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Temperature- and pressure-dependent absorption cross sections of gaseous hydrocarbons at 3.39 μm

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Abstract

The pressure- and temperature-dependent absorption cross sections of several neat hydrocarbons and multi-component fuels are measured using a 3.39 μm helium–neon laser. Absorption cross section measurements are reported for methane, ethylene, propane, n-heptane, iso-octane, n-decane, n-dodecane, JP-10, gasoline and jet-A with an estimated uncertainty of less than 3.5%. The experimental conditions range from 298 to 673 K and from 500 to 2000 Torr with nitrogen as the bath gas. An apparatus is designed to facilitate these measurements, and specific care is taken to ensure the compositional accuracy of the hydrocarbon/ N_2 mixtures. The absorption cross sections of the smallest hydrocarbons, methane and ethylene, vary with temperature and pressure. The cross sections of larger hydrocarbons show negligible dependence on pressure and only a weak dependence on temperature. The reported data increase the range of conditions and the number of hydrocarbons for which cross section measurements are available at the HeNe laser wavelength.

Keywords: optical absorption, mid-IR, HeNe laser, fuel diagnostic, absorption coefficients

(Some figures in this article are in colour only in the electronic version)

1. Introduction

It has long been known that the 3.39 μm helium–neon laser (HeNe) can be used as a monochromatic source to measure hydrocarbon vapours via optical absorption [1]. The HeNe laser has been used to accurately measure time-resolved hydrocarbon vapour concentration in a variety of practical applications, including shock tubes [2], spark ignition engines [3, 4] and high-pressure combustors [5]. However, many of the previously published absorption coefficient data are only available over a limited range of pressures and temperatures. To make quantitative concentration measurements, in realistic systems with varying conditions, temperature- and pressure-dependent cross section data are required.

Room-temperature measurements have previously been made in a static cell for a number of hydrocarbons from 200 to 650 Torr [6]. Additionally, temperature- and pressure-dependent cross section measurements have been made for

several hydrocarbons including methane, propane, iso-octane and cyclohexane [3, 4, 7, 8]. The HITRAN database [9] can be used to extract temperature- and pressure-dependent spectra of methane, ethane, acetylene and ethylene, but provides no information for other hydrocarbon molecules. High-temperature cross section measurements have been made in a shock tube for several hydrocarbons [10, 11], but the scatter in these data is relatively large. Lacking in the literature is a set of absorption cross section data for a variety of fuels at elevated temperatures with comparisons to previously published literature.

In this paper, we first report the design of a heated absorption cell for measuring temperature- and pressure-dependent absorption cross sections. Procedures for making accurate measurements of hydrocarbon/nitrogen mixtures are described. The absorption cell is then used to make accurate cross section measurements at 3.39 μm for methane, ethylene, propane, n-heptane, iso-octane, n-decane, n-dodecane,

JP-10, gasoline and jet-A, diluted in a nitrogen bath gas (0.03–25% by volume of hydrocarbon) with pressures between 500 and 2000 Torr and temperatures from 25°C to 400°C. When available, the measurements are compared to previous cross section measurements.

2. Experimental setup

Measuring the temperature- and pressure-dependent absorption coefficient accurately requires care when designing the experimental apparatus. Mixtures must be carefully prepared and transferred to a controlled absorption cell. Additionally, to compute the absorption coefficient, the baseline intensity (intensity prior to absorption) must be well-known. This section describes the experimental apparatus used to create mixtures of known composition, place them in an environmentally controlled cell and measure the absorption cross section.

2.1. Optical absorption

Optical absorption is described by the Beer–Lambert relation which states that the transmission of monochromatic light through a uniform absorber decays exponentially with path length:

$$\frac{I}{I_0} = e^{-k_v L} \quad (1)$$

where I is the transmitted intensity, I_0 is the initial intensity, L is the path length of the sample and k_v is the spectral absorption coefficient of the absorbing medium. The quantity $\frac{I}{I_0}$ is referred to as the transmission and the quantity $k_v L$ is known as the absorbance. It is convenient to rewrite this equation in terms of an absorption cross section:

$$\frac{I}{I_0} = e^{-\sigma_v N L} \quad (2)$$

where σ_v is the absorption cross section of the absorbing species (which may be temperature dependent), and N is the molar density of the species in units of mole cm^{-3} . Using the ideal gas law, the cross section of a molecule can be determined if the transmission, path length, temperature, mole fraction and total pressure are known:

$$\sigma_v = \frac{-\ln\left(\frac{I}{I_0}\right)RT}{X_i P L} \quad (3)$$

In this equation, R is the universal gas constant, T is the temperature, X_i is the mole fraction of absorbing species, and P is the total pressure.

Because absorption cross sections are wavelength-dependent, the measured cross sections can depend on the spectral width of the laser source. A 3.39 μm HeNe laser has a centre wavelength of 3392.235 nm in vacuum. The HeNe transition is primarily Doppler broadened with a full width at half max (FWHM) of $\sim 0.01 \text{ cm}^{-1}$. The wavelength emitted by the laser will be confined to one or more narrow (i.e. monochromatic) lines contained beneath this Doppler-broadened emission curve. To ensure that the measured cross section is accurate, the width of the absorption features should be larger than the Doppler width of this transition. While the laser light is spectrally narrow compared to this Doppler width,

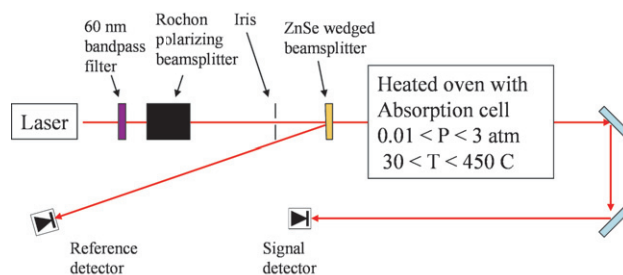


Figure 1. Heated absorption cell and gas handling equipment for mixture preparation and measurement of absorption cross section.

the exact wavelength of the laser emission can vary within the Doppler gain curve as the laser cavity heats up, expands and shifts the longitudinal modes in wavelength. The HITRAN database indicates that the strongest absorption features of methane have broadening coefficients on the order of $0.1 \text{ cm}^{-1} \text{ atm}^{-1}$ (FWHM), resulting in a linewidth of approximately 1 cm^{-1} at atmospheric pressure. Thus, at our high pressures, the HeNe can be considered monochromatic for all of the species studied here.

2.2. Optical arrangement for common mode rejection

The HeNe laser is sensitive to ambient conditions. Thus as the laser heats up and the room temperature fluctuates, the power output of the laser can drift by as much as 30%. Our particular laser was also found to suffer from high-frequency intensity noise with a magnitude of several per cent between 1 Hz and 100 kHz. Because cross section measurements depend directly on accurate knowledge of the baseline intensity, I_0 , a reference detector was used to correct for laser power drift and high-frequency noise. The optical setup for common mode rejection is shown in figure 1.

Because HeNe lasers can simultaneously emit diffuse radiation and coherent light at multiple discrete wavelengths, a narrow-band filter (60 nm FWHM) was used to block all but the intended 3.39 μm radiation. A polarizing beam splitter was used to ensure that the light was linearly polarized. This is necessary when using polarization-sensitive optics such as the wedged beam splitter. An iris was placed after the polarizing beam splitter to attenuate the beam and prevent detector saturation. A zinc selenide wedge was used to direct a portion of the beam onto a reference detector while the rest of the beam passed through the absorption cell onto the signal detector. Measurements were made with an evacuated cell to obtain a linear correction for the baseline signal as a function of the reference detector signal. The uncertainty (one standard deviation) of the corrected baseline intensity is less than 0.5% over a 10 min period.

2.3. Gaseous mixture preparation

Preparation of gas mixtures must be done with care to ensure that the mixture composition is well-known. Our gas-handling equipment was designed to enable preparation of mixtures of nitrogen with gaseous hydrocarbons, such as ethylene, as well as liquid hydrocarbons like n-dodecane and fuel blends like gasoline and Jet-A.

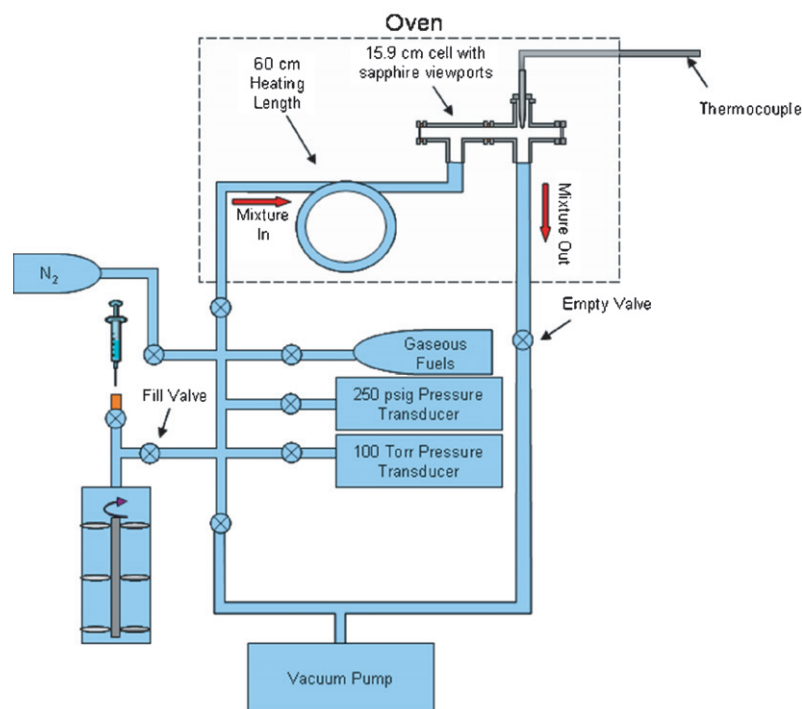


Figure 2. Heated absorption cell and gas handling equipment for mixture preparation and measurement of absorption cross section.

A gas manifold was used to connect bottles of gaseous nitrogen and hydrocarbons, pressure manometers, a mixing tank, the vacuum system and the heated absorption cell (figure 2). The manifold and mixing tank were heated to $\sim 100^\circ\text{C}$ with heating tape, minimizing condensation of low vapour pressure components. Dilute mixtures of hydrocarbon and nitrogen were prepared in the mixing tank. A magnetic stirrer with three tiers of brass mixing vanes was used to blend the hydrocarbon and nitrogen gases. The stainless steel mixing tank was equipped with an additional valve connected to a septum for liquid injection. The manifold had a valve connecting it to the vacuum pump with an ultimate vacuum of $\sim 100\ \mu\text{Torr}$, measured with a thermocouple gauge. The leak rate of the system was $\sim 350\ \mu\text{Torr min}^{-1}$. The manifold was equipped with a manometer rated for 100 Torr of peak pressure and a second manometer rated for 13 000 Torr of peak pressure. The uncertainties of the manometers are $\pm 10\ \text{mTorr}$ and $\pm 1\ \text{Torr}$, respectively.

Mixture preparation for gaseous hydrocarbons such as methane and ethylene was performed in the following manner. First, the manifold and mixing tank were evacuated to less than 10 mTorr, the precision of our pressure gauge. The ultimate vacuum was verified with a thermocouple gauge. Next the manifold and mixing tank were filled with pure hydrocarbon gas to the nominally-desired partial pressure. The valve connecting the mixing tank to the manifold was closed and the manifold was evacuated and refilled with nitrogen to a pressure greater than the pressure inside the mixing tank. The contents of the mixing tank were then diluted with nitrogen to the desired total pressure. Finally, the mechanical stirrer mixed the hydrocarbon/nitrogen mixture for approximately 15 min. Prior to filling the cell, some of the mixture was discarded through the vacuum system to remove any unmixed nitrogen in dead volume near the valve.

The procedure for mixture preparation was modified when neat hydrocarbon liquids and liquid fuel blends were measured. Neat, liquid hydrocarbons were subjected to multiple freeze/pump/thaw cycles to remove high vapour pressure impurities, such as dissolved air. Liquid fuel blends were subjected to one freeze/pump/thaw to remove most of the dissolved air while maintaining the fuel composition. The liquid was then injected through a septum into the evacuated mixing tank. For neat hydrocarbons, the valve connecting the tank to the manifold and pressure gauges remained open and the hydrocarbon pressure could be measured after the liquid had evaporated. For hydrocarbon blends, such as gasoline, this valve was initially closed. The injected fuel was allowed to evaporate and mix for several minutes before the valve to the manifold was opened and the fuel pressure was measured. This precaution ensured that the fuel vapour inside the mixing tank was homogeneous even though the high vapour pressure components evaporate preferentially.

2.4. Heated absorption cell for cross section measurements

The absorption cell was placed inside an oven for uniform heating. The stainless steel cell has a 15.9 cm path length. The viewports, sapphire brazed to stainless steel, limit the maximum pressure and temperature of the cross section measurements to 450°C and 3.3 atm. Approximately 60 cm of corrugated flexible stainless steel tubing (12.5 mm diameter) was contained within the oven and connected the manifold to the absorption cell. This heated inlet ensured that the mixture reached a uniform temperature before entering the absorption cell. A K-type thermocouple near the laser beam path measured the temperature of the gas in the cell (uncertainty $< 1\%$).

Table 1. Comparison of measured cross section, uncertainty estimates and measurement technique for hydrocarbon data at room temperature.

Hydrocarbon	Reference	Total pressure (Torr)	σ (298 K) ($\text{m}^2 \text{mole}^{-1}$)	Uncertainty	Technique
Methane	This work	760	21.1	3%	HeNe
	[8]	760	25.3	\times	HeNe
	[4]	760	21.9	2% ^a	HeNe
	[7]	760	22.5	5%	HeNe
	[9]	760	21.4	\times	Calculation
	[1]	30.4	36.7	\times	HeNe
Ethylene	[13]	760	19.5	3%	FTIR
	This work	760	0.459	3.5%	HeNe
	[9]	760	0.386	\times	Calculation
	[13]	760	0.426	3%	FTIR
	[14]	760	0.391	2%	HeNe
Propane	This work	760	20.2	3.4%	HeNe
	[13]	760	21.2	3%	FTIR
	[10]	760	20.7	20%	HeNe
	[8]	760	23.9	\times	HeNe
	[1]	760	48.9	\times	HeNe
	[1]	23	20.3	\times	HeNe
n-heptane	This work	760	45.2	3.4%	HeNe
	This work	10	45	4%	HeNe
	[13]	760	44.3	3%	FTIR
	[10]	760	46.5	20%	HeNe
	[6]	650	36.9	5%	HeNe
	[1]	7.6	48.9	\times	HeNe
	[2]	10	44.9	1%	HeNe
Iso-octane	This work	760	47.3	3.4%	HeNe
	[13]	760	47	3%	FTIR
	[10]	760	46.5	20%	HeNe
	[6]	650	39.9	5%	HeNe
	[4]	760	45.7	2% ^a	HeNe
n-decane	This work	760	54.6	3.4%	HeNe
	[6]	650	15.9	5%	HeNe
	[2]	1	56.3	1%	HeNe
	[1]	3.04	28.1	\times	HeNe
n-dodecane	This work	760	53.5 ^b	5%	HeNe
	[13]	760	57.5 ^b	'Best effort'	FTIR
	[13]	760	53.4	'Best effort'	FTIR
Gasoline	This work	760	28.1 ^b	3.2%	HeNe
	[1]	15.2	25.7	\times	HeNe
Jet-A	This work	760	43.8	4.2%	HeNe
	[1] (Kerosene)	2.3	28.1	4%	HeNe
	[1] (JP-4)	22.8	41.6	\times	HeNe
	[1] (JP-5)	2.3	53.8	5%	HeNe
JP-10	This work	760	90	3.4%	HeNe

^a Uncertainty estimates using statistical analysis only.^b Temperature of 323 K.

To measure the cross section of a mixture, the cell and manifold were first evacuated and the mixture was allowed to flow into the cell. As the cell was filled, data from the high-pressure manometer and the two detectors were continuously recorded, providing continuous pressure-dependent transmission from 500 to 2000 Torr. For the fill rates used, the residence time of the mixture in the heated inlet ranged from 2 to 10 s and the time in the cell was less than 2 s. Cross section measurements could have been made at pressures below 500 Torr, but additional mixtures would have been required for high-accuracy data due to the lower absorption. Measurements above 2000 Torr were avoided in most cases so the viewports would not be damaged.

Because the cross section data were acquired as the cell was being filled, it was necessary to verify that the

temperature measured by the thermocouple accurately reflects the temperature of the gases in the measurement beam path. To do this, the cell was filled at varying flow rates with little effect on the measured cross section. This indicates that the 60 cm heating length is sufficient to ensure a uniform temperature throughout the measurement cell for the flow rates used.

The gas handling system and heated absorption cell design enabled accurate control over a range of temperatures and pressures while the optical setup allowed corrections for fluctuations in laser intensity over long periods of time. With this system, accurate cross section measurements of neat hydrocarbons and fuel blends, dilute in nitrogen, were made while preventing sample contamination and inhomogeneous evaporation of blended fuels.

3. Absorption coefficient data at 3.39 μm

The absorption coefficient at 3.39 μm was measured for a variety of neat gaseous and liquid hydrocarbons as well as several hydrocarbon fuel blends in a nitrogen bath gas (0.03–25% by volume). Our measurements and estimated uncertainties are compared with room-temperature data from the literature in table 1. With the exception of dodecane and Jet-A, uncertainties for all of our measurements are $\leq 3.5\%$. Because of the low vapour pressures of Jet-A and dodecane, uncertainties for these fuels are $\leq 5\%$. The data are reported in this section in order of molecular weight. The cross sections of the low molecular weight hydrocarbons methane, ethylene and propane are shown to exhibit decreasing dependence on temperature and pressure with increasing molecular weight. Next, the cross sections of n-heptane, iso-octane, n-decane and n-dodecane are reported with comparisons to available literature. Finally, the cross sections of fuel blends are reported.

3.1. Absorption cross section of low molecular weight hydrocarbons

The absorption cross section of methane at 3.39 μm was measured from 25 °C to 400 °C and from 500 to 2300 Torr (figure 3). The measurements show excellent agreement with the HITRAN database, Perrin *et al* and Tomita *et al*. Because the cross section data exhibit pressure dependence, it is likely that they will also be sensitive to the effects of instrument broadening. Examination of the 0.1 cm^{-1} resolution spectra measured by Sharpe, obtained using an FTIR spectrometer, indicates that this resolution is not sufficient to completely resolve the absorption spectrum of methane at one atmosphere of pressure. Thus, the discrepancy with Sharpe can be attributed to instrument broadening of the narrow methane features.

An uncertainty analysis can be used to determine the sensitivity of the cross section measurements to uncertainties in the measured quantities:

$$\frac{d\sigma_v}{\sigma_v} = \sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta T}{T}\right)^2 + \left(\frac{\Delta I_0}{I_0} \frac{1}{\ln\left(\frac{I}{I_0}\right)}\right)^2 + \left(\frac{\Delta I}{I} \frac{1}{\ln\left(\frac{I}{I_0}\right)}\right)^2}. \quad (4)$$

The magnitude of the estimated uncertainties is indicated by the error bars in the figures. However, due to the range of cross sections displayed in figure 3, the error bars in the current data are not visible, but uncertainties are estimated at less than 3.5% for all data points. The main factors contributing to uncertainty in our cross section measurements are uncertainties in T , I_0 and X_i . Multiple measurements made under similar conditions were found to be repeatable within the estimated uncertainty.

The cross section measurements of ethylene are plotted in figure 4. Our data differ somewhat from the available literature. The difference between our data and the HITRAN data is about 16%. Sharpe *et al* compared the integrated area of the 3 μm band of ethylene with EPA and NIST measurements as well as the HITRAN database and found that the HITRAN database band area is approximately 18% lower than the three

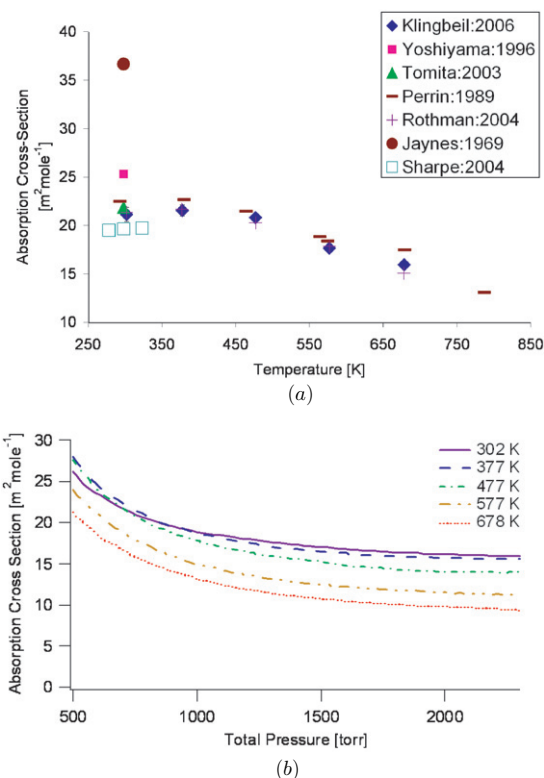


Figure 3. Absorption cross section of methane ($X_{\text{methane}} \sim 0.5\%$): (a) at 1 atm as a function of temperature, (b) as a function of temperature and pressure.

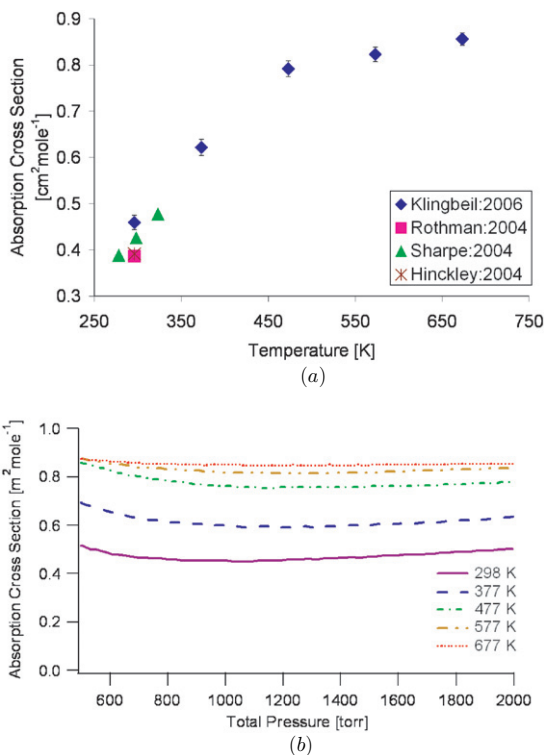


Figure 4. Absorption cross section of ethylene ($X_{\text{ethylene}} \sim 25\%$): (a) at 1 atm as a function of temperature, (b) as a function of temperature and pressure.

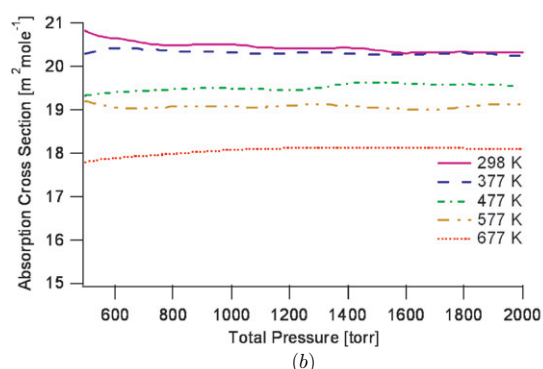
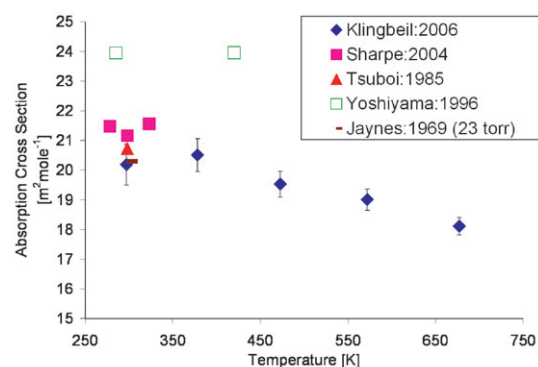


Figure 5. Absorption cross section of propane ($X_{\text{propane}} \sim 0.8\%$): (a) at 1 atm as a function of temperature, (b) as a function of temperature and pressure.

sets of FTIR measurements; this suggests that the HITRAN data for ethylene may be suspect [12].

Our measurements also indicate some dependence of the cross section on pressure, indicating that the ethylene spectrum measured by Sharpe will be affected by instrument broadening. This instrument broadening effect, together with an estimated uncertainty of $\leq 3\%$, can account for the $\sim 7\%$ difference between our data and the data reported by Sharpe.

The cross section of propane (figure 5) shows good agreement with the bulk of the available literature, including the FTIR data reported by Sharpe. Because it shows little dependence on pressure, instrument broadening of the FTIR data is also not expected to be an issue. The Jaynes measurement of a propane/air mixture at 760 Torr was significantly higher than the other reported measurements and was not plotted, but is listed in table 1. The Jaynes measurement of pure propane at 23 Torr is in good agreement with other available data.

3.2. Absorption cross section of high molecular weight hydrocarbons

The absorption cross sections of n-heptane and iso-octane vapour have been reported by several authors [1–3, 6, 10, 13]. Our measurements show excellent agreement with the bulk of the available literature (figures 6 and 7). (Note: the room temperature data in figure 6 were offset slightly to aid in viewing of the individual data points.) With the exception of the Sharpe *et al* data, all of the measurements were

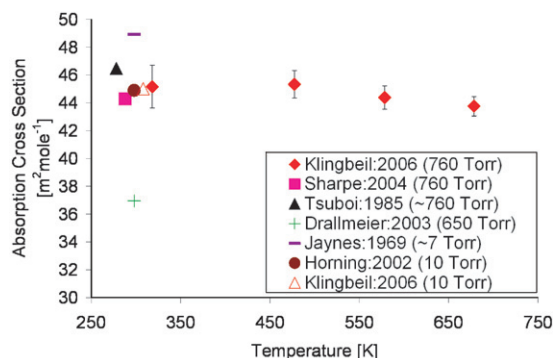


Figure 6. Absorption cross section of n-heptane at 1 atm as a function of temperature ($X_{\text{heptane}} \sim 0.2\%$).

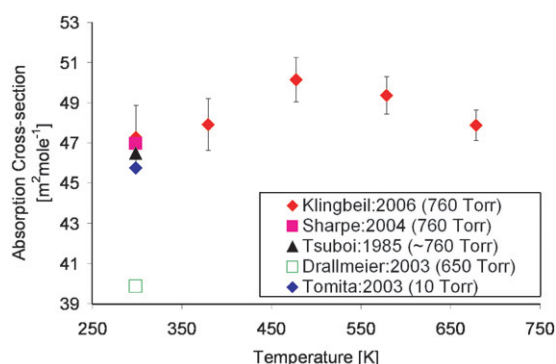


Figure 7. Absorption cross section of iso-octane at 1 atm as a function of temperature ($X_{\text{iso-octane}} \sim 0.3\%$).

obtained using a 3.39 μm HeNe laser. While the smaller hydrocarbons like methane, propane and ethylene show some pressure dependence, no pressure dependence was measured for n-heptane or iso-octane between 500 and 2000 Torr.

To make a valid comparison of our measurements with the laser absorption data reported by Horning, and by Jaynes and Beam, we also performed cross section measurements at low pressure (~ 10 Torr) using neat n-heptane. We found that our low pressure data are in agreement with our high pressure data and with the low pressure data reported by Horning [2]. For both hydrocarbons, the data reported by Drallmeier fall well below the other measurements. In addition, the Drallmeier data show some pressure dependence, while our cross section measurements are independent of pressure. Examination of the spectra of n-heptane and iso-octane measured by Sharpe reveals bands of absorption features that are not spectrally resolved [13]. The absorption bands of higher molecular weight hydrocarbons do not have spectrally resolved absorption features, as they do with methane and ethylene. Because they are spectrally broad, it is not likely that pressure broadening will affect their absorption cross section at any particular wavelength.

The absorption cross sections of n-decane and n-dodecane were measured as a function of temperature and pressure (figures 8 and 9). However, because of the low vapour pressure at room temperature, the measurements of n-dodecane were performed from 323 to 673 K. As with n-heptane and iso-octane, no pressure dependence was observed

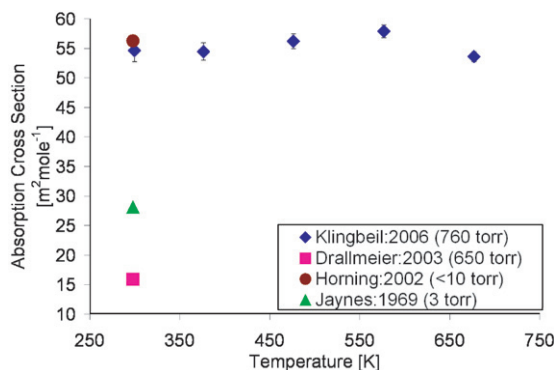


Figure 8. Absorption cross section of n-decane at 1 atm as a function of temperature ($X_{\text{decane}} \sim 0.2\%$).

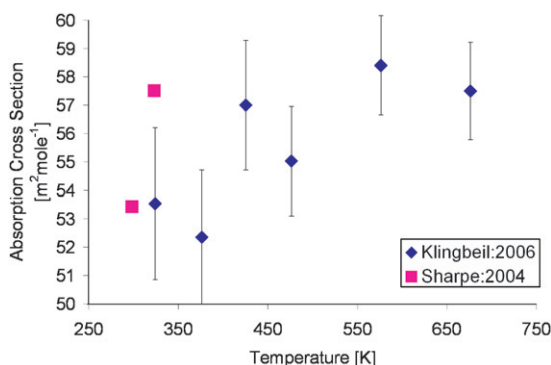


Figure 9. Absorption cross section of n-dodecane at 1 atm as a function of temperature ($X_{\text{dodecane}} \sim 0.02\%$).

with these hydrocarbons between 500 and 2000 Torr. The cross section measurements of n-decane agree well with the low-pressure, room-temperature measurements reported by Horning. The n-decane cross section data reported by both Drallmeier, and Jaynes and Beam fall below our measurements. The cross section measurements of n-dodecane agree with the Sharpe data within the limits of uncertainty in both sets of data. The statistical scatter in the Sharpe data was 6.4% and 3% at 298 and 323 K, respectively, but this accounts only for the scatter in the measurements. The estimated uncertainty for these measurements was ‘best effort’.

3.3. Absorption cross section of practical fuels

The absorption cross sections of JP-10, gasoline and Jet-A were measured as a function of temperature and pressure (figures 10–12). More information about the specific blend of gasoline and Jet-A used are reported by Gauthier *et al* [15] and Dean *et al* [16], respectively. The gasoline had a molecular weight of $\sim 90 \text{ kg kmol}^{-1}$ and a C/H ratio of ~ 1.86 . The Jet-A had an approximate formula of $\text{C}_{11}\text{H}_{22}$. The temperature was varied from 298 to 673 K for JP-10, 323 to 673 K for gasoline and 373 to 673 K for Jet-A. The minimum temperature for measurements was limited by difficulties in assuring complete vaporization of the multi-component fuels at low temperatures, but little temperature dependence is seen over this temperature

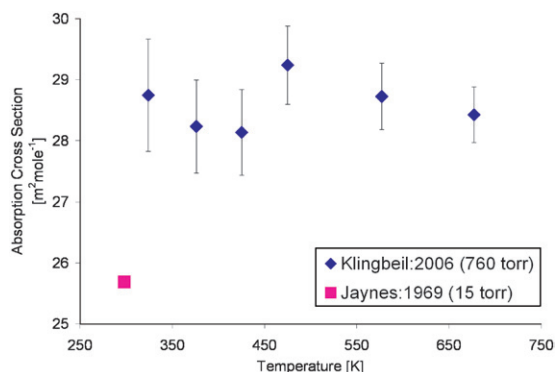


Figure 10. Absorption cross section of gasoline at 1 atm as a function of temperature ($X_{\text{gasoline}} \sim 0.2\%$).

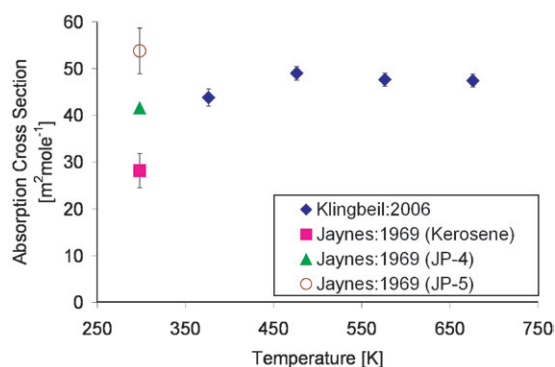


Figure 11. Absorption cross section of Jet-A at 1 atm as a function of temperature ($X_{\text{Jet-A}} \sim 0.03\%$).

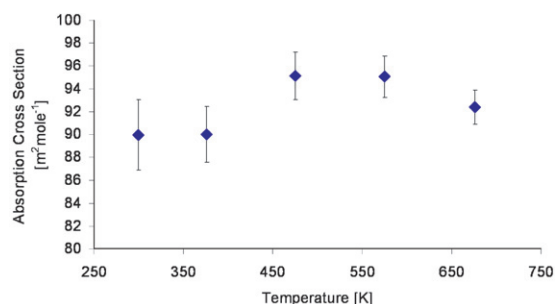


Figure 12. Absorption cross section of JP-10 at 1 atm as a function of temperature ($X_{\text{JP-10}} \sim 0.2\%$).

range. The pressure was varied from 500 to 2000 Torr with no effect on the measured cross section.

Because gasoline is a fuel blend, the proportion of components in the fuel is highly variable. With this in mind, the gasoline cross section data reported by Jaynes and Beam show surprising agreement with our measurements, indicating that the cross section of gasoline may not depend heavily on the particular blend used.

Jaynes and Beam also reported cross section measurements of kerosene, JP-4 and JP-5 at room temperature. Jet-A is a blend of hundreds of compounds, as are kerosene, JP-4 and JP-5. Our high temperature Jet-A cross section measurements agree with the JP-4 data provided by Jaynes and

Beam. The cross sections of JP-5 and kerosene do not agree well with our Jet-A data, but these particular measurements reported by Jaynes and Beam have large uncertainties due to low vapour pressure at room temperature. This comparison indicates that the cross section of Jet-A may be relatively insensitive to the particular blend.

JP-10 is composed of a single component with a polycyclic structure that is dissimilar to the alkanes, alkenes and aromatics that comprise the bulk of Jet-A and JP fuels. Thus the absorption cross section of JP-10 (figure 12) is found to be vastly different from those of the other JP fuels. A large cross section implies that a JP-10 sensor using absorption of the 3.39 μm wavelength will have good detection capabilities.

4. Summary

A heated cell was designed to measure the temperature- and pressure-dependent absorption cross section of neat hydrocarbons and fuel blends. The experimental apparatus was designed to enable measurements of neat hydrocarbons as well as multi-component blends, diluted in nitrogen bath gas for high pressure mixtures.

Absorption cross sections for several neat hydrocarbons and real fuels were measured and found to be consistent with past (mostly room-temperature) data. Measurements of low molecular weight hydrocarbons such as methane and ethylene were shown to exhibit pressure dependence at atmospheric pressure. These hydrocarbons also exhibit temperature dependence because the absorption cross section is only affected by a small number of individual transitions. The cross sections of larger hydrocarbons were found to be independent of pressure and nearly independent of temperature. Because the absorption at 3.39 μm is affected by the increasing number of nearby absorption features, the temperature dependence of any particular feature becomes less significant.

The cross sections of three practical fuels were also measured and compared to similar data taken at low pressures. The measurements showed good agreement between similar types of blended fuels, indicating that the absorption cross section of fuel blends may be relatively insensitive to variations in composition.

These data provide critical cross section information for relevant hydrocarbon species and fuel blends. The cross sections can be used to make accurate concentration measurements in a variety of environments such as an internal combustion engine, a gas turbine combustor or a pulse detonation engine.

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