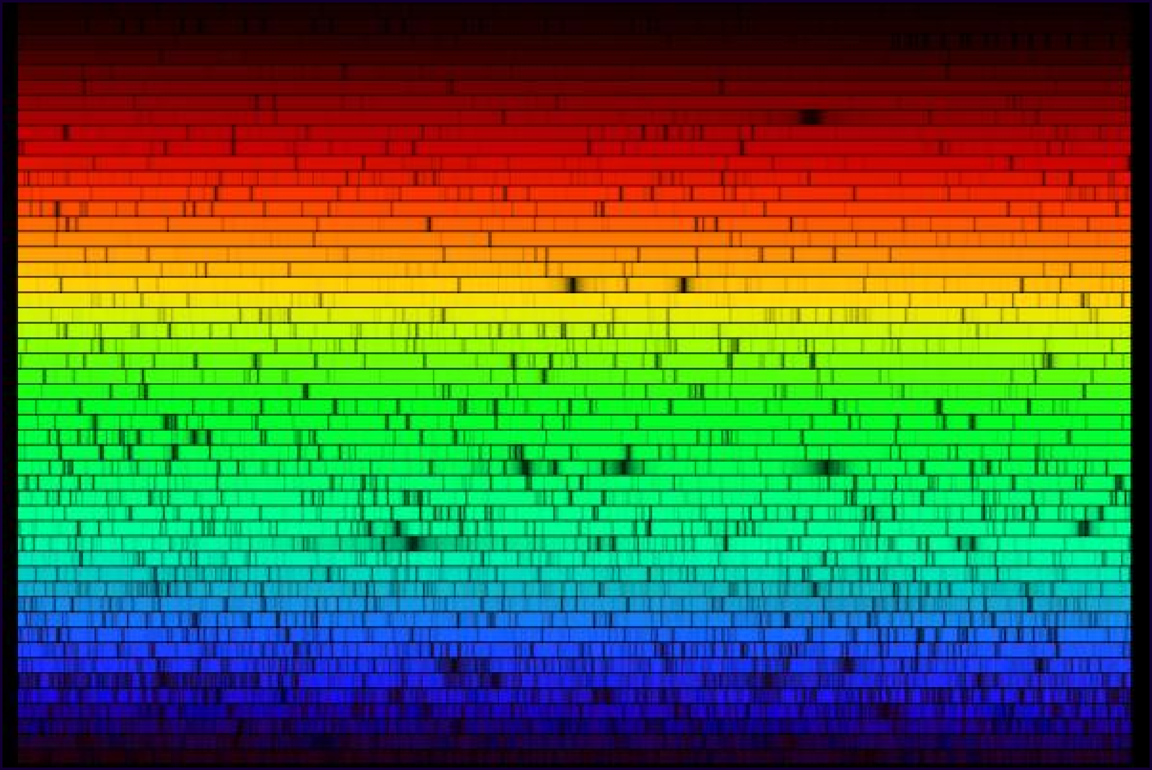
Light and matter

Astronomy 101
Syracuse University, Fall 2016
Walter Freeman

October 31, 2017



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- Study advice...

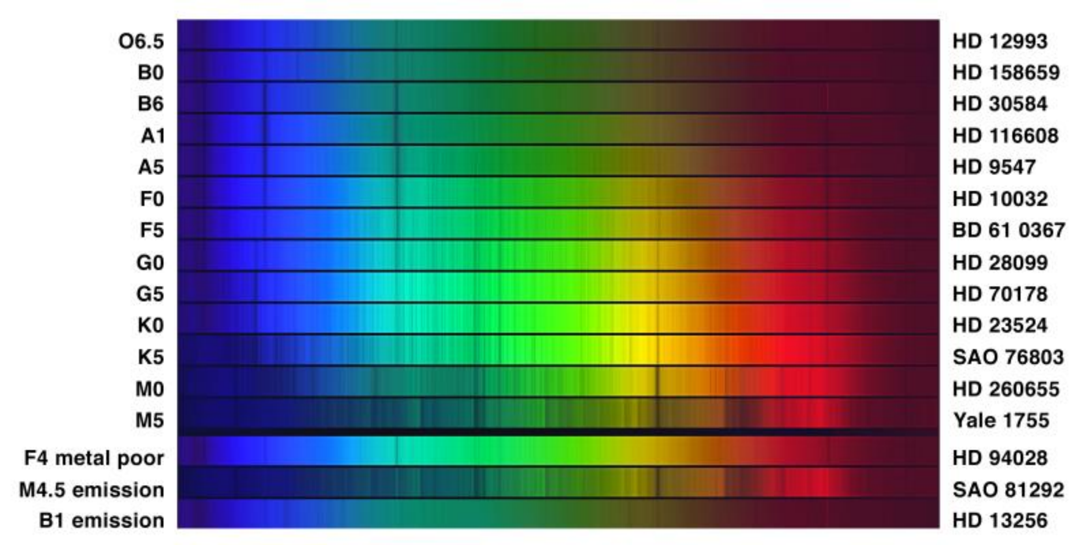
Last time

Last time we saw that all objects with a temperature emit a broad spectrum of light.

As an object gets hotter, the light coming from it:

- … becomes brighter
- … shifts to shorter wavelengths ("becomes bluer")

Which of these stars is hottest?



A: O6.5

B: K5

C: G5

D: F4 “metal poor”

Chemistry done quick†

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

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

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† Does not replace your introductory chemistry class on your transcript

Atomic transitions

Here's a sample atom (on the document camera). These energy levels aren't real; I just made them up for demonstration.

Can the electron in this atom go from $n = 1$ ("ground state") to $n = 2$ (an "excited state")?

A: Yes, since it's just moving from here to there

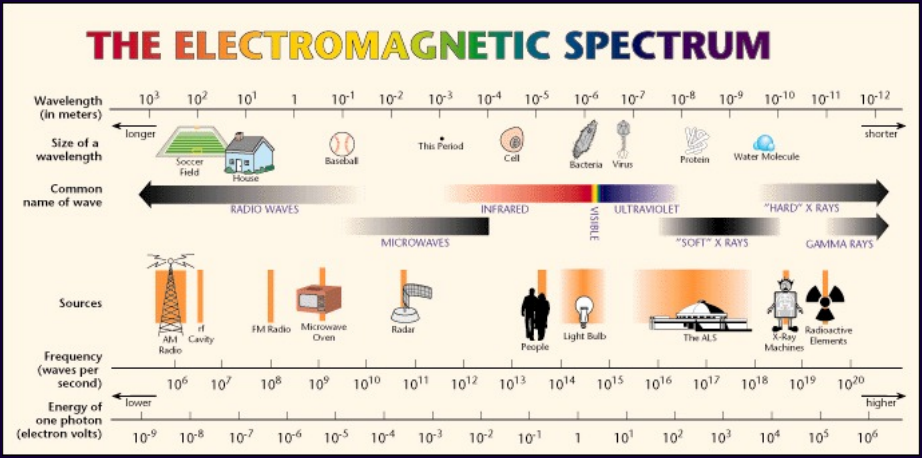
B: Yes, but only if I give it 4 eV of energy from somewhere

C: No, because atoms have a definite state

D: No, because that doesn't conserve energy

Atomic transitions: absorption

This extra energy usually comes from a *photon* – a particle of light. Remember that photons carry energy with them: the shorter the wavelength, the higher the energy.



An atom can absorb a photon with just the right energy, jumping up to a higher energy level in the process.

What energies of photon can our sample atom absorb if it starts in $n = 1$?

A: 4 eV

B: 4 eV, 3 eV, 2 eV, or 1 eV

C: 4 eV, 7 eV, 9 eV, or 10 eV

D: Any value up to 10 eV

E: Any value between 4 eV and 10 eV

Suppose our atom absorbs a photon of 9 eV. What happens?

A: It will emit a photon of 9 eV

B: It will emit a 2 eV photon, then a 7 eV photon

C: It will emit a 5 eV photon, then a 4 eV photon

D: It will emit a 2 eV photon, then a 3 eV photon, then a 4 eV photon

E: It will emit a 3 eV photon, then a 6 eV photon

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.
- An atom can absorb a photon and jump up to a higher level, conserving energy
- ... an atom in a higher level can emit photons, jumping back down, conserving energy.

... that's it. :)

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

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E: Orange, because this is Syracuse, darnit!

Complete *Lecture Tutorials* pp.65-69.

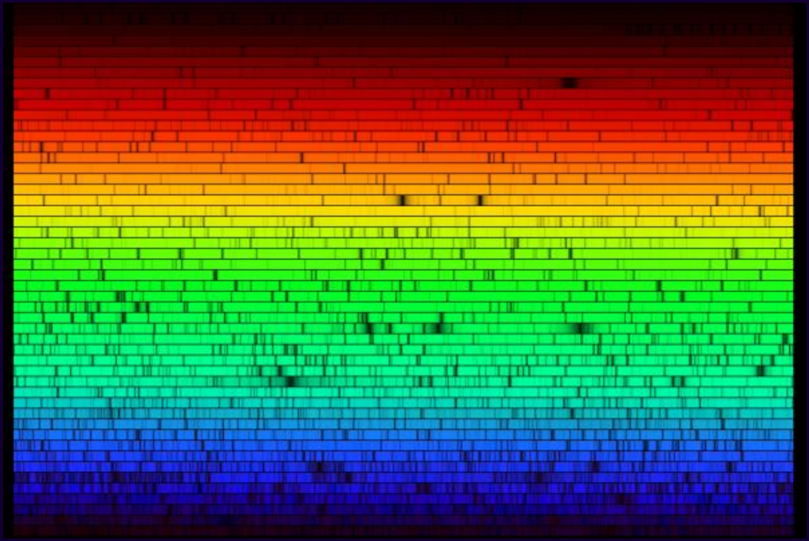
After this, we'll talk about another application of this idea.

Emission spectra

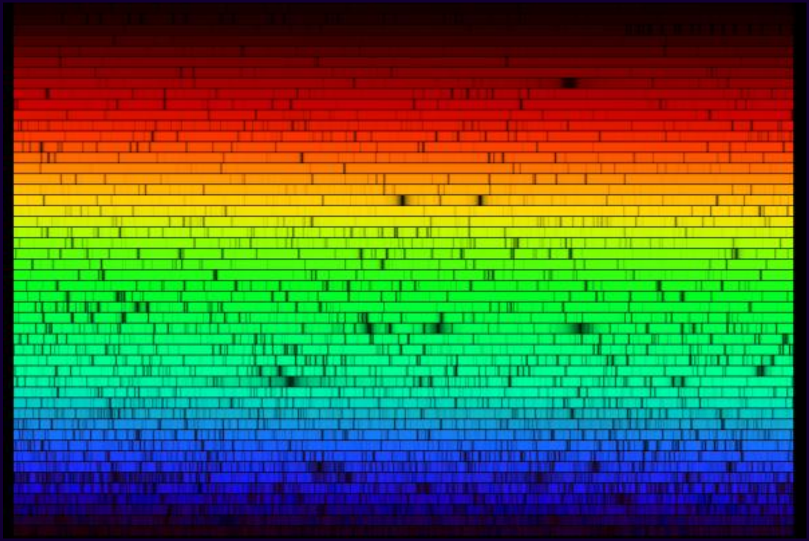
Every chemical element has a unique *spectrum*: the colors of light that it can emit and absorb.

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 (thermal radiation)



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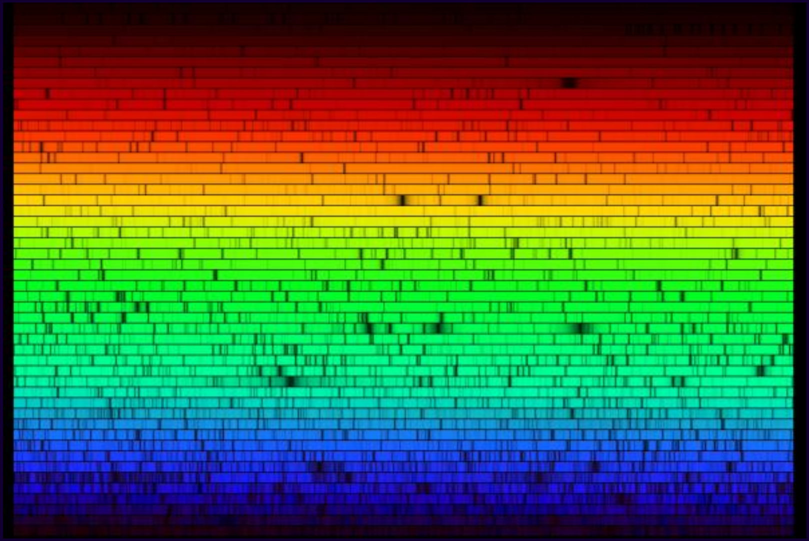

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This picture tells us what's in the Sun!

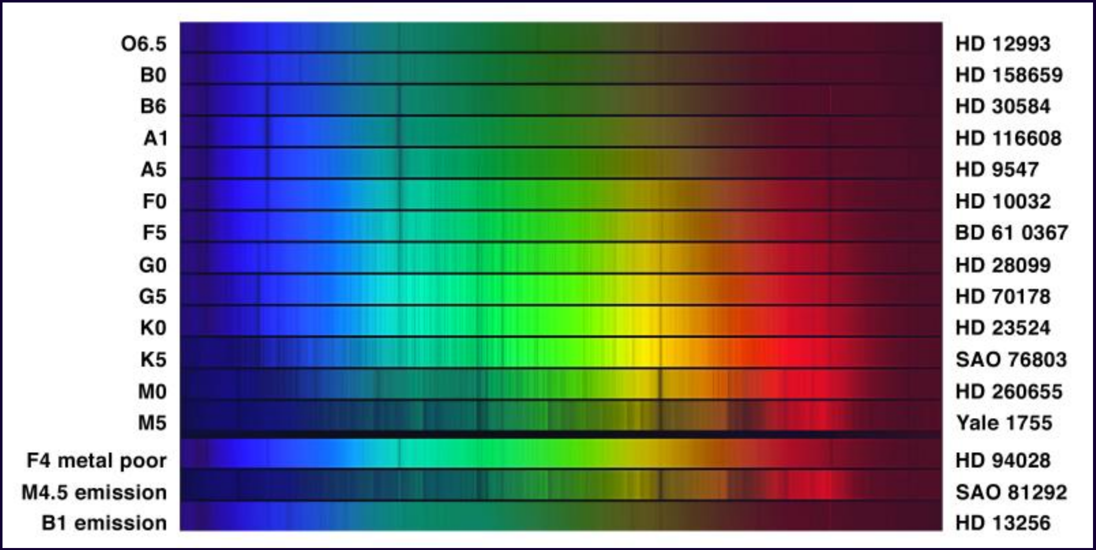
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

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



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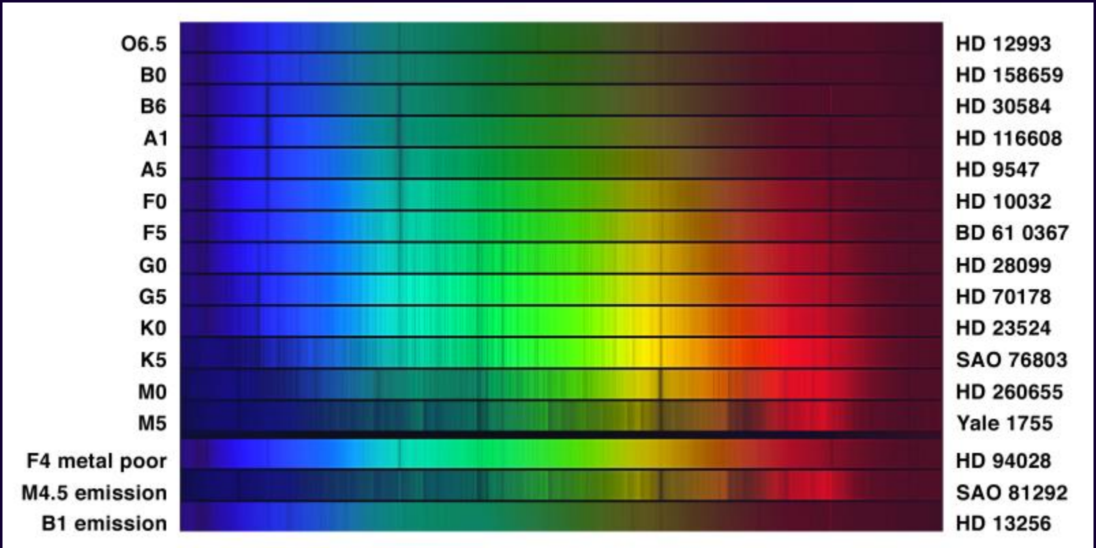

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“The cosmos is also within us. We are made of star-stuff. We are a way for the universe to know itself.”

–Carl Sagan, *Cosmos*

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- 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.)