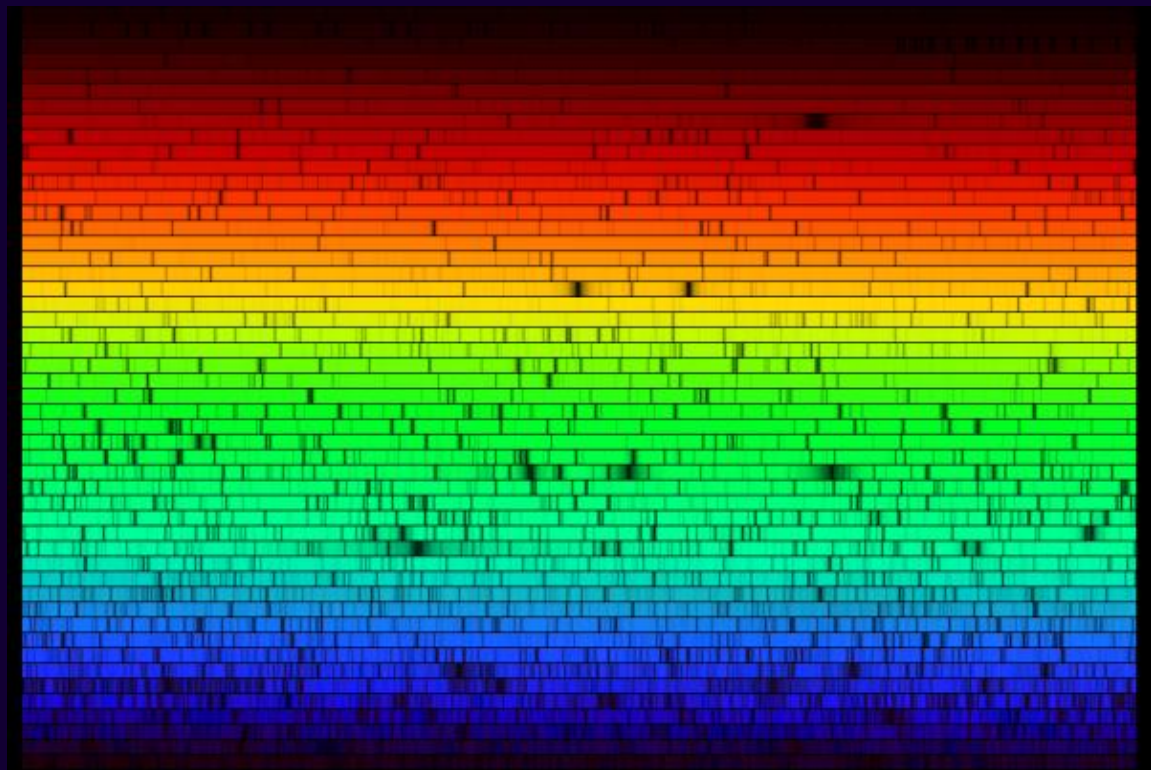


Light and matter

Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

October 22, 2020



Announcements

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- “Midterm evaluations” – confusion, and my bad!
 - The university's “midterm evaluation” thing was *not* part of this class...
 - ... but the syllabus *does* mention one!
 - We will be doing that next week

Help hours coming up

Friday morning:

- 8am - 9:15am
- (Break for boring meeting – I'd rather be with you all!)
- 12pm-1:30pm

Ask me...

- ... if you still couldn't figure something out about Project 3
- ... about your upcoming paper
- ... anything else!

Extra help for your papers

Our coach Xinning (Lisa) Li has offered to help folks with their papers.

Extra help for your papers

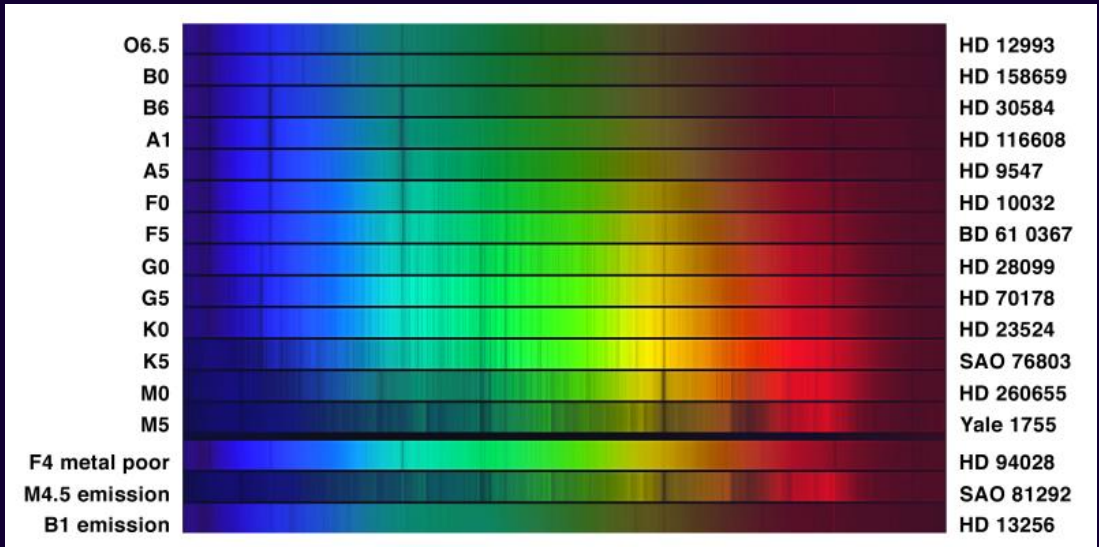
Our coach Xinning (Lisa) Li has offered to help folks with their papers. She will be holding these meetings on Zoom: both Friday and Saturday 10:30-12:00. She will be using her own Zoom rooms for these; I'll send the links out after class.

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 **particular** amounts of energy!

We call these “energy levels”, and measure their 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
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[†] Does not replace your introductory chemistry class on your transcript

Atomic transitions

Each electron lives in one of these energy levels at all times.

They are not physical locations, but patterns of orbiting the nucleus. Higher energy levels orbit further away.

They **cannot** be in between.

If you add energy, you can move an electron to a higher energy level.

Atomic transitions

Imagine a sample atom with five energy levels:

- $n = 1$, with 0 eV of energy (ground state)
- $n = 2$, with 4 eV of energy
- $n = 3$, with 7 eV of energy
- $n = 4$, with 9 eV of energy
- $n = 5$, with 10 eV of energy

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

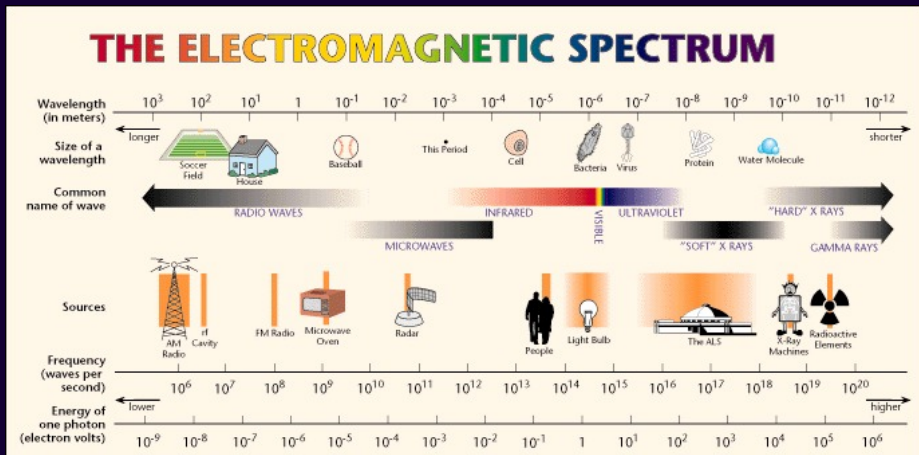
B: Yes, but only if I give it 4 eV of energy from somewhere

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

If an atom is in an excited state (maybe because it has absorbed a photon), it can transition downward, spitting out photons in the process.

It may make **any** allowed transition that jumps between energy levels.

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.
- “Nature does not make change

... 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? (For reference: the visible range is 1.6-3.2 eV.)

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!

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.)

Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV. What does the 5000 K object do?

A: Emit light of a broad range of wavelengths

B: Absorb light of a broad range of wavelengths

C: Emit light made of 3 and 5 eV photons

D: Absorb light made of 3 and 5 eV photons

Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV. What could this cloud of gas do?

A: Emit light of a broad range of wavelengths

B: Absorb light of a broad range of wavelengths

C: Absorb photons with at least 2 eV of energy

D: Absorb photons of 2, 3 and 5 eV, and allow the rest to pass

Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV, and then look at the energies of the photons that come out the other side.

A: Photons with energy 3 and 5 eV

B: Photons with energy 2, 3, and 5 eV

C: Photons of a wide range of energies, *except* 3 and 5 eV

D: Photons of a wide range of energies, *except* 2, 3, and 5 eV

Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV, and then separate its light by color. (Assume that I am a bird and can see ultraviolet light.)

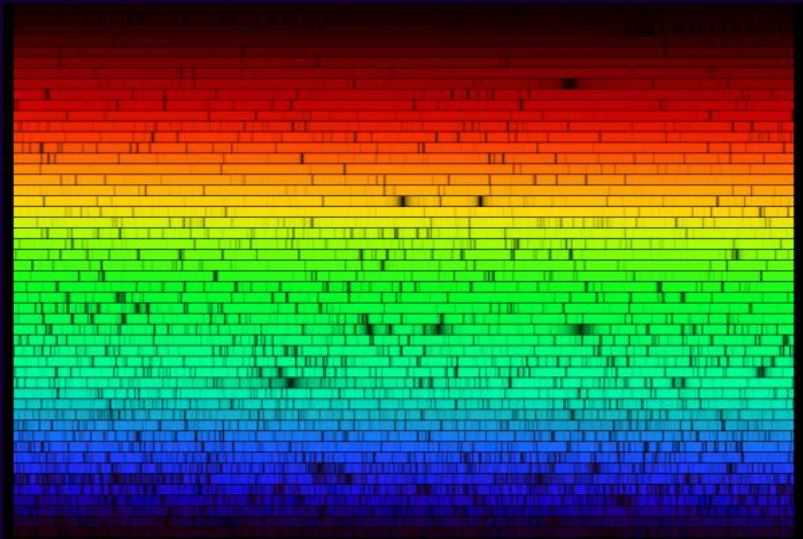
What would I see?

A: Only two bright lines

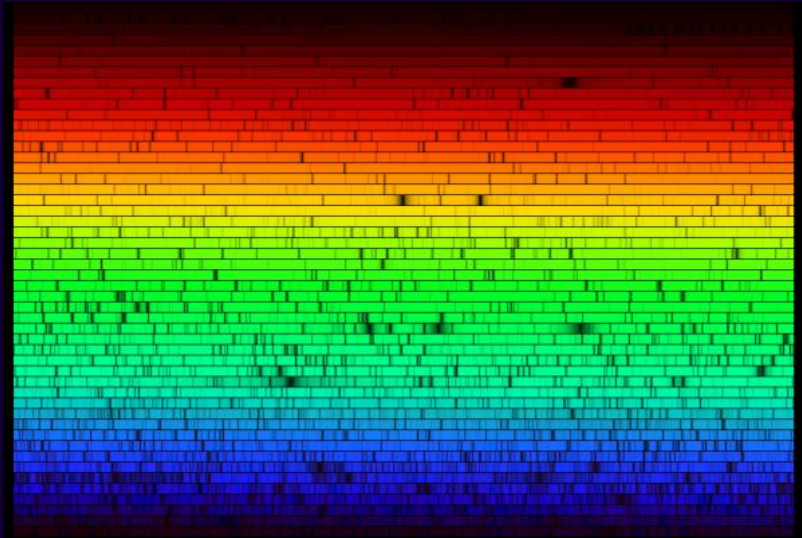
B: Only three bright lines

C: A solid band of color, but with two dark lines

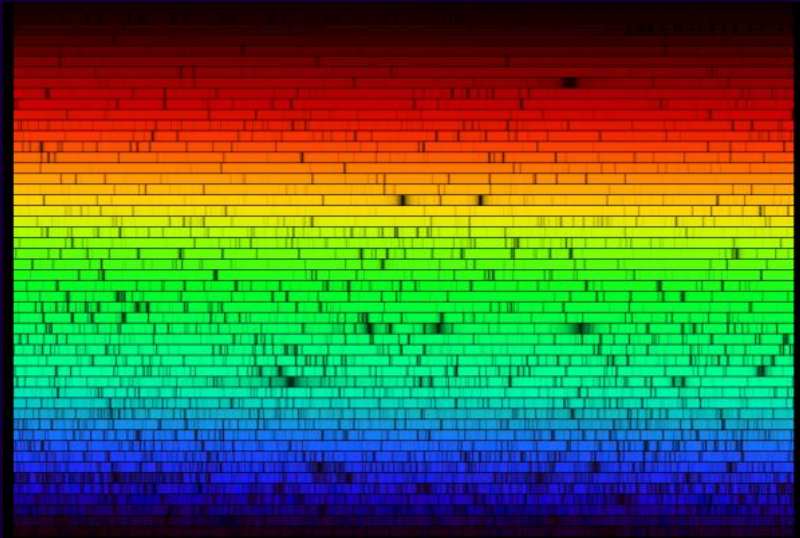
D: A solid band of color, but with three dark lines



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This picture tells us what's in the Sun!

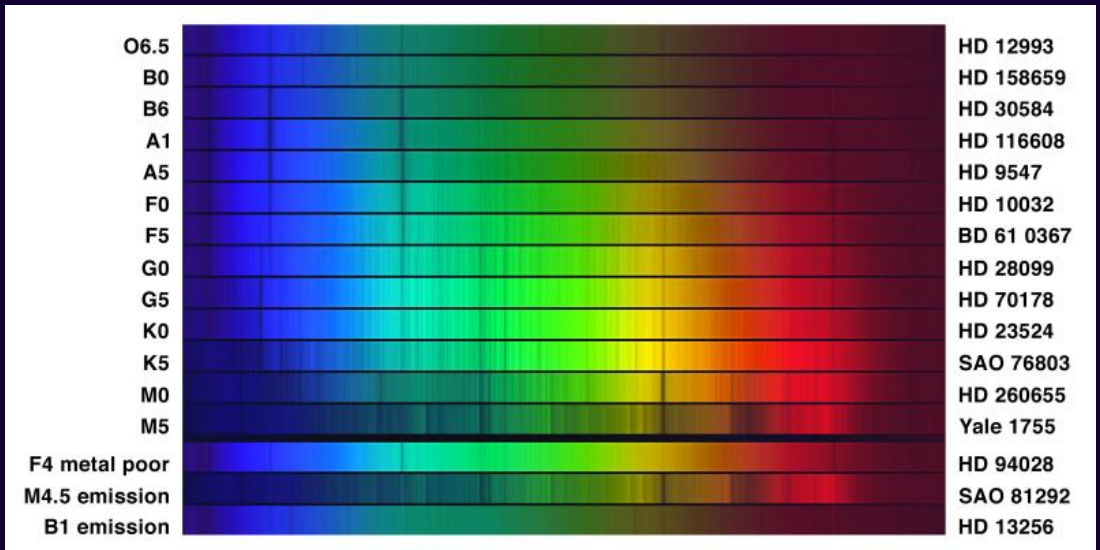
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

A: Something about quantum mechanics is different in the Sun

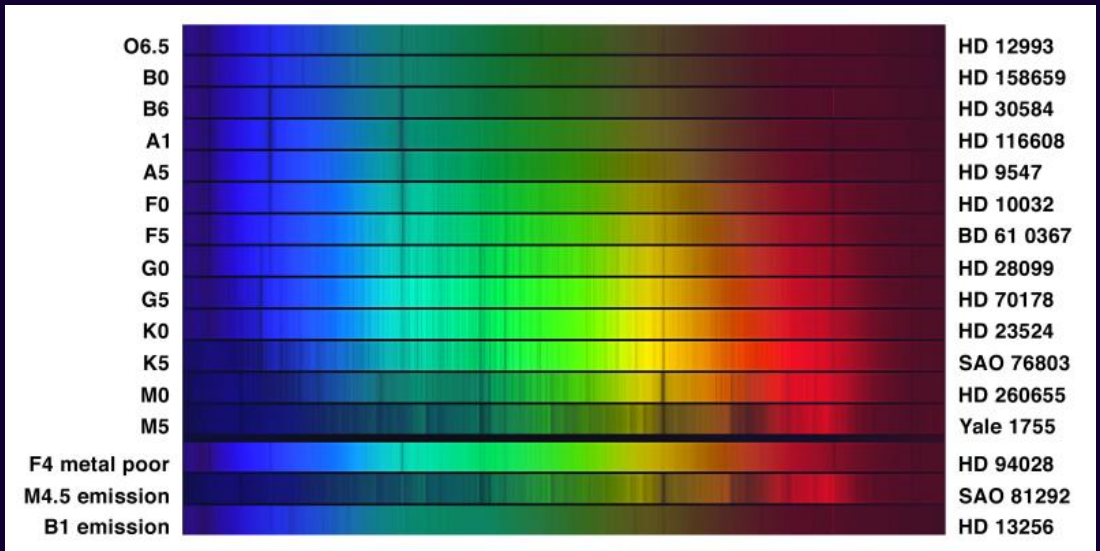
B: Something about light is different in the Sun

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



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



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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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We're very lucky that atomic transitions happen to lie in our visual range!

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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.)



