Chapter 2
Light and Matter

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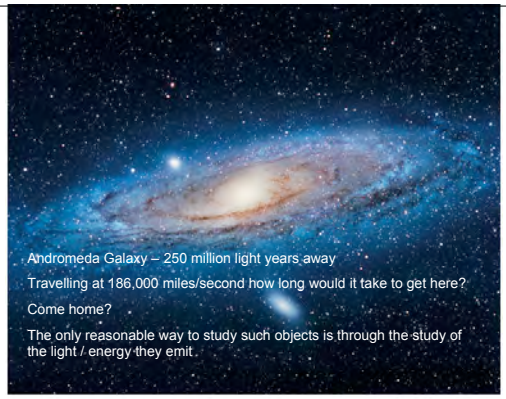
Topics of Chapter 2

- Information from the Skies
- Waves in What?
- The Electromagnetic Spectrum
- Thermal Radiation
- Spectroscopy
- The Formation of Spectral Lines
- The Doppler Effect
- Spectral-Line Analysis

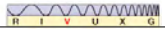


Andromeda Galaxy – 250 million light years away

Travelling at 186,000 miles/second how long would it take to get here?

Come home?

The only reasonable way to study such objects is through the study of the light / energy they emit.



2.1 Information from the Skies

Electromagnetic Radiation: Transmission of energy through space through varying electric and magnetic fields

Example: **Light**

Light travels as a wave

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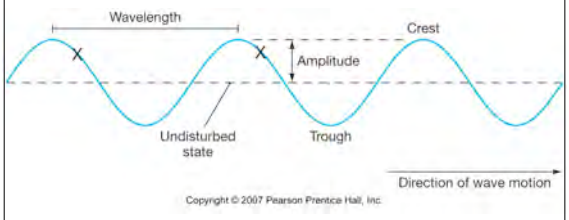
2.1 Information from the Skies

Wave motion: transmits energy without the physical transport of material



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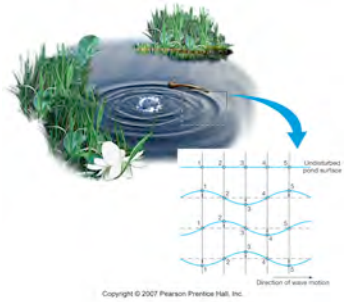
2.1 Information from the Skies

Example: water wave

Water just moves up and down

Wave travels and can transmit energy



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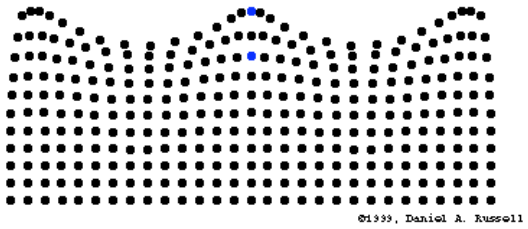
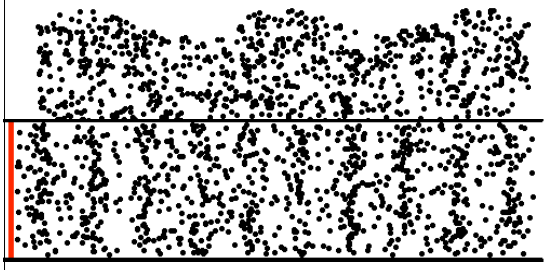
Water wave



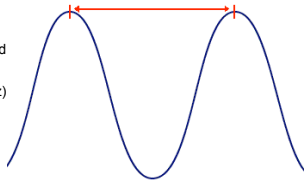
Transverse and Longitudinal waves



2.1 Information from the Skies

Cycle – one complete crest and trough

1 cycle per second – Hertz (Hz)



Frequency: number of cycles that pass a given point per second

Period: time between passage of successive crests

Relationship:

Period = 1 / Frequency

2.1 Information from the Skies

Wavelength: distance between successive crests

Velocity: speed at which crests move

Relationship:

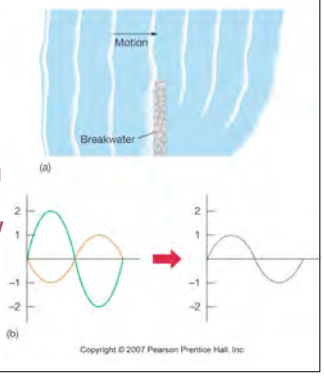
Velocity = Wavelength / Period

2.2 Waves in What?

Diffraction: the bending of a wave around an obstacle

Refraction: bending of a wave when going through a new medium

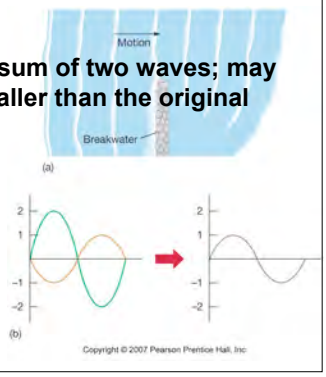
Reflection: bouncing back of a wave



Interference: the sum of two waves; may be larger or smaller than the original waves

Constructive interference - overlapping waves increase the net wave

Destructive interference - overlapping waves cancel to reduce the net wave

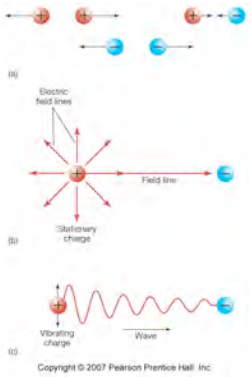


2.2 Waves in What?

Water waves, sound waves, and so on, travel in a **medium** (water, air, …)

Electromagnetic waves need no medium

Created by **accelerating charged particles**:



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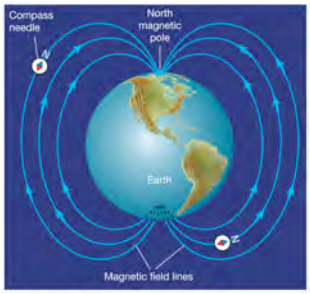
2.2 Waves in What?

Magnetic and electric fields are inextricably intertwined.

A magnetic field, such as the Earth's shown here, exerts a force on a moving charged particle.



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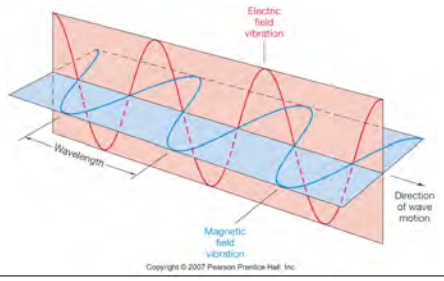
2.2 Waves in What?

Electromagnetic waves: Oscillating electric and magnetic fields. Changing electric field creates magnetic field, and vice versa



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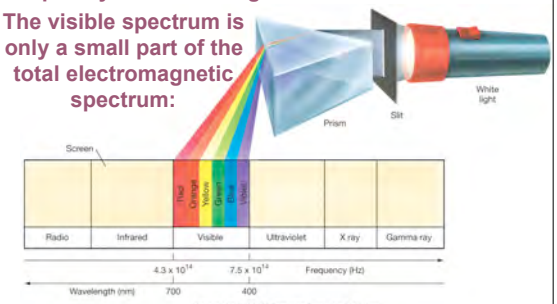
2.3 The Electromagnetic Spectrum

Different colors of light are distinguished by their frequency and wavelength.

The visible spectrum is only a small part of the total electromagnetic spectrum:



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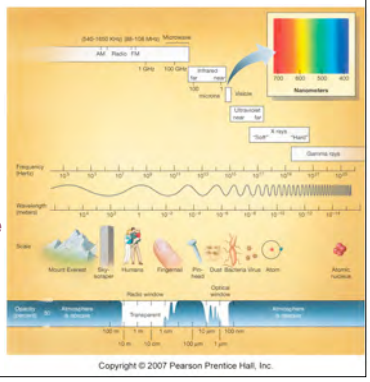
2.3 The Electromagnetic Spectrum

Different parts of the full electromagnetic spectrum have different names, but there is no limit on possible wavelengths.



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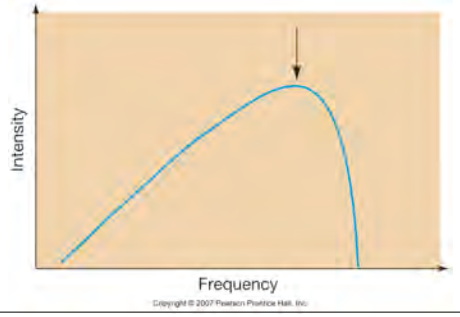
2.3 The Electromagnetic Spectrum

Note that the atmosphere is only **transparent** at a few wavelengths – the **visible**, the **near infrared**, and the part of the **radio** spectrum with frequencies higher than the AM band. This means that our atmosphere is absorbing a lot of the electromagnetic radiation impinging on it, and also that astronomy at other wavelengths must be done above the atmosphere.

Also note that the horizontal scale is **logarithmic** – each tick is a factor of 10 smaller or larger than the next one. This allows the display of the longest and shortest wavelengths on the same plot.

2.4 Thermal Radiation

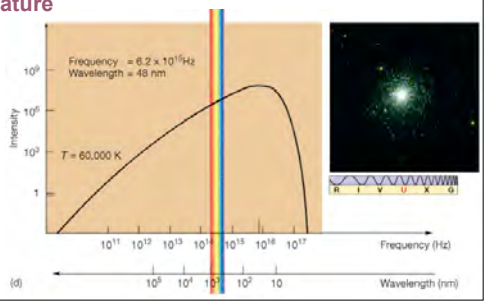
Blackbody Spectrum: radiation emitted by an object depending only on its temperature



2.4 Thermal Radiation

Radiation Laws

1. Peak wavelength is inversely proportional to temperature



2.4 Thermal Radiation

Radiation Laws

2. Total energy emitted is proportional to fourth power of temperature

$$F = \sigma T^4.$$

energy per unit area

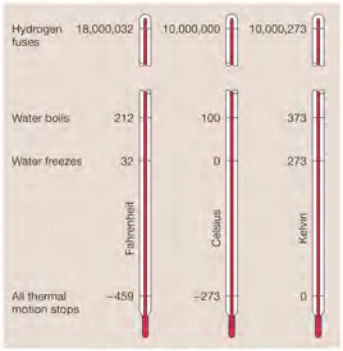
temperature to the fourth power

constant

More Precisely 2.2

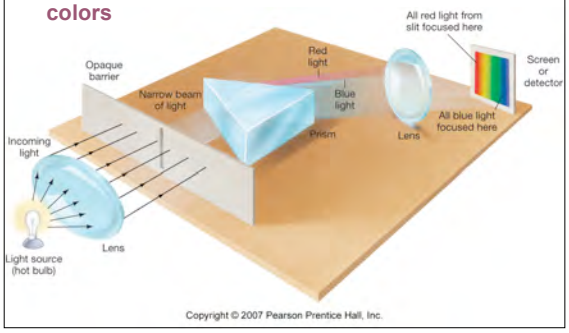
Kelvin Temperature scale:

- **All thermal motion ceases at 0 K**
- **Water freezes at 273 K and boils at 373 K**



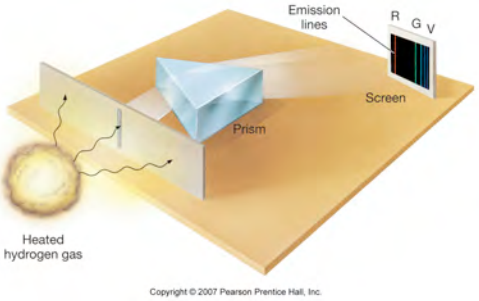
2.5 Spectroscopy

Spectroscope: splits light into component colors



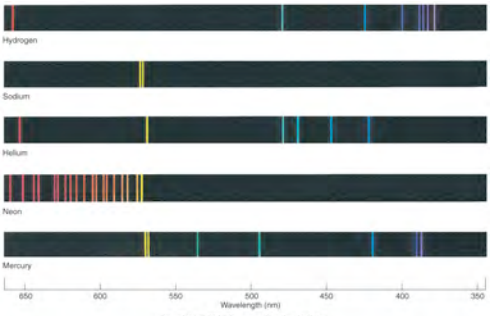
2.5 Spectroscopy

Emission lines: single frequencies emitted by particular atoms



2.5 Spectroscopy

Emission spectrum can be used to identify elements:



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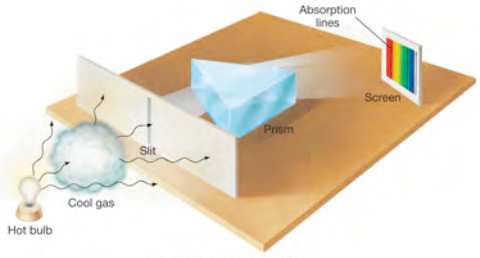
2.5 Spectroscopy

Absorption spectrum: if a continuous spectrum passes through a cool gas, atoms of the gas will absorb the same frequencies they emit



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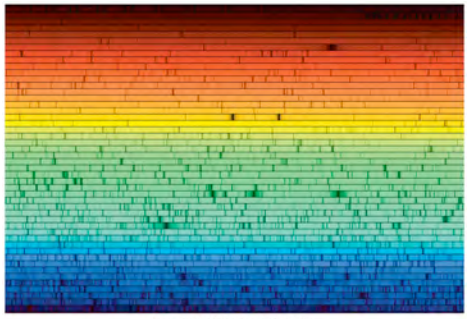
2.5 Spectroscopy

Absorption spectrum of the Sun:



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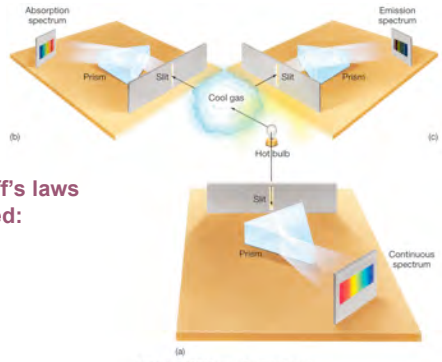
2.5 Spectroscopy

Kirchhoff's Laws:

- Luminous solid, liquid, or dense gas produces **continuous spectrum**
- Low-density hot gas produces **emission spectrum**
- Continuous spectrum incident on cool, thin gas produces **absorption spectrum**

2.5 Spectroscopy

Kirchhoff's laws illustrated:



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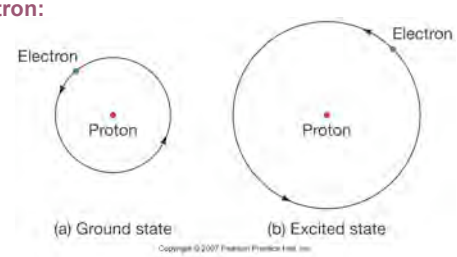
2.6 The Formation of Spectral Lines

Existence of spectral lines required new model of **atom**, so that only certain amounts of energy could be emitted or absorbed.

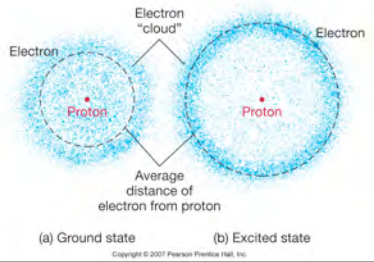
Bohr model had certain allowed orbits for electron:



2.6 The Formation of Spectral Lines

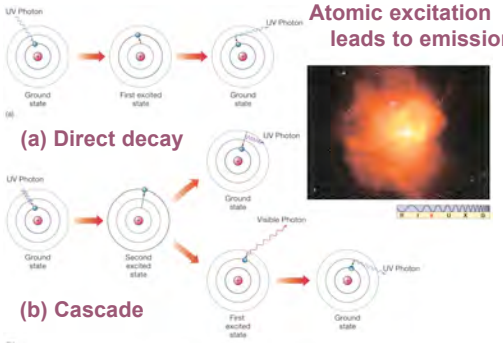
Emission energies correspond to energy differences between allowed levels.

Modern model has **electron "cloud"** rather than orbit:



2.6 The Formation of Spectral Lines

Atomic excitation leads to emission:



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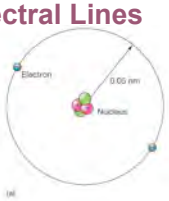
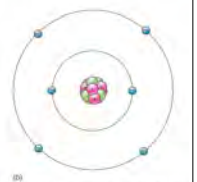
2.6 The Formation of Spectral Lines

Absorption spectrum: created when atoms absorb photons of right energy for excitation



Multielectron atoms: much more complicated spectra, many more possible states

Ionization changes energy levels



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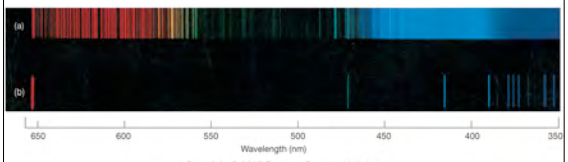
2.6 The Formation of Spectral Lines

Molecular spectra are much more complex than atomic spectra, even for hydrogen:

(a) Molecular hydrogen (b) Atomic hydrogen



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2.7 The Doppler Effect

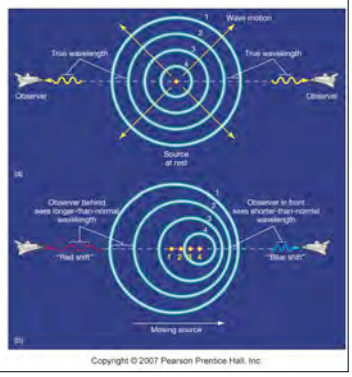
If one is moving toward a source of radiation, the wavelengths seem shorter; if moving away, they seem longer

Relationship between frequency and speed:

$$\frac{\text{apparent wavelength}}{\text{true wavelength}} = \frac{\text{true frequency}}{\text{apparent frequency}} = 1 + \frac{\text{recession velocity}}{\text{wave speed}}$$

2.7 The Doppler Effect

Depends only on the relative motion of source and observer:



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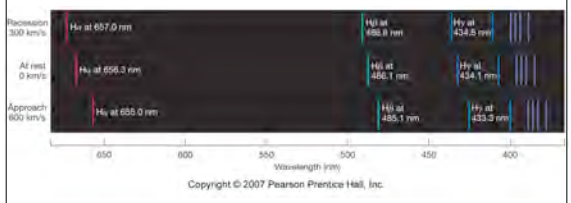
2.7 The Doppler Effect

The Doppler effect shifts an object's entire spectrum either towards the red or towards the blue:



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Summary of Chapter 2

- Wave: period, wavelength, amplitude
- Electromagnetic waves created by accelerating charges
- Visible spectrum is different wavelengths of light
- Entire electromagnetic spectrum:
- radio waves, infrared, visible light, ultraviolet, X-rays, gamma rays
- Can tell the temperature of an object by measuring its blackbody radiation

Summary of Chapter 2, cont.

- Spectroscope splits light beam into component frequencies
- Continuous spectrum is emitted by solid, liquid, and dense gas
- Hot gas has characteristic emission spectrum
- Continuous spectrum incident on cool, thin gas gives characteristic absorption spectrum

Summary of Chapter 2, cont.

- Spectra can be explained using atomic models, with electrons occupying specific orbitals
- Emission and absorption lines result from transitions between orbitals
- Doppler effect can change perceived frequency of radiation
- Doppler effect depends on relative speed of source and observer