Van-der-Waal Dimers in the KATRIN Windowless Gaseous Tritium Source

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The KArlsruhe TRItium Neutrino Experiment

aim: measurement of the neutrino mass with 0.2 eV/c² sensitivity (90% CL)

Tritium

\[
\begin{align*}
E_0 &= 18.6 \text{ keV} \\
\text{Helium-3}
\end{align*}
\]

\[
\begin{align*}
\text{Count rate (arb.)} \\
\text{Energy (keV)} \\
\text{E-E}_0 (\text{eV}) \\
\end{align*}
\]

\[
\begin{align*}
\text{m}_\nu &= 0 \text{ eV} \\
\text{m}_\nu &= 1 \text{ eV}
\end{align*}
\]
Tritium beta-decay

\[
\text{Tritium} \quad \text{Helium-3}
\]

\[
\text{n} \quad \text{e}^{-} \quad \nu_{e}
\]

\[
\text{p} \quad \text{p}
\]
Molecular tritium beta-decay

\[ T_2 \rightarrow \text{e}^- + ^3\text{He}^+ + T \]
Molecular tritium beta-decay

Fermi's golden rule:

\[ W_{i \rightarrow f} = \frac{2\pi}{\hbar} |\langle i | V | f \rangle|^2 \rho(E_f) \]

Beta spectrum depends on initial and final state distribution
Initial state distribution

Vibration

ortho/para $T_2$, $D_2$, $H_2$

Rotation

Temperature + pressure

Concentration

$T_2$

$DT$

$HT$

$D_2$

$HD$

$H_2$
Initial state distribution

Vibration

Rotation

orth/para $T_2$, $D_2$, $H_2$

Van-der-Waals clusters

Temperature + pressure

Concentration

$T_2$

$DT$

$HT$

$D_2$

$HD$

$H_2$
Initial state distribution

Vibration

Rotation

Concentration

ortho/para $T_2$, $D_2$, $H_2$

Van-der-Waals clusters

Influence of clusters to neutrino mass measurement needs to be known!
Experimental method: IR absorption spectroscopy
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Sensitive to:
- Intermolecular interaction → Van-der-Waals complex
- Composition
- Vibration / rotation
- Ortho/para ratio
- Temperature
Experimental method: IR absorption spectroscopy

Sensitive to:
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Ideal method: IR spectra only possible with intermolecular interaction
TApIR Setup

- Temperature: 18 K to 35 K
- Only H2 HD D2 mixtures
Experimental Setup

- TApIR sample cell
- Sapphire window
- \(Q_2\)
- He
- Spectrometer
- Cryo cube
- Detector
Focus of this talk

- Can we see clusters at all?
  - Liquid Phase:
    - High cluster density
    - High signal expected

- Can we see cluster in the gaseous phase?

- Does the cluster concentration depend on the temperature and pressure?
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Liquid phase, \( \sim 20 \text{ K} \)

2\textsuperscript{nd} vibrational band

2 independent measurements

\begin{align*}
\text{absorbance} & \quad 0,4 \\
& \quad 0,3 \\
& \quad 0,2 \\
& \quad 0,1 \\
& \quad 0,0 \\
\text{wavenumber (cm}^{-1}) & \quad 7000 \\
& \quad 8000 \\
& \quad 9000 \\
\end{align*}

- \( Q_1S_1(0) \)
- \( Q_2S_0(1) \)
- \( Q_1Q_1 \)
- \( Q_2 \)
- \( Q_2S_0(0) \)
- \( Q_1S_1(1) \)
Liquid phase, \(~20\, K\)

2\(^{nd}\) vibrational band

1 measurement of \(H_2/D_2\) mixture

- \(H_2\)
- \(D_2\)
- \(H_2/D_2\) interaction

absorbance

wavenumber (cm\(^{-1}\))
Liquid phase, ~20 K

2nd vibrational band

1 measurement of H₂/D₂ mixture

- H₂
- H₂/D₂ interaction

Additional lines caused by hetero-molecular clusters
Liquid phase, \(\sim 20 \text{ K}\)

2\textsuperscript{nd} vibrational band

1 measurement of \(\text{H}_2/\text{D}_2\) mixture

\(\text{H}_2/\text{D}_2\) interaction

Additional lines caused by hetero-molecular clusters

...and not by HD
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H₂-D₂-Dimers in the gaseous phase at ~30K, 2 bar pressure

1st vibrational band

Absorbance $A = -\log_{10}(T)$

wavenumber (cm⁻¹)
H₂-D₂-Dimers in the gaseous phase at ~30K, 2 bar pressure

1st vibrational band
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D$_2$ gas phase, 27K

D$_2$ 1$^{st}$ vibrational band

$S_0(0)^{D2} Q_1^{D2}$

$S_0(1)^{D2} Q_1^{D2}$

absorbance

wavenumber (1/cm)
$^2\text{D}_2$ gas phase, 27K, density corrected

$^2\text{D}_2$ 1$^{\text{st}}$ vibrational band

$S^0_0(0)^{^2\text{D}_2} Q_1^{^2\text{D}_2}$

$S^0_1(1)^{^2\text{D}_2} Q_1^{^2\text{D}_2}$

Absorbance/density (m$^3$/kg)

Wavenumber (1/cm)

2.8 bar
2.0 bar
1.5 bar
1.0 bar
0.5 bar

Preliminary
D$_2$ gas phase, 2.8 bar

D$_2$ 1$^{\text{st}}$ vibrational band

$S_0(0)^{D_2} Q_1^{D_2}$

$S_0(1)^{D_2} Q_1^{D_2}$

absorbance

wavenumber (cm$^{-1}$)

preliminary
D$_2$ gas phase, 2.8 bar, density corrected

D$_2$ 1$^{\text{st}}$ vibrational band

$S_0(0)^{D_2} Q_1^{D_2}$

$S_0(1)^{D_2} Q_1^{D_2}$

absorbance/density (m$^3$/kg)

wavenumber (cm$^{-1}$)
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Outlook

- Detailed temperature and pressure dependency analysis

- Impact on KATRIN
  - Systematic study of temperature and pressure influence on clusters, WGTS between ~27 and 33 K
  - Cluster concentration?
    → systematic influence on neutrino mass can be simulated

- Gas phase with tritium
  - New T$_2$ApIR experiment
    → commissioning 2017
THANK YOU FOR YOUR ATTENTION!