Molecular Thermodynamics
Week 1 Lecture Assessments
Energy Unit Conversions

December 11, 2013

`Thermovid_01_03`

A) Determine the energy, E, of a photon with a wavelength of 400 nm expressed in joules and in wavenumber units.

(a) 7.495×10^{-1} joules; 25,000 cm^{-1}
(b) 7.495×10^{-20} joules; 25,000 cm^{-1}
(c) 4.966×10^{-19} joules 12,500 cm^{-1}
(d) $\boxed{4.966 \times 10^{-19} \text{ joules; } 25{,}000 \text{ cm}^{-1}}$
(e) 4.966×10^{-17} joules; 25,000 cm^{-1}
(f) 4.966×10^{-17} joules; 50,000 s^{-1}

<u>Answers:</u>
A review from general chemistry: Electromagnetic energy is carried by discrete bundles of energy called photons. The energy, E, of a photon is given by

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

where ν is the frequency of light and h is Planck's constant (6.6261×10^{-34} J·s). The relationship between the speed of light, c, the frequency, ν, and the wavelength of the light, λ is

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

Combining (1) and (2), you can verify that

$$E = \frac{hc}{\lambda} \tag{3}$$

Equation (3) tells us that the energy of electromagnetic radiation is *inversely* proportional to its wavelength, λ. A quantity known as the wavenumber, $\tilde{\nu}$, is defined as $\tilde{\nu} = 1/\lambda$ such that

$$E = hc\tilde{\nu}. \tag{4}$$

Energy in wavenumbers is frequently expressed in cm^{-1} (*inverse* cm).

Therefore, to calculate the frequency, in Hertz, s^{-1}, we can directly convert from wavelength to frequency using (2), thus:

$$\nu = \frac{c}{\lambda} = \frac{1}{400 \text{ nm}} \left(\frac{10^9 \text{ nm}}{1 \text{ m}}\right) \left(\frac{2.998 \times 10^8 \text{ m}}{\text{s}}\right) = 7.495 \times 10^{14} \text{ s}^{-1}$$

Now we can use (1) to convert to joules:

$$E = h\nu = 6.626 \times 10^{-34}\text{J} \cdot \text{s} \left(\frac{7.495 \times 10^{14}}{\text{s}} \right) = 4.966 \times 10^{-19} \text{ J}$$

To convert to wavenumbers, we can simple convert nanometers to centimeters and take the inverse of the number:

$$400 \text{ nm} \left(\frac{10^{-7}\text{cm}}{\text{nm}} \right) = 4 \times 10^{-5} \text{ cm}$$

and therefore,

$$\bar{\nu} = \frac{1}{4 \times 10^{-5} \text{ cm}} = 25,000 \text{ cm}^{-1}$$