Using Raman Spectroscopy to Demonstrate Simple Harmonic Motion

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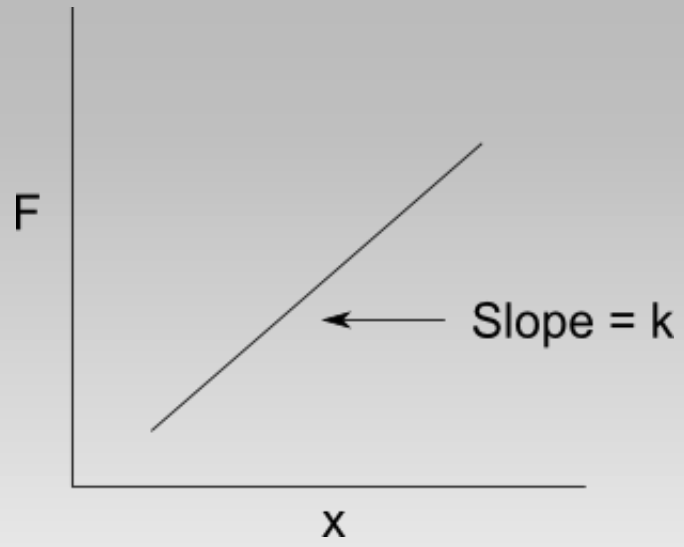
Current Simple Harmonic Motion Lab for Physics I

- Students measure the spring constant using a static measurement: $F = kx$



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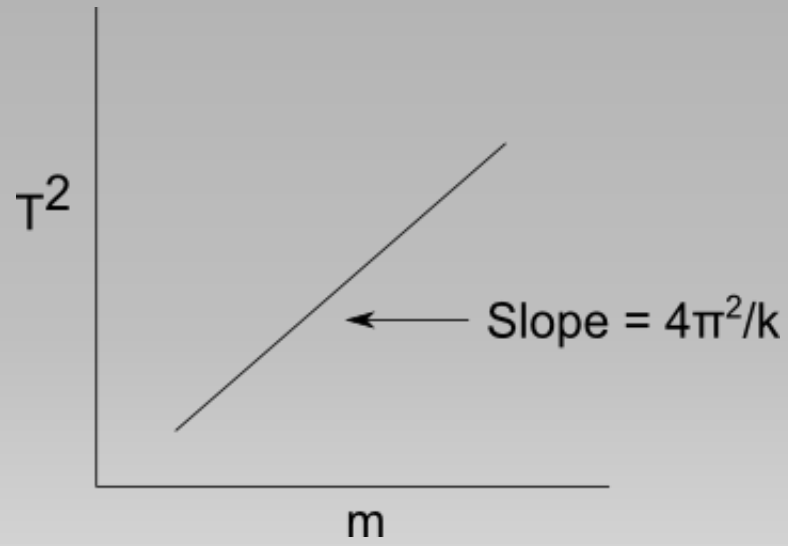
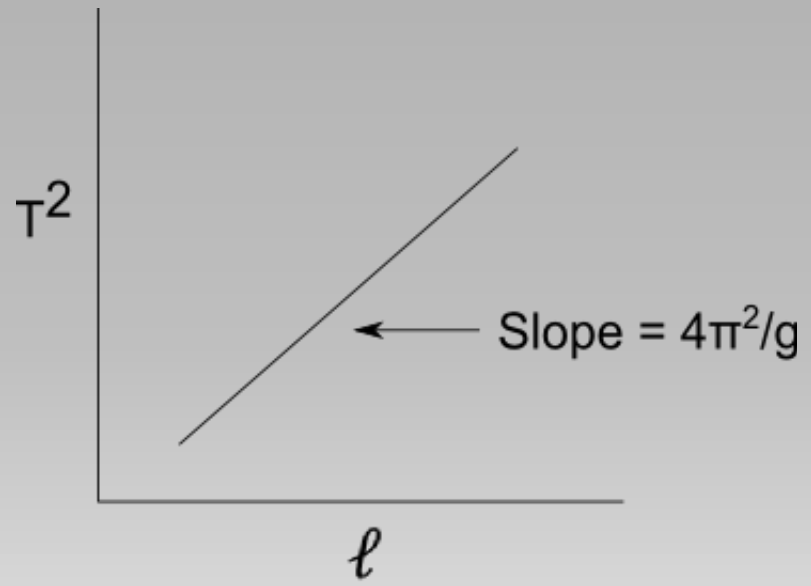
- Students measure the spring constant using periodic motion: $T = 2\pi\sqrt{\frac{m}{k}}$



- Compare the two values for the spring constant, k

- Students measure the gravitational acceleration using a pendulum: $T = 2\pi\sqrt{\frac{\ell}{g}}$



- Compare the value of g to 9.8 m/s^2

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Raman Spectroscopy

- Raman scattering is an inelastic scattering of an incident laser source by the molecular vibrations and rotations of the molecule.

- The scattered photons have lost energy and their frequencies correspond to the vibrational and rotational frequencies of the molecule.

Portable Raman Spectrometer

- SciAps Inspector 500
- 300 mW 1030 nm Class III laser
- 100 – 2500 cm^{-1} spectral range
- 8 – 10 cm^{-1} resolution

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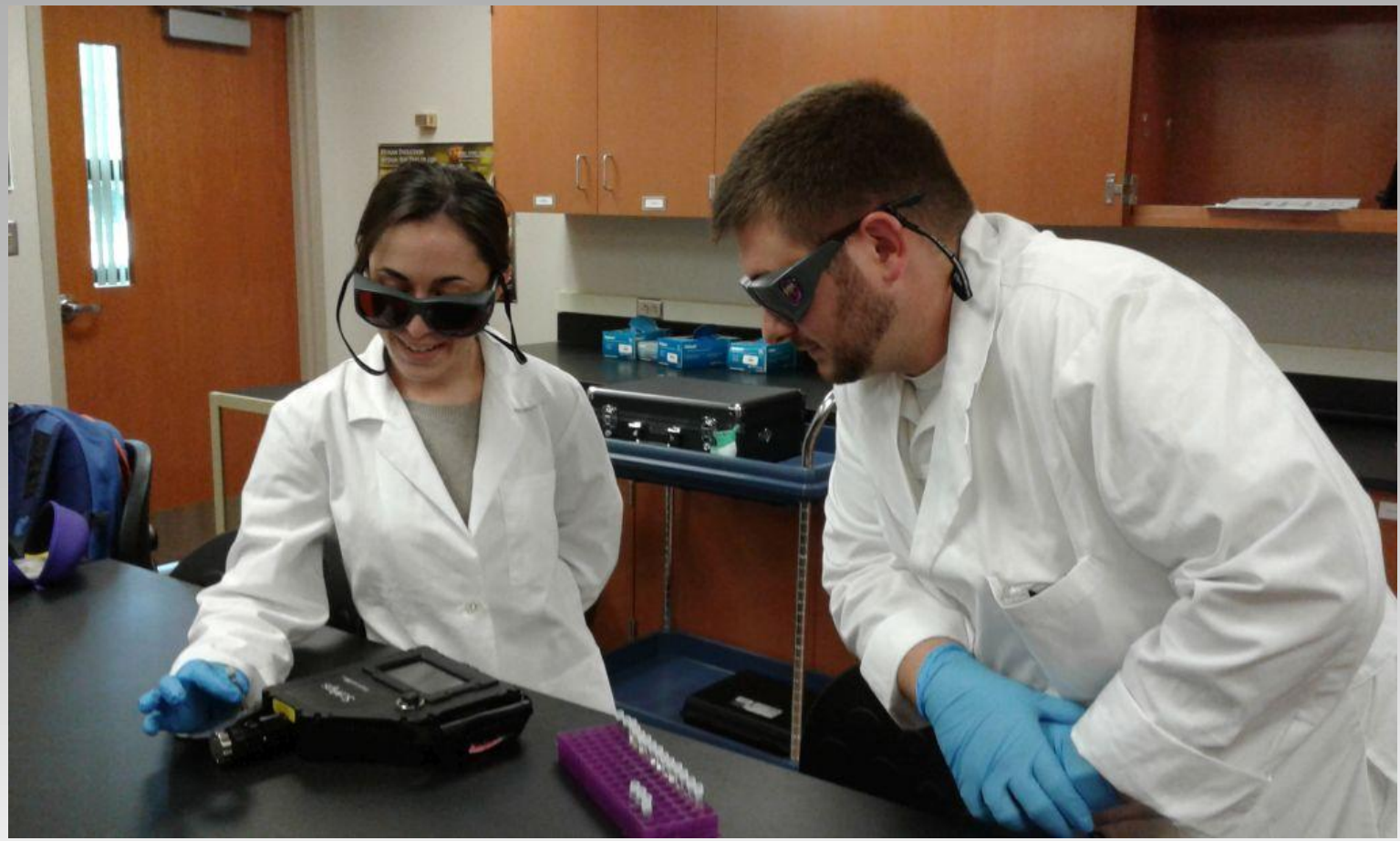
Simple Harmonic Motion with Carbon Bonds



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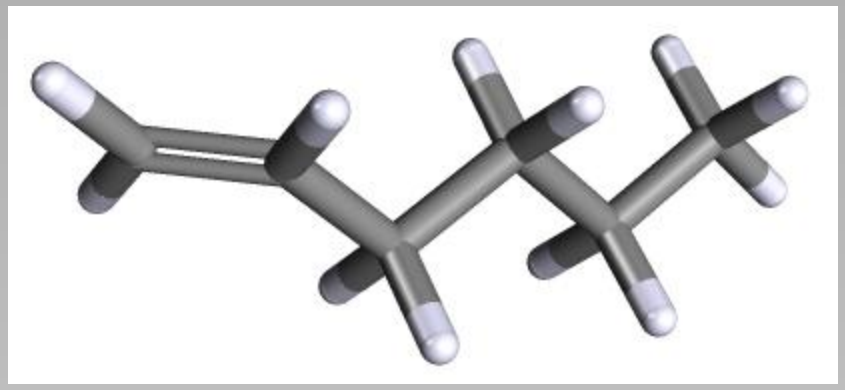
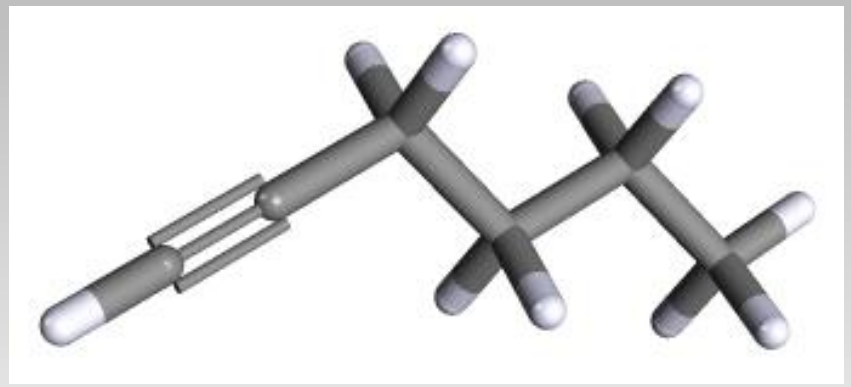
Molecules Containing Carbon-Carbon Single, Double and Triple Bonds

- 1-Hexene has one double bond and four single bonds



- 1-Hexyne has one triple bond and four single bonds



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Experimental Procedure

- Measure the spectra of 1-hexene and 1-hexyne.
- Copy the data from the Raman Spectrometer into an Excel spreadsheet template. The spreadsheet identifies the wavenumber of the single, double, and triple bonds.
- Calculate the spring constant for the different bonds.

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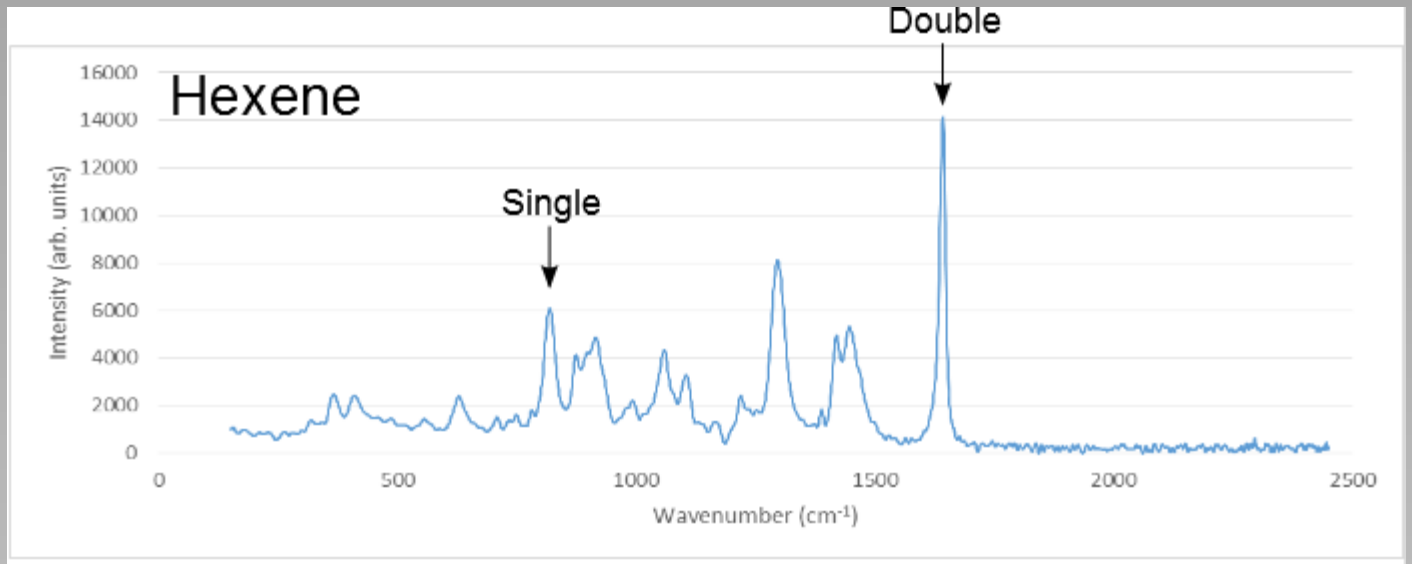

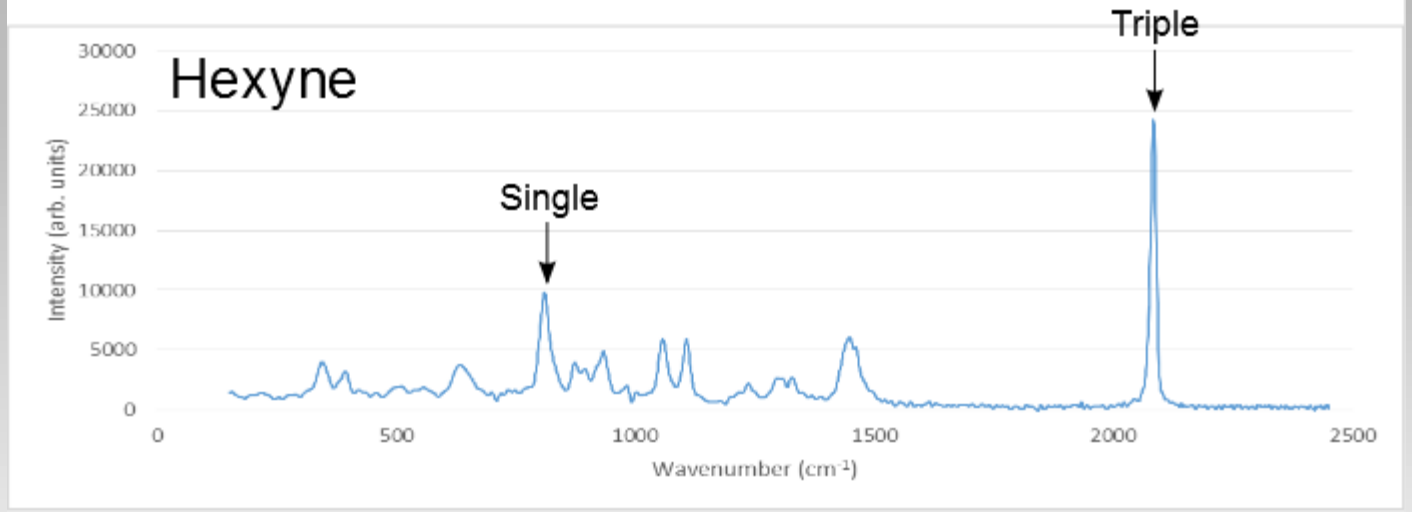

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Sample Calculation for the Single Bond of 1-Hexene

$T = 2\pi\sqrt{\frac{\mu}{k}}$, where $\mu = \frac{m_1 m_2}{m_1 + m_2}$ is the reduced mass

The oscillation is observed as an EM wave, so $T = \frac{\lambda}{c}$

Solve for k to get, $k = 4\pi^2 \mu c^2 \left(\frac{1}{\lambda}\right)^2$

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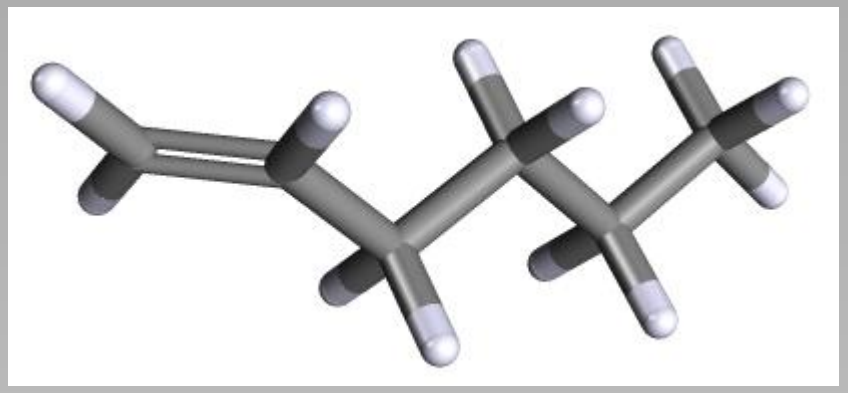
$$m_1 = (12 + 3 \times 1)\,\text{u} = 15\,\text{u}$$

$$m_2 = (12 \times 5 + 9 \times 1)\,\text{u} = 69\,\text{u}$$

$$\mu = \frac{(15)(69)}{15 + 69} = 12.3\,\text{u}$$



$$k = 4\pi^2(12.3\,\text{u})\left(1.66 \times 10^{-27}\,\frac{\text{kg}}{\text{u}}\right)\left(3 \times 10^8\,\frac{\text{m}}{\text{s}}\right)^2\left(818 \times 10^2\,\frac{1}{\text{m}}\right)^2$$

$$= \boxed{485\,\frac{\text{N}}{\text{m}}}$$

Experimental Design Challenges

- Smaller organic compounds would be simpler spring systems to analyze, however…
  - They are gases at room temperature
  - Gases give a weaker signal from the Raman spectrometer
- Challenges with using 1-hexene and 1-hexyne
  - Volatile solvents
  - Strong chemical smell
  - Either special handling or a hood required
- Raman spectrometer uses a Class III Laser which requires protective gear

Educational Outcomes

- Interdisciplinary approach to the study of springs
- Students get hands-on experience with a state-of-the-art instrument
- Learning experience for FCC's NSF interns
  - Developed the experimental protocol
  - Teaching assistants for the trial run of the experiment in Physics I

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