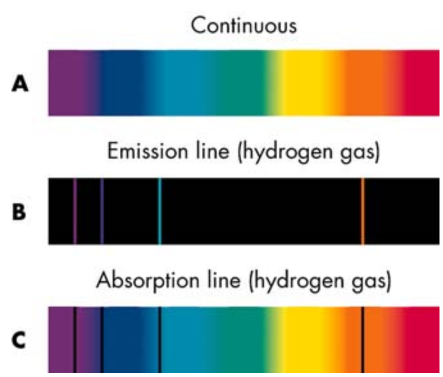


Spectroscopy

- Spectral analysis of <u>light emitting objects</u> yields information about elemental composition and relative abundance of elements by splitting the light given off into its component colors. Each of these colors is indicative of a specific atomic transition. All elements have a unique spectral "fingerprint"

- There are three types of spectra: bright line or emission line spectra, continuous spectra, dark line or absorption line spectra.

- Emission spectra are produced by low-density gasses that radiate energy at specific wavelengths characteristic of the element or elements that make up the gas. The spectrum consists of a number of bright lines against a dark background.



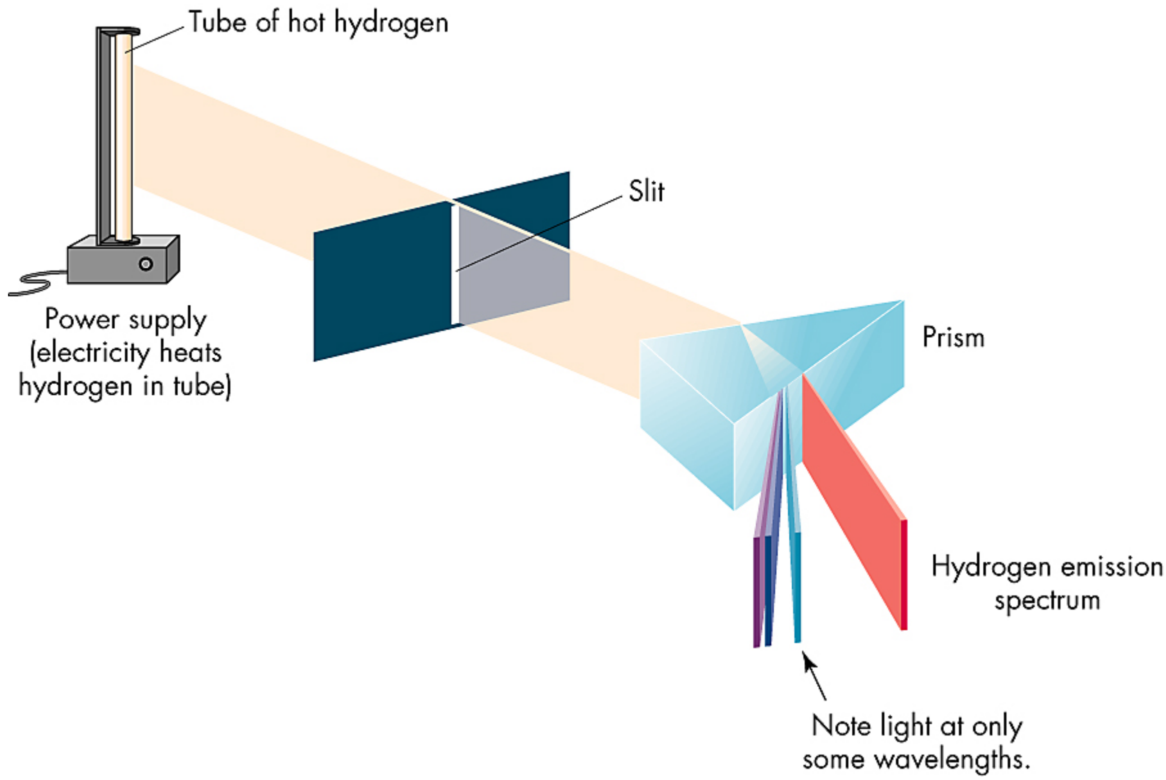
- Continuous spectra are produced by solids, liquids or dense gases. The spectrum appears as a smooth transition of all colors in the visible spectrum from the shortest or the longest wavelength without any gaps between the colors.

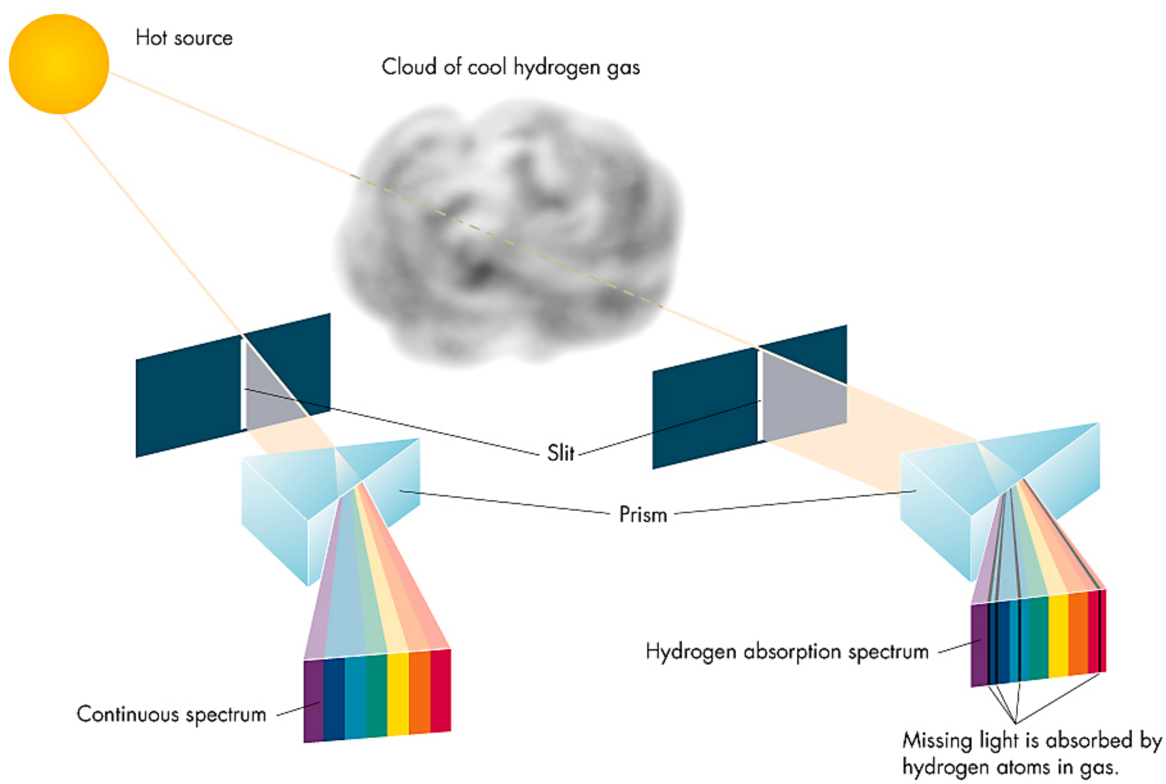
- Absorption spectra are produced when a cooler gas absorbs specific wavelengths of light passing through it. The wavelengths absorbed are determined by the elements that compose the gas. Since no two elements absorb the exact same wavelengths, it is possible to determine the elemental composition of the gas by examining the spectra.

- A dark line or absorption spectrum appears as a continuous spectrum of all colors with a number of dark lines through it. The K and H lines in the solar spectrum, for instance, are due to ionized calcium in the outer layers of the sun's atmosphere. If the dark lines are closely spaced in some parts the clumps of dark lines are known as bands.

How Spectrometers Work

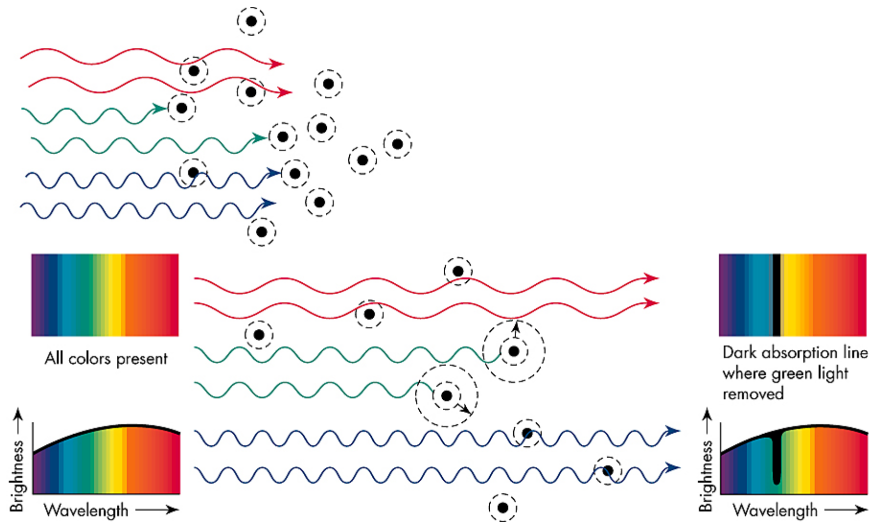
Spectrometers may use either prisms or diffraction gratings to separate light into its component colors

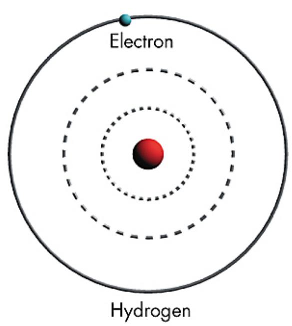


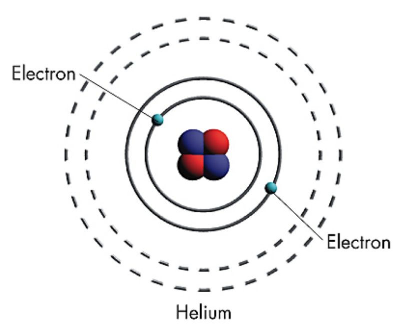


Why Atoms Produce Light

- As light travels through any dense medium it is scattered
- Scattering occurs as the electrons in atoms absorb light, jumping to a higher energy level, and emit light when they fall back to a lower energy level
- The less dense the medium the more the light is scattered in all directions

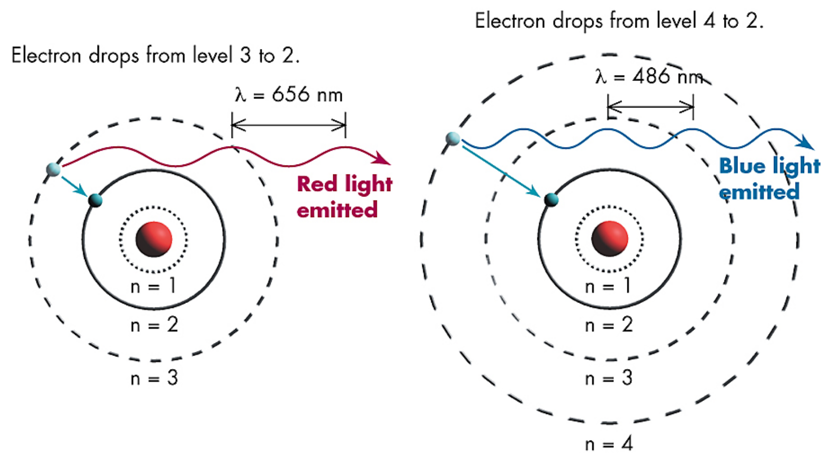


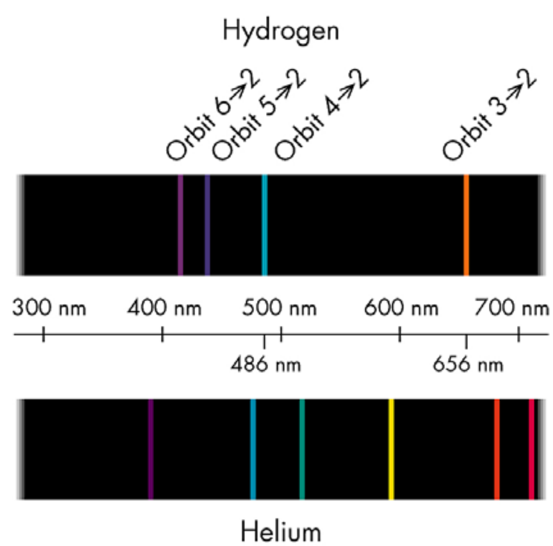




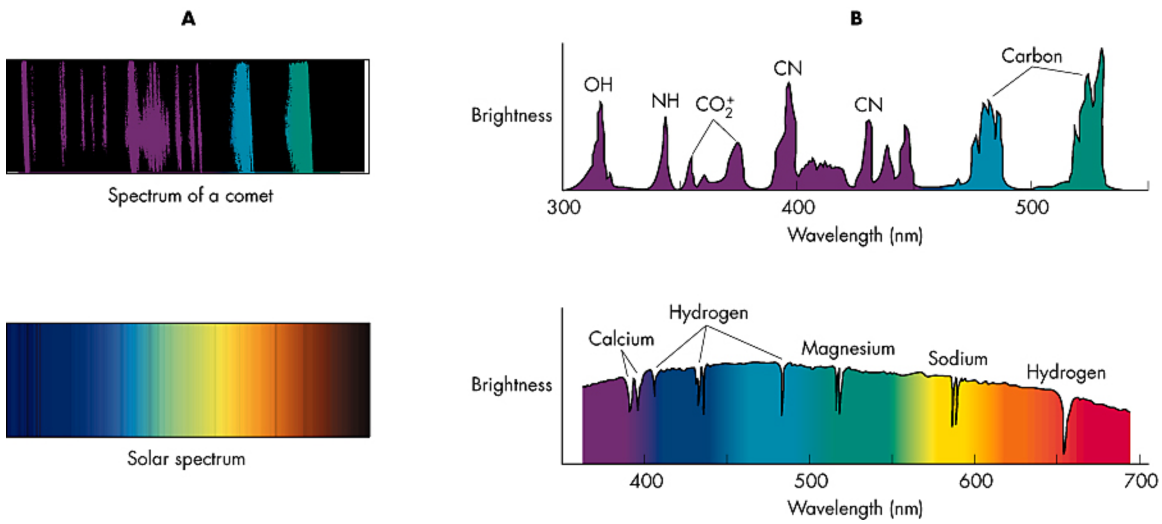
Each electronic transition produces a characteristic wavelength of light

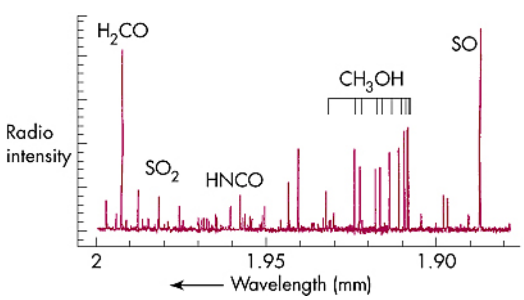
- The wavelength of the transition is related to the width of the state, i.e., the distance between the electron energy levels.
- Longer distances result in more energetic transitions and shorter wavelengths (indicative of greater energy)

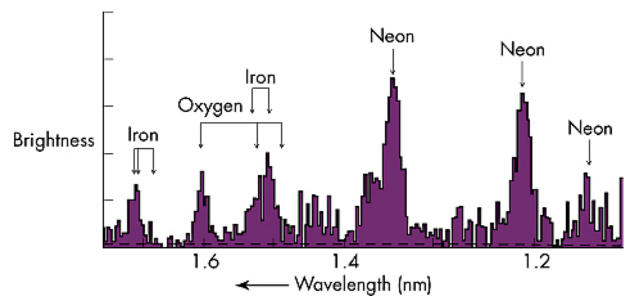




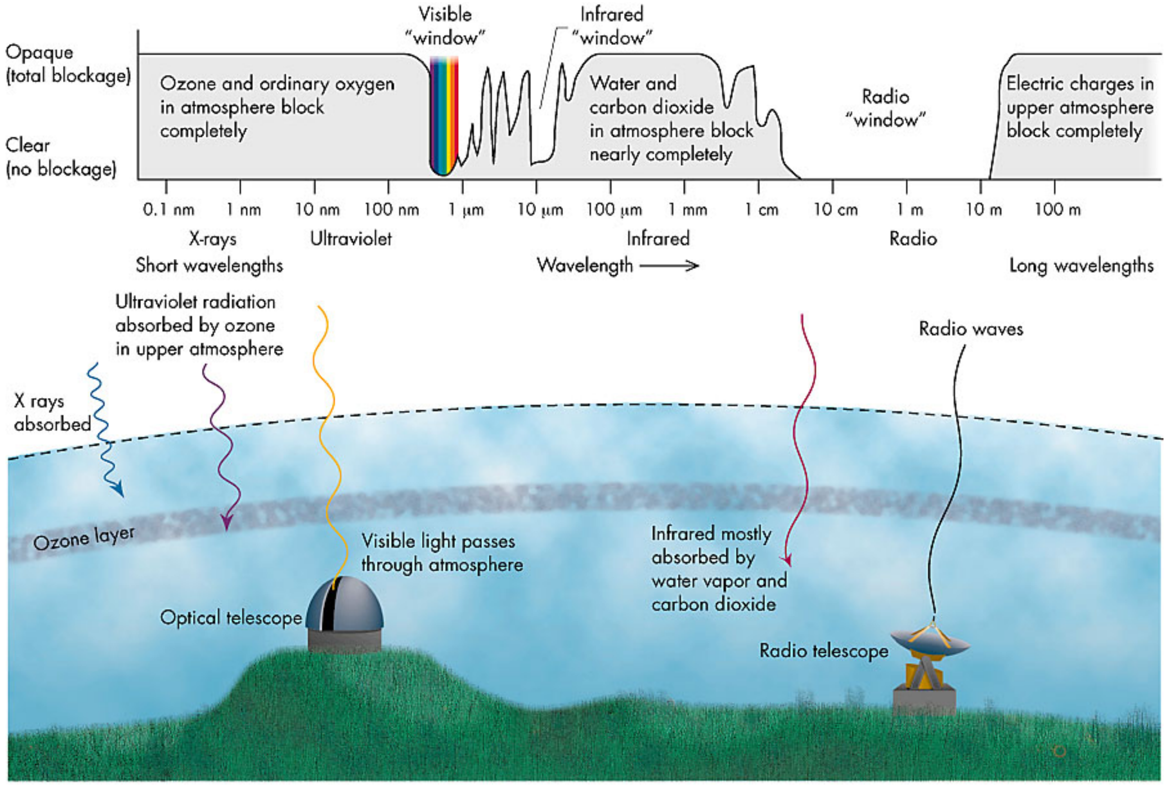
Examples of Spectra







Transparency of Earth's Atmosphere to E/M Radiation



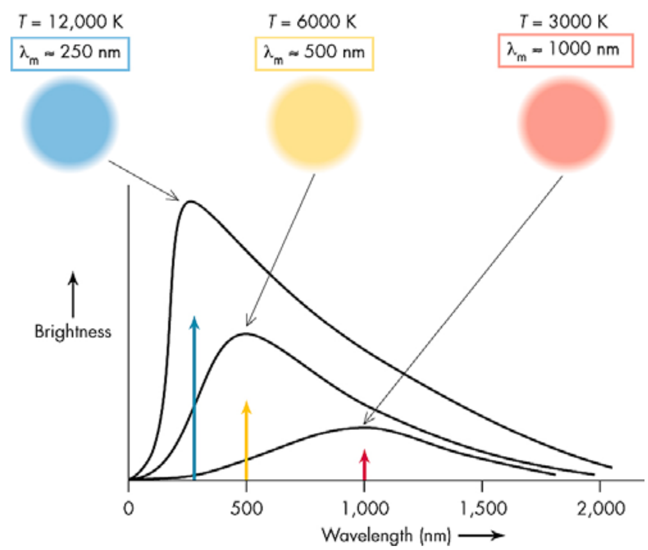
Blackbodies

- A *blackbody* is any object that is 100% efficient at absorbing all of the light that falls on it. Because such an object reflects no light it appears to be black (unless it is heated). When blackbodies get hot, either through efficiently absorbing radiation or other external means they are also very efficient radiators of energy. Most blackbodies are high-density materials such as solids.

- There are very few *perfect* blackbodies, but many objects are close enough that we may assume that they are essentially blackbody radiators. Under this assumption Wien's law may be applied to a variety of objects without significant error.

- When an object is a selective absorber and emitter of electromagnetic radiation it obeys Kirchoff's Laws.

Wien's Law



- All objects emit some electromagnetic radiation.
- When objects are heated to any temperature above absolute zero they emit a spectrum of wavelengths but emit most strongly in a narrow region of wavelengths closely associated with a particular temperature.
- When this radiation is in the visible region the relationship between intensity, temperature and color is known as Wien's Law.
- Hotter objects emit more strongly in the shorter wavelength region.
- Wien's law applies perfectly only to a *blackbodies*.

How Light May Be Used to Determine Distance and Speed: Doppler Shift

Any relative motion between an observer and a source of light or any form of e/m radiation results in a *Doppler Shift*, i.e., a shifting of spectral lines toward either shorter or longer wavelengths. Objects moving towards an observer undergo a blue shift and objects moving away from an observer undergo a red shift.