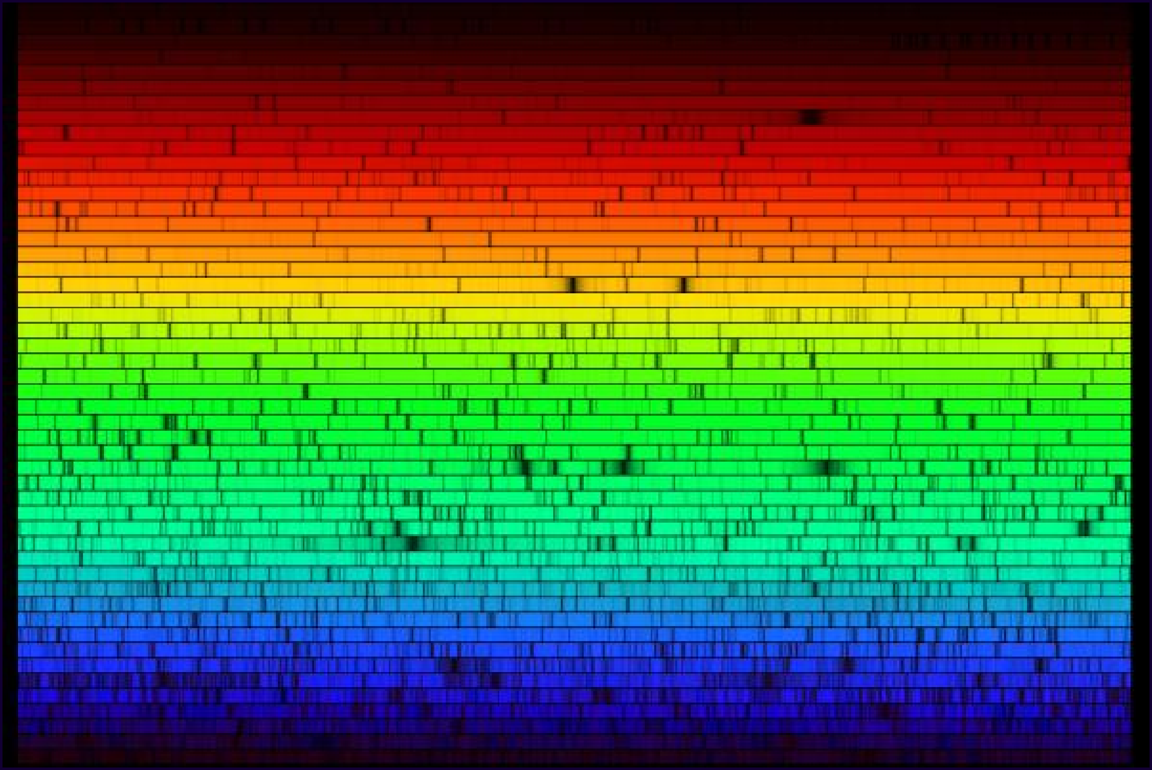
Light and matter

Astronomy 101
Syracuse University, Fall 2016
Walter Freeman

October 27, 2016



Announcements

-

Chemistry done quick†

A wave in empty space can have any frequency/wavelength it likes, as we learned Tuesday.

But a *confined* wave can have only very particular frequencies – the resonant frequencies of the box you put it in.

Quantum mechanics says that electrons have wave properties, and that frequency corresponds to energy!

- In an atom, the electric force confines the electron-waves to a region near the nucleus (I can't show you this)

Chemistry done quick†

A wave in empty space can have any frequency/wavelength it likes, as we learned Tuesday.

But a *confined* wave can have only very particular frequencies – the resonant frequencies of the box you put it in.

Quantum mechanics says that electrons have wave properties, and that frequency corresponds to energy!

- In an atom, the electric force confines the electron-waves to a region near the nucleus (I can't show you this)
- In a drum, the frame of the drum confines the drumhead-waves to a circular cavity. I **can** show you this!
- The shape is different, but there is a close analogy here:
- The different wave-shapes in a drum correspond to the different atomic energy levels in chemistry!

Chemistry done quick†

A remarkable consequence of quantum mechanics:

Electrons in an atom can only have **very particular** amounts of energy!

These energy levels correspond to the resonant frequencies of the "box" they're trapped in.

We measure this energy in "electron volts" (eV).

- Usually all the electrons live in the lowest available levels
- There's a limit to how many electrons can be in each level
- Atoms "fill up" the levels starting from the bottom
- This process leads to the periodic table

Chemistry done quick†

A remarkable consequence of quantum mechanics:

Electrons in an atom can only have **very particular** amounts of energy!

These energy levels correspond to the resonant frequencies of the "box" they're trapped in.

We measure this energy in "electron volts" (eV).

- Usually all the electrons live in the lowest available levels
- There's a limit to how many electrons can be in each level
- Atoms "fill up" the levels starting from the bottom
- This process leads to the periodic table

† Does not replace your introductory chemistry class on your transcript

Chemistry done quick†

- As in the drum, the energy levels in atoms are controlled by two numbers:
  - “Inside-to-outside wiggliness”: **principal quantum number** n
  - “Around-and-around wiggliness”: **angular quantum number** l

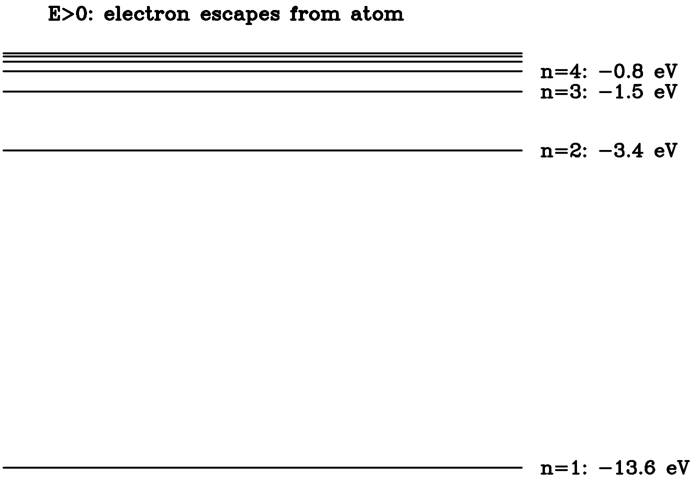
Chemistry done quick†

- As in the drum, the energy levels in atoms are controlled by two numbers:
  - "Inside-to-outside wiggliness": **principal quantum number** n
  - "Around-and-around wiggliness": **angular quantum number** l
- Chemists call $l = 0$ the S-orbitals, $l = 1$ the P-orbitals, $l = 2$ the D-orbitals, and so on.

- In hydrogen, the value of l doesn't affect the energy much at all.
- In other elements, it does a little bit.

Hydrogen

Here's a diagram of the allowed energies for hydrogen.



Chemistry: all I want you to know

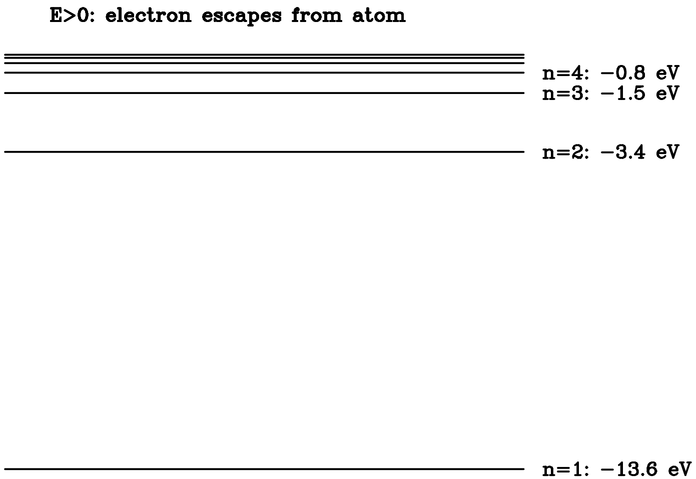
- Electrons occupy certain **energy levels**
- The particular energies that these levels have is **unique** to particular elements: hydrogen has different allowed energies than mercury or neon or sodium etc.

... that's it. :)

Chemistry and light

How do electrons get to different energy levels?

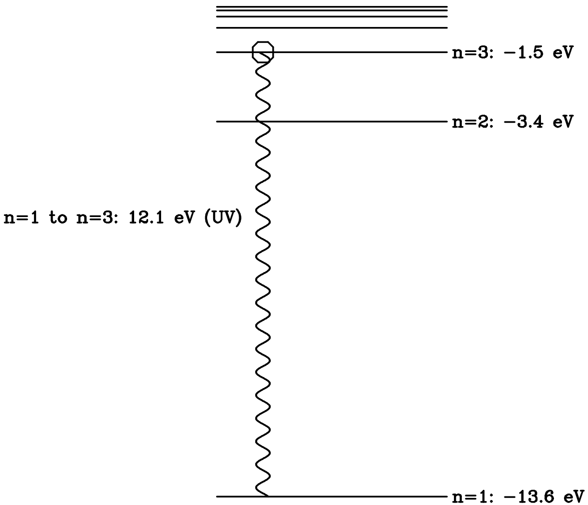
- They can *absorb* a photon and move to a higher energy level
- They can *emit* a photon and move to a lower energy level



Chemistry and light

- They can *absorb* a photon and move to a higher energy level
- They can *emit* a photon and move to a lower energy level

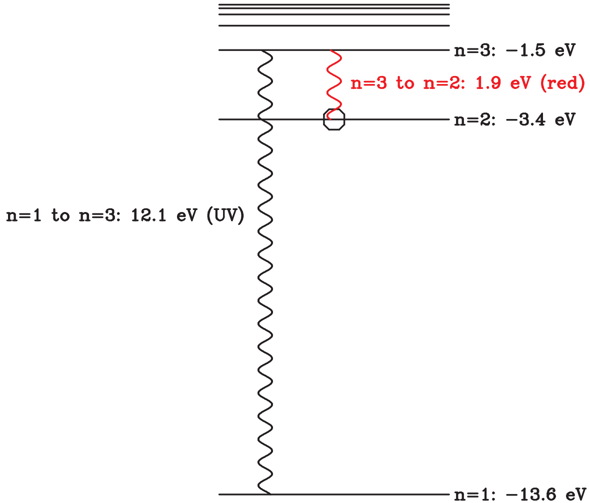
Absorb a 12.1 eV photon and move from $n = 1$ to $n = 3$; this photon is UV.



Chemistry and light

- They can *absorb* a photon and move to a higher energy level
- They can *emit* a photon and move to a lower energy level

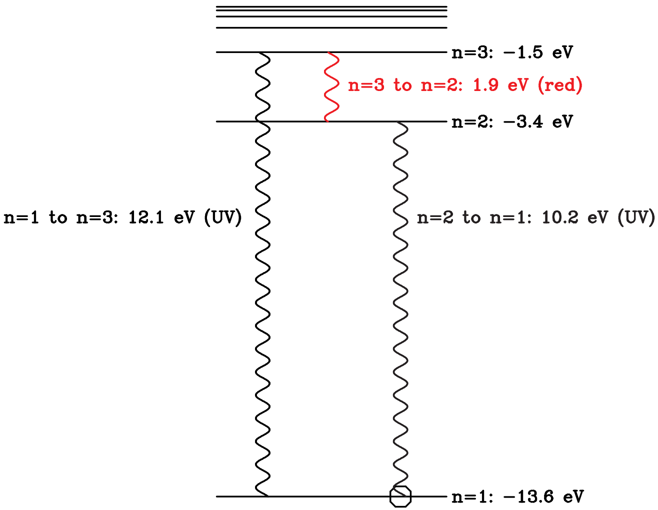
Emit a 1.9 eV photon and move from $n = 3$ to $n = 2$. This is red!



Chemistry and light

- They can *absorb* a photon and move to a higher energy level
- They can *emit* a photon and move to a lower energy level

Emit a 10.2 eV photon and move from $n = 2$ to $n = 1$. (UV, again)



If I take hydrogen and tear the electrons off of the atoms with an electric current, they'll "fall" back down, going through the energy levels down to $n = 1$.

Sometimes they'll skip energy levels; sometimes they'll go in sequence.

If I do this to hydrogen, what color will we see?

A: UV: we won't see it, since the transitions down to $n = 1$ are in the UV

B: Several shades of red: we'll see the transitions down to $n = 2$, which are red

C: Infrared: the transitions at the top are very low energy, corresponding to infrared light which we can't see

D: UV, IR, and red, all at once: all the transitions happen, but we only see the red photons because of the limits of our eyes

If I take hydrogen and tear the electrons off of the atoms with an electric current, they'll "fall" back down, going through the energy levels down to $n = 1$.

Sometimes they'll skip energy levels; sometimes they'll go in sequence.

If I do this to hydrogen, what color will we see?

A: UV: we won't see it, since the transitions down to $n = 1$ are in the UV

B: Several shades of red: we'll see the transitions down to $n = 2$, which are red

C: Infrared: the transitions at the top are very low energy, corresponding to infrared light which we can't see

D: UV, IR, and red, all at once: all the transitions happen, but we only see the red photons because of the limits of our eyes

E: Orange, because this is Syracuse, darnit!

Complete *Lecture Tutorials* pp.65-69.

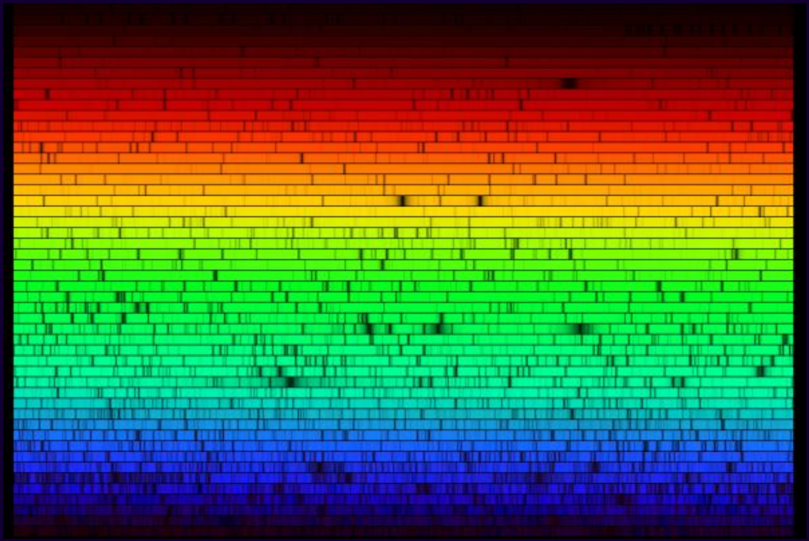
After this, we'll talk about another application of this idea.

Emission spectra

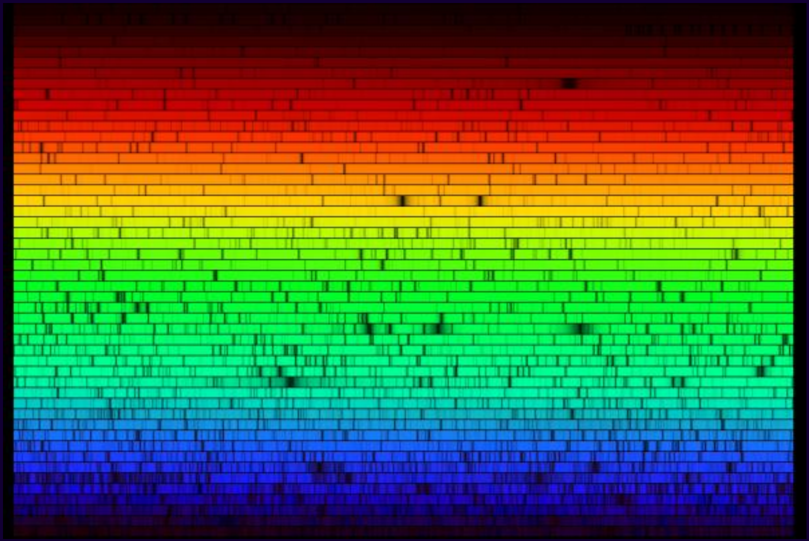
Every chemical element has a unique *spectrum*: the colors of light that it can emit and absorb.

Other colors simply pass through.

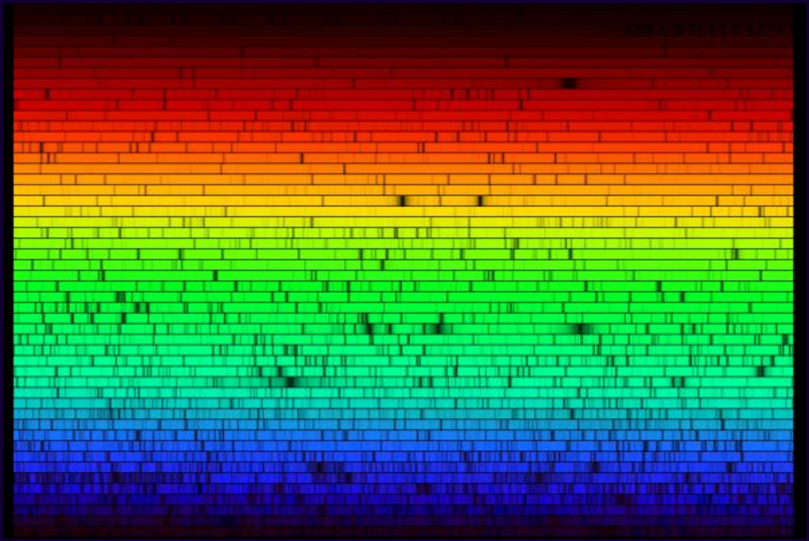
(Molecules have these spectra too: their electron energy levels are more complicated.)



- The hot core of the Sun emits light of all wavelengths (you'll learn why next class)



- The hot core of the Sun emits light of all wavelengths (you'll learn why next class)
- The gases in the cooler atmosphere absorb light of their particular wavelengths



- The hot core of the Sun emits light of all wavelengths (you'll learn why next class)
- The gases in the cooler atmosphere absorb light of their particular wavelengths

This picture tells us what's in the Sun!

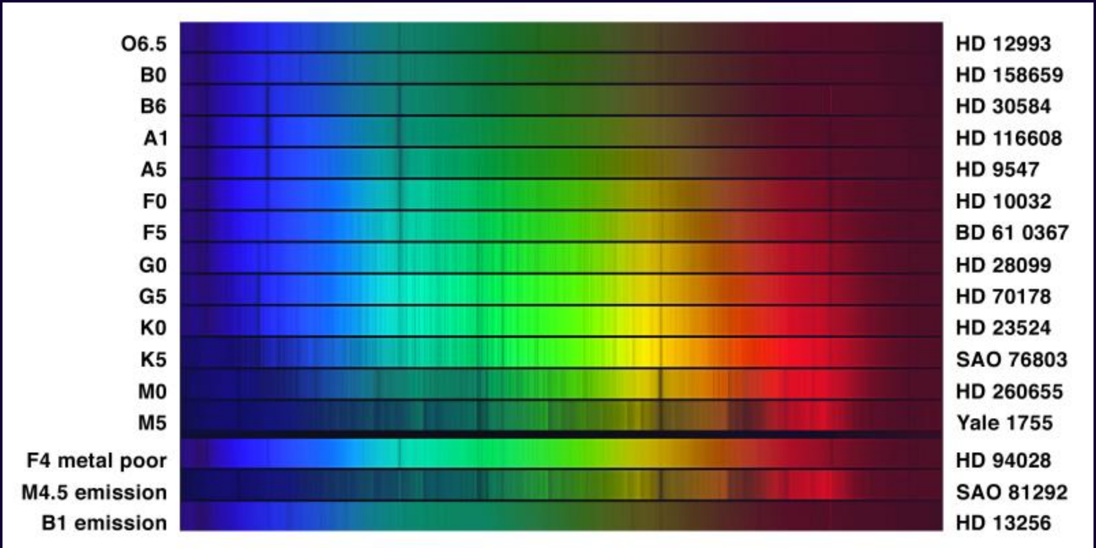
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

A: Something about quantum mechanics is different in the Sun

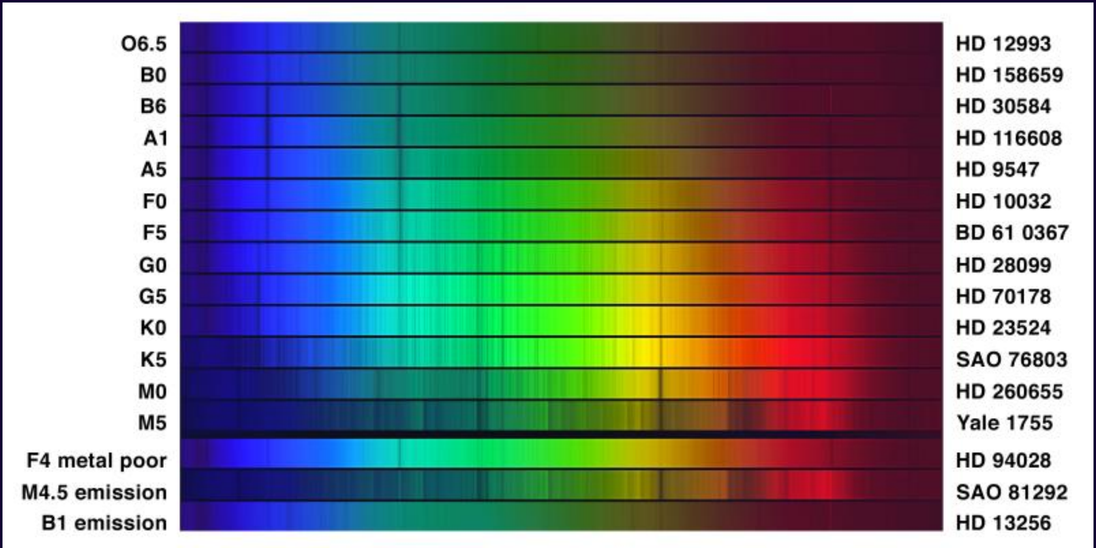
B: Something about light is different in the Sun

C: There's an element in the Sun that's not on Earth – call it **sunium**

D: The extreme temperature of the Sun causes new lines to appear in its gas



All the stars are made of the same stuff – the same stuff as we are.



All the stars are made of the same stuff – the same stuff as we are.

"The cosmos is also within us. We are made of star-stuff. We are a way for the universe to know itself."

–Carl Sagan, *Cosmos*

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!
There are others that are very interesting to astronomers:

- Molecular vibrations: infrared

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!
There are others that are very interesting to astronomers:

- Molecular vibrations: infrared
- Molecular *rotations*: microwave

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!
There are others that are very interesting to astronomers:

- Molecular vibrations: infrared
- Molecular *rotations*: microwave
- "Hyperfine structure" energy levels in hydrogen: 21 cm radio waves

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!
There are others that are very interesting to astronomers:

- Molecular vibrations: infrared
- Molecular *rotations*: microwave
- "Hyperfine structure" energy levels in hydrogen: 21 cm radio waves

This last is particularly interesting: it is a very particular frequency, echoing out from all corners of the Universe, that says: hydrogen is here. (Hydrogen is 75% of the universe.)