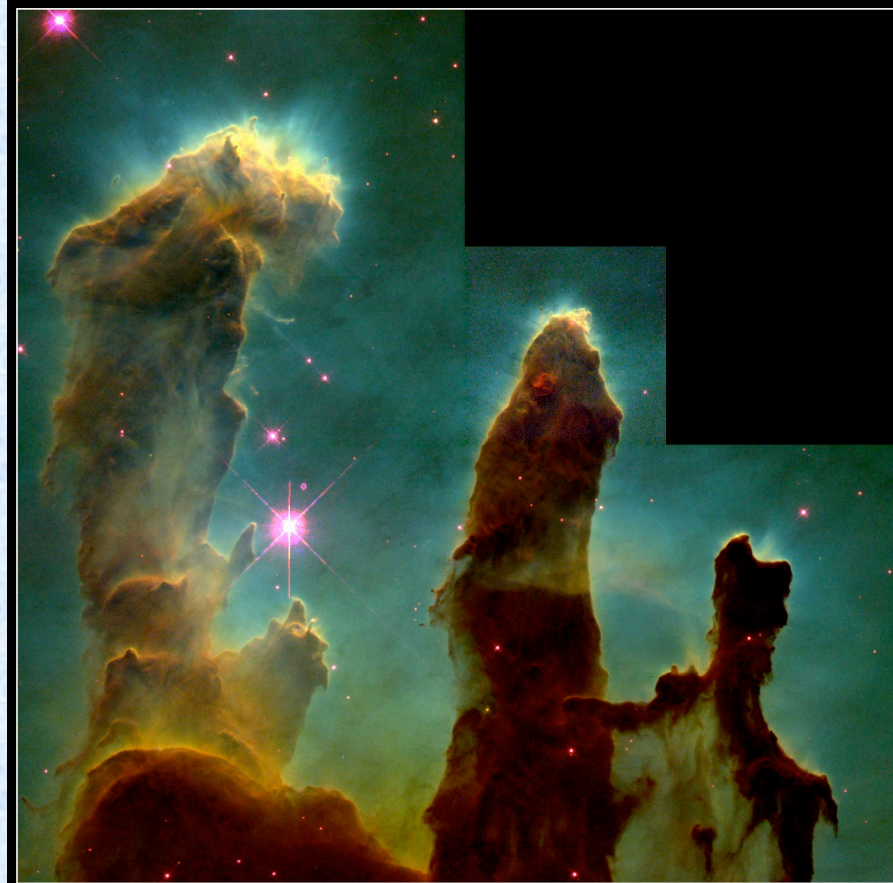


Astronomy 1 – Winter 2011



Gaseous Pillars in M16 • Eagle Nebula
Hubble Space Telescope • WFPC2

PRC95-44a • ST ScI OPO • November 2, 1995 • J. Hester and P. Scowen (AZ State Univ.), NASA



Lecture 8; January 24 2011

Previously on Astro 1

- **Light as a wave**
- **The Kelvin Temperature scale**
- **What is a blackbody?**
 - **Wien's law:** λ_{max} (in meters) = $(0.0029 \text{ K}\cdot\text{m})/T$.
 - **The Stefan-Boltzmann law:** $F = \sigma T^4$.
 - Cosmic microwave background

Stargazing event

- **When: March 7 (and 8 if necessary)**
- **Where: Broida Rooftop**
- **How: sign up with Bill or Sagar. Maximum 50/night. First come first served. If the first night is full we'll do the second.**

Today on Astro 1

- **What are photons?**
 - light can have particle-light properties. The particles of light are called photons: $E = h\nu = hc/\lambda$
- **Why is the sky is blue and sunsets red?**
 - Interaction between light and atmosphere
- **What are stars and interstellar gas made of?**
 - The same elements we see on Earth, mostly Hydrogen, He, Oxygen, Carbon
- **What causes spectral lines?**
 - Atomic structure

Question 8.1 (iclickers!)

- If all stars are considered perfect blackbodies, then it should follow that all stars
 - A) of the same composition emit the same energy flux
 - B) of the same size emit the same energy flux
 - C) traveling at the same speed emit the same energy flux
 - D) of the same temperature emit the same energy flux

Light is also a particle: Planck's Law

$$E = \frac{hc}{\lambda} \quad \text{or} \quad E = h\nu$$

E = Energy of a photon

h = Planck's constant =
 $6.625 \times 10^{-34} \text{ J s}$

c = speed of light

λ = wavelength of light

ν = frequency of light

Example: DNA molecules are easily broken when hit with ultraviolet light at 260 nm (why you get cancer from sunburns). How much energy does a single photon at this wavelength have?

$$E = \frac{hc}{\lambda} = \frac{(6.625 \times 10^{-34} \text{ J s})(3.00 \times 10^8 \text{ m/s})}{2.60 \times 10^{-7} \text{ m}} = 7.64 \times 10^{-19} \text{ J}$$

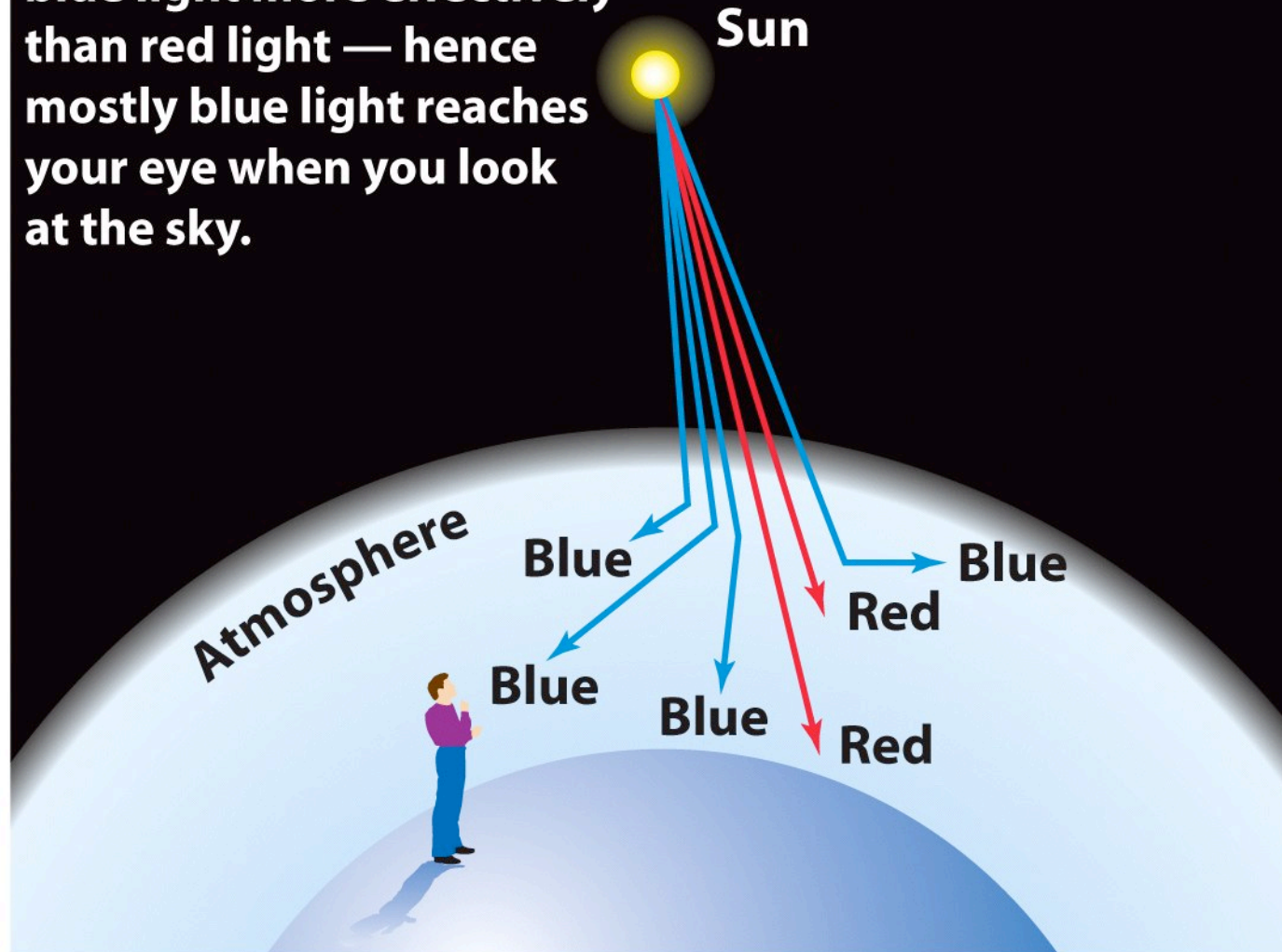
Question 8.2 (iclickers!)

• In what way does a photon of blue light not differ from a photon of yellow light in a vacuum

- A) wavelength
- B) color
- C) energy
- D) speed

Why is the sky blue and the sunset red?

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

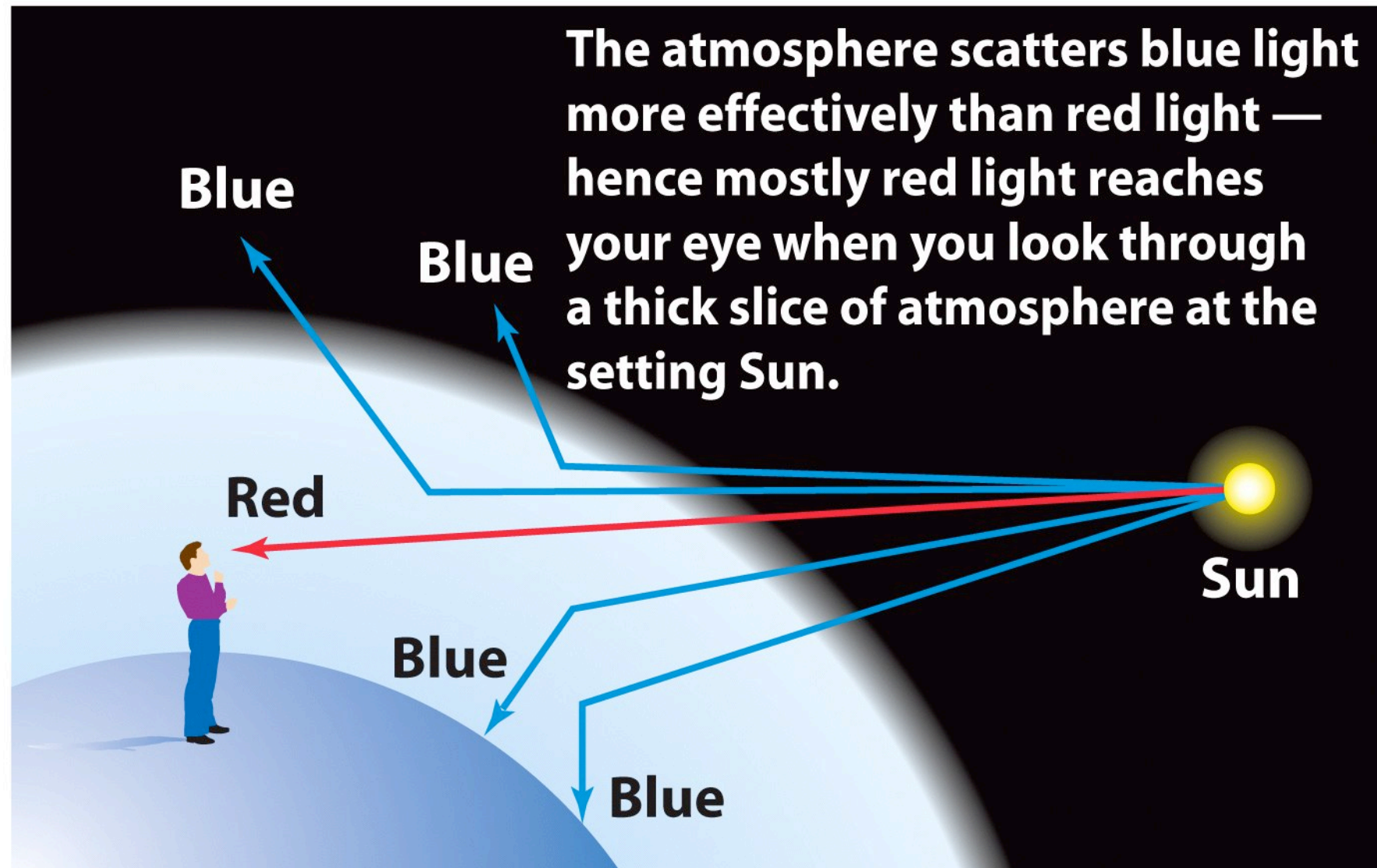


Why the sky looks blue

Box 5-4a

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The atmosphere scatters blue light more effectively than red light — hence mostly red light reaches your eye when you look through a thick slice of atmosphere at the setting Sun.

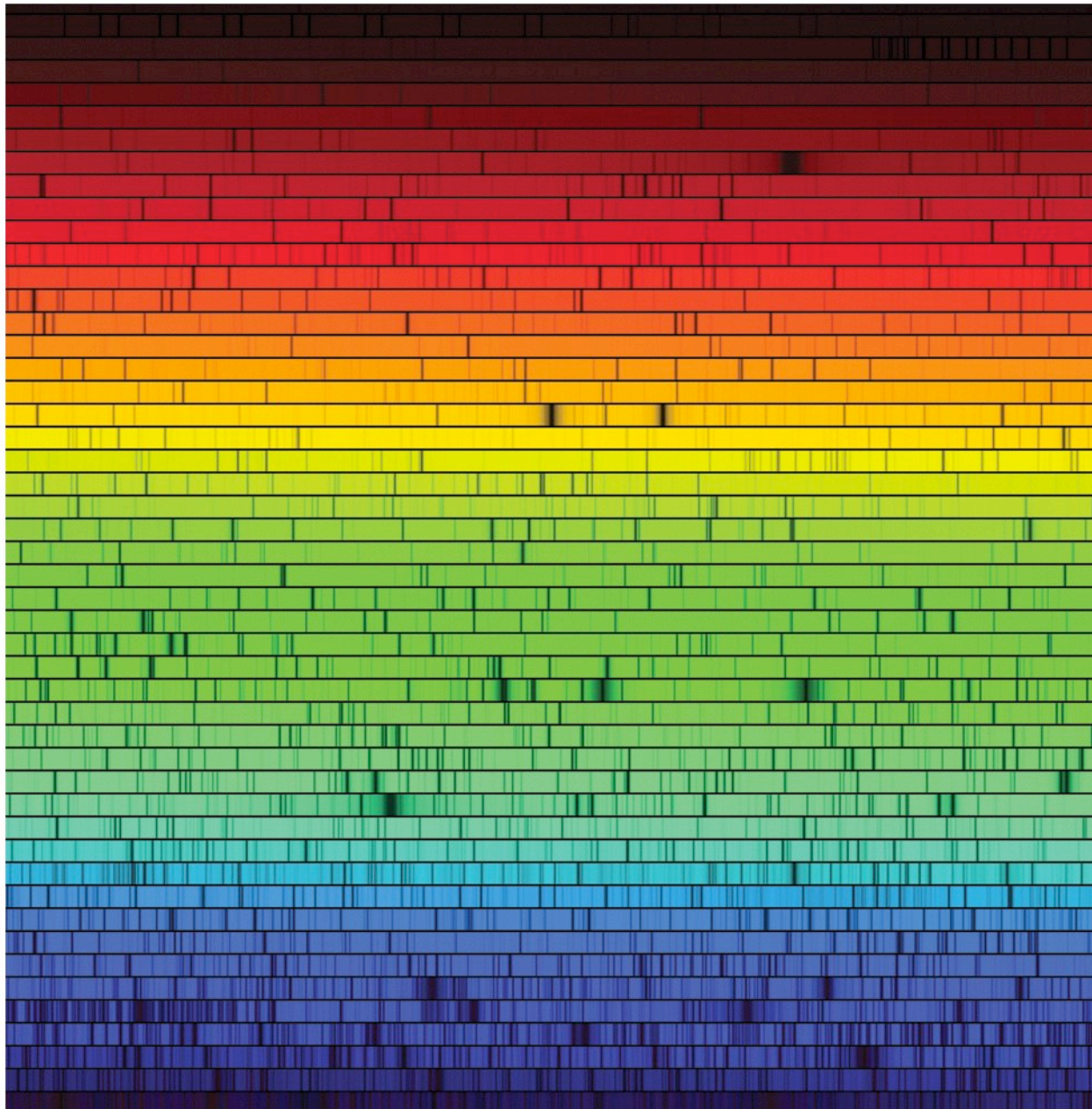
Why the setting Sun looks red

Box 5-4b

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Spectra as the “fingerprints” of nature

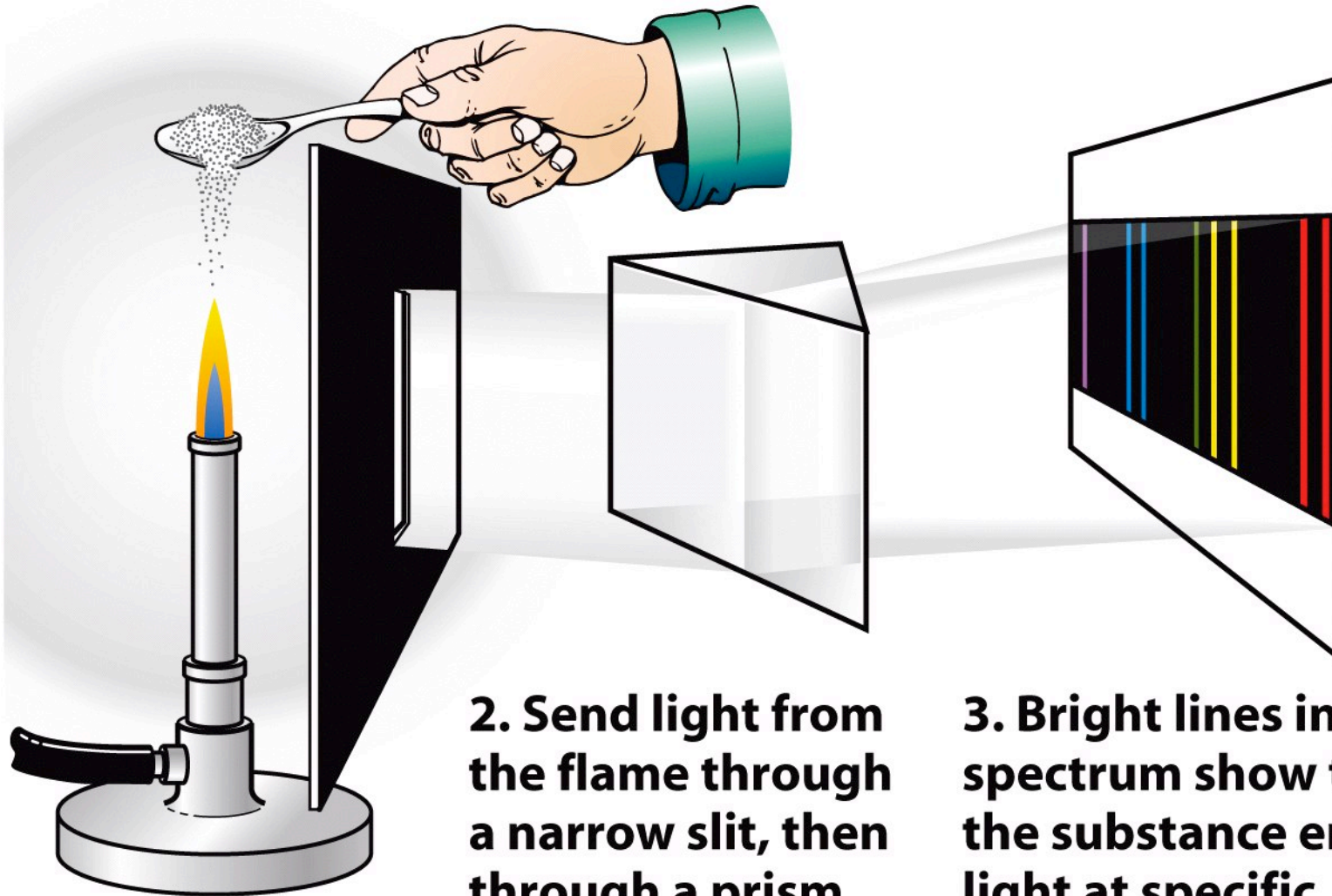


The Sun's Spectrum

In 1814 Joseph von Fraunhofer magnified the solar spectrum seen through a prism, and found hundreds of dark lines.

Figure 5-13
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1. Add a chemical substance to a flame



2. Send light from the flame through a narrow slit, then through a prism

3. Bright lines in the spectrum show that the substance emits light at specific wavelengths only

Kirchoff's Laws

1. A hot, dense object such as a blackbody emits a **continuous spectrum** covering all wavelengths.
2. A hot, transparent gas produces a spectrum that contains bright (**emission**) lines.
3. A cool, transparent gas in front of a light source that itself has a continuous spectrum produces dark (**absorption**) lines in the continuous spectrum.

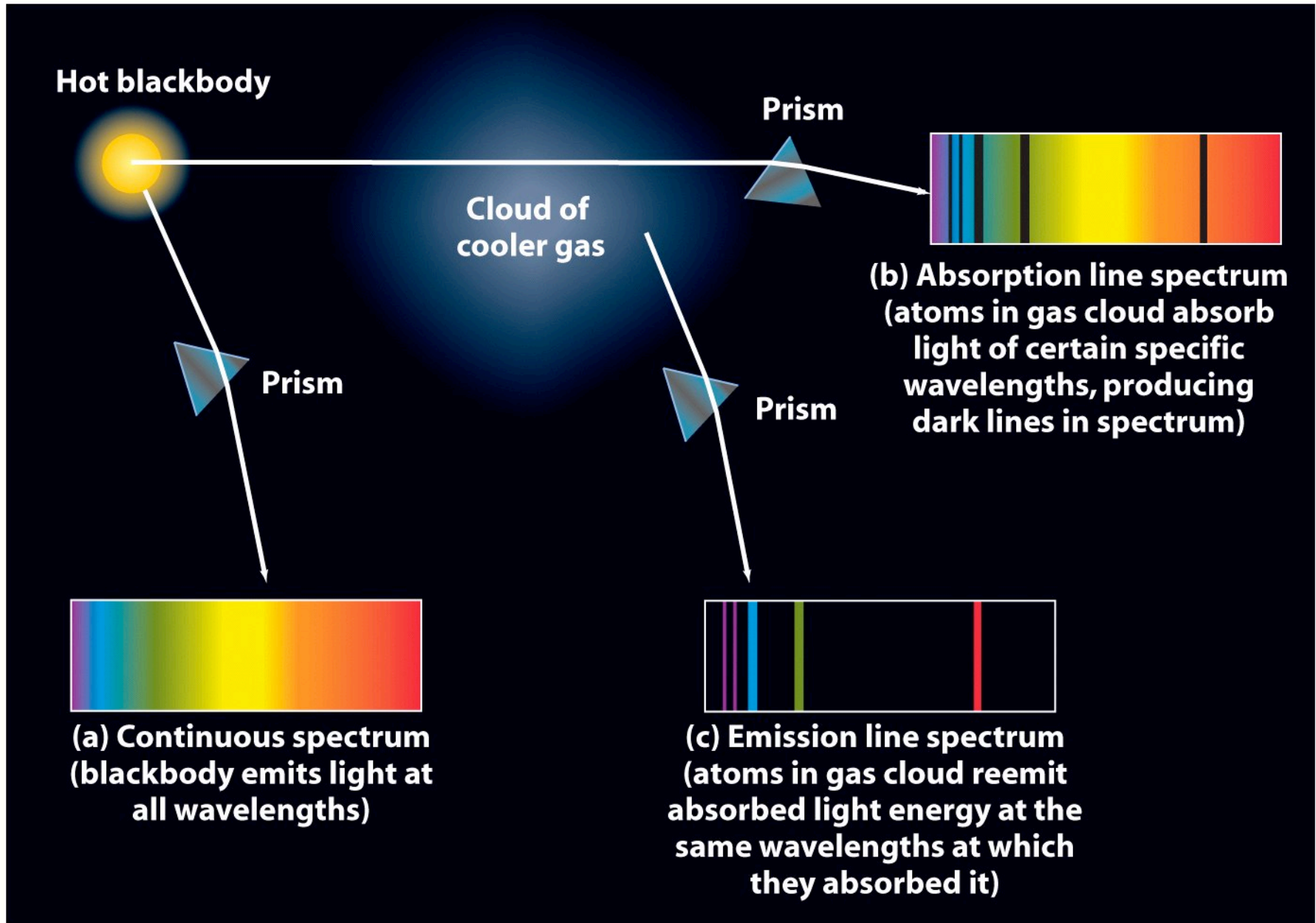


Figure 5-16
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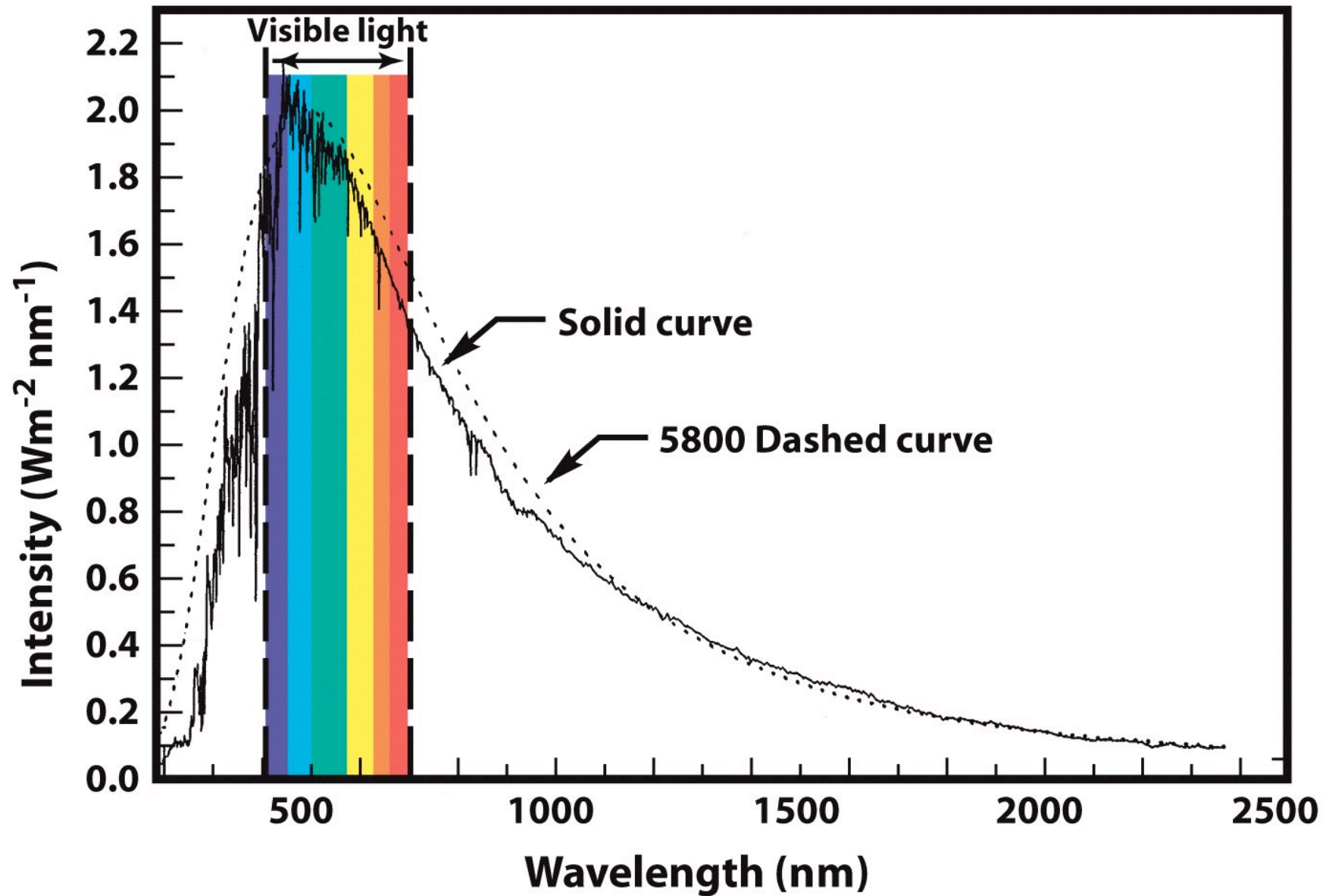


Figure 5-12
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The energy output of the sun.

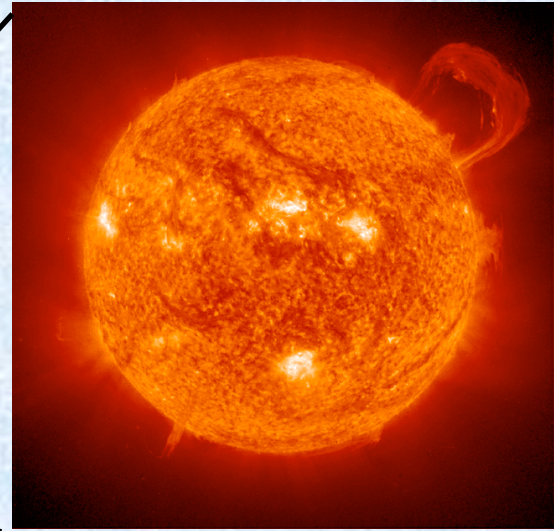
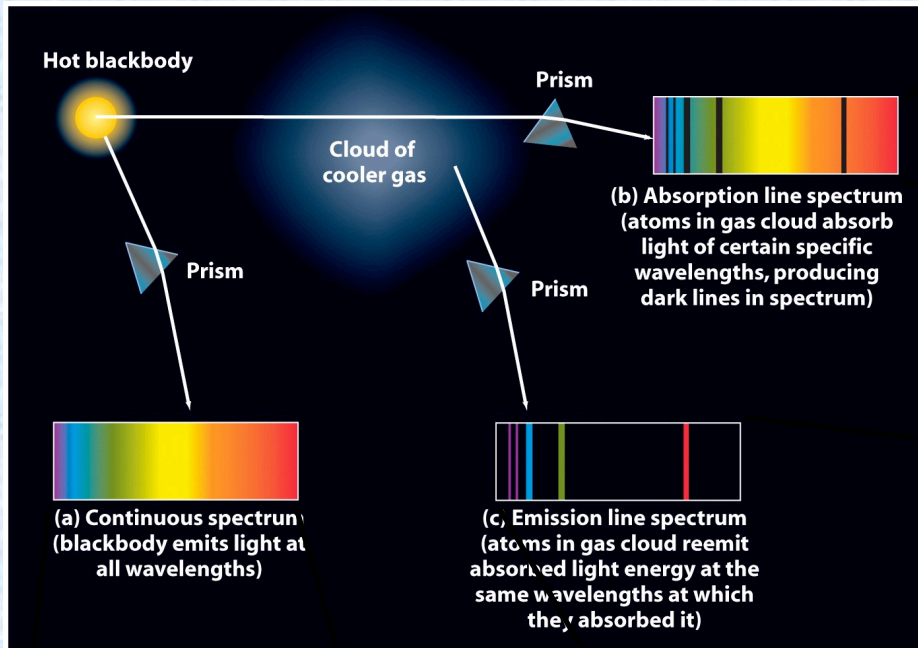
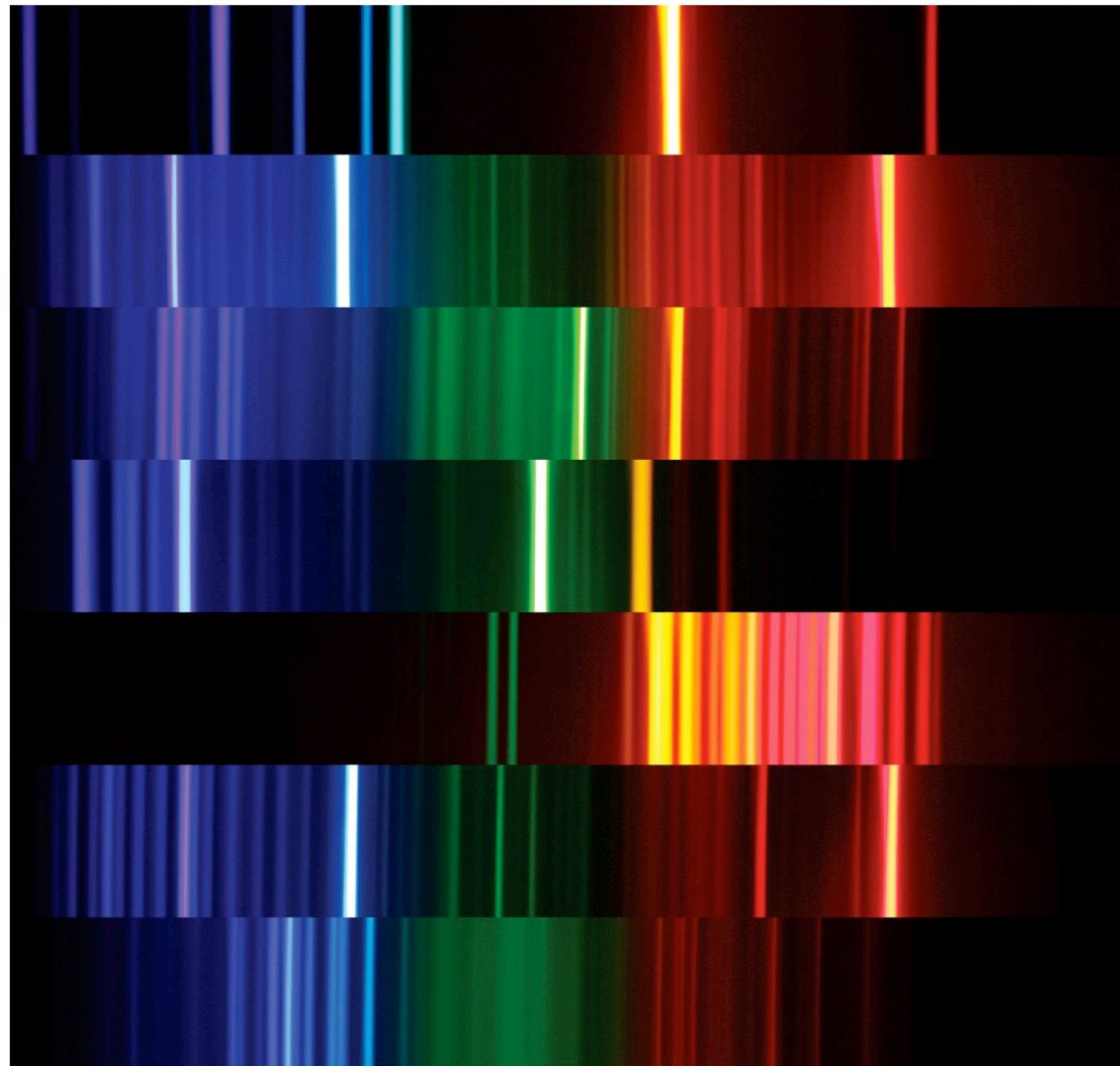


Figure 5-16
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Helium (He)

Hydrogen (H₂)

Krypton (Kr)

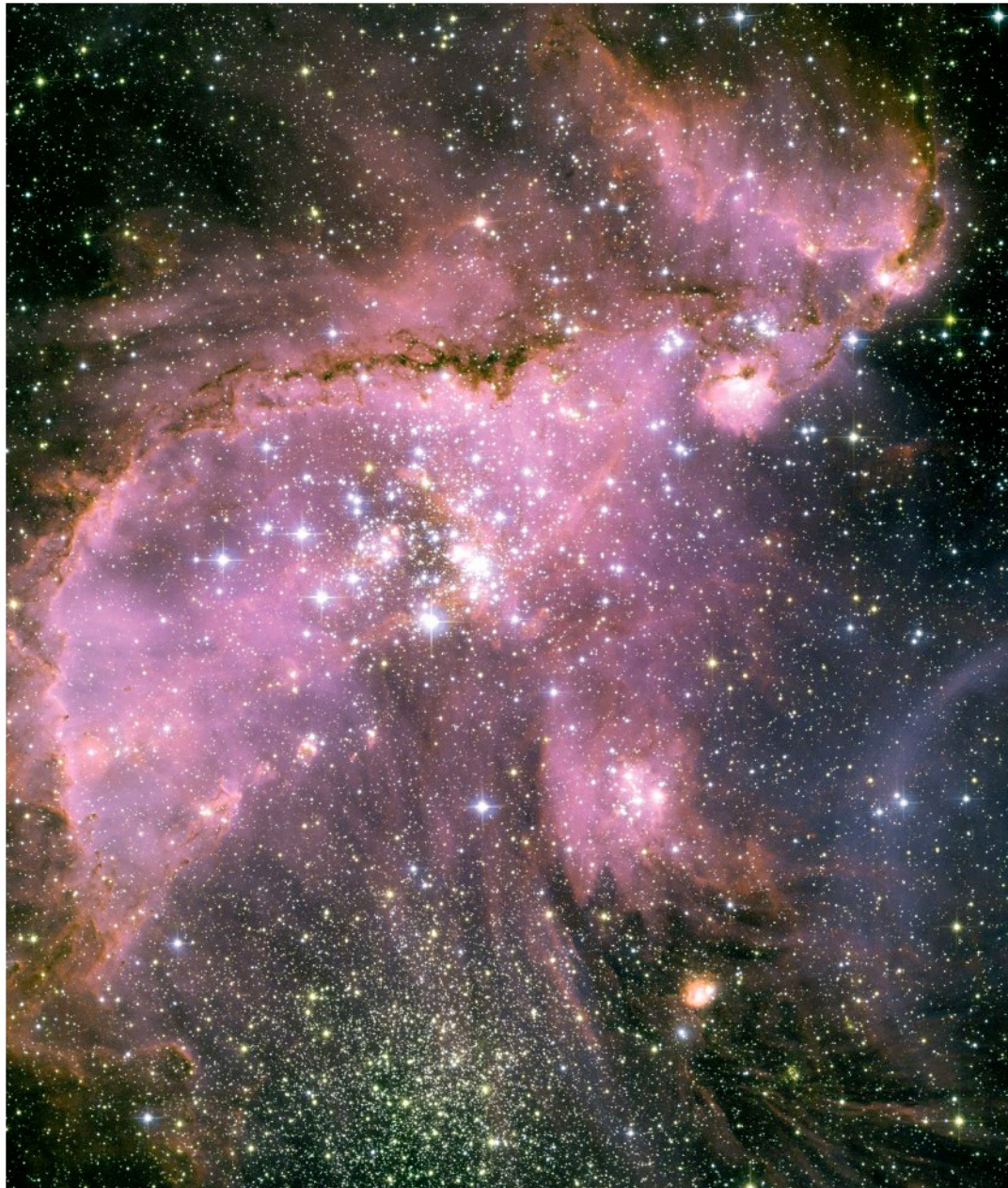
Mercury (Hg)

Neon (Ne)

Water vapor (H₂O)

Xenon (Xe)

Figure 5-15
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The glowing gas cloud in this Hubble Space Telescope image lies 210,000 light-years away in the constellation Tucana (the Toucan). Hot stars within the nebula emit high-energy, ultraviolet photons, which are absorbed by the surrounding gas and heat the gas to high temperature. This heated gas produces light with an emission line spectrum. The wavelength of red light emitted by the nebula is 656 nm, characteristic of hydrogen gas

Figure 5-18
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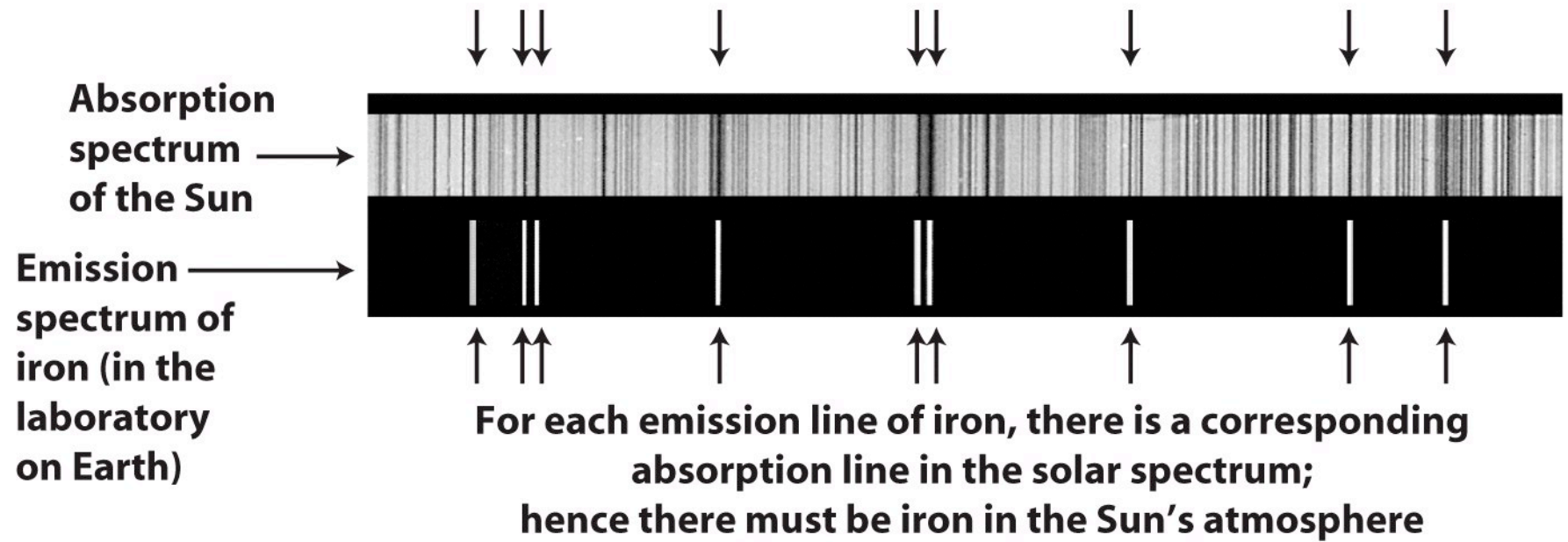


Figure 5-17
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Periodic Table of the Elements

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	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn																											
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uug	115 Uup	116 Uuh																													
		<table border="1"> <tbody> <tr> <td>58 Ce</td> <td>59 Pr</td> <td>60 Nd</td> <td>61 Pm</td> <td>62 Sm</td> <td>63 Eu</td> <td>64 Gd</td> <td>65 Tb</td> <td>66 Dy</td> <td>67 Ho</td> <td>68 Er</td> <td>69 Tm</td> <td>70 Yb</td> <td>71 Lu</td> </tr> <tr> <td>90 Th</td> <td>91 Pa</td> <td>92 U</td> <td>93 Np</td> <td>94 Pu</td> <td>95 Am</td> <td>96 Cm</td> <td>97 Bk</td> <td>98 Cf</td> <td>99 Es</td> <td>100 Fm</td> <td>101 Md</td> <td>102 No</td> <td>103 Lr</td> </tr> </tbody> </table>															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	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
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																															
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																															

Box 5-5 part 2

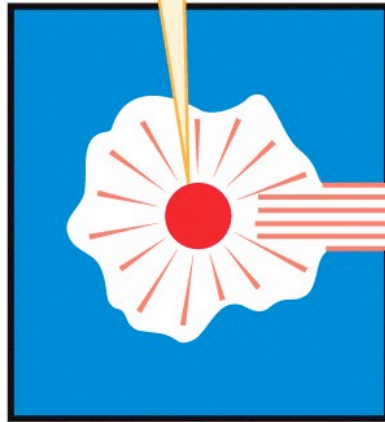
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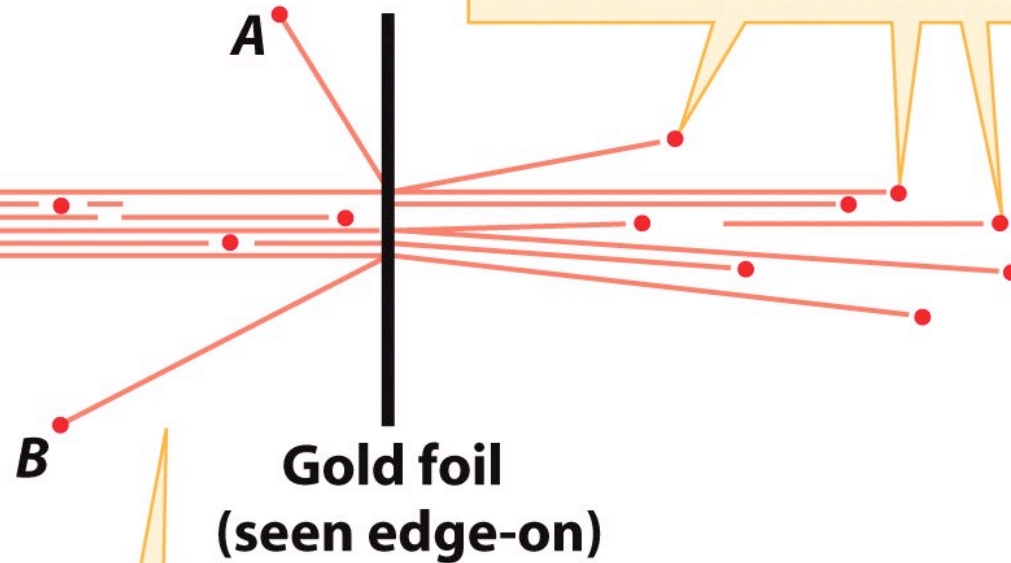
Atomic number is the number of protons in an atom.

**What causes spectral lines?
The structure of atoms**

Radioactive substance emits alpha particles.



Most alpha particles pass through the foil with very little deflection.



Occasionally an alpha particle rebounds (like *A* or *B*), indicating that it has collided with the massive nucleus of a gold atom.

Figure 5-19
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Rutherford's Experiment

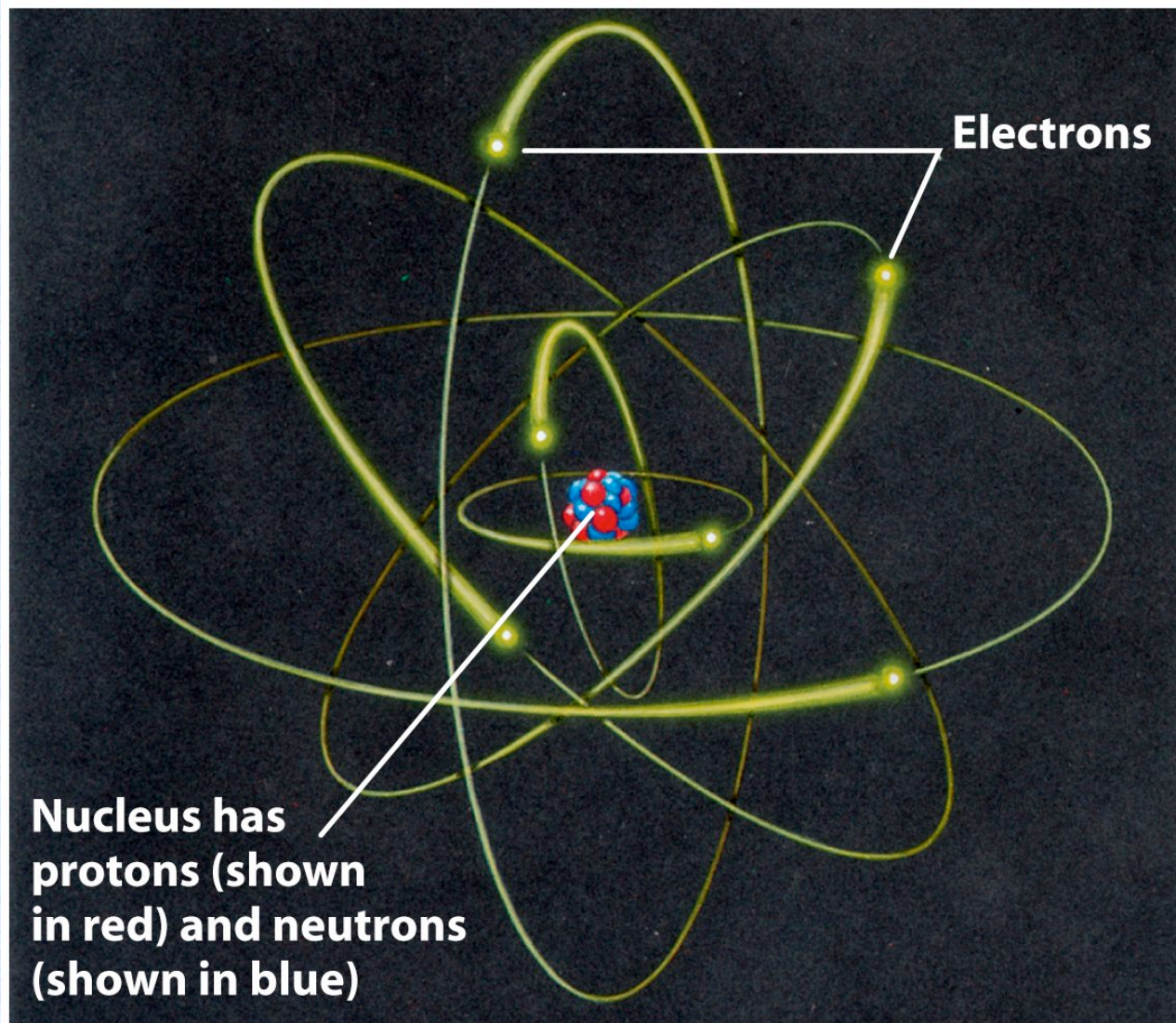
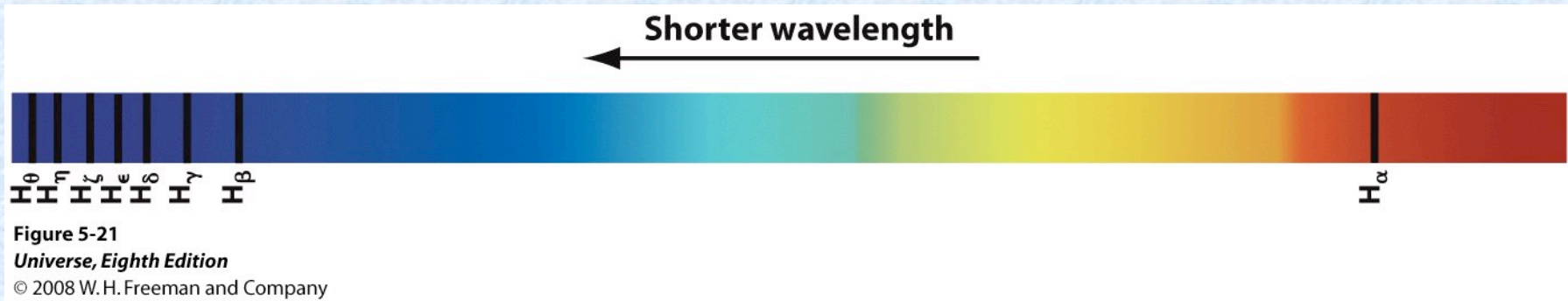


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Rutherford's model of the atom.

Today we know this is not exactly correct – electrons do not orbit the nucleus, but the basic idea is right -- protons and neutrons exist in the nucleus, and electrons are outside of it.



In 1885 Swiss schoolteacher Johann Jakob Balmer, by trial and error, created a formula that can predict where lines of hydrogen fall in the spectrum of a star.

We still call these Balmer lines.

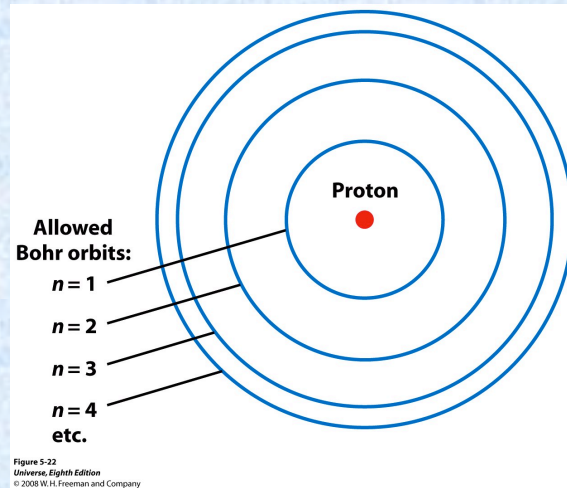
$$\frac{1}{\lambda} = R \left(\frac{1}{4} - \frac{1}{n^2} \right)$$

R = Rydberg constant = $1.097 \times 10^7 \text{ m}^{-1}$

n = any integer greater than 2



Niels Bohr
1885-1962



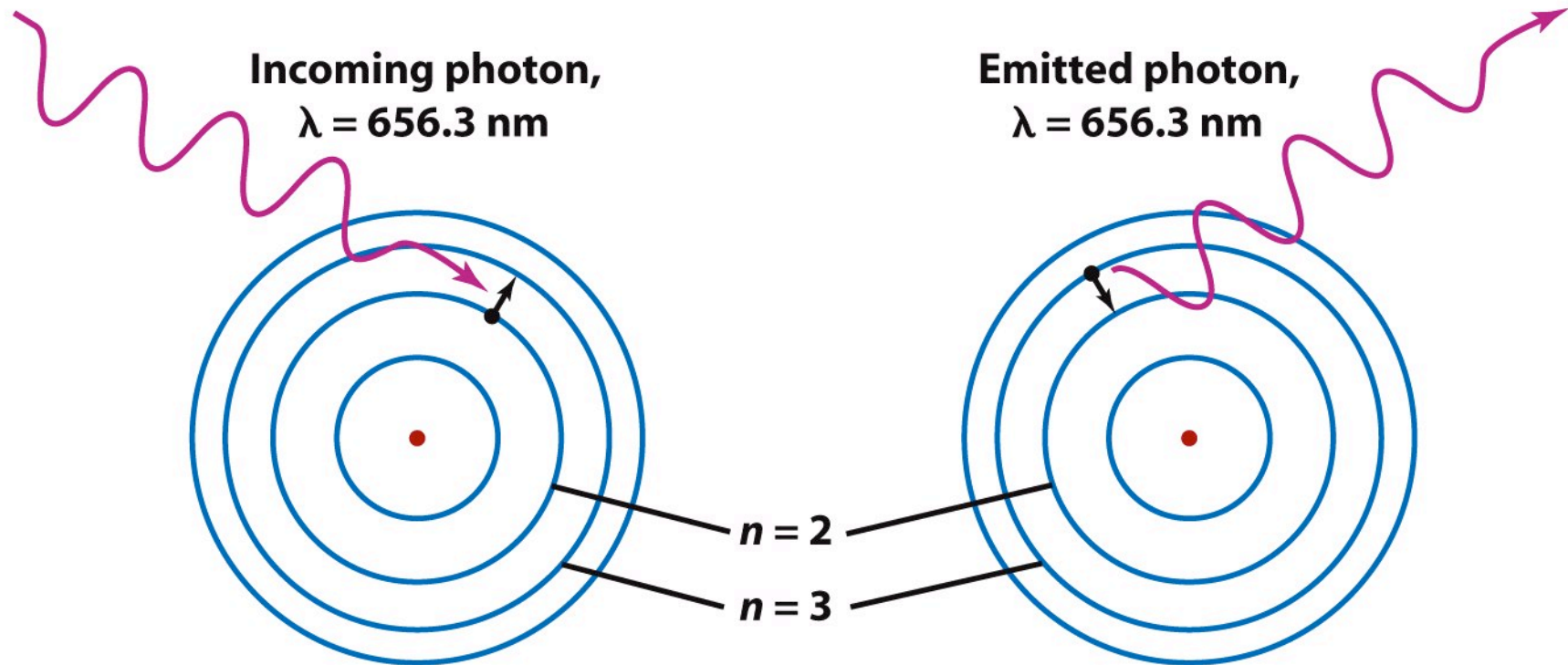
The Bohr model
of the atom

Was a postdoc with Rutherford.
In 1912, to explain discrete
nature of spectral lines,
hypothesized that electron orbits
are quantized (quantum
mechanics!).



Bohr and Einstein, 1925

The quantum nature of light is related to the quantum nature of atoms!



(a) Atom absorbs a 656.3-nm photon; absorbed energy causes electron to jump from the $n = 2$ orbit up to the $n = 3$ orbit

(b) Electron falls from the $n = 3$ orbit to the $n = 2$ orbit; energy lost by atom goes into emitting a 656.3-nm photon

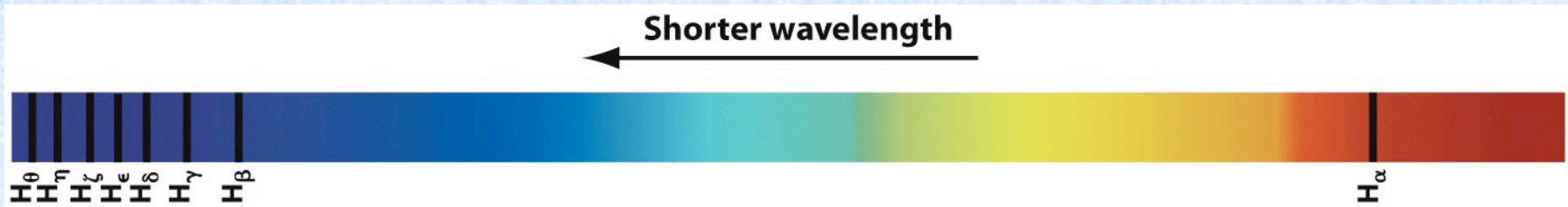


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$$\frac{1}{\lambda} = R \left(\frac{1}{4} - \frac{1}{n^2} \right)$$

The Balmer series and formula.

R = Rydberg constant = $1.097 \times 10^7 \text{ m}^{-1}$

Bohr figured out the physical explanation for Balmer's formula – the spectra from stars depends on the structure of atoms!

$$\frac{1}{\lambda} = R \left(\frac{1}{N^2} - \frac{1}{n^2} \right)$$

N = lower orbital
 n = higher orbital

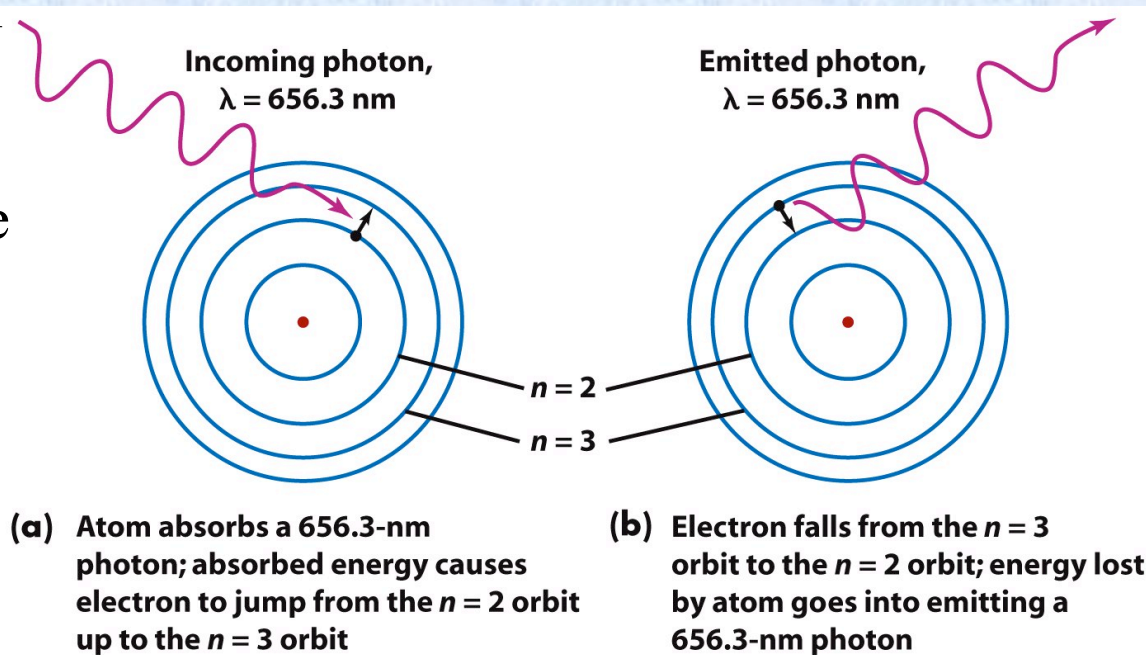


Figure 5-23
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Electron Transitions in the Hydrogen Atom

The same wavelength occurs whether a photon is emitted or absorbed.

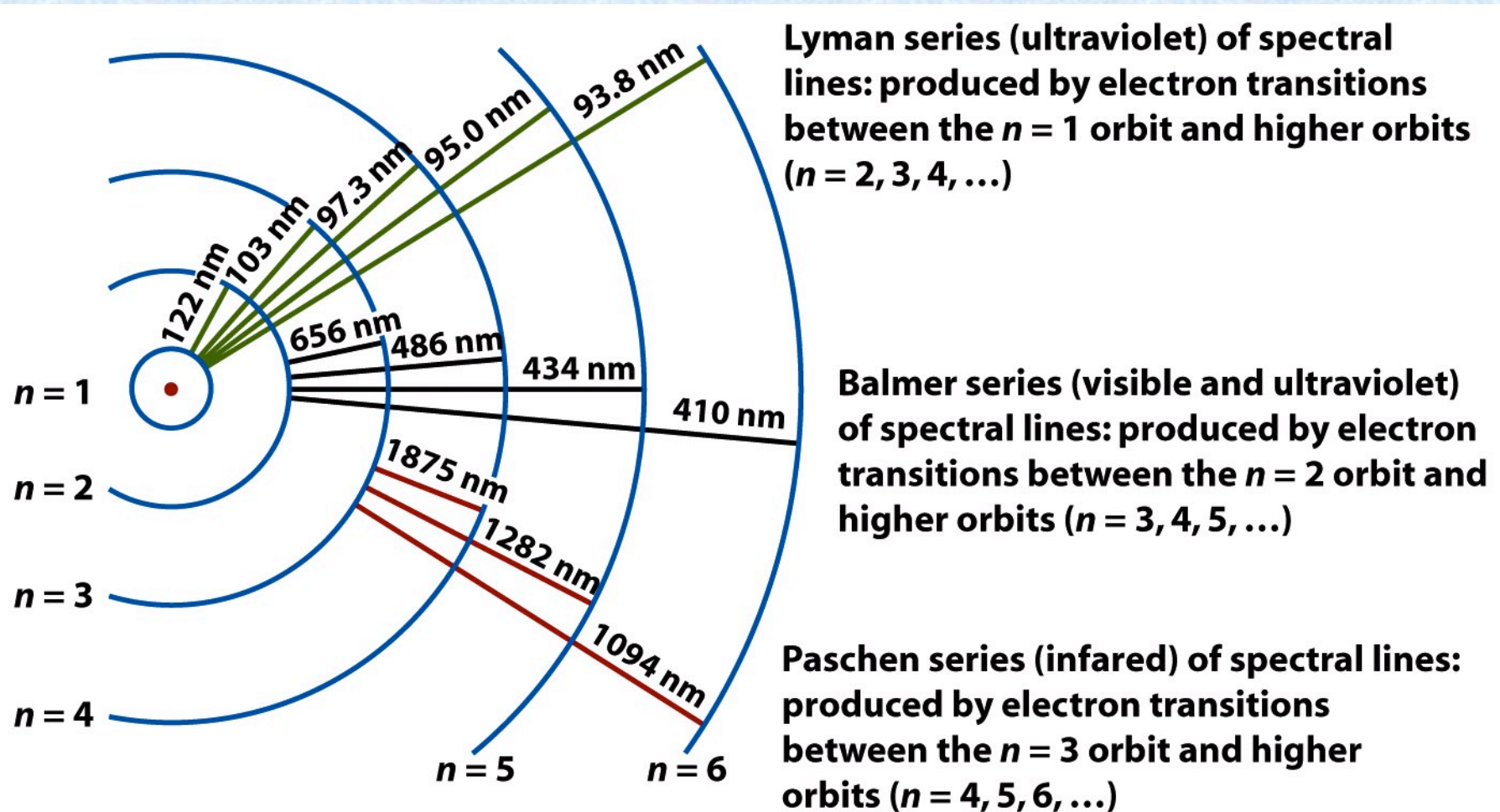


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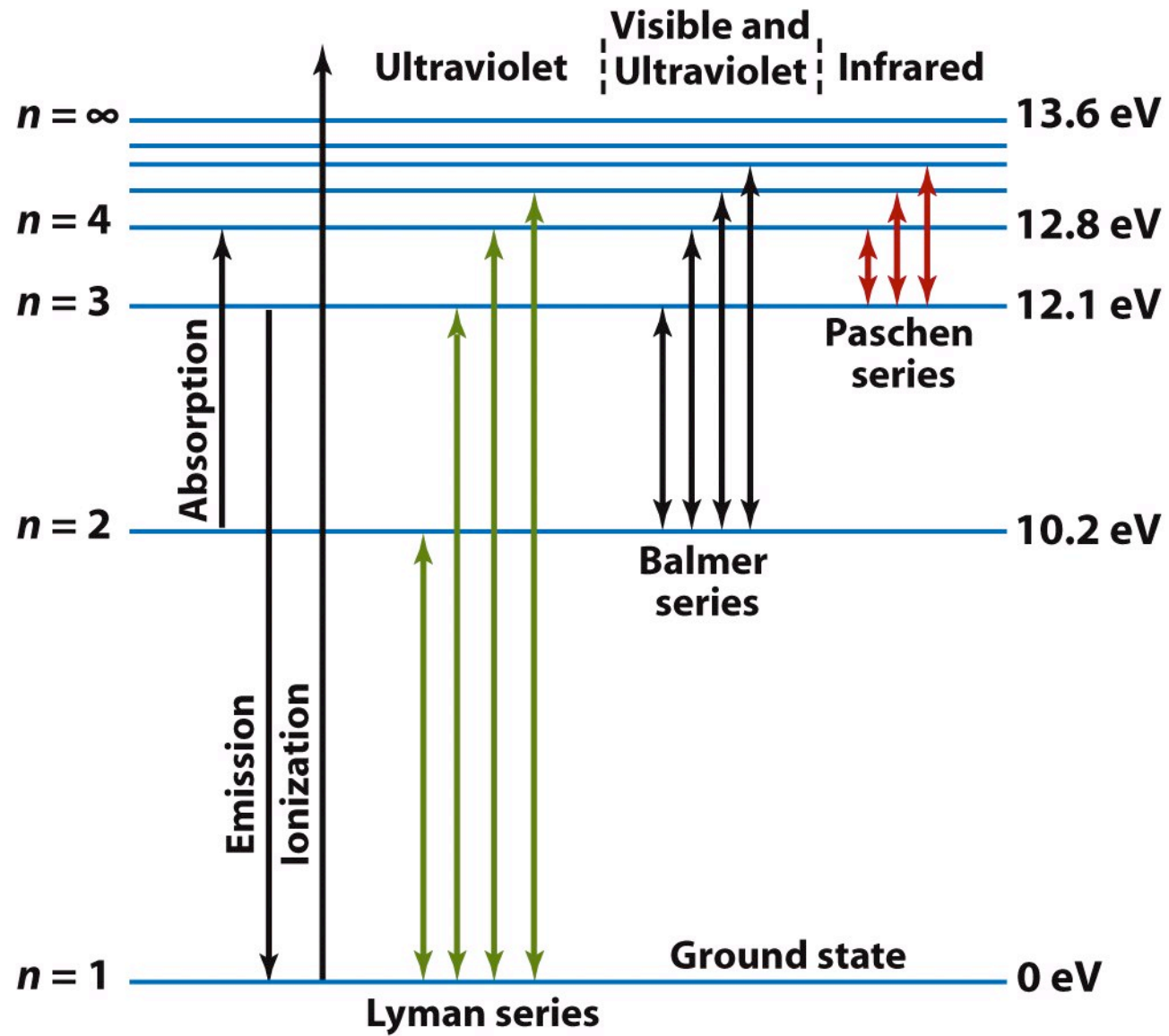


Figure 5-25
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Question 8.3 (iclickers!)

- Most of the mass of ordinary matter resides in the
 - A) electrons and nuclei, shared equally
 - B) nuclei of atoms
 - C) electron around the nuclei of atoms
 - D) energy stored within the atom in electromagnetic forces

Summary

- **What are photons?**
 - light can have particle-light properties. The particles of light are called photons: $E = h\nu = hc/\lambda$
- **Why is the sky is blue and sunsets red?**
 - Interaction between light and atmosphere
- **What are stars and interstellar gas made of?**
 - The same elements we see on Earth, mostly Hydrogen, He, Oxygen, Carbon
- **What causes spectral lines?**
 - Atomic structure

The End

See you on wednesday!