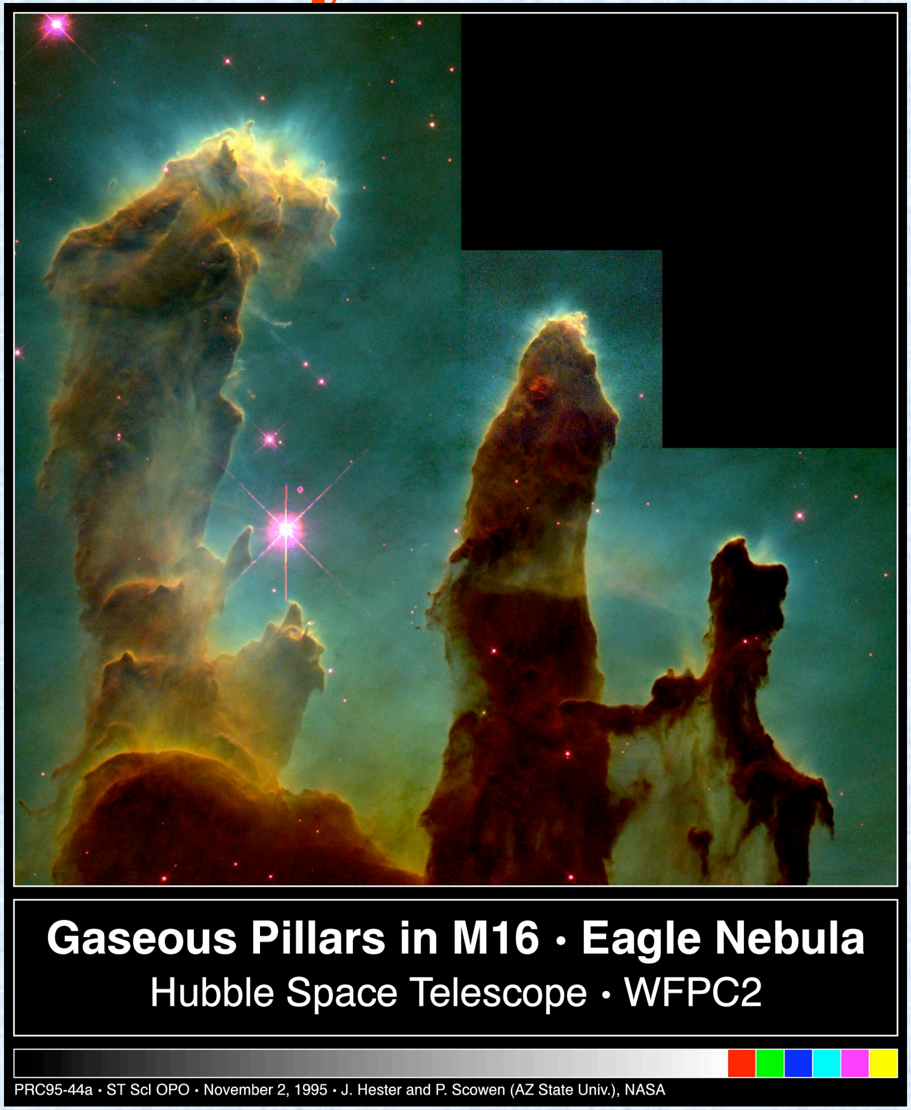
Astronomy 1 – Winter 2011



Lecture 7; January 19 2011

Previously on Astro1

- **What is light?** Light is electromagnetic radiation

Homework – Due 01/26/11

- On your own: answer all the review questions in chapter 6
- To TAs: answer questions 6.32 6.36 6.48 6.40

Today on Astro1

- Blackbodies
- Photons
- The color of the sky
- What are stars and interstellar gas made of?

Blackbody

Definition of a blackbody

- A blackbody is an idealized object that absorbs all radiation falling on it. It does not reflect light, instead it re-emits light.

- A blackbody does not have to look black! The Sun is nearly a blackbody.

- Light in thermal equilibrium

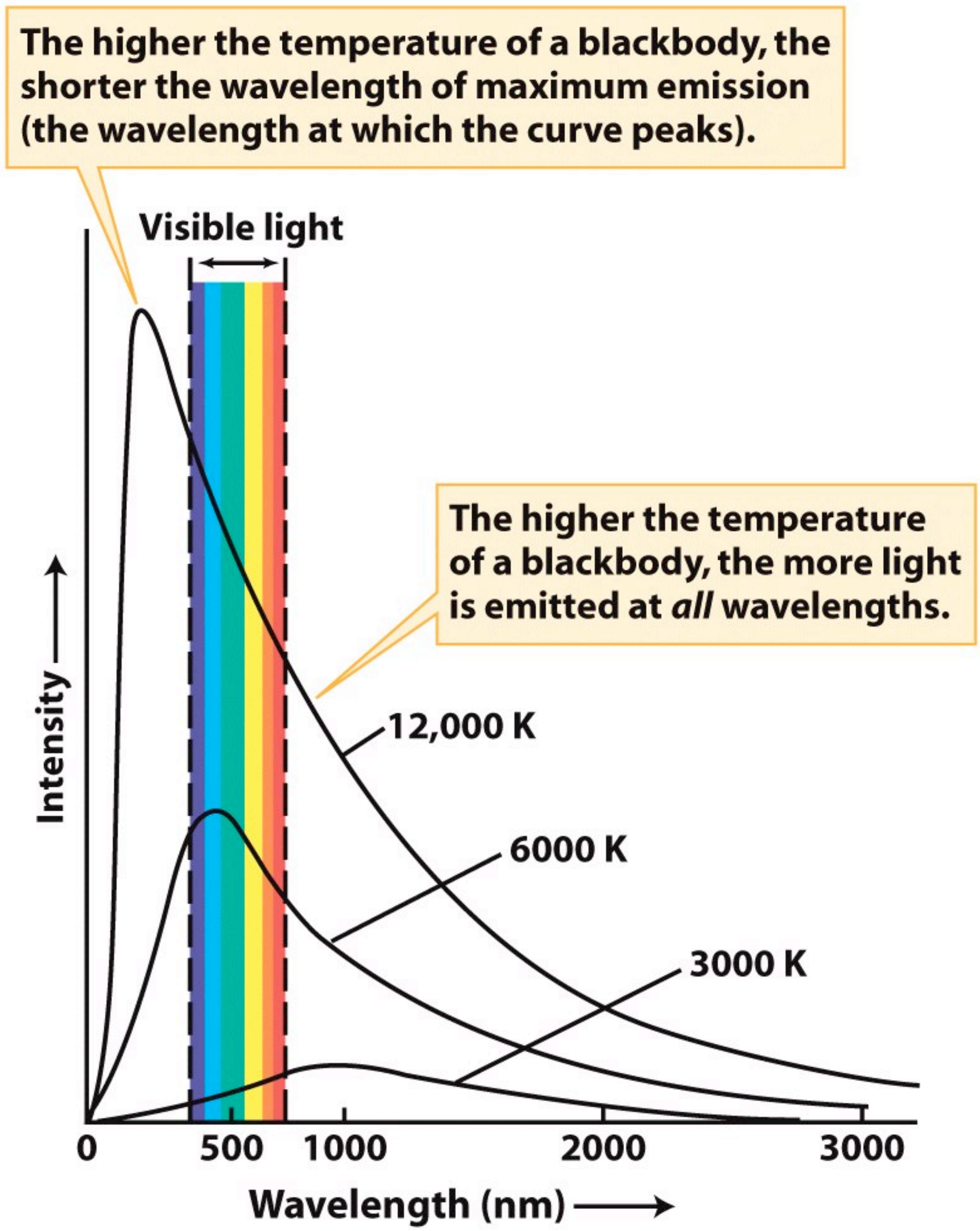


Figure 5-11
Universe, Eighth Edition

Blackbody Curves

Each curve shows the intensity of light at every wavelength that is emitted by a blackbody at a particular temperature. The rainbow-colored band shows the range of visible wavelengths. The vertical scale has been compressed so that all three curves can be seen; the peak intensity for the 12,000 K curve is actually about 1000 times greater than the peak intensity for the 3000 K curve.

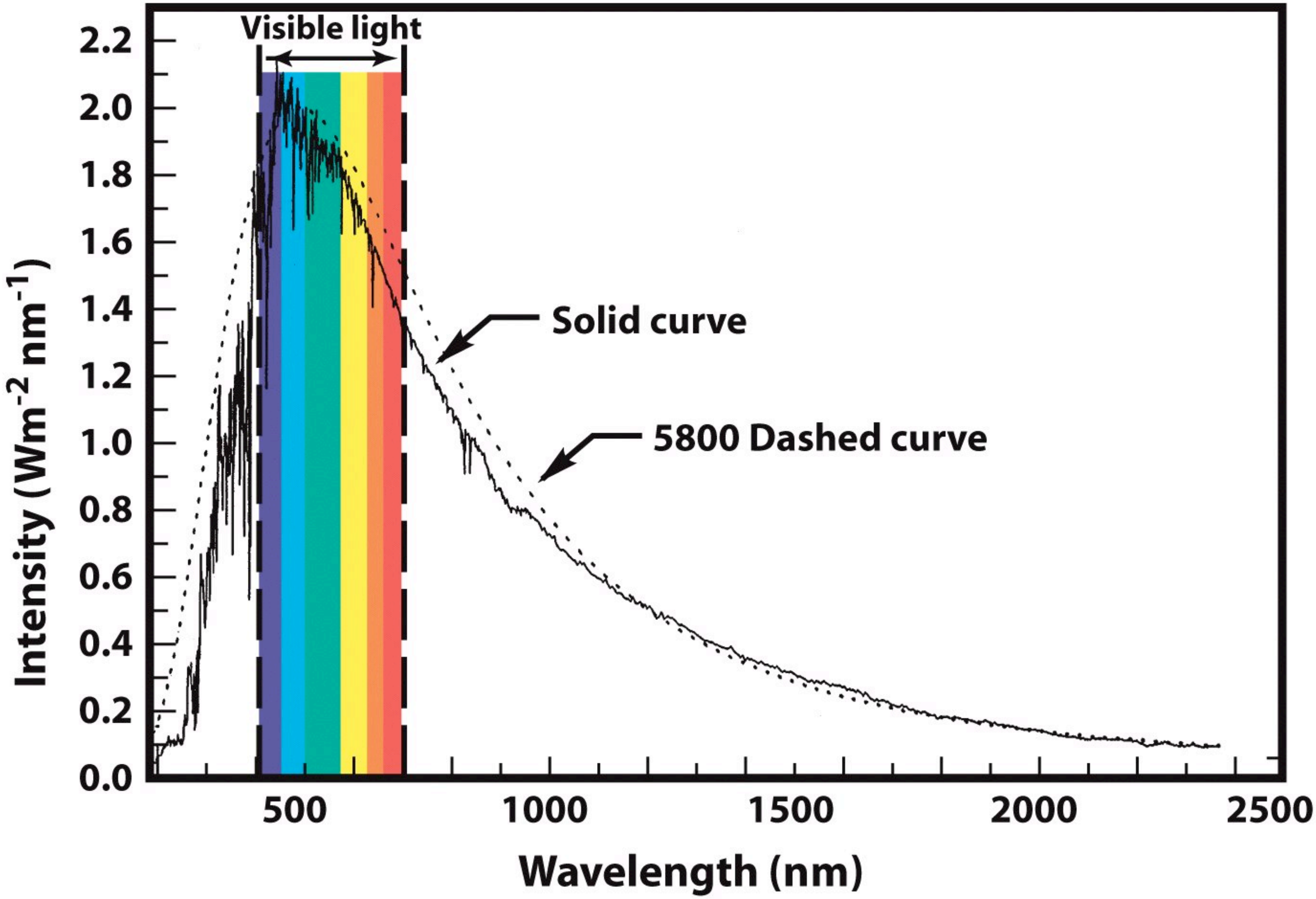


Figure 5-12
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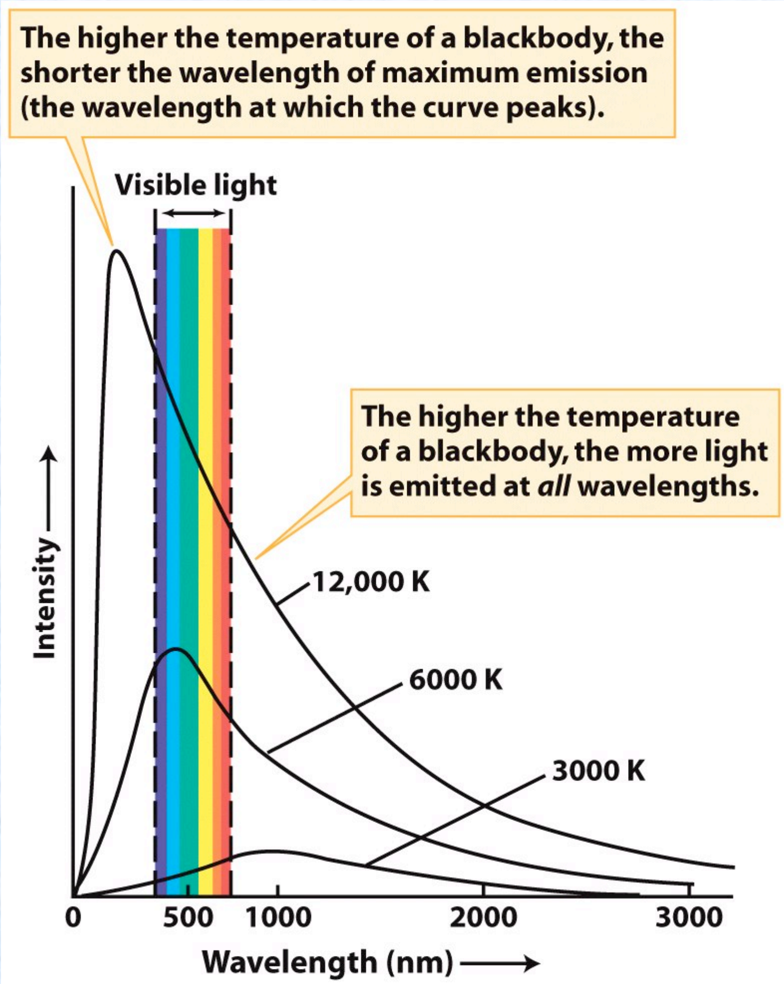

Figure 5-11
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Wien's Law for a blackbody

$$\lambda_{\max} = \frac{0.0029Km}{T}$$

λ_{max} = wavelength of maximum emission of the object (in meters)

T = temperature of the object (in Kelvins).

(The K and m above are units of Kelvins and meters).

Example: At which peak wavelength do people radiate?

Human temperature in K = 273+37 = 310K

$$\lambda_{\max} = \frac{0.0029Km}{310K} = 9.4 \times 10^{-6} m = 9400nm$$

This is in the infrared!

Figure 5-10
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An Infrared Portrait

In this image made with a camera sensitive to infrared radiation, the different colors represent regions of different temperature. Red areas (like the man's face) are the warmest and emit the most infrared light, while blue-green areas (including the man's hands and hair) are at the lowest temperatures and emit the least radiation.

Energy flux

Energy is usually measured in Joules (J).

One joule per second is a Watt (W) – a measure of power.

Flux is the amount of energy per second passing through one square meter.

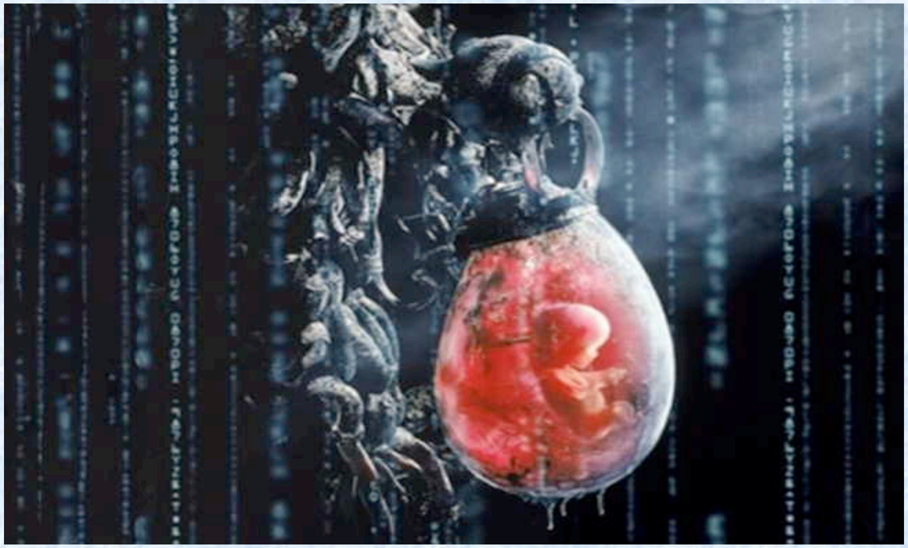
The Stefan-Boltzmann Law gives the flux of a blackbody of a given temperature.

$F = \sigma T^4$

σ (a constant)= 5.67×10^{-8} W m^{-2} K^{-4}

T = Temperature in Kelvins

In the movie *The Matrix* – people are used as batteries. If the average human's bodily surface area is 1.7 m^2, and has an average temperature of 37°C, how much energy per second (power) does a person radiate?



Answer. Treating a person as a blackbody, use the Stefan-Boltzmann law to determine the energy radiated per second per square meter, then multiply by the body's surface area to get the energy radiated per second.

Human temperature in K = 273+37 = 310K

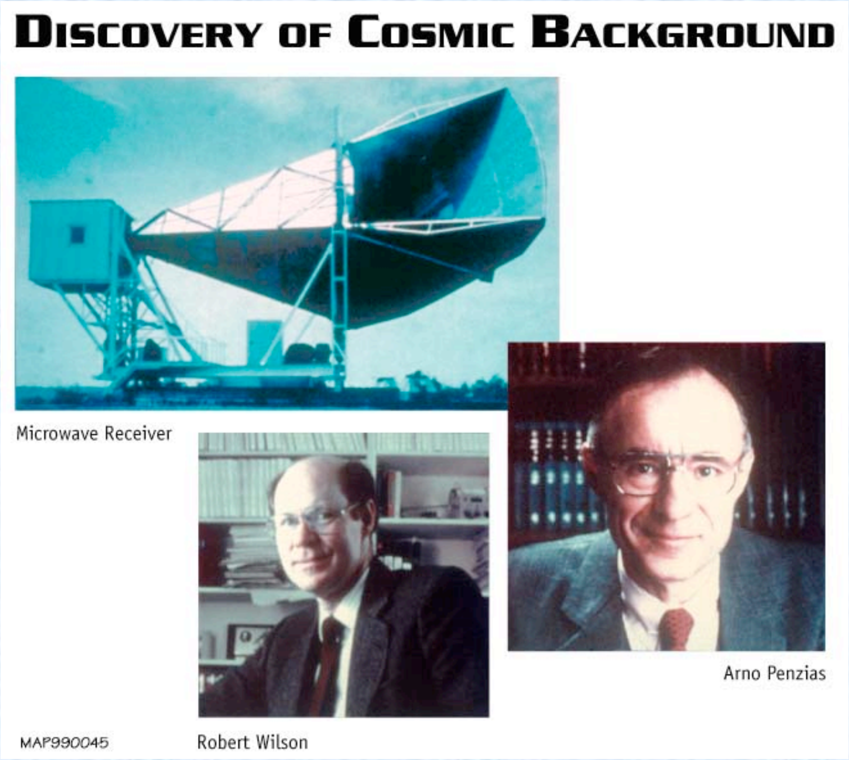
$F = \sigma T^4 = (5.67\times10^{-8}\ W\ m^{-2}\ K^{-4})(310\ K)^4 = 524\ W\ m^{-2}$

Power = $524\ W\ m^{-2}\ (1.7 m^2) = 891\ W$

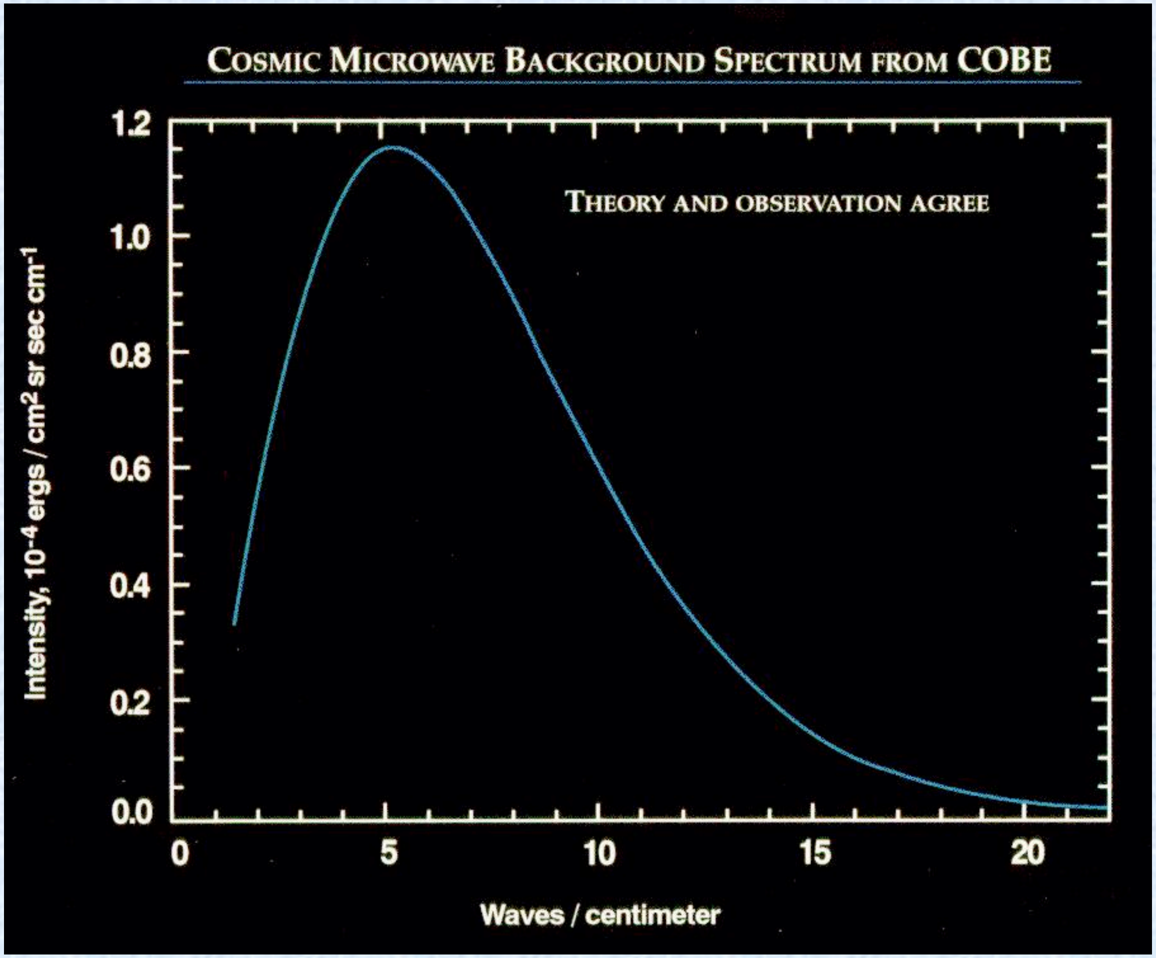
About the power of a toaster!

A very important blackbody: Cosmic Microwave Background

- The cosmic microwave background was discovered as a background “noise” a real problem for telecommunication satellites
- Wherever Penzias and Wilson pointed their antenna they would detect a microwave signal, very uniform across the sky
- This signal is now called the cosmic microwave background…



Cosmic Microwave Background.
The CMB is a "perfect" Blackbody



COBE FIRAS 1989; T=2.725 K

Question 7.1 (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

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

E = Energy of a photon
h = Planck's constant = 6.625×10^{-34} J s
c = speed of light
λ = wavelength of light
ν = frequency of light

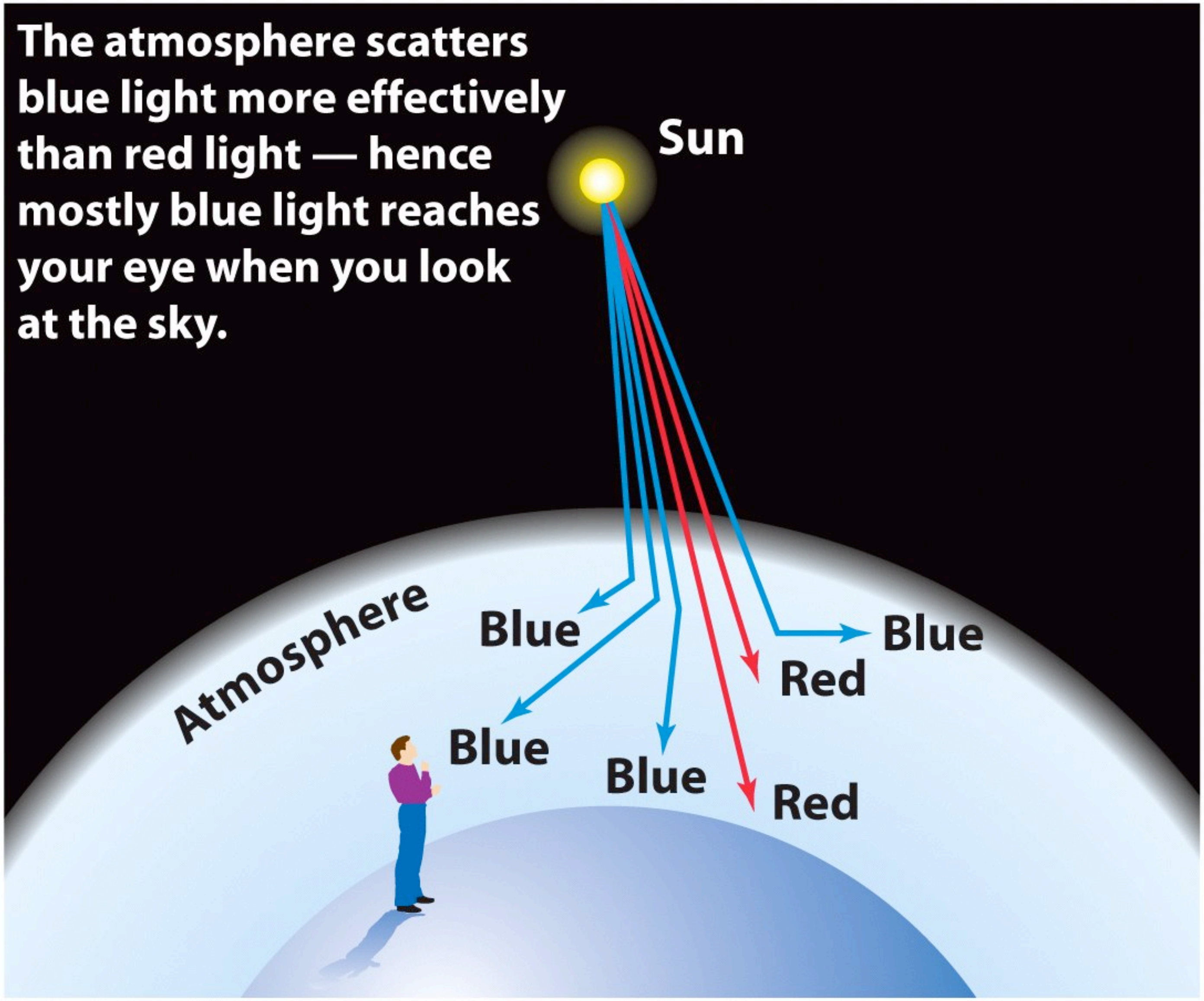
Example: DNA molecules are easily broken when hit with ultraviolet light at 260 nm (why you get cancer from sunburns). How much energy does a single photon at this wavelength have?

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

Question 7.2 (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?



Why the sky looks blue

Box 5-4a
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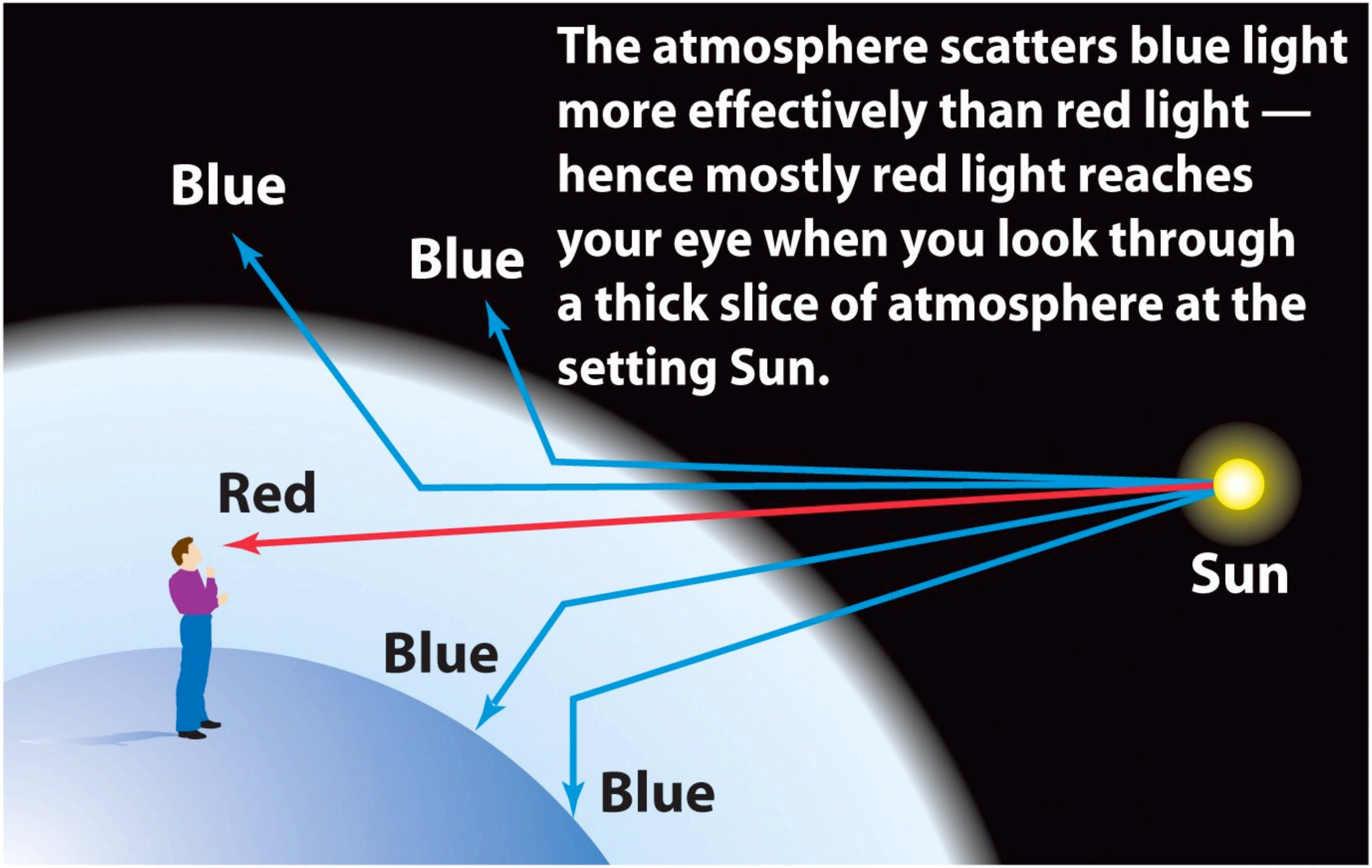

Why the setting Sun looks red

Box 5-4b
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Spectra as the “fingerprints” of nature

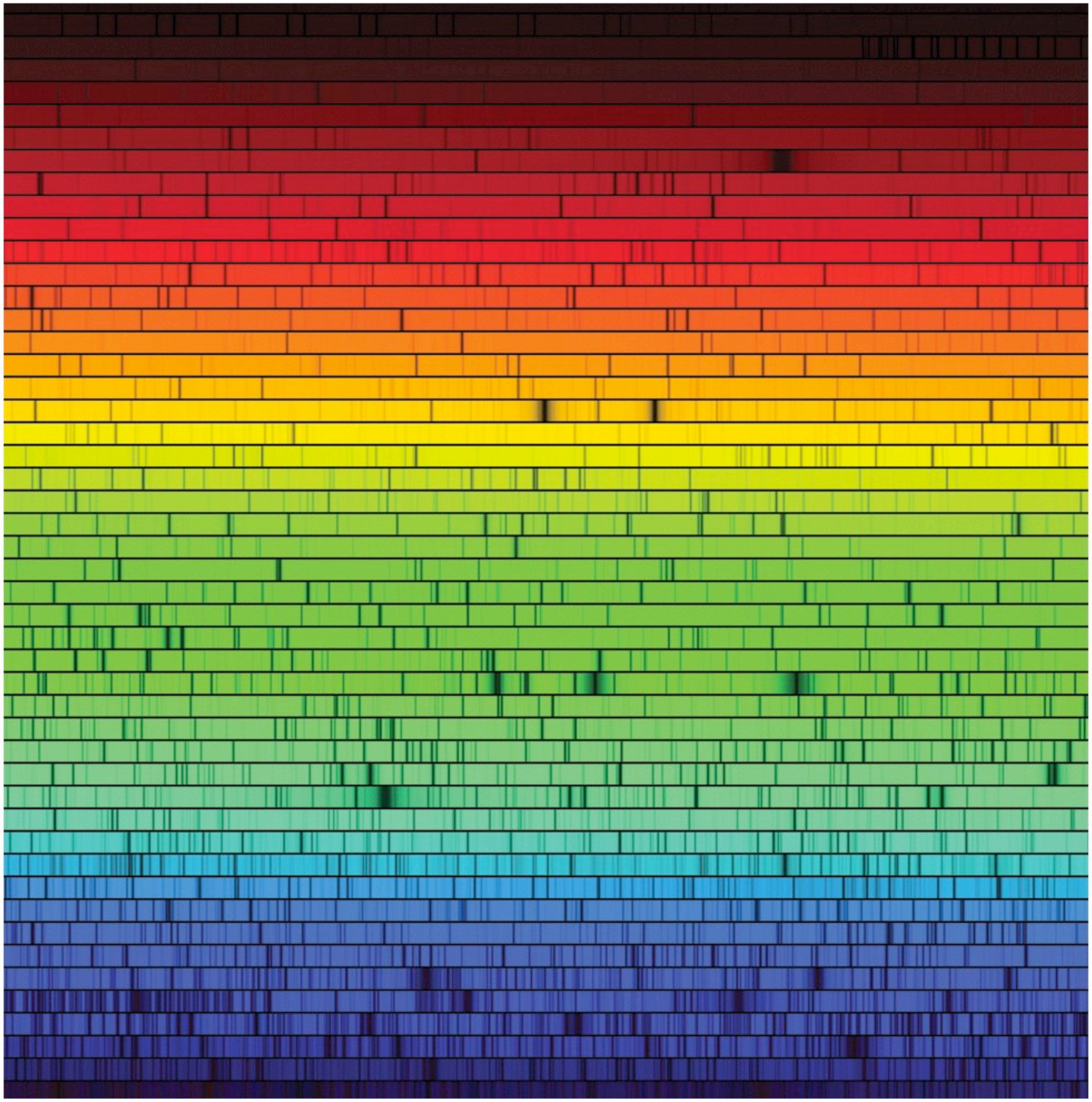

Figure 5-13
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The Sun's Spectrum

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

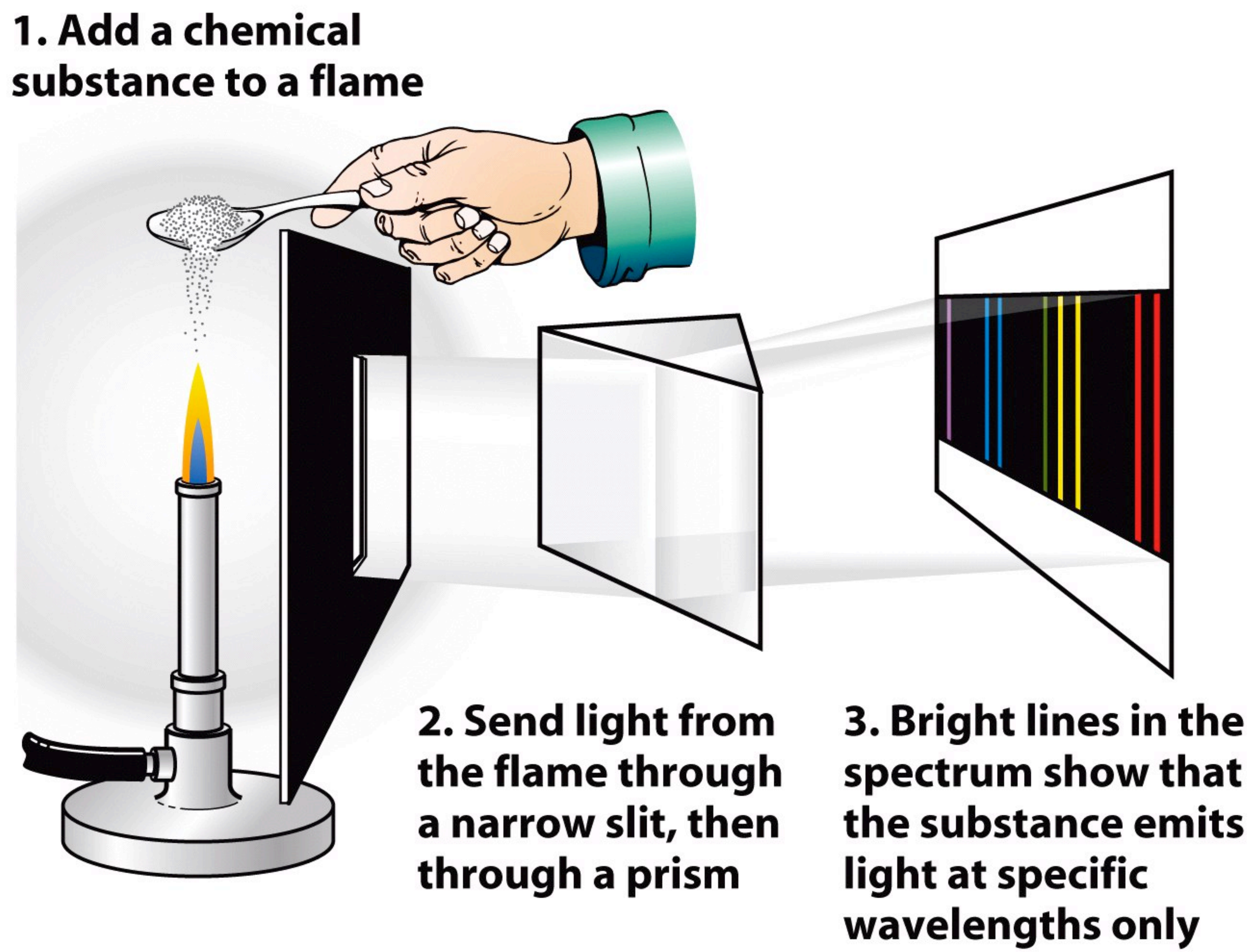

Figure 5-14
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Kirchoff’s Laws

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.

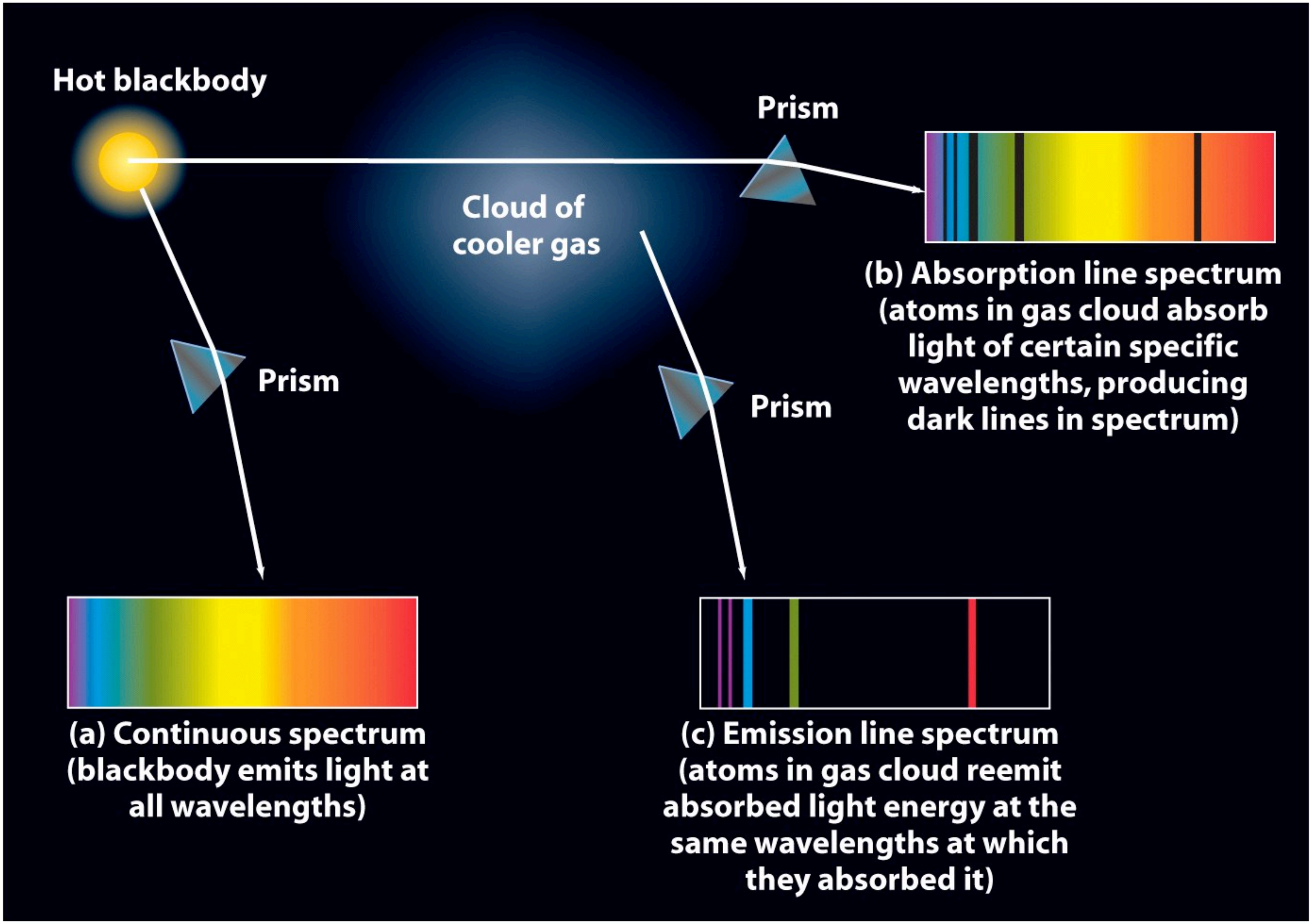

Figure 5-16
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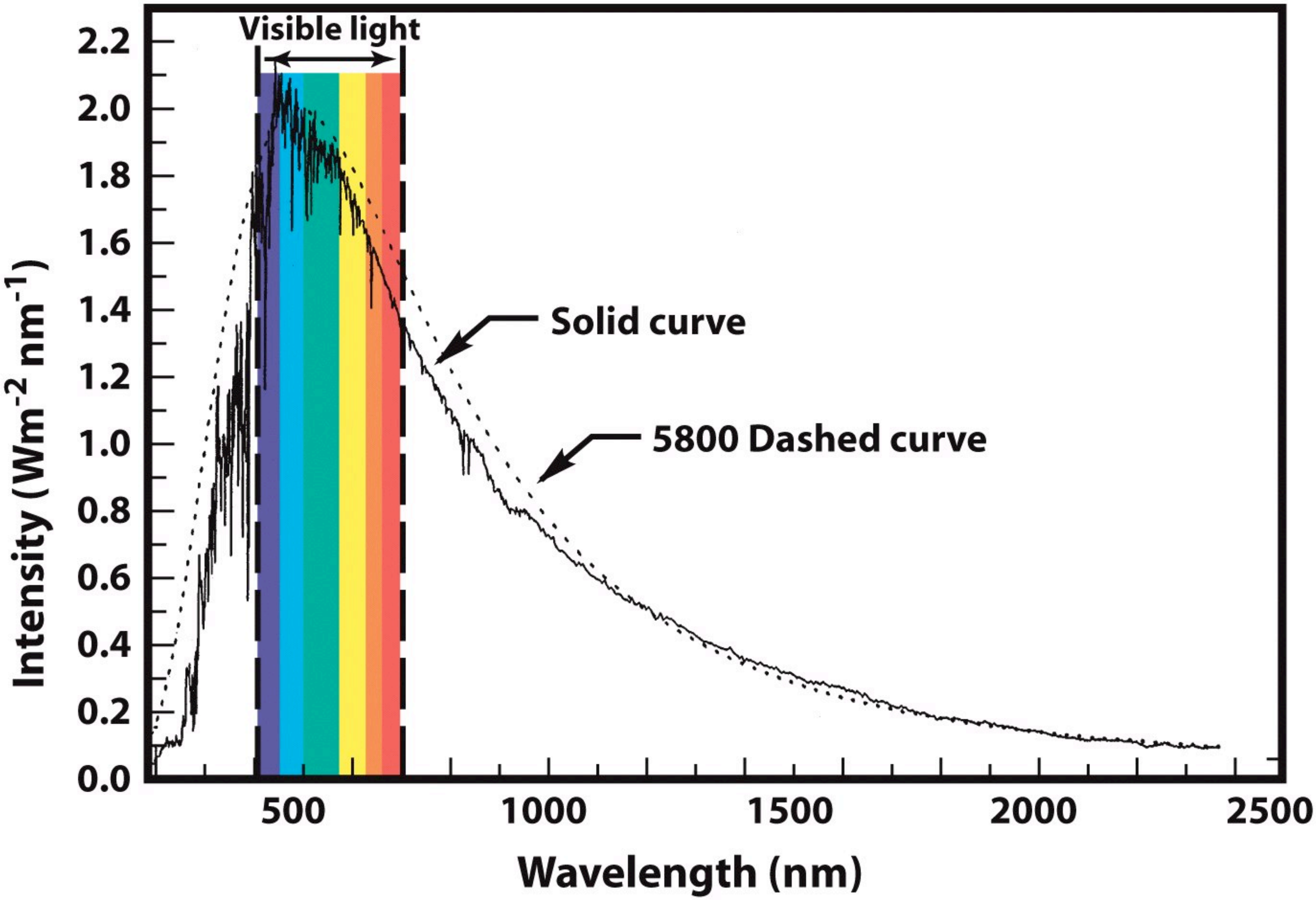

Figure 5-12
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The energy output of the sun.

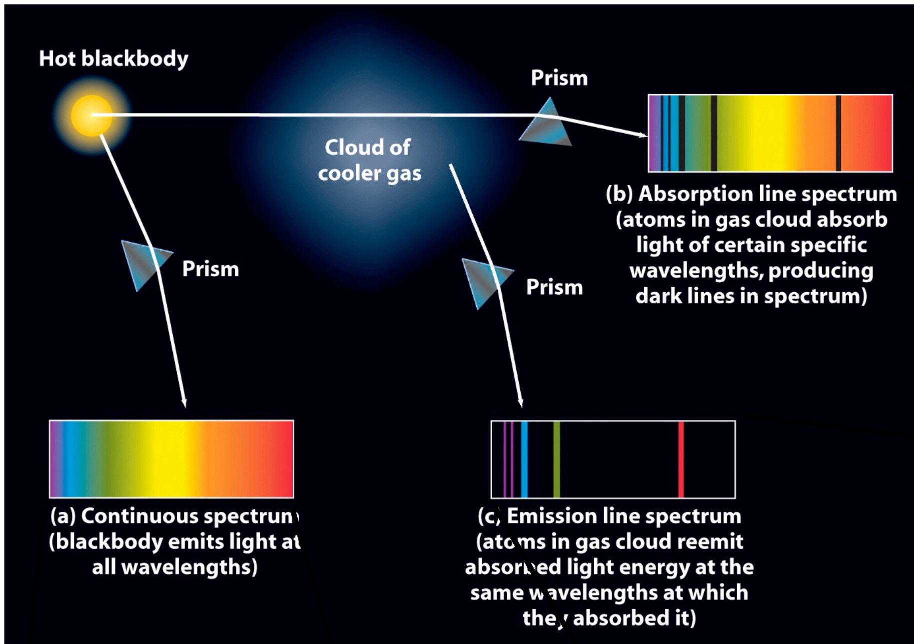

Figure 5-16
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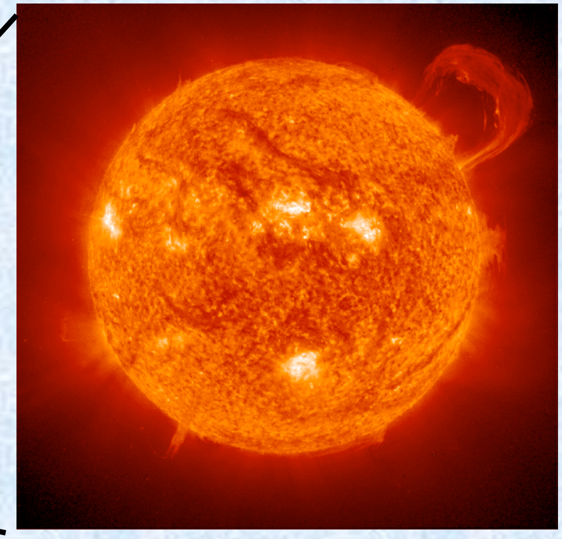

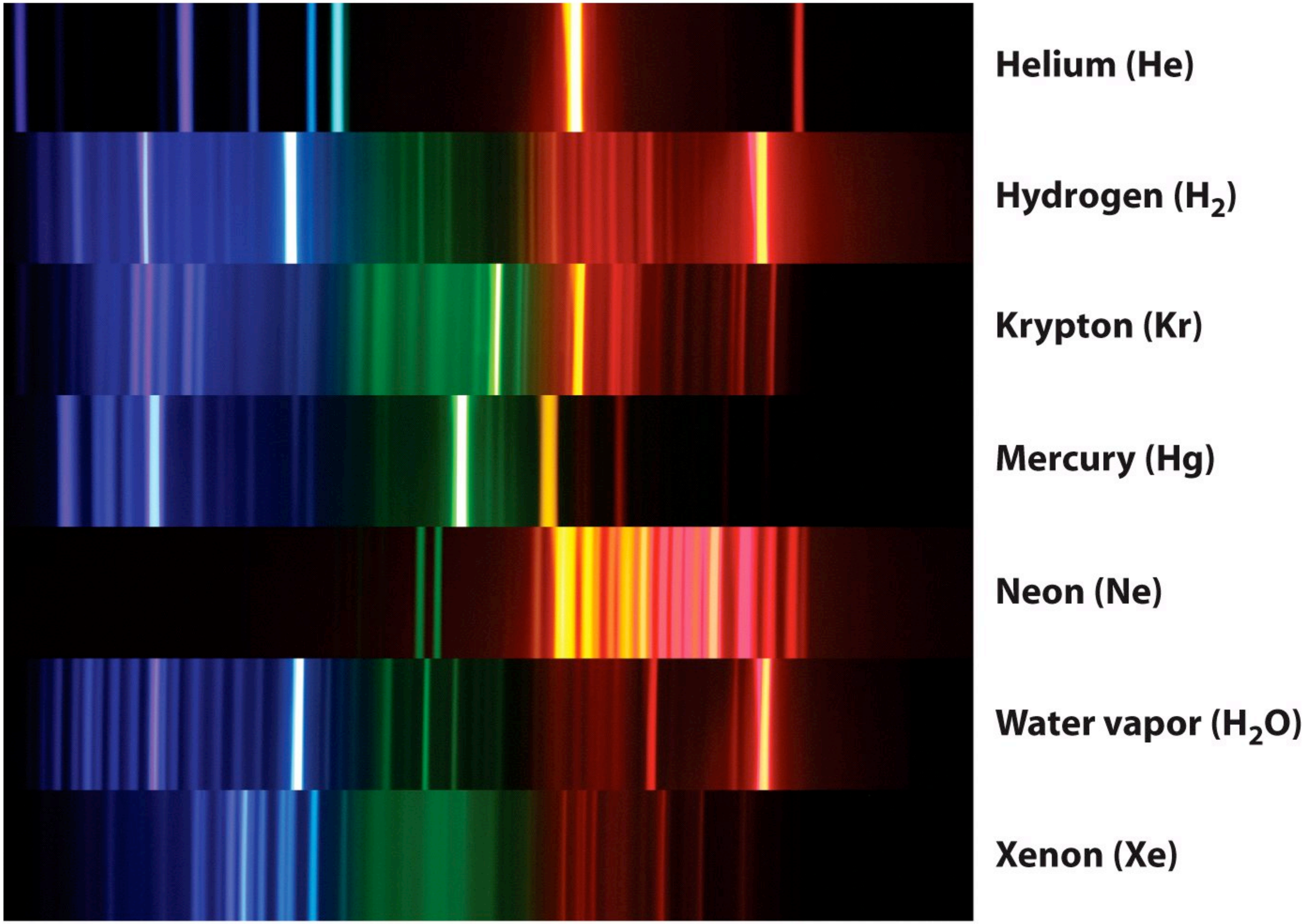

Figure 5-15
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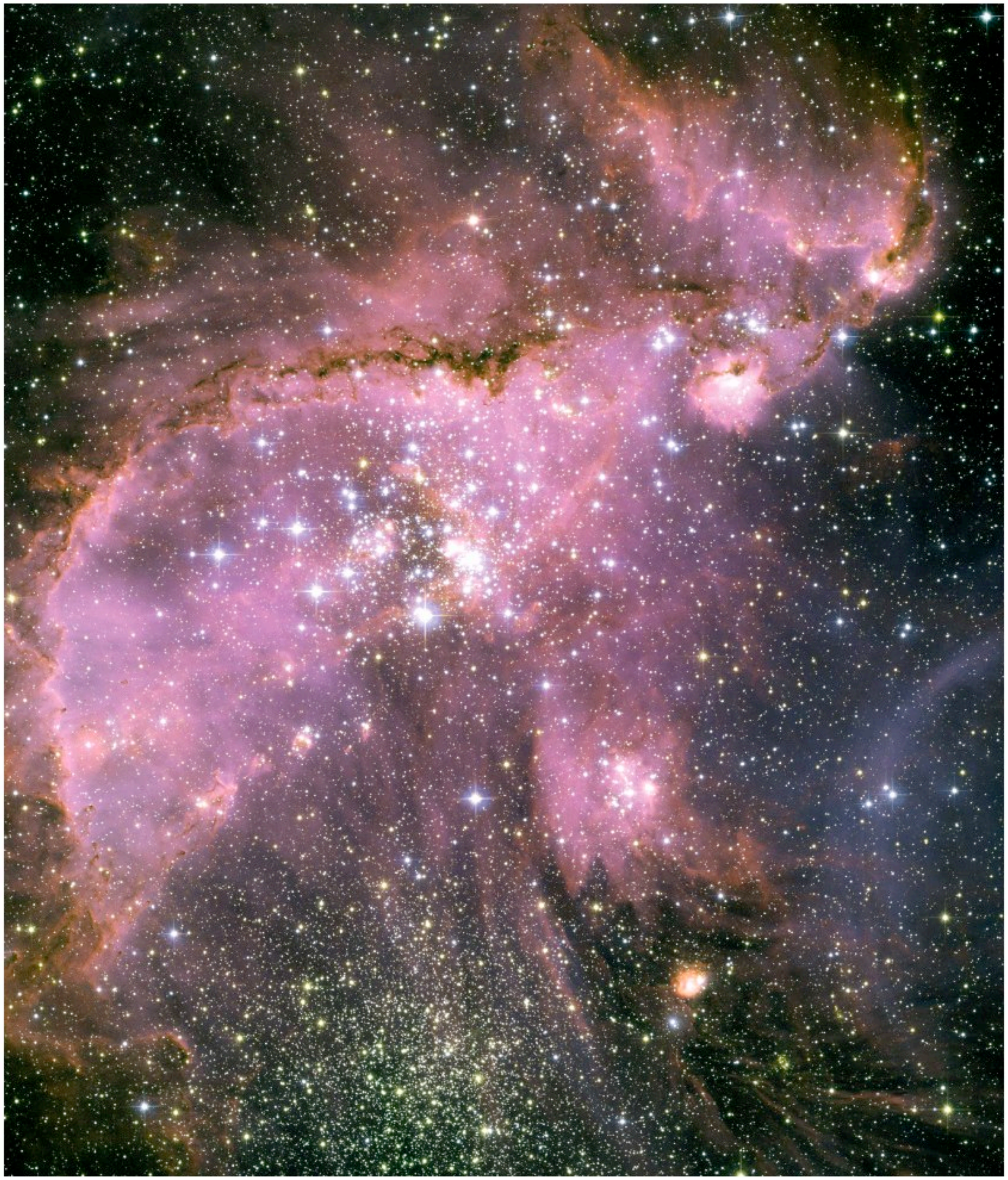

Figure 5-18
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The glowing gas cloud in this Hubble Space Telescope image lies 210,000 light-years away in the constellation Tucana (the Toucan). Hot stars within the nebula emit high-energy, ultraviolet photons, which are absorbed by the surrounding 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

The Ring Nebula is a shell of glowing gases surrounding a dying star. The spectrum of the emitted light reveals which gases are present.

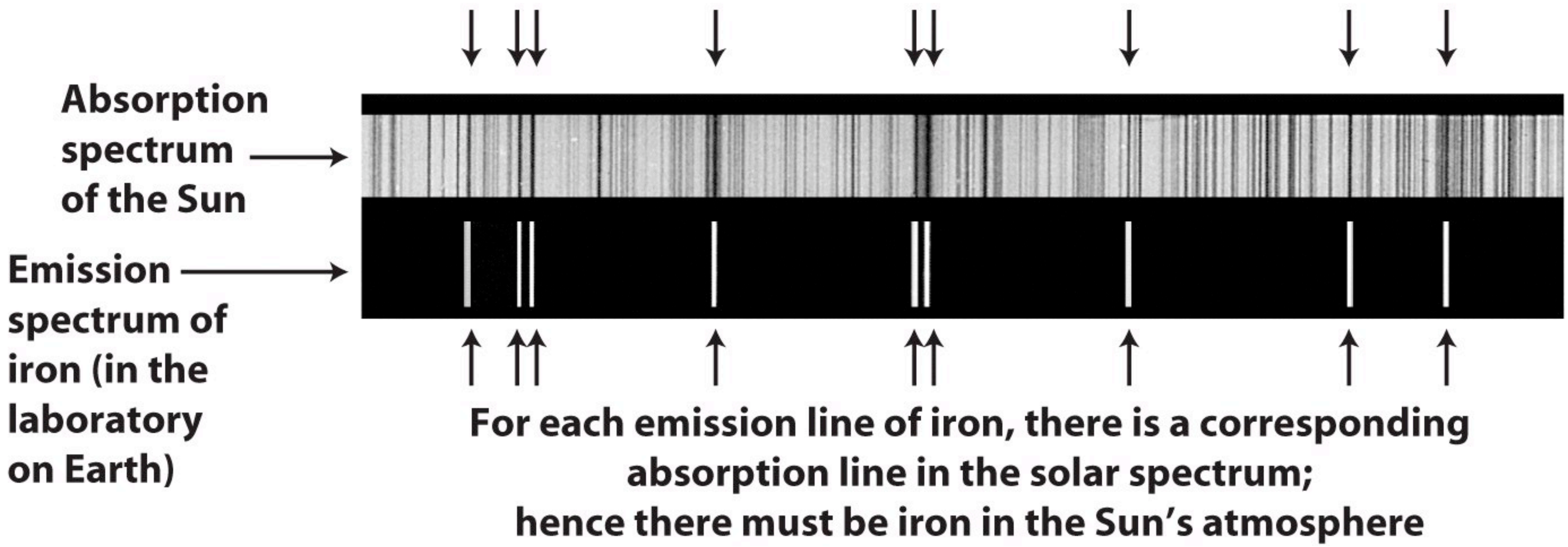

Figure 5-17
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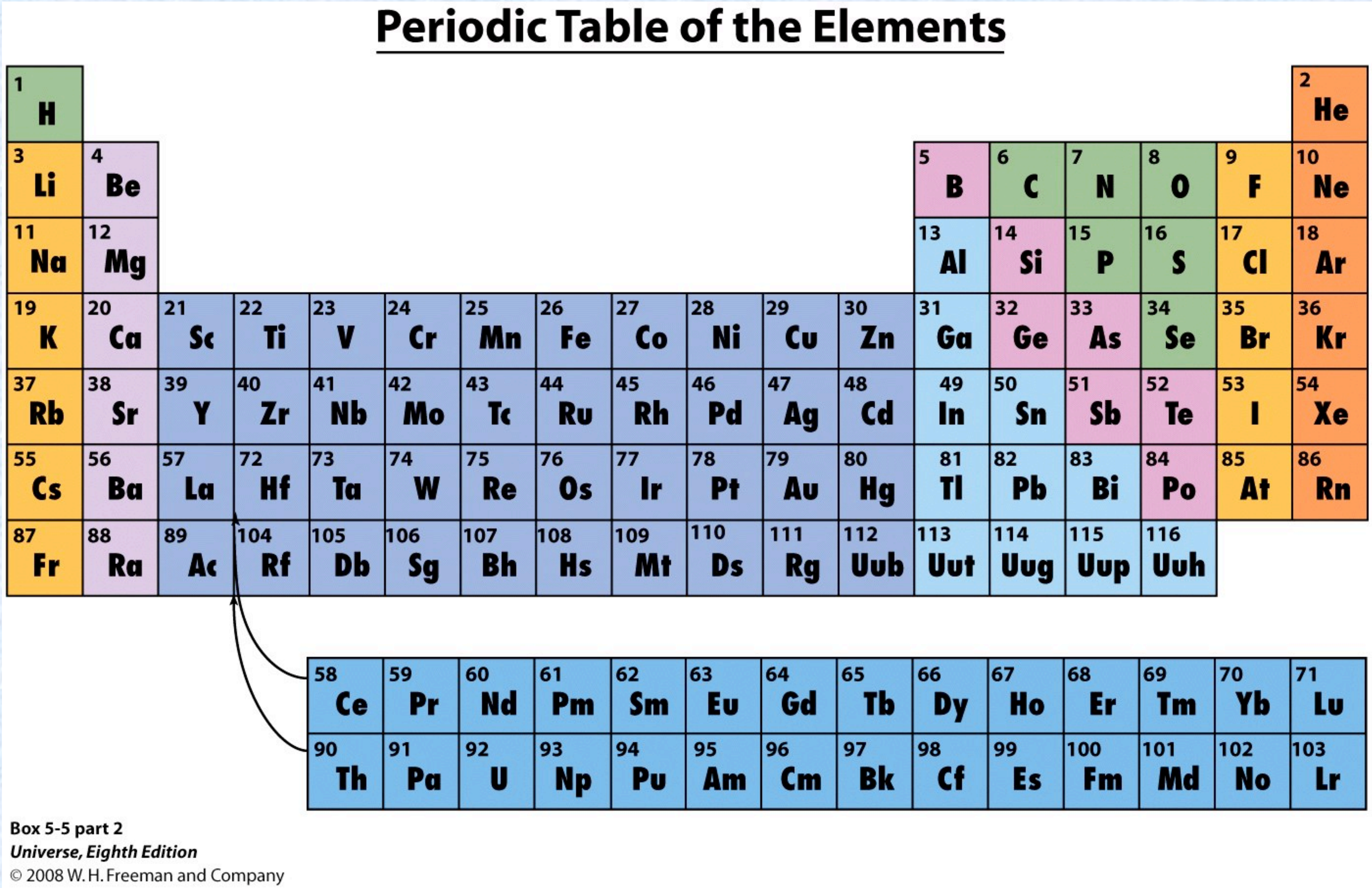

Atomic number is the number of protons in an atom.

Question 7.3 (iclickers!)

- If light from a hot, dense star is viewed through a cool cloud of gas,
  - A) the spectrum of the star will be seen unchanged because the gas cloud is cool
  - B) only specific wavelengths of light will be removed from the spectrum
  - C) the whole spectrum will be reduced in intensity
  - D) the atoms of the gas cloud will add energy to the overall spectrum, producing emission at specific wavelengths

Summary

- **What is a blackbody?**
  - **Wien's law**: λ_{max} (in meters) = (0.0029 K·m)/T.
  - The **Stefan-Boltzmann law**: $F = \sigma T^4$.
- **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
- **Kierchoff's Laws**
- **What are stars and interstellar gas made of?**
  - The same elements we see on Earth, mostly Hydrogen, He, Oxygen, Carbon

The End

See you on Friday (midterm)!