INTRODUCTION

Prerequisite Knowledge

- Familiarity with the topics of continuous, emission, and absorption spectra
- Know that electromagnetic waves can have a large range of possible wavelengths
- Know that different types of electromagnetic waves have different wavelengths
- Know that visible light is a type of electromagnetic wave

Goals

- Understand which types of objects produce continuous, emission, and absorption line spectra
- Understand why we observe an absorption line spectrum when looking at the Sun (and other stars)

Pre-activity Question

1) Which of the following spectra is produced by the Sun?
   a) **dark line absorption spectrum**
   b) bright line emission spectrum
   c) continuous spectrum

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Figure Discussion

The figure depicts a schematic representation of possible spectral analysis scenarios. The spectra are intentionally shown as resulting from three distinct sources.

1) **[Continuous spectrum]**

   Questions 1, 2, and 3 check student factual knowledge regarding spectra. The figure is supplied to help students with visualizing the physical situations that produce continuous, emission, and absorption line spectra.

2) **[Emission spectrum]**

3) **[A continuous spectrum of light from a hot dense source passes through a low density cloud where individual wavelengths of light are absorbed, the emitted light form the cloud then passes through a prism.]**

4) **[The missing light was absorbed by the cloud.]** Light passing through the low density cloud interacts with the molecules and atoms in the cloud. As a result, only very specific wavelengths of light will be absorbed by the cloud, depending upon the molecules and atoms present in the cloud.

   The absorbed light is re-emitted in every direction. So only a very much smaller fraction of the absorbed light reaches the prism, this is why the relative intensities at the absorbed wavelengths appear darker than the rest of the spectrum.

5) **[Absorption spectrum]** Since the Sun has a low-density gaseous atmosphere surrounding a hot, dense core, it is similar to the bottom scenario shown in the figure. So, light that was emitted from the core would have some of its light absorbed by the atmosphere, creating an absorption spectrum.

6) **[Continuous spectrum]** If a star only had a hot, dense core, but not the atmosphere, then it would be similar to the top scenario in the figure. So the light emitted from the hot, dense core would create a continuous spectrum.

7) **[Student 1 is correct]** Student 2 incorrectly defines the role that the Moon's surface will play in reflecting sunlight. Student 1 correctly identifies moonlight as reflected sunlight, and light from the Sun has already been identified as forming an absorption spectrum.

   Student 1's answer is intentionally written to sound more compelling to help those students inclined toward Student 2's pre-instructional thinking. Note that the Moon is treated as a perfect reflector for this problem.

8) **[Spectrum #1 top, Spectrum #2 bottom]** Spectrum #2 shows more absorption lines, implying that the light has passed through both the Sun's atmosphere and Earth's atmosphere.

   This question serves as a last check to establish whether students can reason about the physical situation that produces an absorption spectrum.

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INTRODUCTION

Prerequisite Knowledge

- Basic familiarity with the EM spectrum, including the names, relative (not actual values, just comparative) wavelengths, frequencies and energies of the different forms of light
- Basic understanding of the Bohr model of the atom
- Basic understanding of how energy level transitions are related to absorption and emission of light

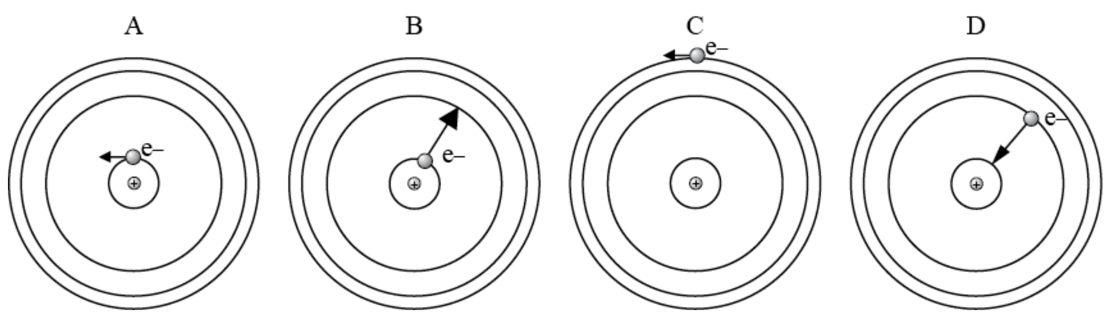
Goals

- Be able to reason about what occurs in the atom when different forms of light are absorbed or emitted
- Be able to reason about situations involving how atoms and electrons are related to the lines found in emission and absorption spectra
- Practice estimation and analytical reasoning skills

Pre-activity Question

1) Energy is released from atoms in the form of light when electrons
   a) **move from high energy levels to low energy levels.**
   b) move in their orbit around the nucleus.
   c) move from low energy levels to high energy levels.
   d) are emitted by the atom.
   e) are absorbed by atoms.

Use the drawings below to answer the next two questions.



2) Which drawing (not to scale) represents the process by which an absorption line is formed?
   [B]

3) Which drawing (not to scale) represents the process by which an emission line is formed?
   [D]

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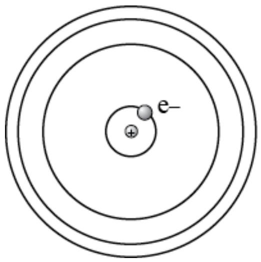
1) 

Students may incorrectly draw the spacing between the energy levels. Many students also confuse the ground energy level with the outer most energy level. Don't worry about this because this will be confronted in the following questions, and they will be asked to redraw it in Question 10.

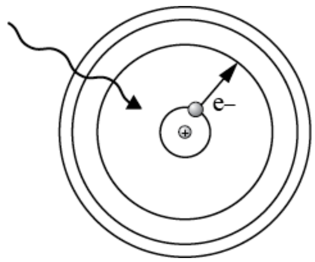
2) **[No]** For an atom to emit light an electron has to move from a higher energy level to a lower energy level. If all of the atom's electrons are in the ground state, they are all in the lowest energy level, so none of the electrons can move down to a lower energy level and therefore the atom cannot not emit light.

3) **[Case B]** The amount of energy a photon emitted by an atom will have is directly related to the difference in energy of the high and low energy levels that the electron moves between. Since there is a greater difference between the third exited state and the ground state than there is between the first exited state and the ground state, the energy emitted in Case B will be greater.

4) **[Student 2]** Student 1 correctly thinks that the electron energy levels get progressively larger and larger the farther away they are from the atom's nucleus; however, it is Student 2 who correctly states that the distance/spacing between the energy levels gets smaller the further away they are from the nucleus. More energy is required to move the electron up one energy level the closer it is to the nucleus—moving from the ground state requiring the most—so the farther away the electron is, the less energy it requires to move up one energy level, which is represented by showing the orbits closer and closer together as you get farther and farther away from the nucleus.

5) **[Absorption spectrum]** Since the cloud of gas is diffuse and relatively cool, the electrons in the atoms of the gas are in the lowest possible energy state. This means that as the photons of light from the solid, glowing-hot object pass through the cloud, the electrons in the cloud can absorb some of the photons. Also, only particular photons, of a particular wavelength or color, can be absorbed by the electrons since there are only particular distances—or energy level transitions—between the energy levels that the electron can move. Since those photons are absorbed in the cloud, they are absent from the light that passes through the cloud causing an absorption spectrum to be detected.

6)

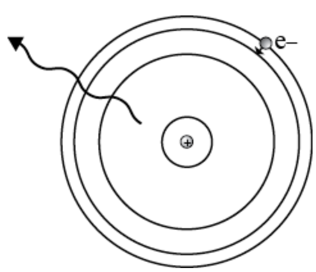


Since this is supposed to represent an atom in a gas cloud that is absorbing light, the squiggly arrow is showing the photon entering (being absorbed by) the atom, and the straight arrow is showing the electron moving from a lower energy level to a higher energy level.

Many students confuse the movement of the electron with the absorption of the photon, and will draw an electron in a higher energy level with an arrow pointing to a lower energy level (representing emission). Asking these students to identify which circles represent the greatest energy and whether going from a lower energy to a higher energy would require a photon to be absorbed or emitted from the atom will typically help get students back on track. It is not necessary that students label the electron.

7) **[Emission spectrum]** Since the neon gas is getting energy from the electricity the sign is plugged into, the electrons in the atoms of the neon gas are continually being moved into higher energy levels further away from the nucleus. However, the electrons can't stay at these higher energy levels indefinitely, so they drop down to lower energy levels and emit a photon in the process. Only particular photons, of a particular wavelength or color, can be emitted by the atoms since there are only particular distances—or differences between energy levels — that the electron can move. For neon, the dominant wavelengths of the photons emitted are at the red end of the spectrum, so the "OPEN" sign appears red.

8)

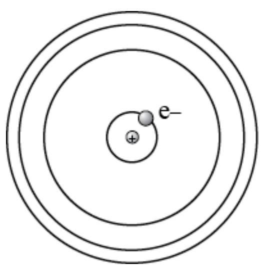


Since this is supposed to represent an atom in a neon sign causing an emission spectrum, the straight arrow is showing the electron moving from a higher energy level to a lower energy level, and the squiggly arrow shows the photon leaving (being emitted by) the atom.

Many students confuse the movement of the electron with the emission of the photon, and will draw an electron in a lower energy level with an arrow pointing to a higher energy orbit (representing absorption). Asking these students to identify which circle represents the least energy and whether going from a high energy to a lower energy would require a photon to be absorbed or emitted from the atom will typically help get students back on track. It is not *necessary that students label the electron. In addition, note that the straight arrow in this figure is located between the highest two energy levels, indicating a photon with lower energy would be emitted, to represent the red light of the neon sign. Students should not be expected to accurately represent a transition for red light at this point. Questions 9-11 will help students better understand the relationship between the colors of photons being absorbed and emitted by atoms and the energy differences between levels of transition of the electron.*

9) **[Student 2 is correct]** Student 1 incorrectly thinks that when you electrify a gas all colors of light are emitted causing white light—or a continuous spectrum. However, a continuous spectrum is emitted from solid, hot objects, as was stated in Question 5. Student 2 correctly thinks that the gas in the sign must be different than neon so that the electrons in the different gas are moving between energy levels that are different distance apart than they are in neon. Student 2 also correctly thinks that this different distance between energy levels must be bigger in the gas that is causing the "OPEN" sign to be yellow instead of red. Since yellow light has more energy than red light, the electrons in the yellow "OPEN" sign would have to move between energy levels of a greater distance to emit mainly yellow photons.

10)



11) a) **[D]** Violet light is high-energy visible light and since this question states that the light is absorbed we would look for the case in which the electron moves the greatest distance from its initial energy state, outward to a higher energy level (absorption).

Students may have difficulty deciding between B and D, not taking into consideration that violet light is high-energy light so they should choose the one that has the electron moving the greater distance. Students may also confuse the direction of motion of the electron with the absorption or emission of the photon, so they may choose C or E instead of D. For students struggling with the direction of the change in energy level, ask them to turn back to their drawing in Question 6 to verify which direction the straight arrow was pointing.

b) **[C]** Blue light is high-energy visible light and since this questions states that the light is emitted we would look for the case in which the electron moves the greatest distance from its initial energy state, toward the nucleus to a lower energy level (emission).

Students may have difficulty deciding between C and E, not taking into consideration that blue light is high-energy light so they should choose the one that has the electron moving the greater distance. Students may also confuse the direction of motion of the *electron with the absorption or emission of the photon, so they may choose B or D instead of C. For students struggling with the direction of the change in energy level, ask them to turn back to their drawing in Question 8 to verify which direction the straight arrow was pointing.*

c) **[B]** Since we used choice "D" for part "a" of this question, and are now dealing with the absorption of green light, the only other choice showing absorption is "B". And since the difference in energy levels for choice "B" is less than choice "D" it is consistent that green light would be absorbed rather than violet as was the case in part "a"**.**

Students may have difficulty deciding between B and D, not taking into consideration that green light has lower energy than violet light so they should choose the one that has the electron moving the shorter distance. Students may also confuse the direction of motion of the electron with the absorption or emission of the photon, so they may choose C or E instead of B. For students struggling with the direction of the change in energy level, ask them to turn back to their drawing in Question 6 to verify which direction the straight arrow was pointing.

d) **[E]** Since we used choice "C" for part "b" of this question, and are now dealing with the emission of orange light, the only other choice showing emission is "E". And since the difference in energy levels for choice "E" is less than choice "C" it is consistent that orange light would be emitted rather than blue as was the case in part "b"**.**

Students may have difficulty deciding between C and E, not taking into consideration that orange light has less energy than blue light so they should choose the one that has the electron moving the shorter distance. Students may also confuse the direction of motion of the electron with the direction of motion of the photon, so they may choose B or D instead of E. For students struggling with the direction of the change in energy level, ask them to turn back to their drawing in Question 8 to verify which direction the straight arrow was pointing.

e) **[A]**

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