

Energy Levels and Atomic Spectra

Student Worksheet

Answer the following questions during or after your study of energy levels and atomic spectra.

1. Compare (as quantitatively as possible) the peak wavelength and total intensity emitted by an object at 300 K and an object at 150 K.
2. Approximately what temperature must a blackbody be to have its peak wavelength in the visible part of the electromagnetic spectrum?
3. How much energy does a single photon of radio waves carry? The wavelength of the radio wave in a vacuum is 2.00 m.
4. Why does an electron in the second energy level have more energy than one in the ground state, according to the Bohr model of the atom?
5. Why does an electron in neutral Lithium (atomic number = 3) have less energy than an electron in doubly ionized Lithium?
6. In a particular atom, an electron moves from $n = 3$ to the ground state ($n = 1$), emitting a photon with frequency 5.2×10^{15} Hz as it does so. What is the difference in energy between $n = 3$ and $n = 1$ in this atom?
7. What transitions correspond to the Balmer series? The Lyman series? The Paschen series?
8. Why does a molecule often have more energy levels associated with it than a single atom?
9. What are the three types of spectra, and how are they each produced?
10. Why do most stars produce absorption spectra?
11. Besides using the peak wavelength emitted in its blackbody curve, how can a star's spectrum tell you its temperature?
12. Which is hotter, a B star or a K star?
13. What does a red-shift in a spectrum indicate?
14. What does a magnetic field do to a spectra line? What is this called?

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Teacher Notes

This worksheet is intended to accompany the Energy Levels and Atomic Spectra PowerPoint (Energy Levels and Atomic Spectra.pptx) created as part of Haystack Observatory's RET project on Physics and MOSAIC. The PowerPoint can be used as an in-class presentation, but also could be re-envisioned as a Webquest-type activity of self-directed learning.

1. Compare (as quantitatively as possible) the peak wavelength and total intensity emitted by an object at 300 K and an object at 150 K.

Because $\lambda_{\text{max}} \sim 1/T$, the 150 K object will have a peak wavelength that is double the 300 K object. Because Intensity $\sim T^4$, the 300 K object will emit $(300/150)^4$ or 2^4 or 16 times more total energy than the 150 K object.

2. Approximately what temperature must a blackbody be to have its peak wavelength in the visible part of the electromagnetic spectrum?

The temperature should be approximately the same temperature as the surface of the sun, or in the 5000 K range. This is obtained by comparison with the blackbody curves included in the power point lesson, or by simple comparison with the sun.

3. How much energy does a single photon of radio waves carry? The wavelength of the radio wave in a vacuum is 2.00 m.

$$E = hf = hc/\lambda = (6.626 \times 10^{-34})(3.0 \times 10^8)/2.00 = \mathbf{9.94 \times 10^{-26} \text{ J}}$$

4. Compare the average position of an electron relative to the nucleus in the ground state with an electron in a higher energy level in the Bohr model of the atom.

The electron in the ground state is a location that is closer to the nucleus, and therefore, more stable. Electrons in higher energy states are further from the nucleus and are therefore less tightly bound to the nucleus.

5. Why does an electron in neutral Lithium (atomic number = 3) have less energy than an electron in doubly ionized Lithium?

In neutral Lithium, there are two other electrons in the atom besides the one in question. Thus, while the electron is attracted to the nucleus, it is repelled by the other electrons, resulting in less energy than in ionized Lithium, where the attraction is the only force in question.

6. In a particular atom, an electron moves from $n = 3$ to the ground state ($n = 1$), emitting a photon with frequency 5.2×10^{15} Hz as it does so. What is the difference in energy between $n = 3$ and $n = 1$ in this atom?

Change in energy = energy of photon emitted

$$\Delta E = hf = (6.626 \times 10^{-34})(5.2 \times 10^{15}) = \mathbf{3.4 \times 10^{-18} \text{ J}}$$

7. What transitions correspond to the Balmer series? The Lyman series? The Paschen series?
Balmer series: electrons between $n = 2$ and higher in atomic hydrogen. Lyman series: electrons between $n = 1$ and higher in atomic hydrogen. Paschen series: electrons between $n = 3$ and higher in atomic hydrogen.
8. Why does a molecule often have more energy levels associated with it than a single atom?
In addition to having electrons that can exist in excited energy states, molecules have additional modes of excitement, including oscillations of the atoms that make up the molecule and rotations of the molecule as a whole.
9. What are the three types of spectra, and how are they each produced?
Continuous spectra: are produced by luminous, dense gases or liquids.
Emission spectra: are produced by rarefied luminous gas.
Absorption spectra: are produced by cool gases illuminated by another source.
10. Why do most stars produce absorption spectra?
The centers of stars produce a lot of energy in the form of a continuous spectrum. This light then passes through the outer atmosphere of the star, introducing some absorption lines as the cool(er) gas absorbs some specific frequencies corresponding to its chemical composition.
11. Besides using the peak wavelength emitted in its blackbody curve, how can a star's spectrum tell you its temperature?
By analyzing the strength of various lines in a spectrum, you can infer the temperature. For example, molecules only exist in relatively cool gases, since when a gas gets very warm, there is too much energy for the atoms to remain chemical bonded to each other in the form of molecules. Also, if you consider the Balmer series of hydrogen (corresponds to transitions between $n = 2$ and higher energy levels), the lines should only be visible when a gas is warm enough to excite electrons to the second energy level but not so warm as to completely ionize the atoms and separate the electrons from their protons. By comparing the strength of different lines corresponding to different elements, a temperature can be determined with fairly high accuracy.
12. Which is hotter, a B star or a K star?
B is hotter, since it comes first in the O B A F G K M scheme.
13. What does a red-shift in a spectrum indicate?
Red-shift indicates that the spectrum of an astronomical object has been shifted towards longer wavelengths (lower frequencies) due to the relative, radial motion between the source (the astronomical object) and the observer (us, on Earth). This means, in the vast majority of cases, that the object is moving away from us.
14. What does a magnetic field do to a spectra line? What is this called?
A magnetic field causes the spectral lines to split due to small changes in the energy associated with different spins of the electrons occupying each energy state. This is called the Zeeman effect.