Announcements

- Quiz 3 due tonight
- Quiz 4 covers Chapters 2 & 3, due next Monday
- Problem set 4 is practice for Quiz 4
- Stargazing Wednesday Feb 12 8:00-9:00 pm
- First midterm is Wednesday Feb 19
  - Will cover lectures through today (Lectures 1-8)
  - Textbook up to Chapter 2
  - Problems will be similar to those on quizzes
    - Problems on material through Chapter 2 – includes parts of quiz 4
  - No book, notes or calculator
    - Sheet of formulas will be given
    - Calculations will be doable without a calculator
  - Review in class on Monday Feb 17

Light and Matter

Please read Chapter 2

Today we will cover sections 2.4 to 2.8

Temperature

Temperature is a measure of how fast atoms or molecules are moving.

Hot – atoms moving fast

Cold – atoms moving slowly

When atoms stop moving – lowest possible temperature.

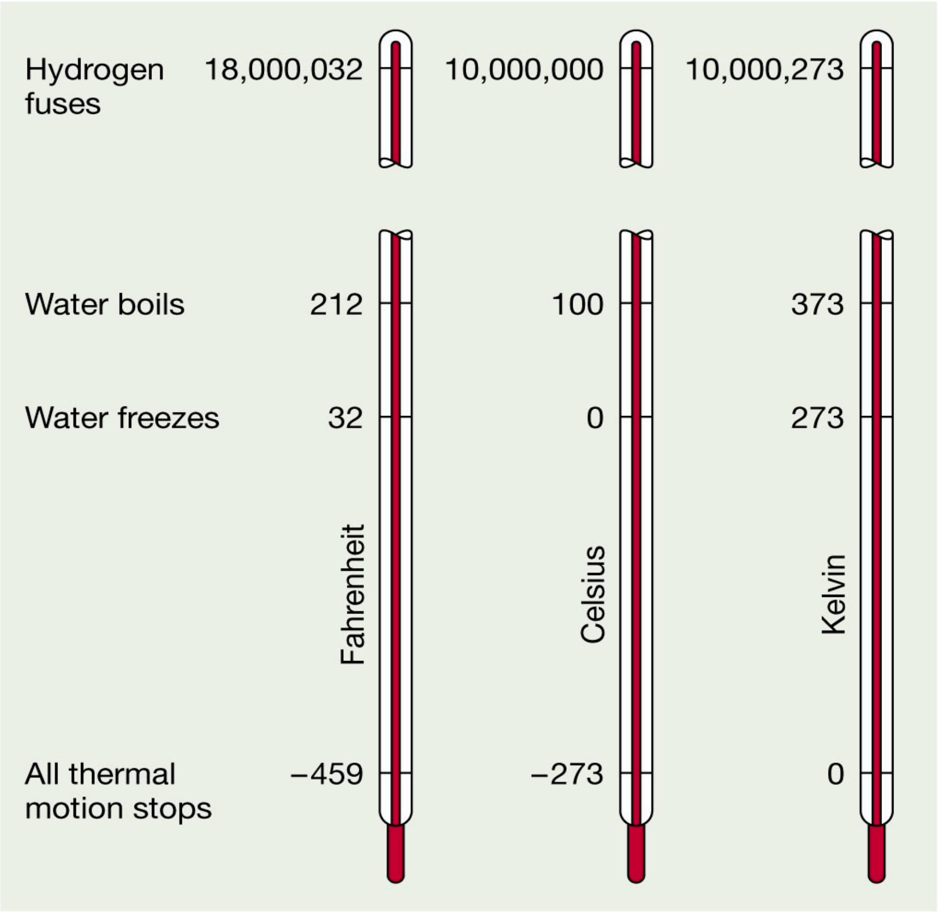
This lowest temperature is called **absolute zero**, which is -273°C (-459°F).

You are familiar with the Fahrenheit and Celsius temperature scales.

A third temperature scale, the Kelvin scale, is designed to be identical to the Celsius scale, except that 0 K is the lowest possible temperature, *absolute zero.*

degrees Kelvin =
degrees Celsius + 273

$T_K = T_C + 273.$

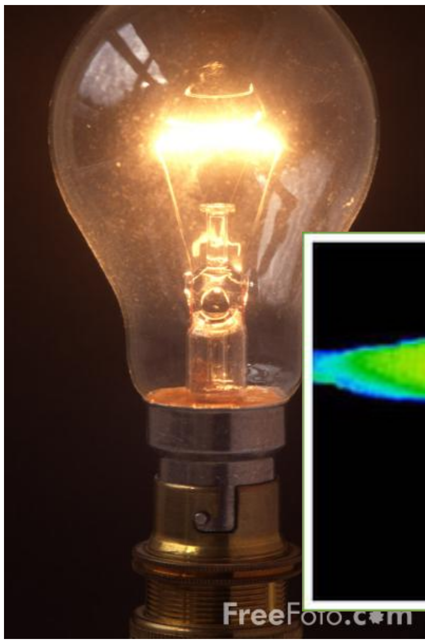


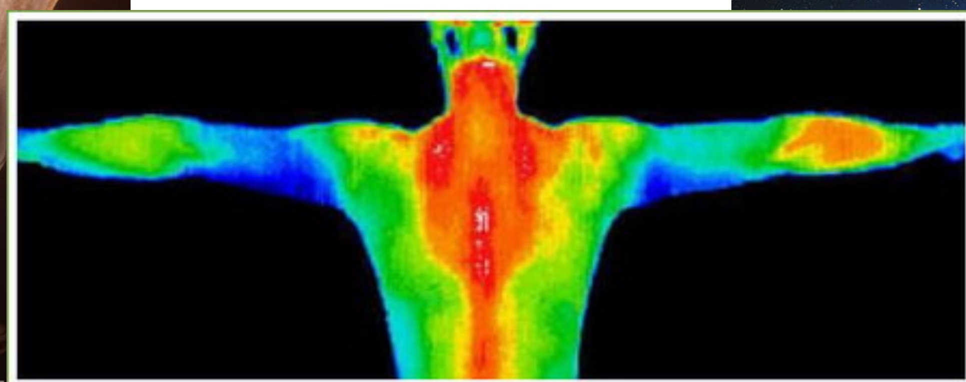
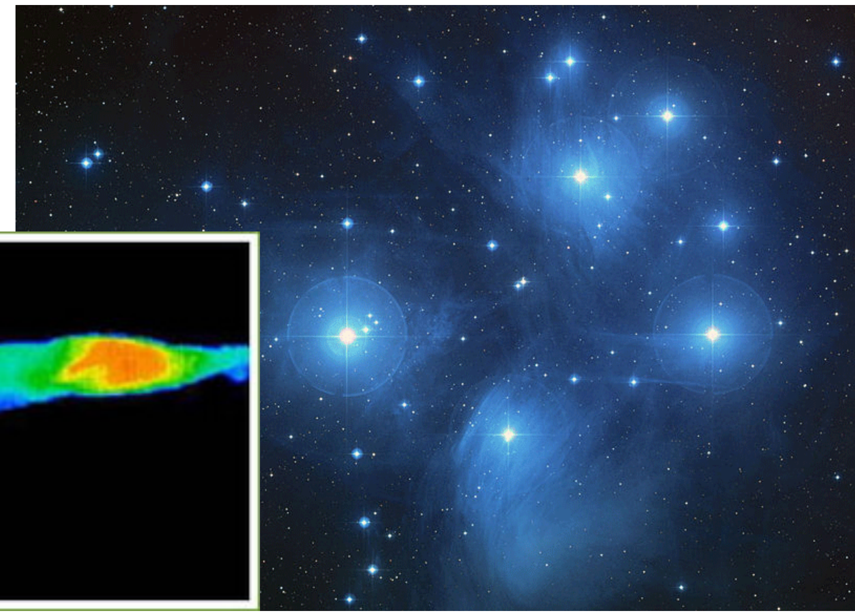
Centers of stars

Molecular clouds where stars form

Thermal radiation:
The continuous blackbody spectrum

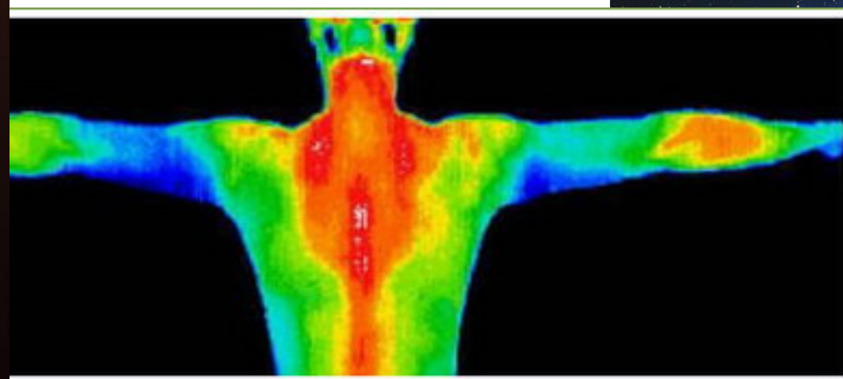
All objects with some temperature emit electromagnetic (EM) radiation – light

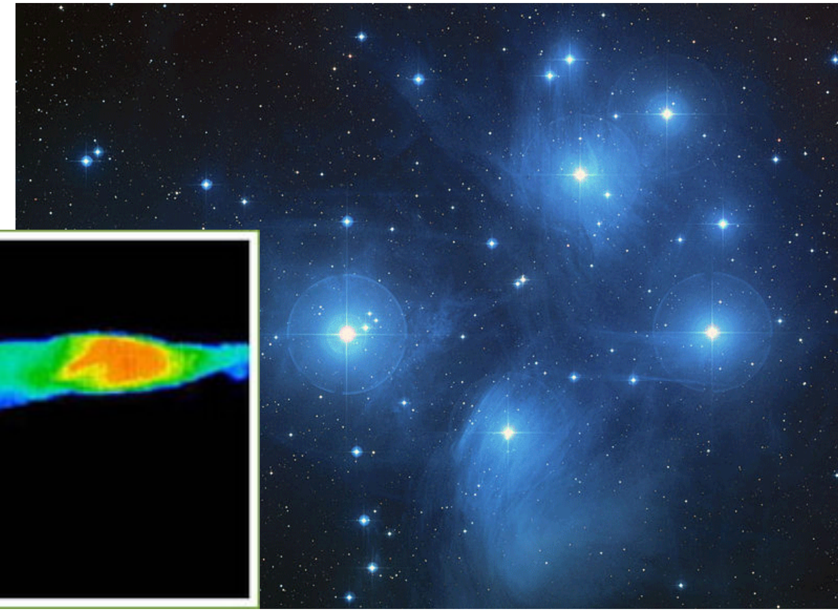


If you break up this radiation, you find some radiation at all wavelengths – it is continuous. So this is called a **continuous spectrum**

These three objects emit different radiation because they are at different temperatures





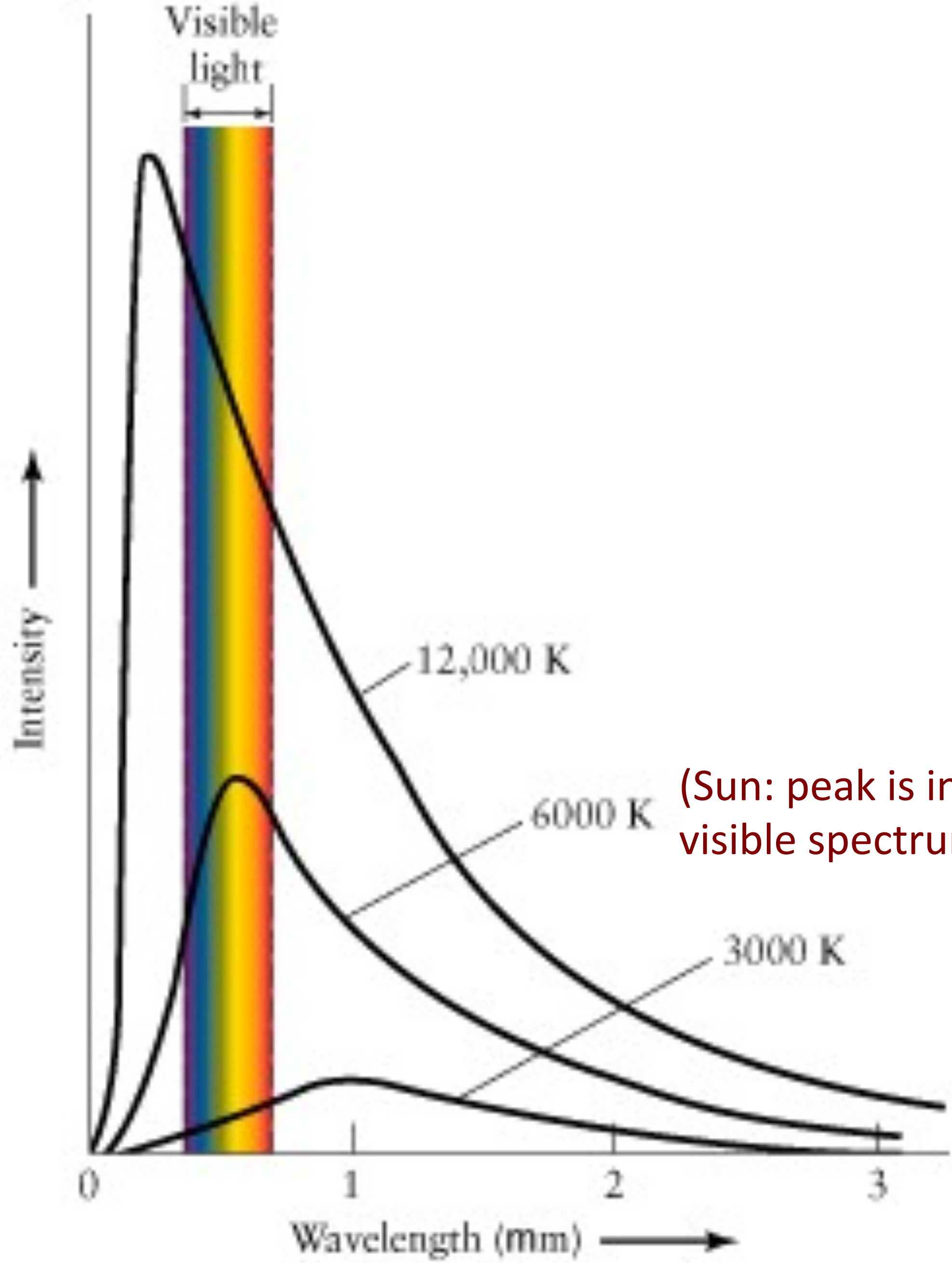
~ 2000 K   310 K   5000 K

- The **hotter** an object is, the **brighter** it is (the more energy it emits per second).
- The **hotter** an object is the **shorter the average wavelength** of the light it emits
- Examples: a light bulb emits visible light, humans emit infrared light

(Note: We're talking about traditional incandescent light bulbs, not the modern fluorescent kind! Fluorescent light bulbs emit another kind of radiation we'll talk about later.)

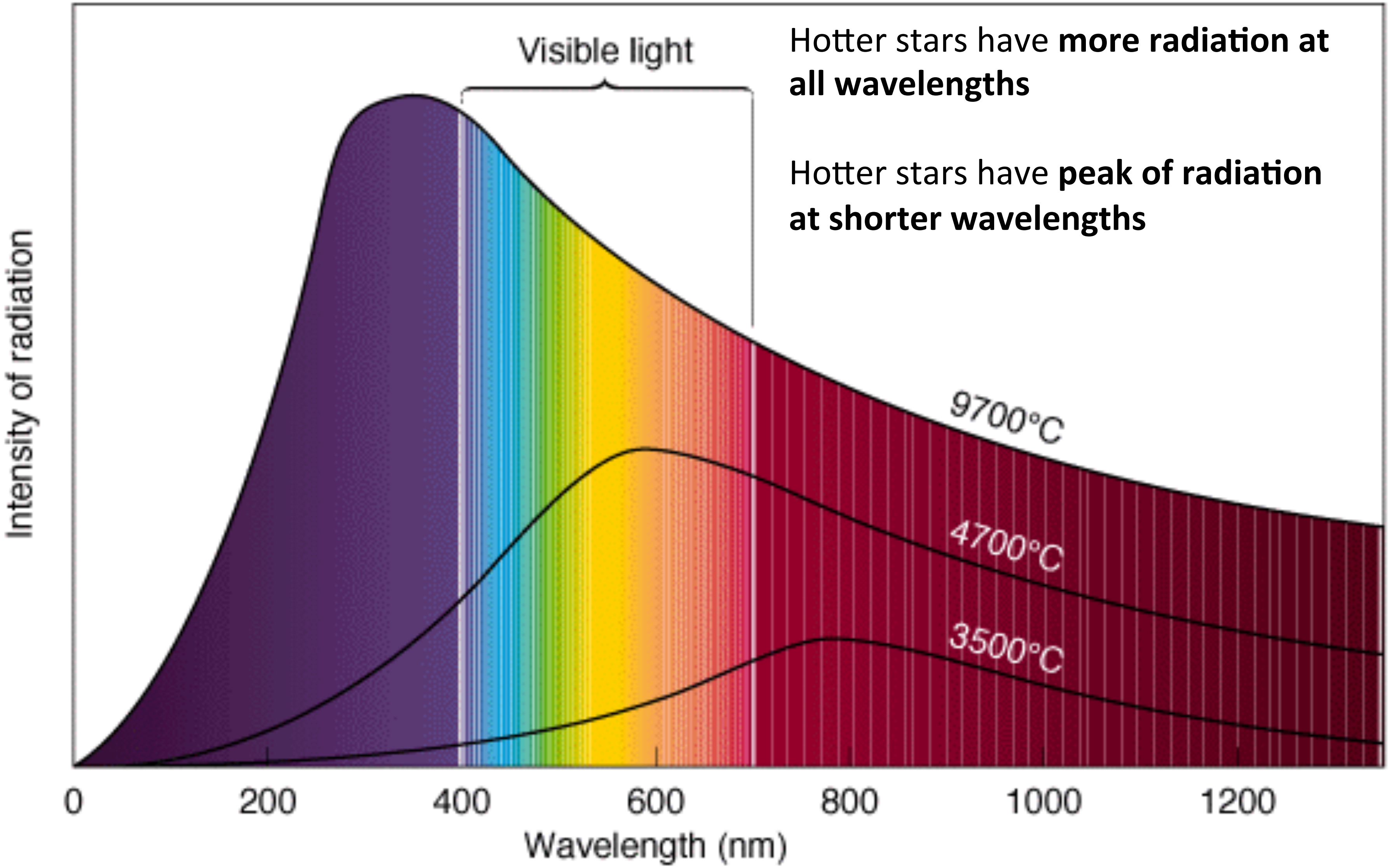
The peak intensity of light emitted by a star (or other hot object) depends on the temperature of the star.

Hotter objects are brighter and have shorter peak wavelengths.



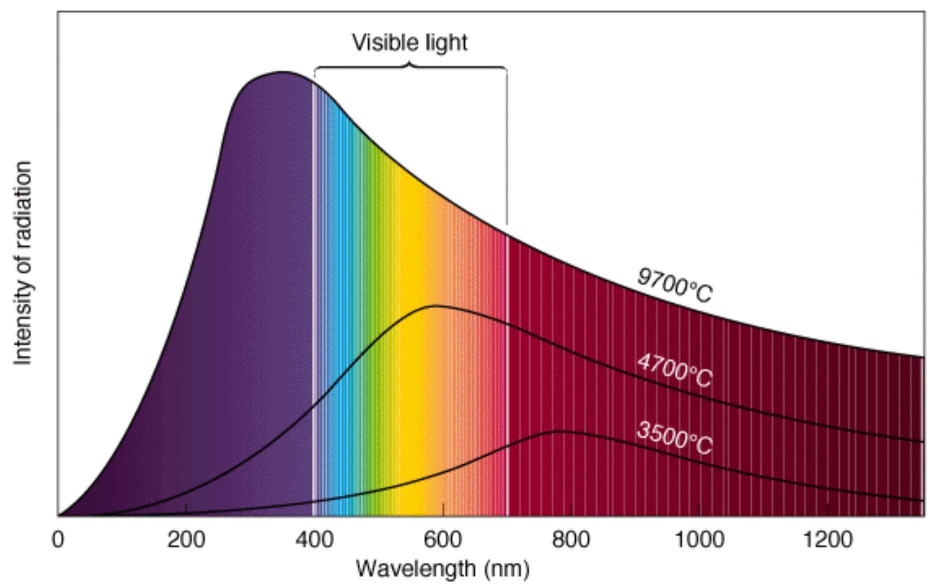
(Sun: peak is in visible spectrum)

Intensity graph for various star temperatures



Acetate 50 (Figure 4-10)

Intensity graph for various star temperatures



Acetate 50 (Figure 4-10)

The radiation that something emits because of its temperature is called **thermal** or **blackbody** radiation, and we can use the peak wavelength of the blackbody curve to determine the temperature of an object.

Nothing radiates as a perfect blackbody, but **stars** come close!

So **hotter stars emit more radiation**, and **the radiation peaks at a shorter wavelength**.

With wavelength λ measured in nanometers and T in degrees Kelvin, the relation between the average wavelength of light emitted by a hot object and the temperature of the object is

$$\lambda = \frac{3 \times 10^6}{T} \text{ nm}$$

To 2 decimal-place accuracy and with λ measured in cm

$$\lambda = \frac{0.29}{T} \text{ cm}$$

Example: Milwaukee at 17^0 C = 290 K

Peak wavelength is 10,000 nm: infrared

$$\lambda = \frac{3 \times 10^6}{T} \text{ nm}$$

A star has a temperature of 2000 K. What is the peak wavelength of light that it emits?

$$\lambda = \frac{3 \times 10^6}{2000} \text{ nm} = 1500 \text{ nm}$$

Recall that the peak wavelength of light from the Sun is at about 480 nm. Is a star with peak wavelength 1500 nm hotter or colder than the Sun?

A Hotter

B Colder

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A Hotter

B Colder

Longer peak wavelength = colder temperature

$$\lambda = \frac{3\times10^{6}}{T}\ \mathrm{nm}$$

A star emits at a peak wavelength of 300 nm. What is the temperature of its surface?

A 0.9 K

B 9000 K

C 10,000 K

D 9×10^{8} K

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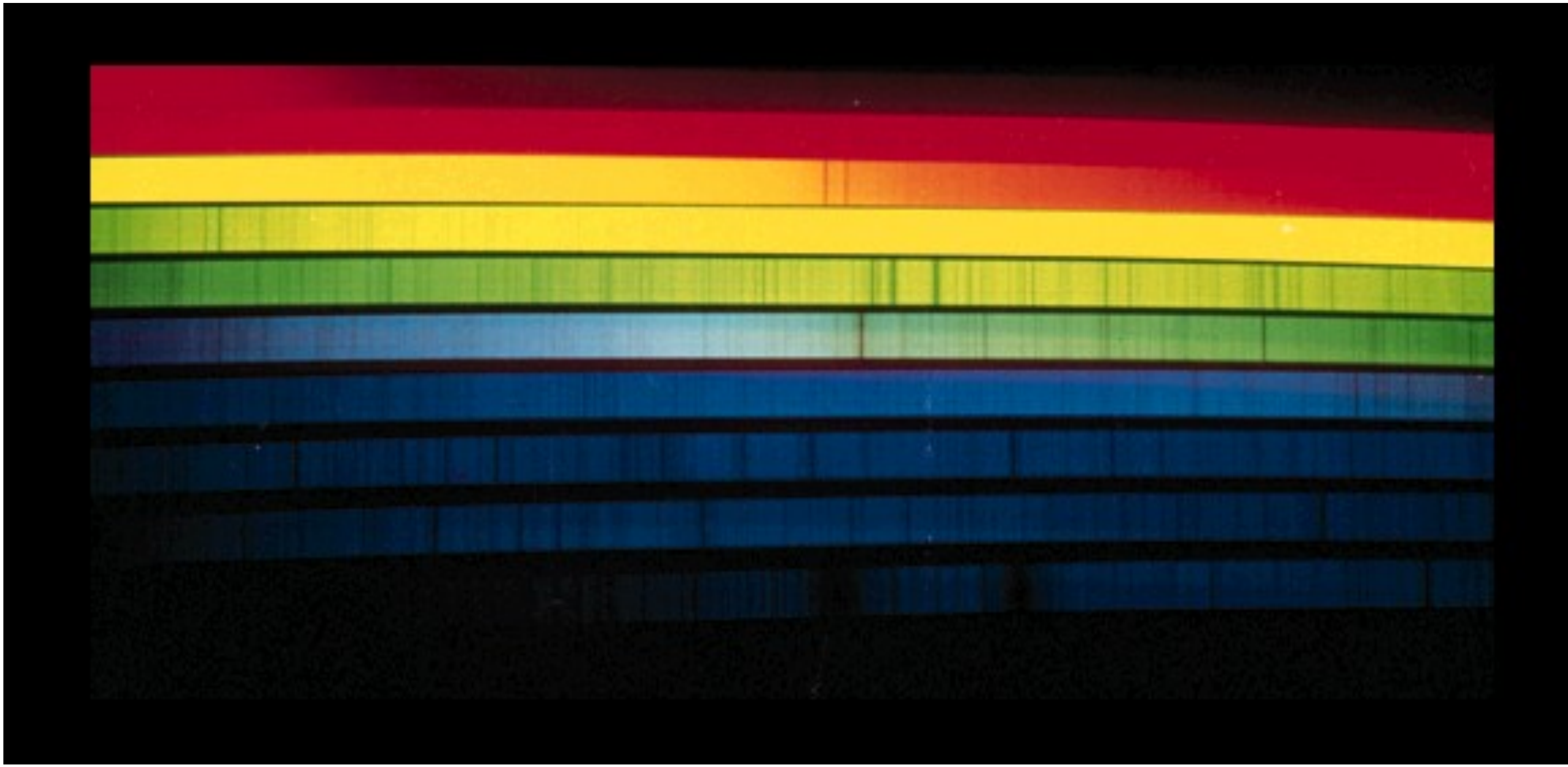
$$T = \frac{3\times10^6}{\lambda}\ \text{K}$$

If wavelength in nm

Atoms and Spectroscopy

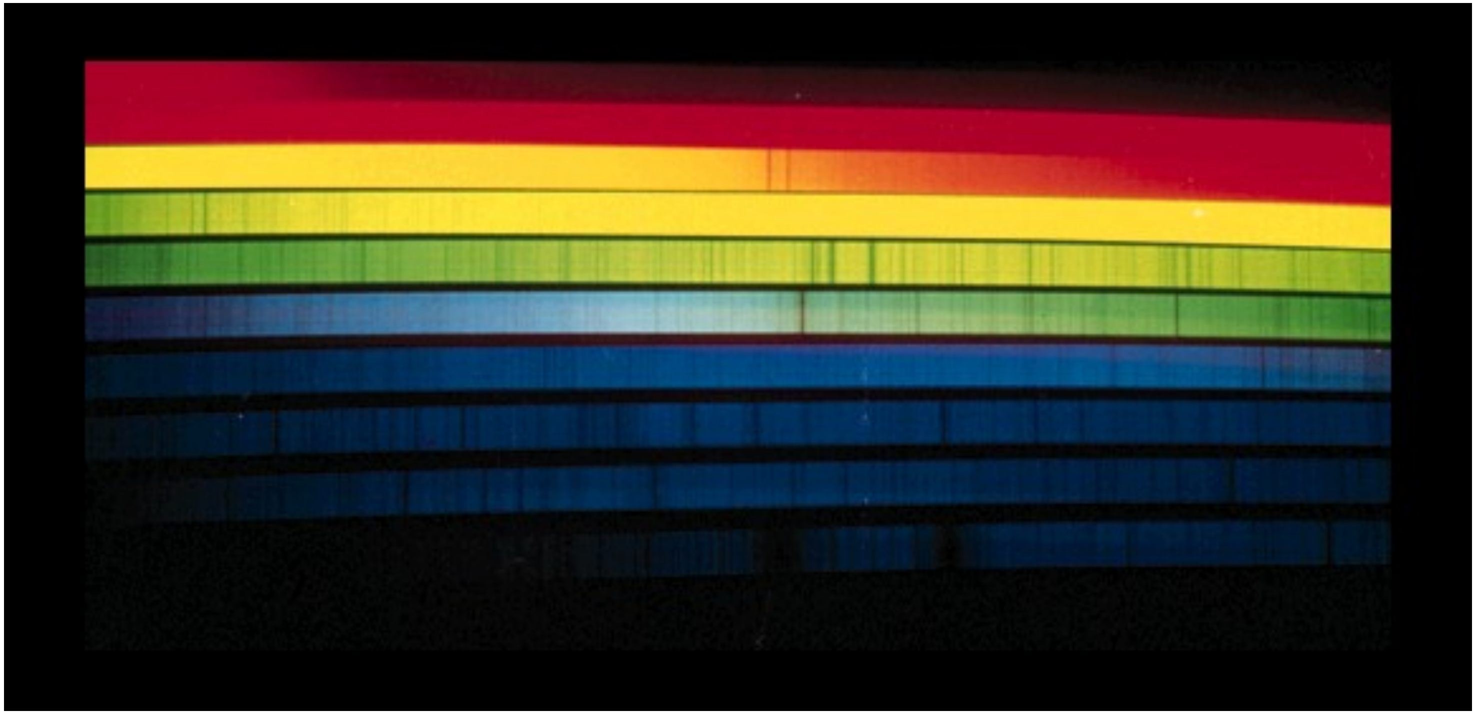
This is the spectrum of the Sun



Notice anything unusual or surprising?

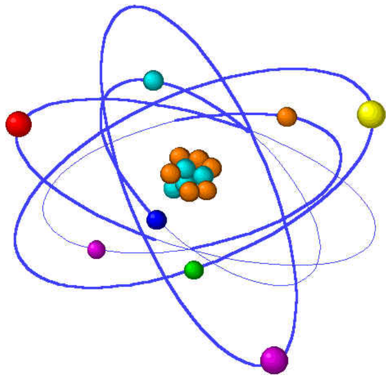
Light from the Sun looks like a continuous spectrum with a set of thin dark lines.

What's going on? What happened to the continuous spectrum?



Let's review some important facts about matter.

All things are made of **atoms**.



Atoms are about 1/10 nm (about 10^{-10} m) in diameter.

Atoms are collections of neutrons, protons and electrons. The neutrons and protons form a very small, very dense nucleus. The electrons orbit the nucleus, bound by electric attraction to the protons.

Opposite charges attract: electrons are negatively charged, and protons are positively charged. Neutrons have no charge.

An atom is about 100,000 times larger than its nucleus

A scale model would have the electrons at the outside of Miller Park, the nucleus a marble at its center

Spectra of isolated atoms

Objects as small as atoms are described by quantum mechanics, and the quantum mechanical behavior of small objects is different in key ways from that of large objects.

In contrast to planets orbiting the Sun, electrons orbiting the nucleus of an atom are restricted to a discrete set of orbits, at fixed distances from the nucleus. In particular, there is a closest allowed orbit.

The closest allowed orbit of an electron is the one with lowest energy, called the **ground state**.

When light hits an electron in an atom, it can kick the electron outward to a more energetic orbit, called an **excited state**. An excited electron will spontaneously fall back down to a closer orbit, and the electron then emits light of a fixed wavelength that depends only on the difference in energy between the two orbits. Longer wavelength light corresponds to a smaller energy difference.

- **When an electron absorbs light, it moves from a closer to a more distant orbit.**

- **When an electron moves from a more distant to a closer orbit, it emits light.**

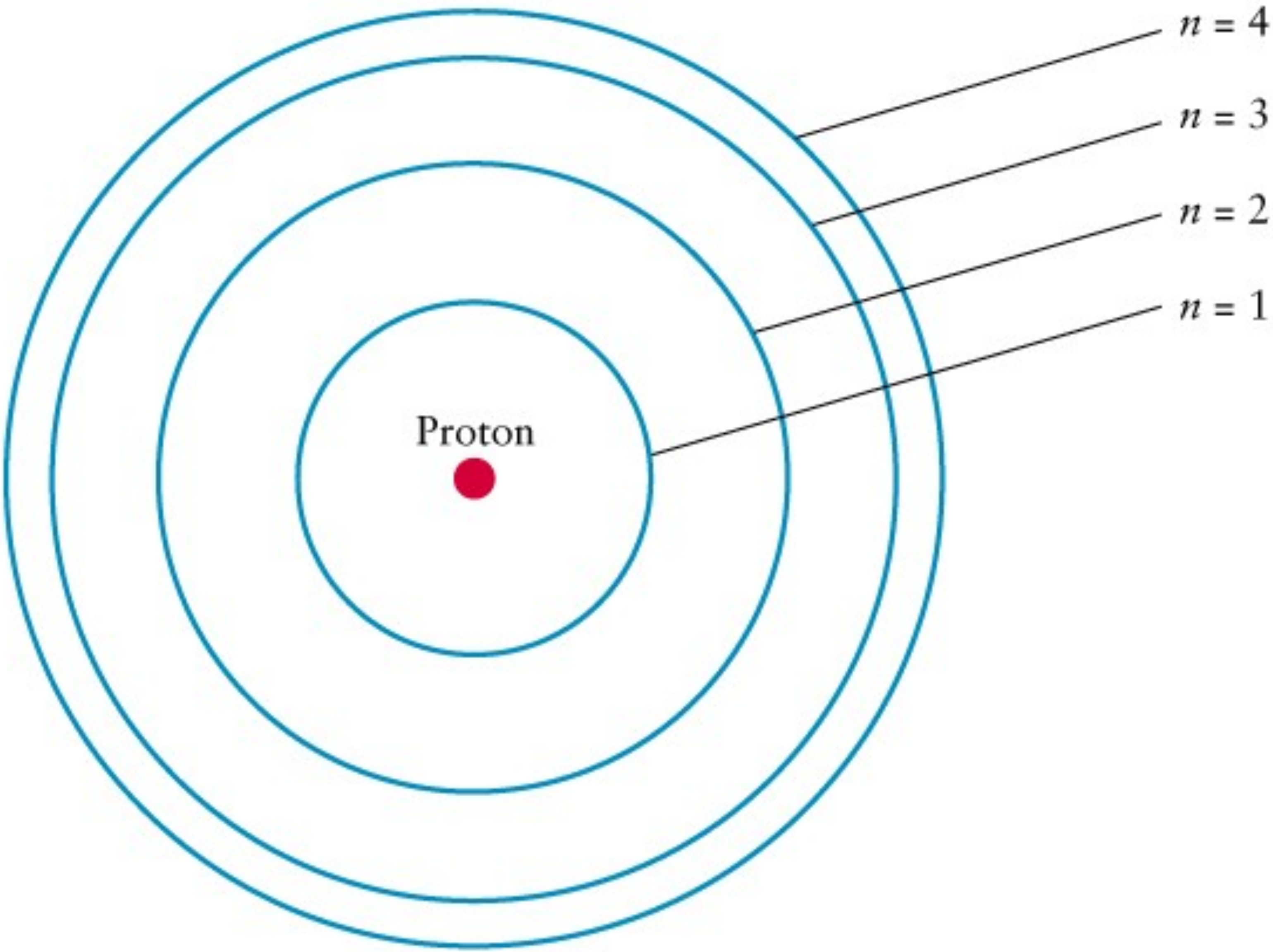
Atoms emit and absorb only those wavelengths of light that can correspond to the energy differences between orbits.

The light emitted or absorbed by isolated atoms is called a *discrete spectrum because only discrete wavelengths are emitted and absorbed: one sees the spectrum as a set of distinct lines.* Each type of atom (each element) has a different set of energy levels and therefore a different set of spectral lines.

- Each element can be identified by its discrete spectrum.

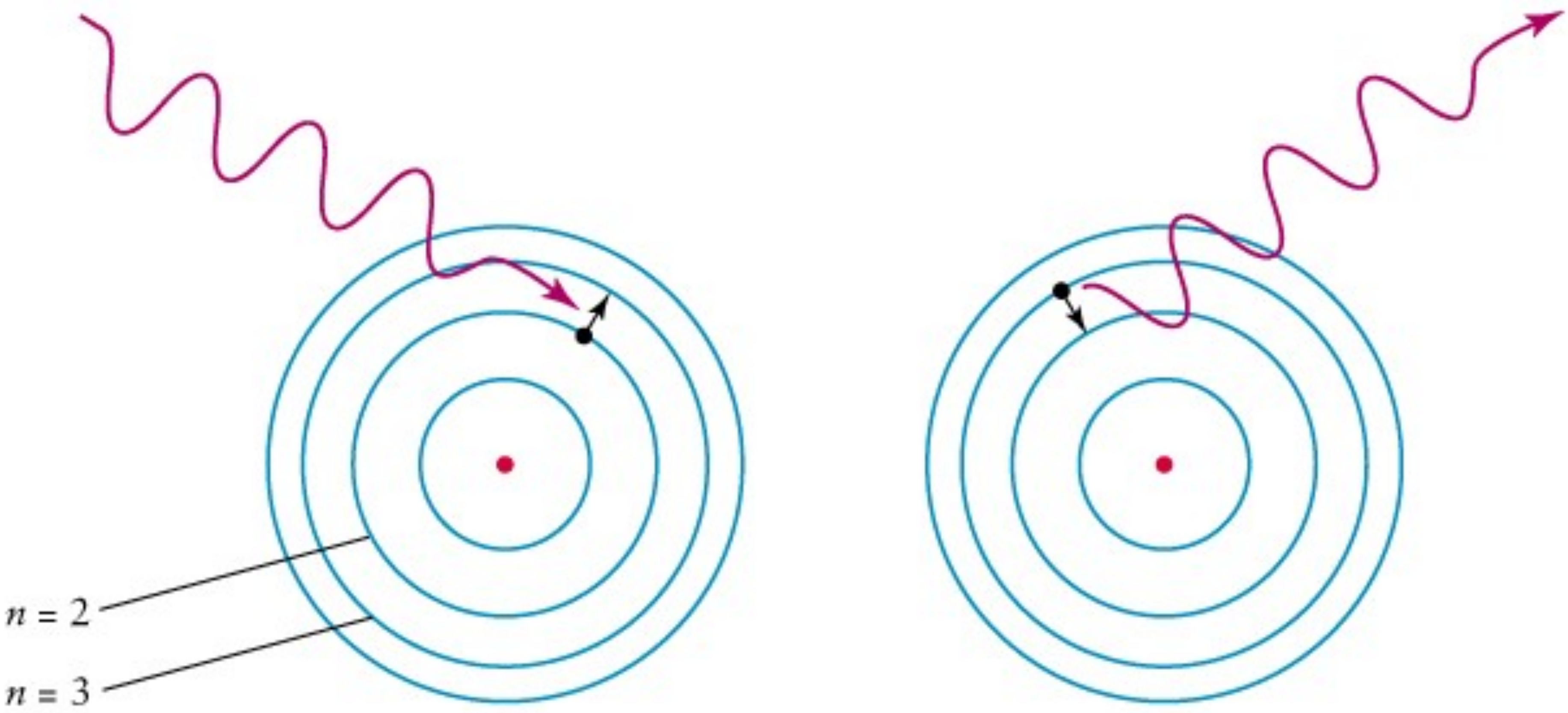
- The spectral lines (wavelengths) that an atom emits are the same as the spectral lines it absorbs

Diagram of the four lowest energy levels (four closest orbits) of the electron in a hydrogen atom



When an electron absorbs light, it moves to a more distant orbit (unless the light is so energetic it knocks the electron off the atom)

When it falls back to a closer orbit, an electron emits light

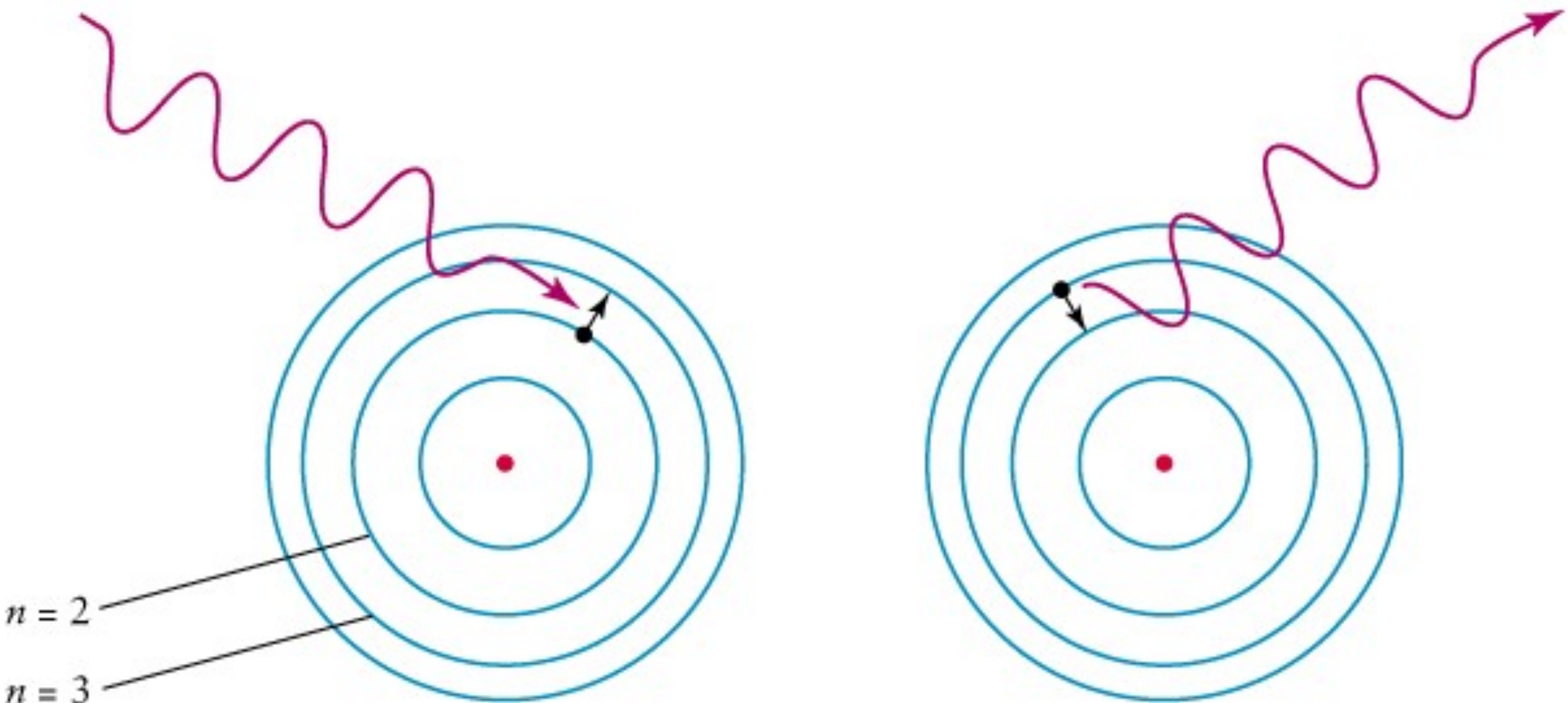


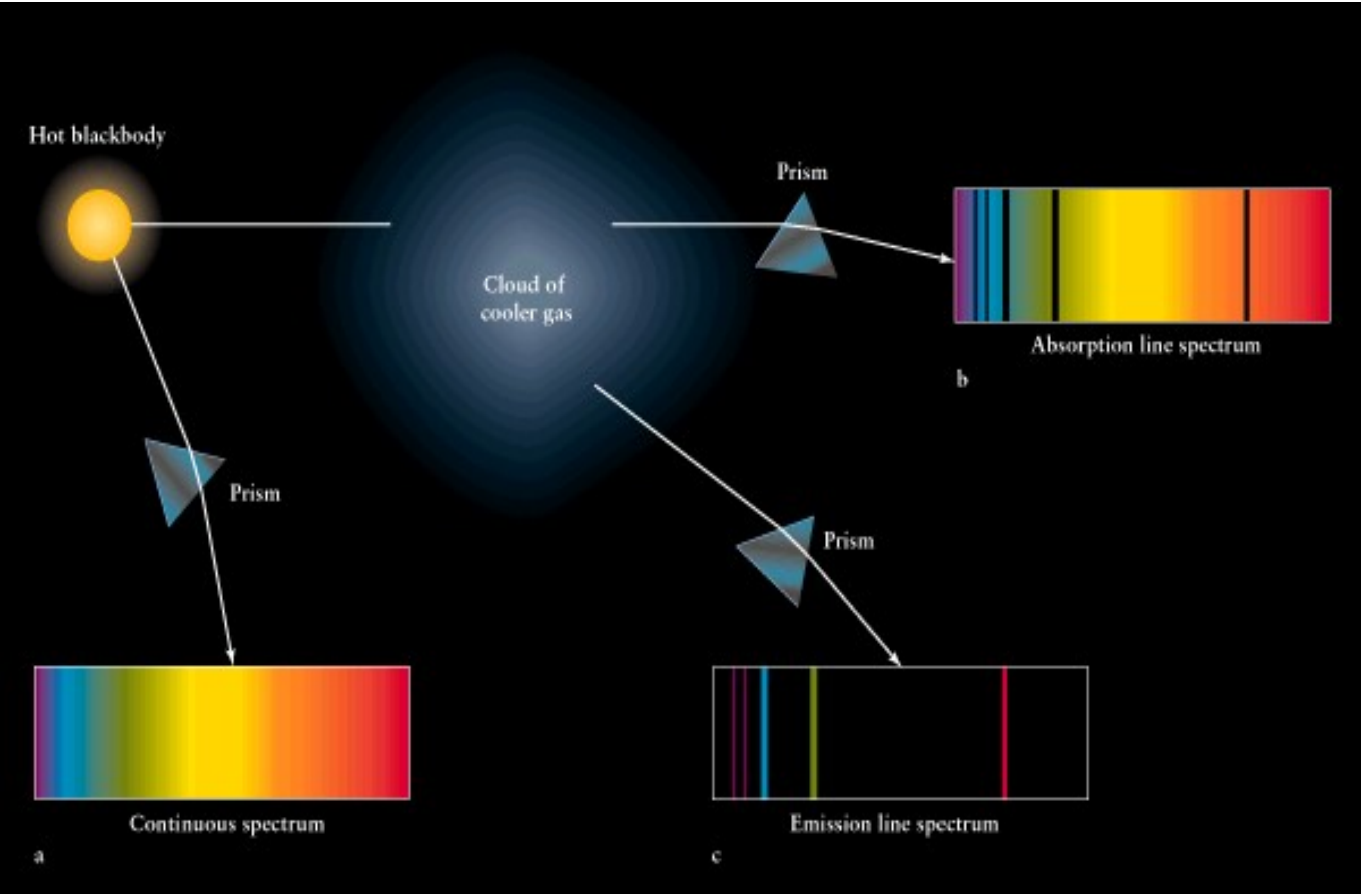
a Absorption b Emission

The energy of the emitted or absorbed light is equal to the difference in energy between the two orbits.

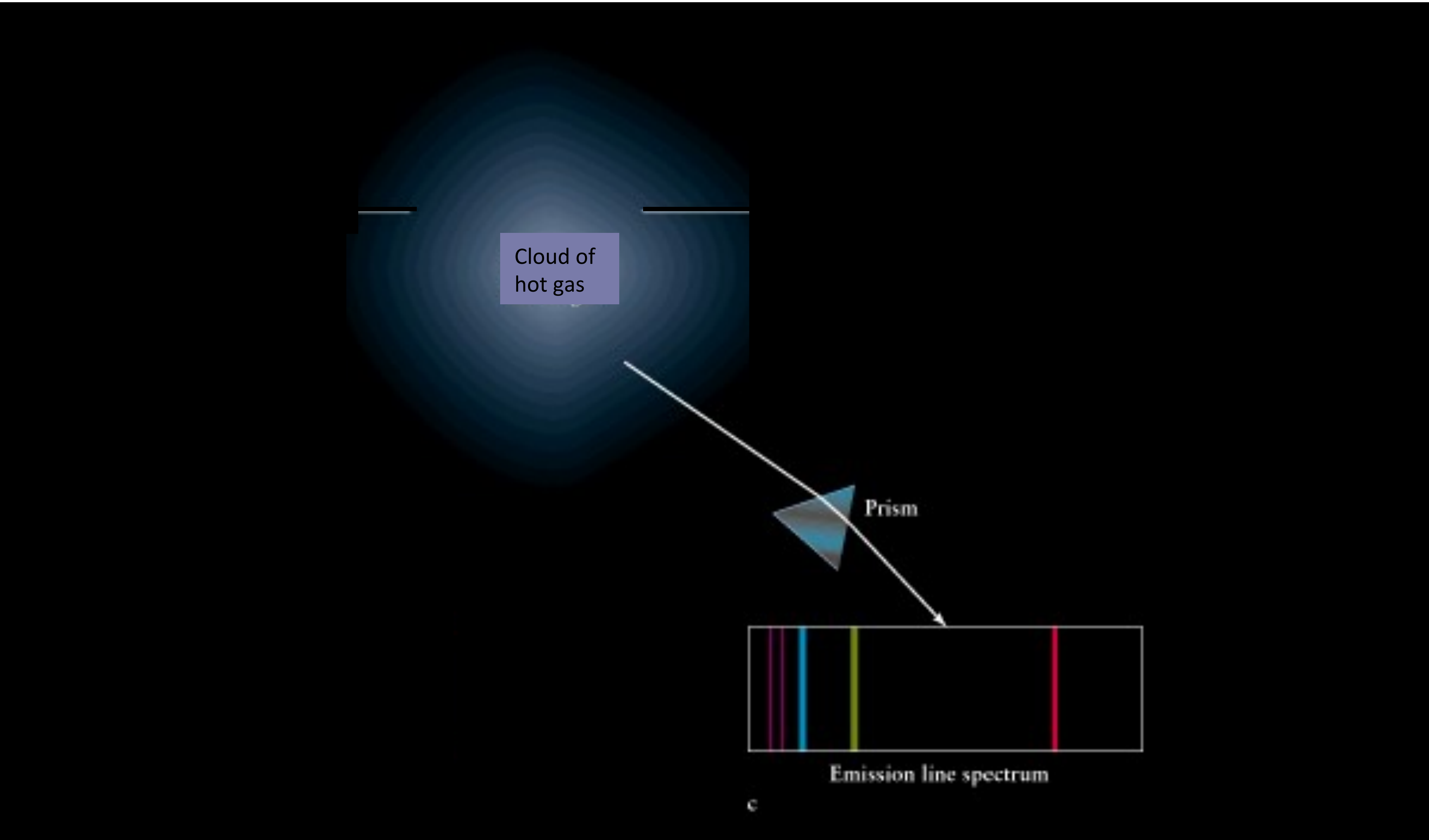
The wavelengths that an atom emits are the same as the wavelengths it absorbs:
The absorption lines and the emission lines of an atom have the same wavelengths.

Atoms emit and absorb a **discrete** spectrum of light

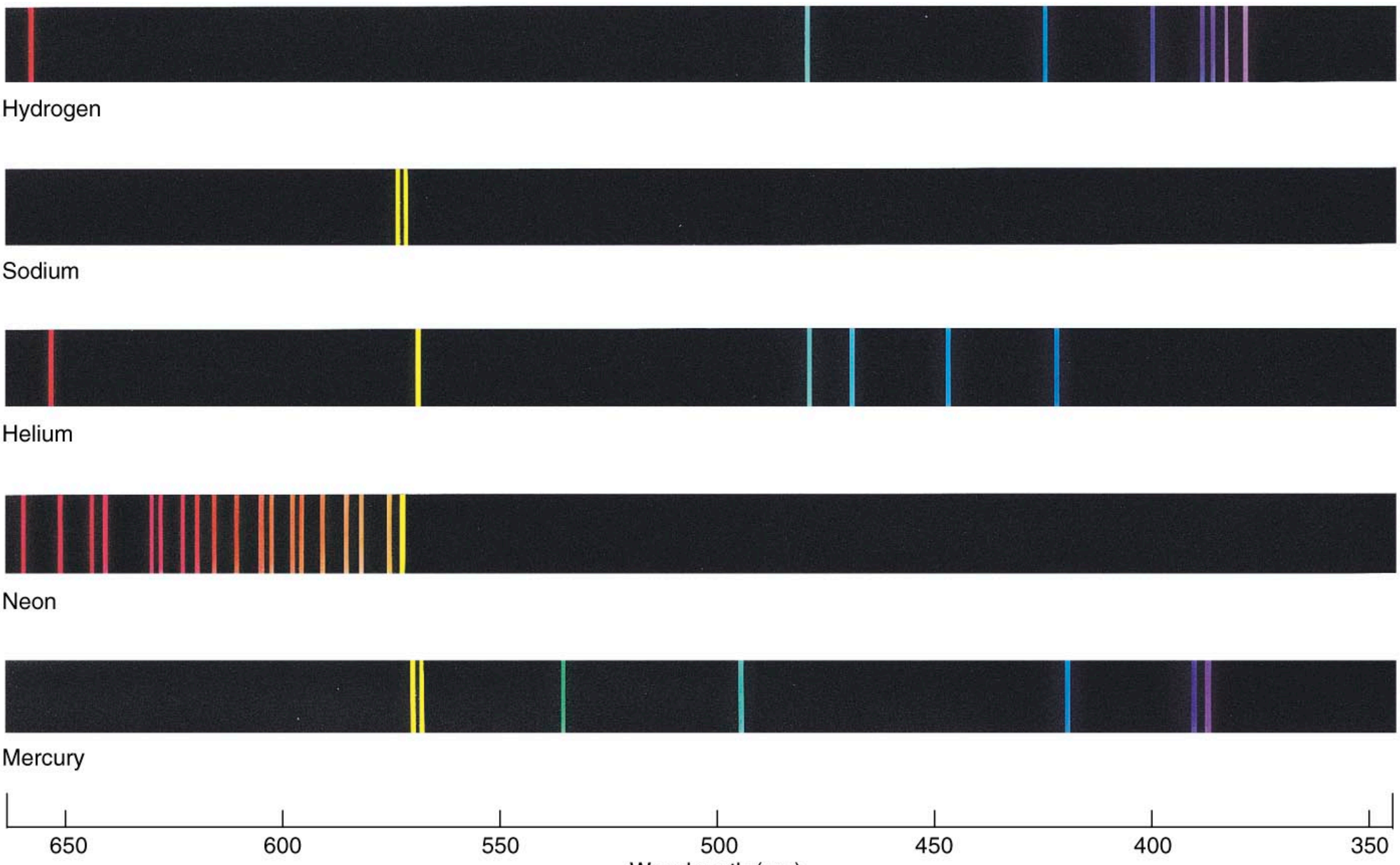



Hot blackbody
Cloud of
cooler gas
Prism
Absorption line spectrum
b
Prism
Prism
Continuous spectrum
a
Emission line spectrum
c

Light emitted by a hot gas of atoms has only those wavelengths that correspond to the energy differences between allowed electron orbits



Elements in stars can be identified by recognizing the patterns of their spectral lines.



We experience this in our everyday lives.

We experience this in our everyday lives.

Different elements differ only in the number of protons in their nuclei.

The lightest elements have the smallest number of protons:

Hydrogen (H) has 1 proton
(and most commonly no neutrons)

Helium (He) has 2 protons
(and most commonly 2 neutrons)

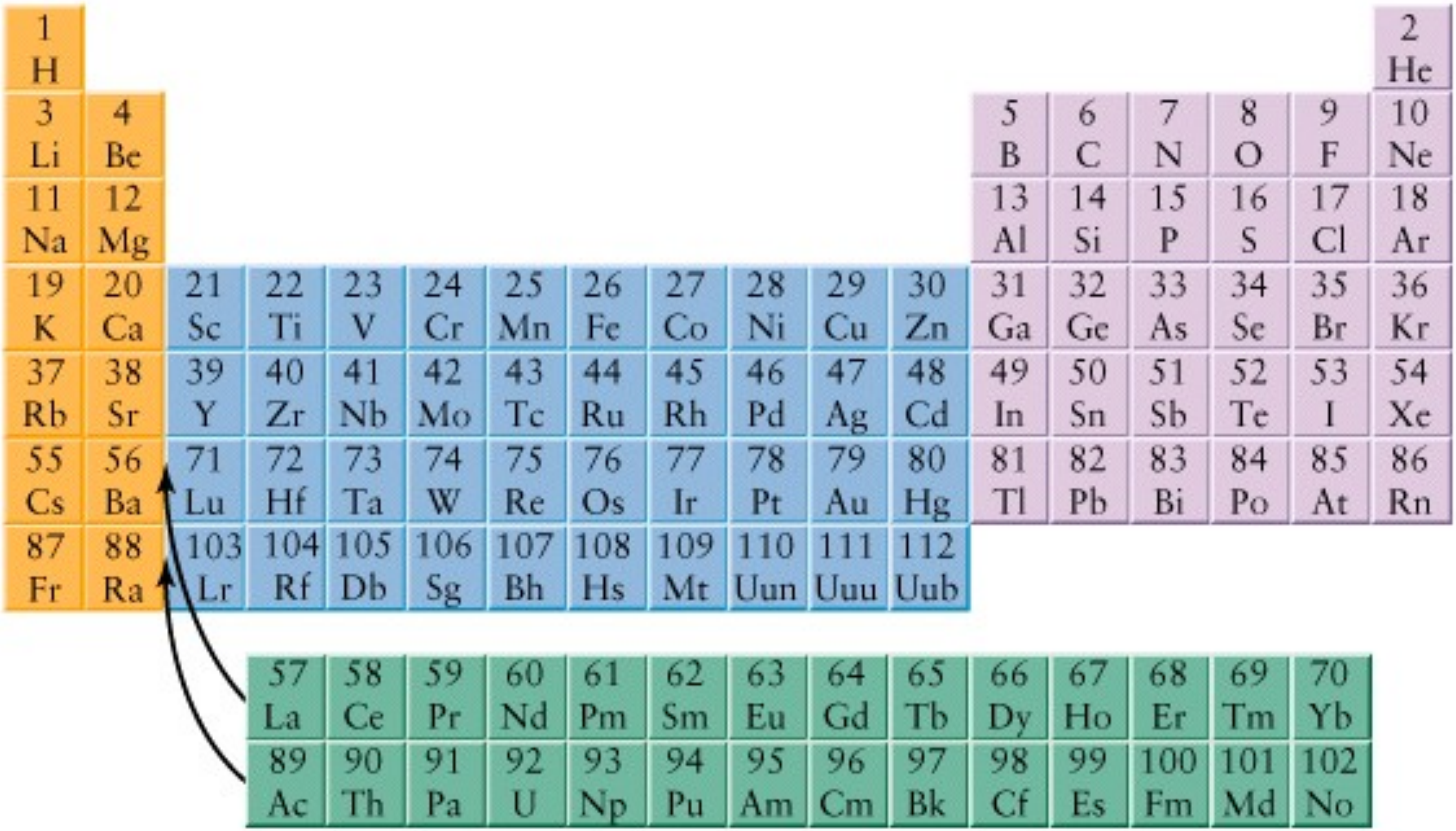
The heaviest elements have many more protons

Iron has 26

Lead has 82

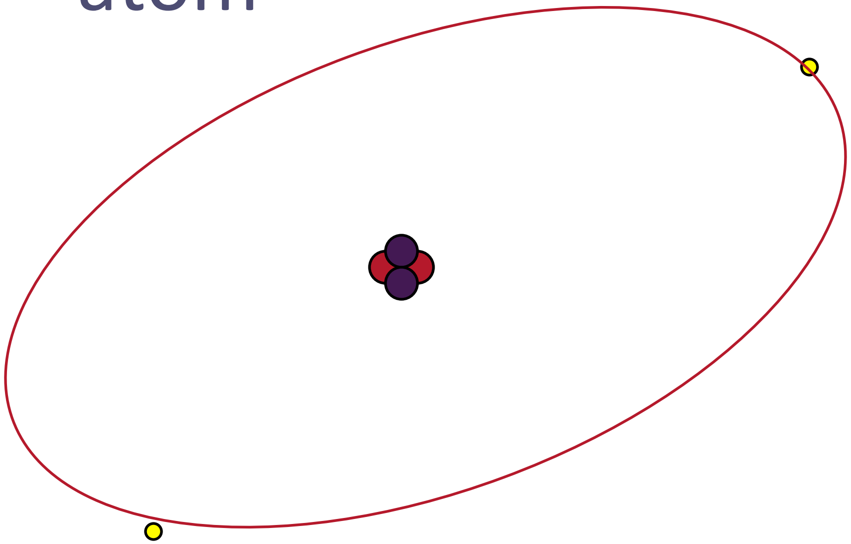
Uranium has 92

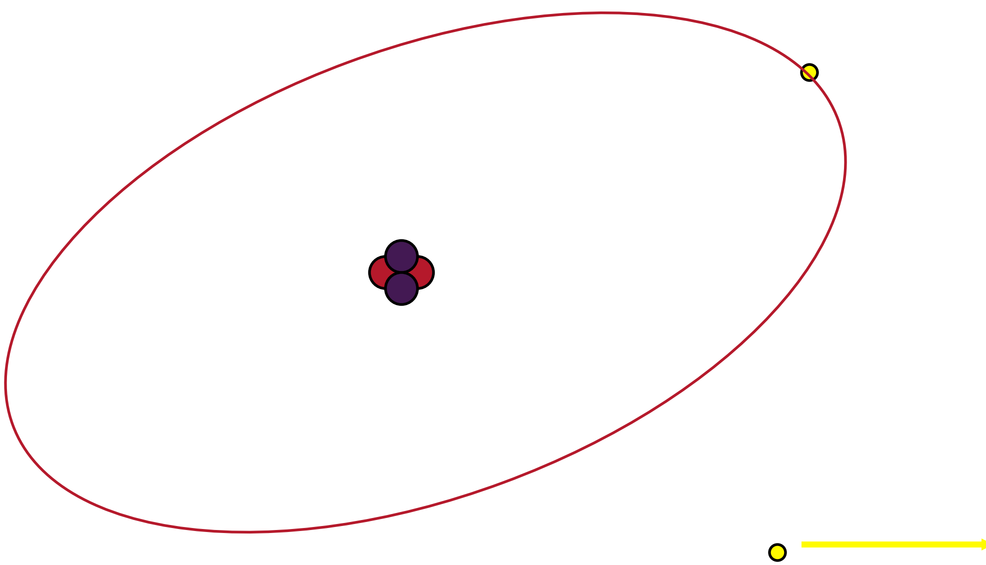
- Here is a table of the atoms, listed by the number of protons in their nucleus (equal to the number of electrons orbiting the nucleus).

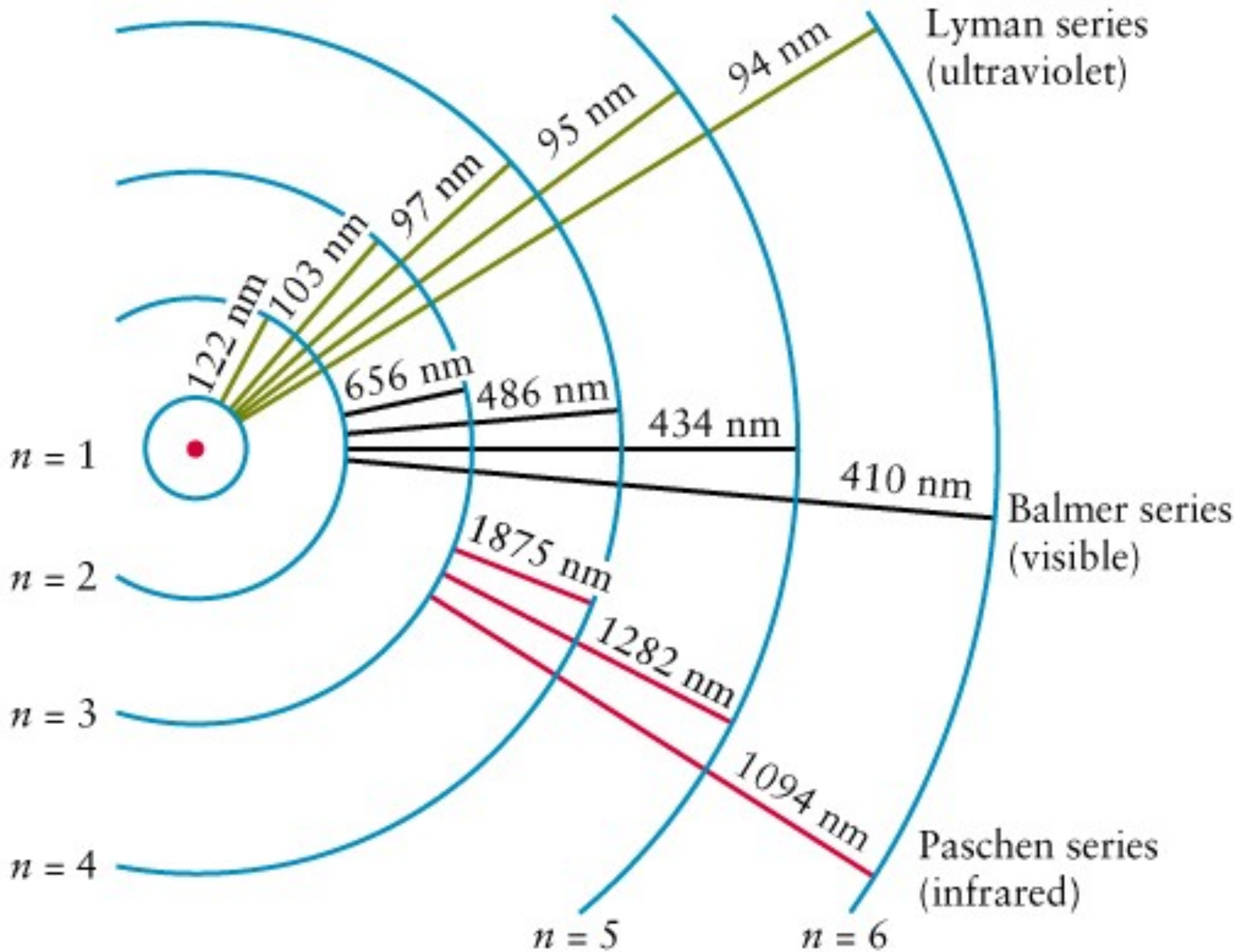

1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
71 Lu
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
103 Lr
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Uun
111 Uuu
112 Uub
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
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

A neutral atom has the same number of protons and electrons. But if you hit its electrons hard enough (e.g. in collisions with other atoms in a hot gas) or if you hit its electrons with energetic enough light (short wavelength light), you can knock them entirely off the atom.

Knocking electrons off an atom is called **ionizing** the atom







Atomic transitions in hydrogen