Laboratory and observational studies of C$_{60}$ and C$_{60}^+$

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I. Motivations for studying C$_{60}$ and C$_{60}^+$

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III. Observational studies of C$_{60}$ with TEXES at IRTF

IV. Spectral studies of C$_{60}^+$
Motivations for Studying $C_{60}$ and $C_{60}^+$

- $C_{60}$ was discovered during experiments designed to simulate outflows of carbon stars.
- $C_{60}$ should be stable in the ISM ($\sim 44$ eV required to break cage).
- $C_{60}$ has been found in sediments related to meteorite impacts.
- $C_{60}$ has been found in LDEF craters.
- $C_{60}$ should be ionized by stellar radiation and “$C_{60}^+$ should be ubiquitously distributed in space.”

(Kroto *Science* 242, 1988)
About $C_{60}$

- $3(60)-6 = 174$ vibrational degrees of freedom
- Icosahedral ($I_h$) Symmetry: 6 five-fold axes, 10 three-fold axes, 15 two-fold axes

- Sixty quantum-mechanically indistinguishable (spin 0) bosons
- Symmetry restrictions on total wavefunction
IR Spectroscopy of C\textsubscript{60}

- 4 \( F_{lu} \) IR active modes \([1432, 1183, 577, 528 \text{ cm}^{-1}]\)
- Gas phase IR spectrum observed at 1065 K; no rotational structure resolved (Frum et al. *Chem. Phys. Lett.* 176, 1991)

A rotationally cold spectrum is required for comparison to interstellar spectra.
Gas Phase Spectral Studies of C$_6^0$

100 W halogen bulbs in copper tubing coil to preheat argon carrier gas.

150 W halogen bulbs to heat oven.

C$_6^0$ sample in oven.

Supersonic expansion adiabatically cools C$_6^0$.

Pressure $> 50$ mTorr. $T > 600$ °C gives vapor.

Argon gas to supersonic expansion.
CW Cavity Ringdown Spectroscopy

- A high finesse cavity is placed around the supersonic expansion.
- Radiation is coupled into the cavity, which is cycled in and out of resonance.
- When the cavity is on resonance the radiation is switched off.
- The exponential decay rate is a direct measurement of absorption.
Current State of the $C_{60}$ Experiment

- Sustained flow of gas phase $C_{60}$ achieved
- Optics for CW cavity ringdown at 1183 cm$^{-1}$ currently being assembled
- Direct absorption $N_2O$ spectrum obtained with a test QCL
Astronomical Spectroscopy of $C_{60}$

- Data obtained June 2003
- Upper limit $\sim 3 \times 10^{15} \text{ cm}^{-2}$
- Need laboratory spectrum!

NASA’s 3-meter IRTF (InfraRed Telescope Facility), Mauna Kea, Hawaii

TEXES: Texas Echelon Cross Echelle Spectrograph

Normalized Flux

Wavenumber [cm$^{-1}$]
Spectroscopy of C$_{60}^+$

The electronic and infrared spectra of C$_{60}^+$ were observed in neon and argon matrices.

(Fulara, Jakobi and Maier *Chem. Phys. Lett.* 211, 1993)

This was used as a basis for observational searches and two DIBs were attributed to C$_{60}^+$.

(Foing and Ehrenfreund *Nature* 369, 1994; *A&A* 319, 1997)
Is $C_{60}^+$ Really a DIB Carrier?

Criteria for these two DIBs to be $C_{60}^+$:
1. The same FWHM ✔
2. Matching relative intensities to lab spectra  ❓
3. Gas-matrix shifts consistent with experimental information  ❓

A gas phase $C_{60}^+$ spectrum is required to answer this question definitively.

“The case for $C_{60}^+$ is better than for many other [DIB] candidates and now rests in the court of laboratory spectroscopists.” (Jenniskens et al. A&A 327, 1997.)
Gas Phase Spectral Studies of $C_{60}^+$

150 W halogen bulbs to heat oven

$T > 600 \, ^\circ C$ gives vapor pressure $> 50 \, \text{mTorr}$

100 W halogen bulbs in a copper tubing coil to preheat argon carrier gas

Electrode at $-V$ gives a discharge for $C_{60}^+$ experiment

$Al_2O_3$ spacer & epoxy to seal and insulate

Supersonic expansion adiabatically cools $C_{60}$

$Ar$
Current State of the $C_{60}^+$ Experiment

- CW cavity ringdown achieved at 950 nm
- Discharge source built from high temperature materials and tested with $N_2/Ar$ and $C_{60}/Ar$
- Cold $N_2^+$ spectrum observed with $N_2/Ar$ discharge while heating gas and oven to > 600°C
- The search for the $C_{60}^+$ spectrum is underway
Cold $\text{N}_2^+$ Ions at High Resolution and Sensitivity

$\alpha_{\text{min}} \sim 2 \times 10^{-9} \text{ cm}^{-1}$

$T_{\text{rot}} = 21 \pm 5 \text{ K}$

FWHM = 0.011 cm$^{-1}$
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