Lesson 3 - Radiation and Spectroscopy

READING ASSIGNMENT

- Chapter 3.1: Information from the Skies
- Chapter 3.2: Waves in What?
- Chapter 3.3: The Electromagnetic Spectrum
  - Discovery 3-1: The Wave Nature of Radiation
- Chapter 3.4: Thermal Radiation
  - More Precisely 3-1: The Kelvin Temperature Scale
  - More Precisely 3-2: More About the Radiation Laws
- Chapter 4.1: Spectral Lines
- Chapter 4.2: Atoms and Radiation
- Chapter 4.3: The Formation of Spectral Lines
  - More Precisely 4-1: The Hydrogen Atom
  - Discovery 4-1: The Photoelectric Effect
- Chapter 4.4: Molecules
- Chapter 3.5: The Doppler Effect
  - More Precisely 3-3: Measuring Velocities with the Doppler Shift
- Chapter 4.5: Spectral-Line Analysis

KIRCHOFF'S LAWS

Read Chapter 4.1.

Kirchhoff's First Law

A luminous solid or liquid, or a sufficiently dense gas, emits light of all wavelengths and so produces a *continuous spectr*um of radiation.

Kirchhoff's Second Law

A low-density, hot gas emits light whose spectrum consists of a series of bright *emission lines* that are characteristic of the chemical composition of the gas.

Kirchhoff's Third Law

A cool, thin gas absorbs certain wavelengths from a continuous spectrum, leaving dark *absorption lines* in their place, superimposed on the continuous spectrum. Once again, these lines are characteristic of the composition of the intervening gas—they occur at precisely the same wavelengths as the emission lines produced by that gas at higher temperature.

SUMMARY OF ABSORPTION AND EMISSION LINE SERIES OF THE HYDROGEN ATOM

Read Chapter 4.2, Chapter 4.3, and More Precisely 4-1.

Lyman series

- Lyman alpha (Lyα)
  - 1^{st} excited state $\leftrightarrow$ ground state
  - 10.2 eV or 121.6 nm photon
- Lyman beta (Lyβ)
  - 2^{nd} excited state $\leftrightarrow$ ground state
  - 12.1 eV or 102.6 nm photon
- Lyman gamma (Lyγ)
  - 3^{rd} excited state $\leftrightarrow$ ground state
  - 12.8 eV or 97.3 nm photon
- ...
- Lyman limit
  - Ionization $\leftrightarrow$ ground state
  - 13.6 eV or 91.2 nm photon
- These are all ultraviolet photons.

Balmer series

- Blamer alpha (Hα)
  - 2^{nd} excited state $\leftrightarrow$ 1^{st} excited state
  - 1.9 eV or 656.5 nm photon
- Balmer beta (Hβ)
  - 3^{rd} excited state $\leftrightarrow$ 1^{st} excited state
  - 2.6 eV or 486.3 nm photon

- Balmer gamma (Hγ)
  - 4^{th} excited state $\leftrightarrow$ 1^{st} excited state
  - 2.9 eV or 434.2 nm photon
- ...
- Balmer limit
  - Ionization $\leftrightarrow$ 1^{st} excited state
  - 3.4 eV or 364.7 nm photon
- These are almost all visible photons.

Paschen series

- Pashen alpha (Paα)
  - 3^{rd} excited state $\leftrightarrow$ 2^{nd} excited state
  - 0.7 eV or 1875.6 nm photon
- Pashen beta (Paβ)
  - 4^{th} excited state $\leftrightarrow$ 2^{nd} excited state
  - 1.0 eV or 1282.2 nm photon
- Pashen gamma (Paγ)
  - 5^{th} excited state $\leftrightarrow$ 2^{nd} excited state
  - 1.1 eV or 1094.1 nm photon
- ...
- Pashen limit
  - Ionization $\leftrightarrow$ 2^{nd} excited state
  - 1.5 eV or 820.6 nm photon
- These are all infrared photons.

Other Series

- Brackett series ($\leftrightarrow$ 3^{rd} excited state), Pfund series ($\leftrightarrow$ 4^{th} excited state), Humphreys series ($\leftrightarrow$ 5^{th} excited state), etc., are all infrared through radio photons.
- Beyond Humphries, these series are increasingly difficult to measure and do not even have names.

MATH NOTES

Waves

Read Chapter 3.1, Chapter 4.2, and Discovery 4-1.

- Wavelength
  - Denoted λ (Greek letter lambda)
  - Measured in meters
- Wave period
  - Denoted P
  - Measured in seconds
- Wave frequency
  - Denoted ν (Greek letter nu)
  - Measured in Hertz (or Hz) = s^{-1}
  - $\nu = 1/P$
- Wave energy
  - Denoted E
  - Measured in Joules (or J) = kg $\times$ m^2 / s^2
  - E is proportional to ν
  - For light
    * h = Planck's constant

$$E = h\nu \tag{1}$$

- Wave speed
  - Denoted v
  - v = $\lambda \times \nu$
  - For light, v = c. Solving for λ and ν yields the following equations.

$$\lambda = \frac{c}{\nu} \tag{2}$$

$$\nu = \frac{c}{\lambda} \tag{3}$$

Wein's Law

Read Chapter 3.4, More Precisely 3-1, and More Precisely 3-2.

- λ_{peak} = wavelength at which blackbody emits most of its radiation
- T = temperature of blackbody

- λ_{peak}= 2.9 mm / (T / 1 K)
- For stars, λ_{peak} is usually measured in nm and T in 1,000s of K. Hence, you might find this, equivalent, form of Wein's law easier to use.

$$\lambda_{\text{peak}} = \frac{2900 \text{ nm}}{(T/1,000 \text{ K})} \tag{4}$$

Stefan's Law

Read Chapter 3.4, More Precisely 3-1, and More Precisely 3-2.

- F = energy flux (energy emitted per unit area and per unit time) of blackbody
- T = temperature of blackbody
- σ (Greek letter sigma) = Stefan-Boltzmann constant

$$F = \sigma T^4 \tag{5}$$

- **In this course, you will never need to use the Stefan-Boltzmann constant to solve a problem.**

Example: Person A has a fever and is 1.01 times hotter than Person B. The energy flux coming off of Person A is how many times greater than the energy flux coming off of Person B?

Solution: LetT_{A} and F_{A} be the temperature and energy flux of Person A. Let T_{B} and F_{B} be the temperature and energy flux of Person B. Then, $F_{\text{A}} = \sigma T_{\text{A}}^4$ and $F_{\text{B}} = \sigma T_{\text{B}}^4$. Dividing the latter equation into the former equation yields: $F_{\text{A}}/F_{\text{B}} = \sigma T_{\text{A}}^4/\sigma T_{\text{B}}^4 = (T_{\text{A}}/T_{\text{B}})^4 = 1.01^4 \approx 1.04$.

Notice that we did not need to know the constant of proportionality, in this case σ, to solve this problem. This is what is called a ratio problem. **Most of the math problems in this course are ratio problems.**

The Doppler Effect

Read Chapter 3.5, More Precisely 3-3, and Chapter 4.5.

- λ_{em} = emitted wavelength

- λ_{obs} = observed wavelength
- $\Delta\lambda$ = change in wavelength
- v = speed of source toward or away from observer
- v_{wave} = wave speed
- $\Delta\lambda/\lambda_{\text{em}} = v/v_{\text{wave}}$
- For light, $v_{\text{wave}} = c$. Solving for $\Delta\lambda$ yields the following.

$$\Delta\lambda = \left(\frac{v}{c}\right) \times \lambda_{\text{em}} \tag{6}$$

- If the source is moving toward you (or you are moving toward it), the observed wavelength is shorter than the emitted wavelength and hence the light is blueshifted.

$$\lambda_{\text{obs}} = \lambda_{\text{em}} - \Delta\lambda \tag{7}$$

- If the source is moving away from you (or you are moving away from it), the observed wavelength is longer than the emitted wavelength and hence the light is redshifted.

$$\lambda_{\text{obs}} = \lambda_{\text{em}} + \Delta\lambda \tag{8}$$

EXERCISE 5

To the human eye, there are red, orange, yellow, yellow-white, white, blue, and blue-violet stars. Why are there no green stars?

EXERCISE 6

Google[1] "Doppler effect applet" and experiment.

HOMEWORK 3

Download Homework 3 from WebAssign. Feel free to work on these questions together. Then submit your answers to WebAssign individually. Please do not wait until the last minute to submit your answers and please confirm that WebAssign actually received all of your answers before logging off.

[1] http://www.google.com/