Outline of the Lecture

• Introduction to Raman Scattering

• Selection Rules for Raman Scattering: Vibrational and Pure Rotational

• Intensities of Raman Transitions
Spontaneous Raman Scattering

- Fixed Frequency Laser
- Photomultiplier or CCD Array
- Spectrometer
- Flame or Plasma
- Beam Dump

Species-specific, spatially resolved, quantitative, weak signal
Selection Rules for Vibrational Raman Scattering

\[ \Delta v = \pm 1, \ \Delta J = 0 \text{ or } \pm 2 \]

Vibrational Stokes
Q-branch \( \Delta J = 0 \)
Q(0) \rightarrow Q(1) \rightarrow Q(2) \rightarrow Q(3)

Vibrational Stokes S-branch \( \Delta J = +2 \)
S(0) \rightarrow S(1)

Vibrational Stokes O-branch \( \Delta J = -2 \)
O(2) \rightarrow O(3)

\( J_e \)
3
2
1
0

\( J_g \)
3
2
1
0
Vibrational Raman Scattering Spectrum - Low Temperature

\[ v_g = 0 \rightarrow v_e = 1 \]

Vibrational Stokes
Q-branch \( \Delta J = 0 \)

Vibrational Stokes
O-branch \( \Delta J = -2 \)

Vibrational Stokes
S-branch \( \Delta J = +2 \)
\[ \Delta v = -1, \ \Delta J = 0 \text{ or } \pm 2 \]
Vibrational Q-Branch Raman Scattering Spectrum - High Temperature

Vibrational Anti-Stokes
Q-branch $\Delta J = 0$

$\nu_e \rightarrow \nu_e - 1$

$1 \rightarrow 0$

$2 \rightarrow 1$

$3 \rightarrow 2$

Vibrational Stokes
Q-branch $\Delta J = 0$

$\nu_g \rightarrow \nu_g + 1$

$0 \rightarrow 1$

$3 \rightarrow 4$

$2 \rightarrow 3$

$1 \rightarrow 2$
Selection Rules: Pure Rotational Raman Scattering

$\Delta v = 0$, $\Delta J = 0$ or $\pm 2$

Pure Rotational S-branch $\Delta J = +2$

Pure Rotational O-branch $\Delta J = -2$

$S(0) \rightarrow S(1) \rightarrow S(2) \rightarrow S(3) \rightarrow O(2) \rightarrow O(3) \rightarrow O(4)$
Pure Rotational Raman Scattering Spectrum

Pure Rotational S-branch
$\Delta J = +2$

Pure Rotational O-branch
$\Delta J = -2$
Pure Rotational Raman Scattering Spectrum

For a rigid rotator, the frequencies of the pure rotational Raman S-branch transitions are given by,

\[
\frac{\varepsilon_i}{hc} + \tilde{\nu}_L = \tilde{\nu}_R + \frac{\varepsilon_f}{hc} \quad \Rightarrow \quad \tilde{\nu}_R = \tilde{\nu}_L + \frac{\varepsilon_i}{hc} - \frac{\varepsilon_f}{hc}
\]

\[
\tilde{\nu}_R = \tilde{\nu}_L + F(J) - F(J + 2) = \tilde{\nu}_L + BJ(J + 1) - B(J + 2)(J + 3)
\]

\[
\tilde{\nu}_R = \tilde{\nu}_L + BJ^2 + BJ - BJ^2 - 5BJ - 6B
\]

\[
\tilde{\nu}_R = \tilde{\nu}_L - 4BJ - 6B
\]

For the pure rotational Raman O-branch transitions,

\[
\tilde{\nu}_R = \tilde{\nu}_L + \frac{\varepsilon_i}{hc} - \frac{\varepsilon_f}{hc} = \tilde{\nu}_L + F(J) - F(J - 2)
\]

\[
\tilde{\nu}_R = \tilde{\nu}_L + BJ(J + 1) - B(J - 2)(J - 1)
\]

\[
\tilde{\nu}_R = \tilde{\nu}_L + BJ^2 + BJ - BJ^2 + 3BJ - 2B
\]

\[
\tilde{\nu}_R = \tilde{\nu}_L + 4BJ - 2B
\]
Pure Rotational Raman Scattering Spectrum

Pure Rotational
S-branch
$\Delta J = +2$

Pure Rotational
O-branch
$\Delta J = -2$


$O(2)$  $O(3)$  $O(4)$  $O(5)$  $O(6)$  $O(7)$  $O(8)$  $O(9)$  $O(10)$  $O(11)$
Intensities of Raman Transitions - Low Temperature

Intensities of Raman Transitions - High Temperature

Raman Temperature Measurements from Contour Fitting

Raman Temperature Measurements from Band Ratios

Raman Temperature Measurements from Stokes to Anti-Stokes Ratio

Raman Temperature, Multispecies Concentration Measurements

Raman Temperature, Multispecies Concentration Measurements
