# Light, Temperature, and Motion

## 1.1 Calculating wavelength and frequency

Example

What is the wavelength of a radio wave that has a frequency of 89.1 $MHz$ (note: 1 $MHz$ = 1,000,000 $Hz$)?

$$
\begin{aligned}
c &= \lambda f \\
\lambda f &= c \\
\lambda &= \frac{c}{f} \\
\lambda &= \frac{3.00 \,\mathrm{x}\, 10^8}{8.91 \,\mathrm{x}\, 10^7} \\
\lambda &= 3.367 \cdots \\
\lambda &= 3.37 \, meters
\end{aligned}
$$

We need to use frequency in $Hz$ (note: 89.1 $MHz$ = 89,100,000 $Hz$ = 8.91 x $10^7$ $Hz$) and the speed of light in $m/s$ (note: $c$ = 300,000,000 $m/s$ = 3.00 x $10^8$ $m/s$) to get the answer in meters (the standard unit of length in the metric system).

Example

What is the frequency of a microwave that has a wavelength of 2.15 $cm$ (note: 1 $cm = 0.01\ m$)?

$$\begin{aligned} c &= \lambda f \\ \lambda f &= c \\ f &= \frac{c}{\lambda} \\ f &= \frac{3.00 \, \text{x} \, 10^{8}}{2.15 \, \text{x} \, 10^{-2}} \\ f &= 1.395348 \, \text{x} \, 10^{10} \\ f &= 1.40 \, \text{x} \, 10^{10} \, Hz \end{aligned}$$

We need to use wavelength in *meters* (note: 2.15 $cm$ = 0.0215 $m$ = 2.15 x $10^{-2}$ $m$) and the speed of light in $m/s$ (note: $c$ = 300,000,000 $m/s$ = 3.00 x $10^{8}$ $m/s$) to get the answer in $Hz$ (the standard unit of frequency).

## 1.2 Blackbody Radiation and Surface Temperature

### 1.2.1 Kelvin Temperature

Believe it or not, temperature is related to how fast the atoms or molecules in an object are moving. The higher the temperature the faster they move. The Kelvin Temperature is a measure of the true temperature of an object. The Kelvin Temperature scale has no negative values and has a lowest possible temperature: Absolute Zero (the temperature where all atomic/molecular motion stops). The temperature scales you may be more familiar with: Fahrenheit and Celsius are related as follows

$$\mathrm{K} = {}^{\circ}\mathrm{C} + 273 = \frac{5}{9}\left({}^{\circ}\mathrm{F} - 32\right) + 273$$

In astronomy, and science in general, the Kelvin scale is used.

### 1.2.2 Surface Temperature T and $\lambda_m$

Example

What is the surface temperature of a star that shines most brightly at a wavelength 7.250 x $10^{-7}$ $m$ (725.0 $nm$)?

$$T = \frac{2.898 \,\mathrm{x}\, 10^6}{\lambda_m} = \frac{2.898 \,\mathrm{x}\, 10^6}{725.0} = 3,997.24\cdots = 3,997\,\mathrm{K}$$

Notice that this formula requires that the wavelength be in nanometers (1 $nm$ = 1 x $10^{-9}$ $m$).

Example

At what wavelength does a star shine most brightly if its surface temperature is 11,000 K?

$$\lambda_m = \frac{2.898 \,\mathrm{x}\, 10^6}{T} = \frac{2.898 \,\mathrm{x}\, 10^6}{11,000} = 263.454\cdots = 263.5\,nm = 2.635 \,\mathrm{x}\, 10^{-7}\,m$$

Notice again that the wavelength from this formula is output in $nm$.

## 1.3 Doppler Effect and Velocity

The formula in your textbook is an approximation to the true formula found below:

$$V = \frac{\left[\left(\frac{\lambda}{\lambda_0}\right)^2 - 1\right]}{\left[\left(\frac{\lambda}{\lambda_0}\right)^2 + 1\right]} c$$

<u>Example</u>
What is the speed, and direction of motion, of a galaxy if the measured wavelength of a specific spectral line from this galaxy is 339.84 $nm$ and the same spectral line here on Earth is measured to be 325.11 $nm$?

First calculate $\left(\frac{\lambda}{\lambda_0}\right)^2$

$$\left(\frac{\lambda}{\lambda_0}\right)^2 = \left(\frac{339.84}{325.11}\right)^2 = (1.0453)^2 = 1.0927$$

Now use this value to calculate the velocity...

$$V = \frac{[1.0927 - 1]}{[1.0927 + 1]}(300,000) = (0.044297)(300,000) = 13,289\, km/s$$

Wow! This galaxy is *really* moving! Notice that we used the speed of light in $km/s$ and that we got an answer in $km/s$. If instead we use the speed of light in $m/s$ then we would get a answer in $m/s$.

The fact that we got a positive speed tells us that this galaxy is moving away from us (at over 29,000,000 MPH!). A negative speed would indicate motion towards us. So we get two pieces of information from the Doppler effect: speed and direction of motion.