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Universe

Tenth Edition

Chapter 5

The Nature of Light

By reading this chapter, you will learn

- | | |
|--|--|
| 5-1 How we measure the speed of light | 5-6 How astronomers can detect an object's chemical composition by studying the light it emits |
| 5-2 How we know that light is an electromagnetic wave | 5-7 The quantum rules that govern the structure of an atom |
| 5-3 How an object's temperature is related to the radiation it emits | 5-8 The relationship between atomic structure and the light emitted by objects |
| 5-4 The relationship between an object's temperature and the amount of energy it emits | 5-9 How an object's motion affects the light we receive from that object |
| 5-5 The evidence that light has both particle and wave aspects | |

Why light?

- With only a very few exceptions*, all the information about stars and galaxies reaches the Astronomers in the form of light

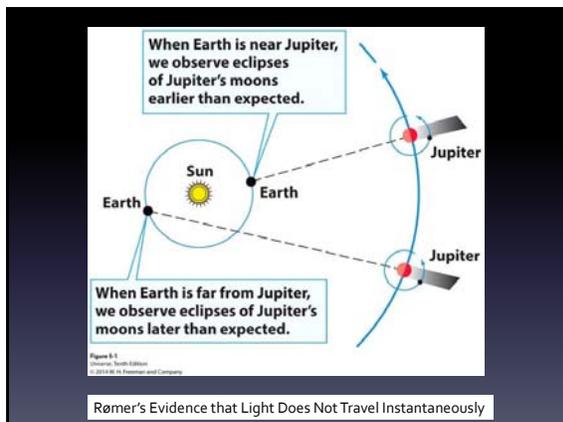
*gravity waves, neutrinos...

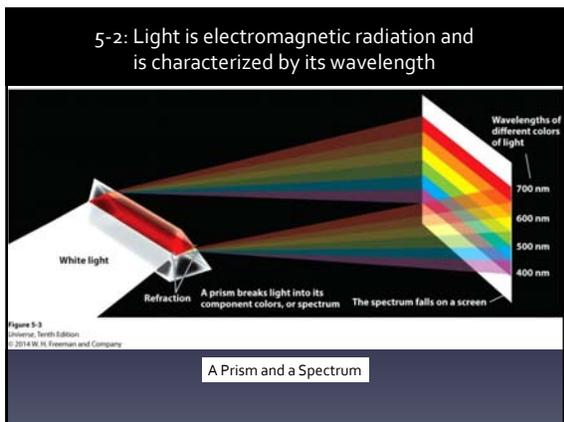
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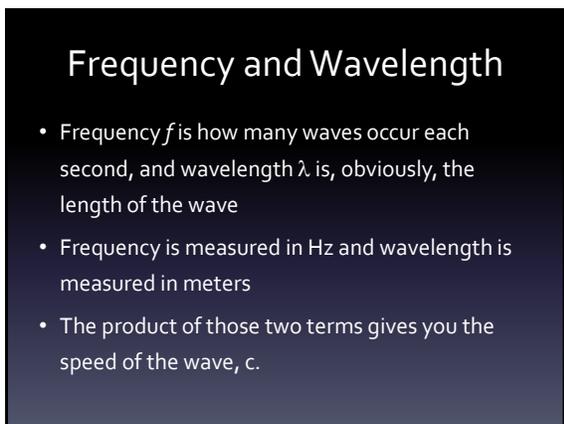
- Light is an *electromagnetic* wave
- It can also be thought of as a particle called a *photon: γ*
- This apparent contradiction is called the *particle/wave duality*
- The apparent contradiction is due to our inability to describe something that is neither entirely a wave nor a particle
- At times it's convenient to speak of light as a wave; at other times convenience begs for a particle

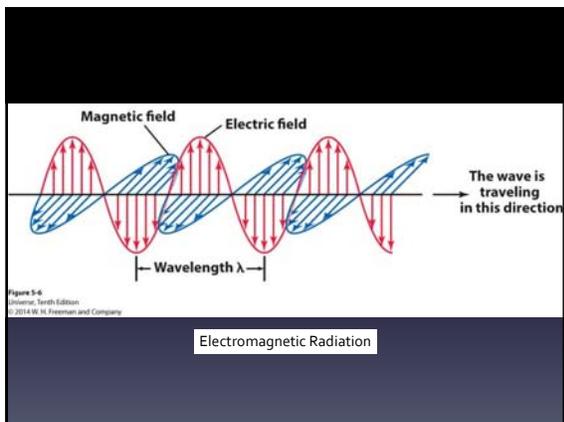
The Speed of Light

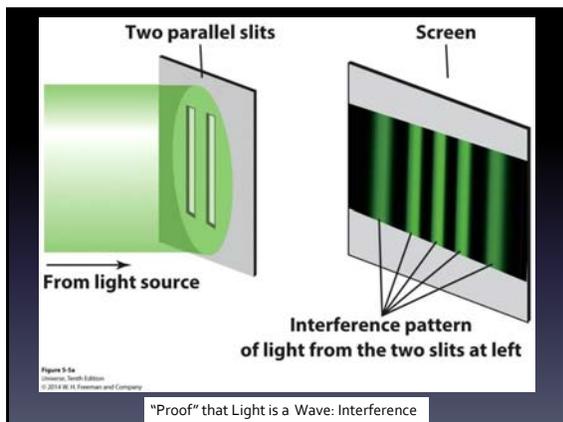
- The speed of light, denoted ' c ', is a fixed speed
- We use c because the speed of a wave is constant in a particular medium
- The ultimate speed limit is 300,000 km/sec, about 186,000 miles a second—670 million miles an hour.
- Light can travel more slowly than this, for instance in glass or water, but never faster

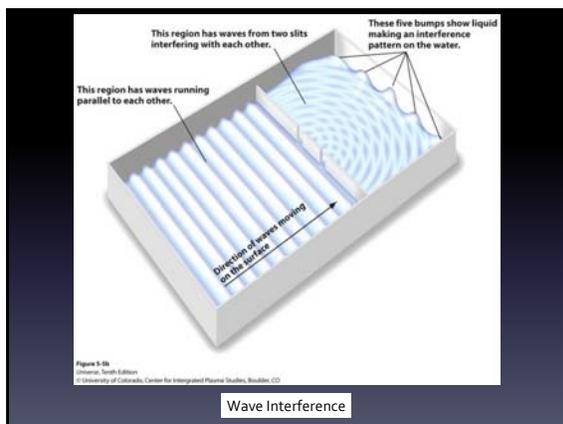


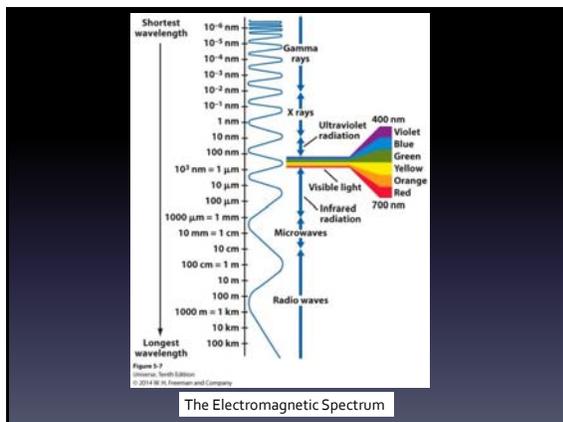






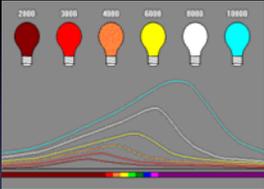


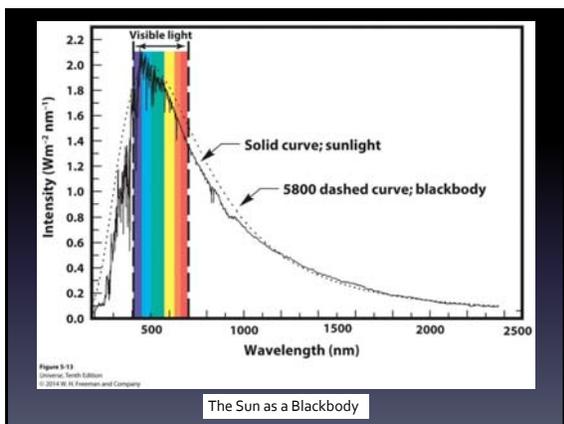


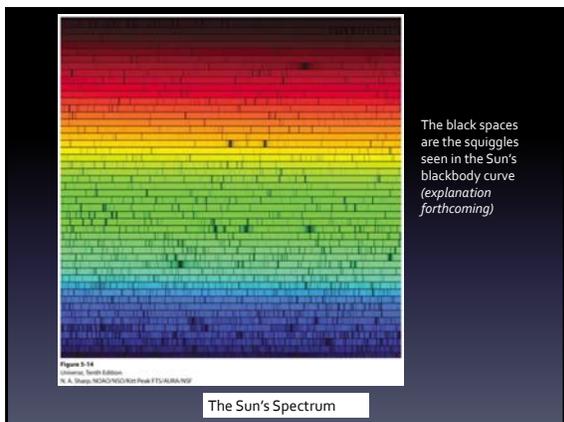


Intrinsic Brightness: Blackbody Radiation

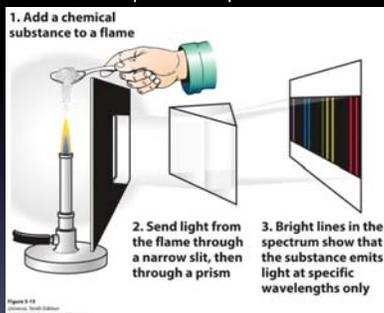
- Stars emit light because they are *hot!*
- Their color is determined by their temperature
- Consequently, their brightness is dependent on their temperature (among other things)







5-6: Each chemical element produces its own unique set of spectral lines



The Kirchhoff-Bunsen Experiment

Periodic Table of the Elements

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
87 Fr	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

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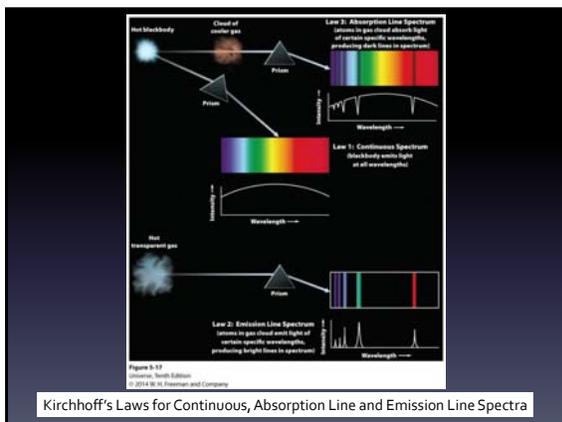
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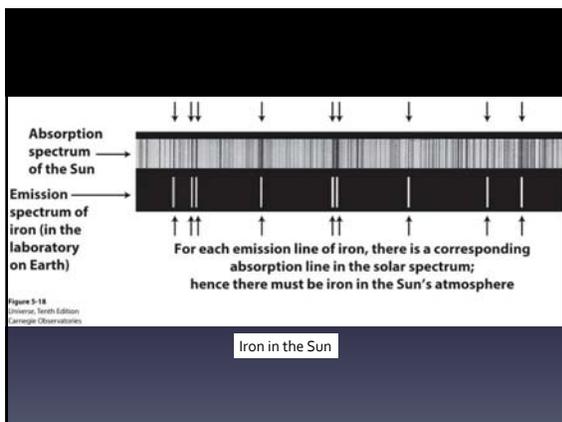
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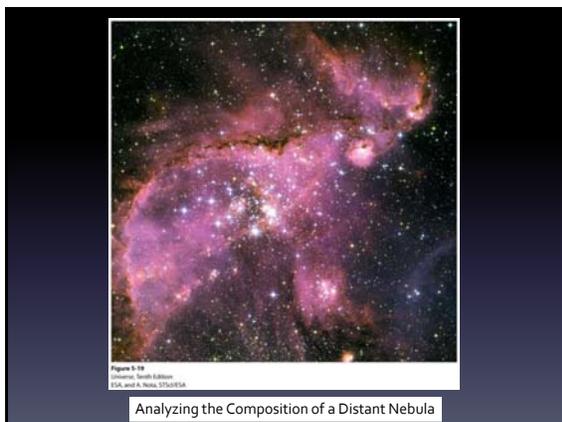
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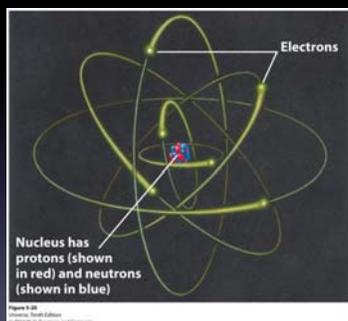
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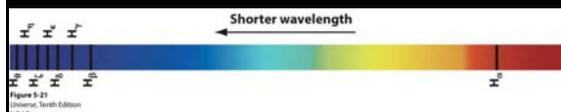


5-7: An atom consists of a small, dense nucleus surrounded by electrons

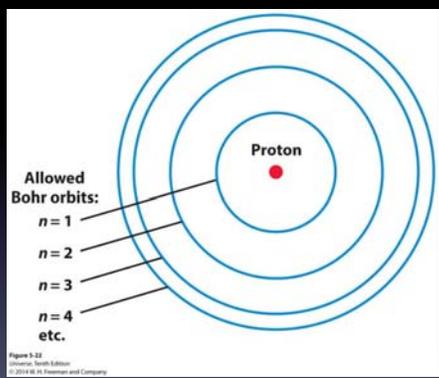


Rutherford's Model of the Atom (he didn't know about neutrons at the time)

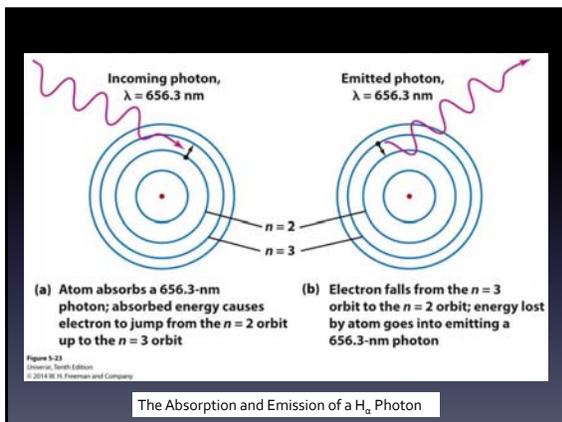
5-8: Spectral lines are produced when an electron jumps from one energy level to another

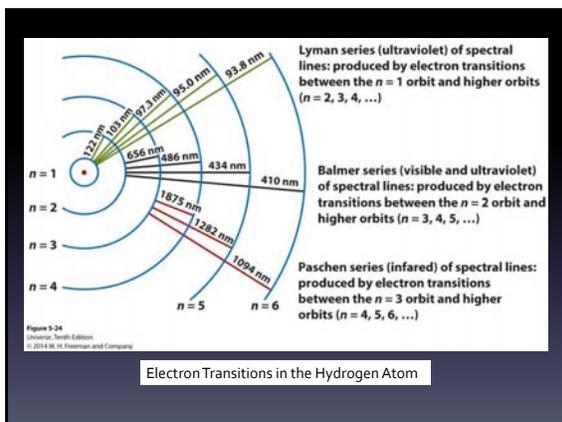


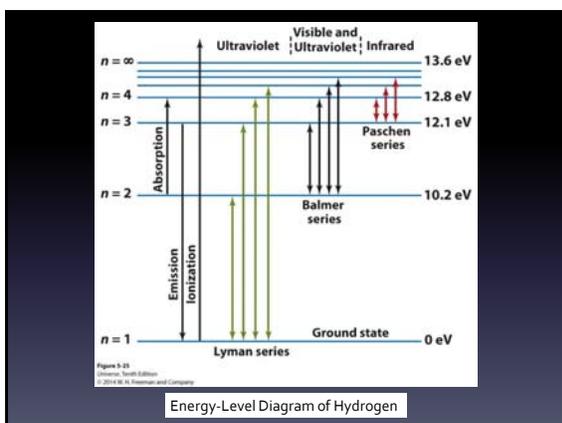
Balmer Lines in the Spectrum of a Star

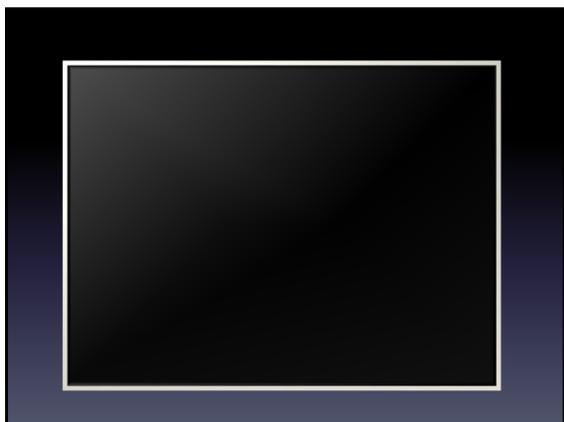


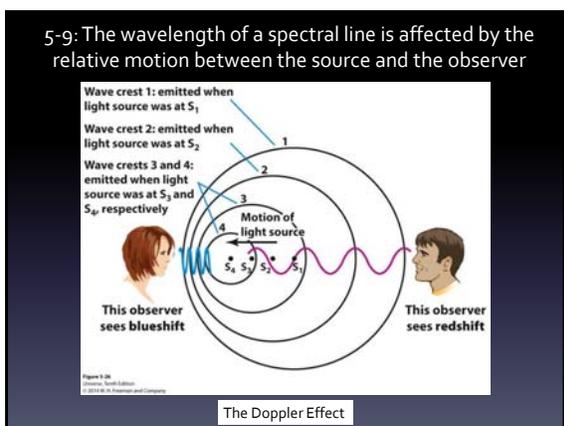
The Bohr Model of the Hydrogen Atom

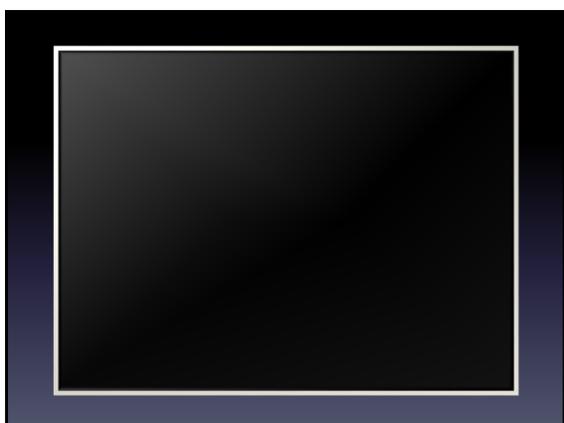












Red Shift

Absorption Lines from our Sun

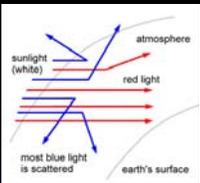
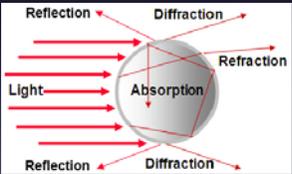


Absorption Lines from a supercluster of galaxies, BAS11
 $v = 0.07 c$, $d = 1$ billion light years

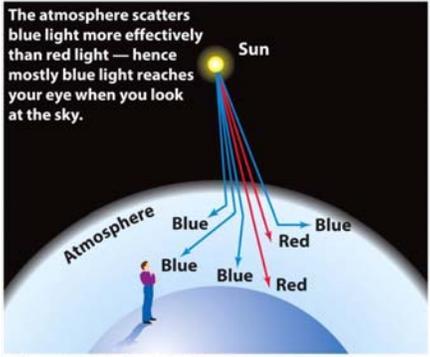


Scattering

- Why the sky is blue
 - Windblown dust
 - Ice crystals in clouds
 - Smog

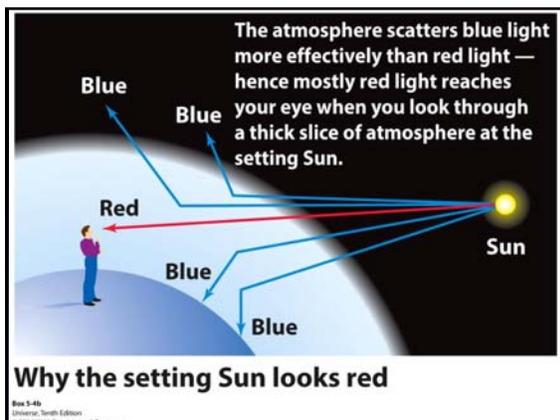



The atmosphere scatters blue light more effectively than red light — hence mostly blue light reaches your eye when you look at the sky.



Why the sky looks blue

Box 3-4a
 University, Sixth Edition
 © 2004 W. H. Freeman and Company



Key Ideas

- **The Nature of Light:** Light is electromagnetic radiation. It has wavelike properties described by its wavelength λ and frequency ν , and travels through empty space at the constant speed $c = 3.0 \times 10^8 \text{ m/s} = 3.0 \times 10^5 \text{ km/s}$.
- **Thermal energy:** The thermal energy of a material comes from the kinetic energy of its microscopic particles (atoms and molecules). The hotter a material, the faster its particles move, and the greater its thermal energy.
- **Blackbody Radiation:** A blackbody is a hypothetical object that is a perfect absorber of electromagnetic radiation at all wavelengths. Stars closely approximate the behavior of blackbodies, as do other hot, dense objects.

Key Ideas

- The intensities of radiation emitted at various wavelengths by a blackbody at a given temperature are shown by a blackbody curve.
- **Wien's law** states that the dominant wavelength (and overall color) at which a blackbody emits electromagnetic radiation is inversely proportional to the Kelvin temperature of the object.
- **Photons:** Light is made of particles called photons. Each photon has a wavelength equal to the wavelength of the light that the photons make up.

Key Ideas

- **Kirchhoff's Laws:** Kirchhoff's three laws of spectral analysis describe conditions under which different kinds of spectra are produced.
- A hot, dense object such as a blackbody emits a **continuous spectrum** covering all wavelengths.
- A hot, transparent gas produces a spectrum that contains bright (**emission**) lines.
- A cool, transparent gas in front of a light source that itself has a continuous spectrum produces dark (**absorption**) lines in the continuous spectrum.

Key Ideas

- **Atomic Structure:** An atom has a small dense nucleus composed of protons and neutrons. The nucleus is surrounded by electrons that occupy only certain orbits or energy levels.
- When an electron jumps from one energy level to another, it emits or absorbs a photon of appropriate energy (and hence of a specific wavelength).
- The **spectral lines** of a particular element correspond to various electron orbital transitions between energy levels in the atom. Each atom has a unique "spectral fingerprint".

Key Ideas

- **The Doppler Shift:** The Doppler shift enables us to determine the line-of-sight (radial) velocity of a light source from the displacement of its spectral lines.
- The spectral lines of an approaching light source are shifted toward short wavelengths (a **blueshift**); the spectral lines of a receding light source are shifted toward long wavelengths (a **redshift**).
- The size of a wavelength shift is proportional to the radial velocity of the light source relative to the observer.
