Broadband Cavity Enhanced Spectroscopy of Acoustically Levitated Liquid Droplets

Anna Jordan and D. Al Fischer

Background

Broadband cavity enhanced spectroscopy (BBCES) is a type of cavity-enhanced spectroscopy that uses a continuous wave broadband light source and a slow, intensity-based, often wavelength-resolved detector to measure extinction of light within an optical cavity.[1] The optical path length is essential to the sensitivity of spectroscopic instruments, as longer path lengths allow for more sensitive measurements. BBCES utilizes two high reflectivity (R > 99.99%) mirrors to achieve a long path length without physically having a long path to the detector. Typically, BBCES is done on gases in a sealed sample cell and has been challenging to apply to liquid samples[2]. Sound, as a mechanical wave, carries momentum that can act on a particle and as force is exerted on a particle converge and are strong from all directions, it can levitate the particle. Acoustic waves can be utilized to trap particles made of different materials[3]. Acoustic levitation uses sound produced by parallel arrays of speakers that generate a series of alternating waves; in short, the area of interference creates a density difference, and a droplet can be suspended in the low-density area[4]. A novel BBCES for liquid samples was developed during the project. The BBCES uses an open cavity design with an acoustic levitator in the middle, to allow liquid droplets to levitate into the light path of the BBCES. The acoustic array would serve as a low-cost, contact free sample holder. In addition, the droplets can be observed with an infrared camera to simultaneously determine the spectral characteristics of the sample using BBCES and the thermochemical characteristics of the sample using infrared imaging.

Methods

The BBCES consists of an optical cavity made from two high-reflectivity mirrors (*R*>99.99%) held in standard kinematic mounts. A Coherent OBIS 445nm CW laser was aligned with the cavity using two turning mirrors (Figure 1). An Ocean Optics USB400 UV-visible grating spectrometer serves as the detector. The levitator holds a liquid sample droplet at the midpoint of the cavity and was positioned by levitating a droplet of deionized water and adjusting the position of the levitator while watching the signal on the spectrometer. The levitator design and operation has been described elsewhere and provided by those authors and used as-is[4]. For a blank sample, DI water was placed in the levitator and a spectrum was acquired. For an absorbing sample, the water was dyed with food coloring produce varying spectra. Red, yellow, green, and black food coloring were diluted in water and droplets were placed in the levitator. A 100% transmittance spectrum was also taken with no sample droplet present. Spectra were collected with an integration time of 10s, with 3 spectra averaged per acquisition.

References

(1) Gagliardi, G.; Loock, H.-P. Cavity-Enhanced Spectroscopy and Sensing; Springer, 2013.

(2) Fiedler, S. E.; A. Hese; Ruth, A. A. Incoherent Broad-Band Cavity-Enhanced Absorption Spectroscopy. Chemical Physics Letters 2003, 371 (3-4), 284–294.

(3) Marzo, A.; Barnes, A.; Drinkwater, B. W. TinyLev: A Multi-Emitter Single-Axis Acoustic Levitator. Review of Scientific Instruments 2017, 88 (8), 085105.

(4) Duranty, E. R.; McCardle, H.; Reichert, W. M.; Davis, J. H. Acoustic Levitation and Infrared Thermography: A Sound Approach to Studying Droplet Evaporation. Chemical Communications 2020, 56 (30), 4224–4227.

Acknowledgements

This work was funded by the WCU Department of Chemistry and Physics, and the Summer Graduate Research Assistantship.

I would like to thank Dr. Eddy Duranty for lending the acoustic levitator used in the experiment and providing guidance on how to use it. I would like to also thank Dr. Al Fischer for his knowledge and guidance throughout the whole project.

Experimental Setup

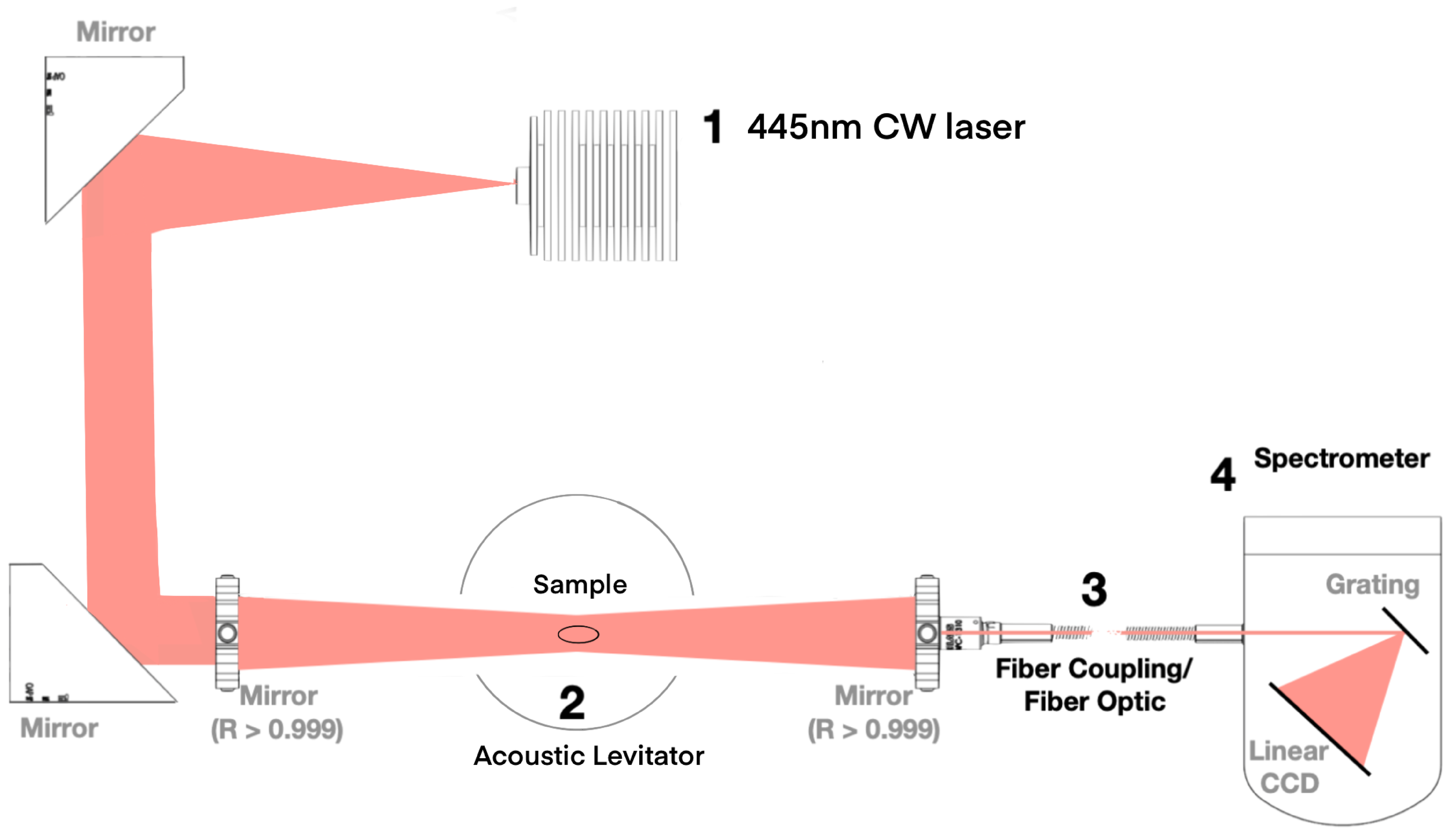

Figure 1: Block diagram of the open-path BBCES instrument with acoustic levitator as a sample holder.

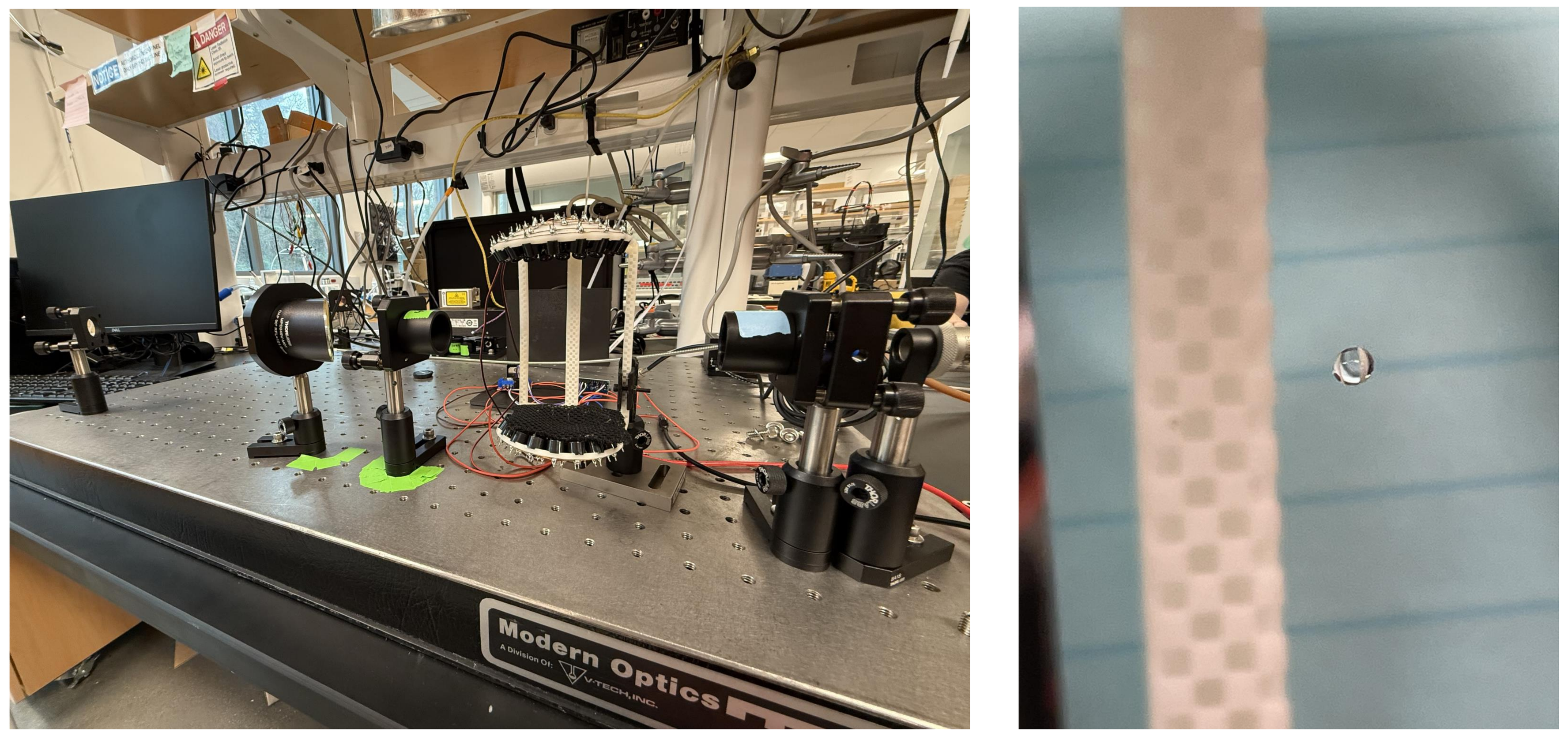

Figure 2: Photograph of the instrument (left) and of the acoustically-levitated sample droplet(right).

Results And Discussion

Figure 3 shows intensity spectra of the red pigment and DI water. The sharp peak occurs at 445nm and the narrow width due to the laser used as the light source. A clear decrease in intensity is seen with the red dye, as would be expected for an absorbing sample, suggesting the levitator provides a feasible method of measuring absorption in liquids using BBCES. However, data was inconsistent from day to day, and we sometimes observed similar decreases in intensity simply from turning the levitator electronics on and off, even with no droplet present. Although the reason for this has not been tracked down, a likely source is electromagnetic interference from unshielded wiring on the levitator. Similarly, the open cavity design is inherently susceptible to changes in the room air (e.g. RH, temperature) and could have led to some noise in the measurements. Finally, the levitator has multiple nodes that can hold a droplet, and there were often inconsistencies in which node the droplet would fall into, such that the height of the levitator had to be frequently adjusted to ensure that the beam would hit the sample.

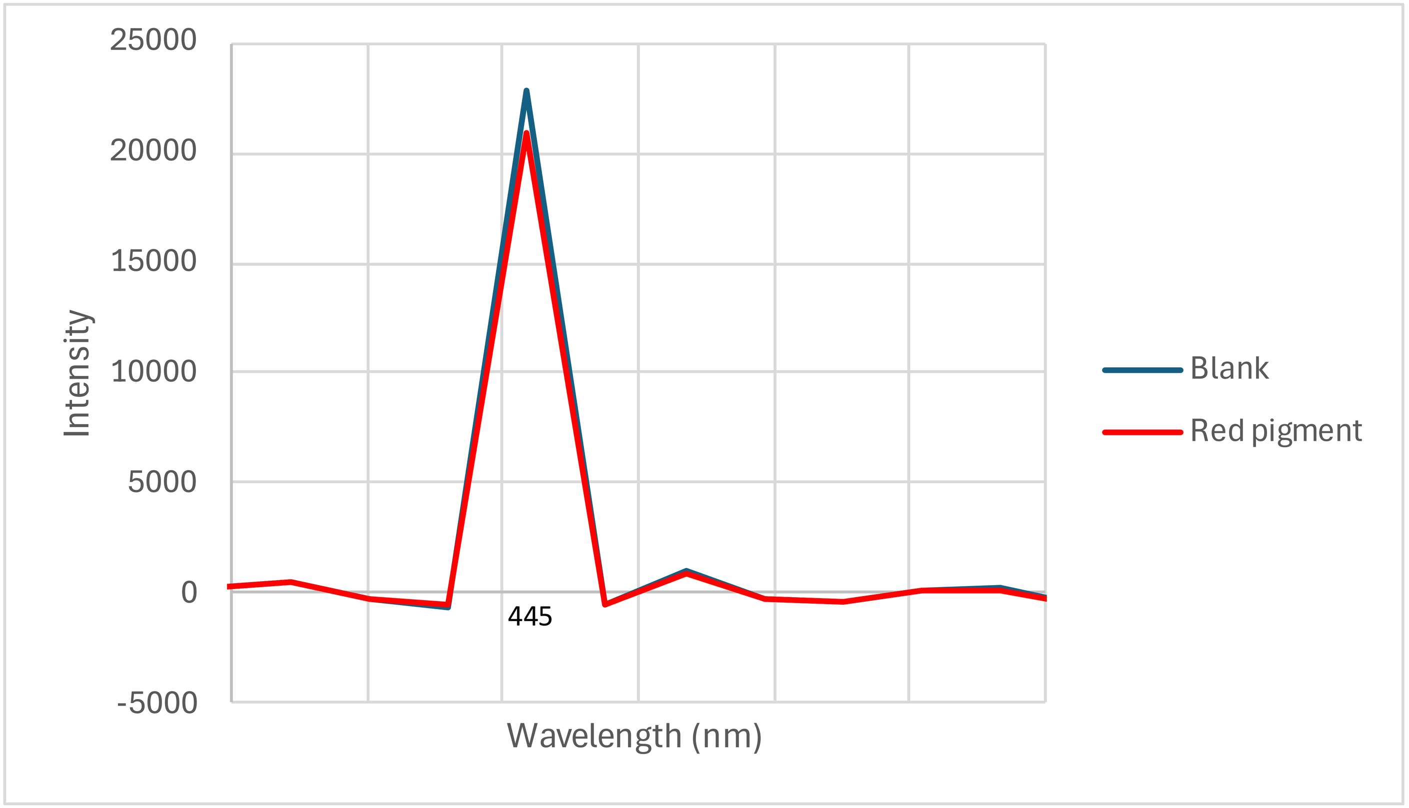

Figure 3: Intensity spectra of the blank and sample (red dye), showing an expected decrease in intensity for the dyed sample.

CONCLUSIONS AND RECOMMENDATIONS

There is some evidence that this instrument could work with additional work to eliminate the sources of errors discussed above. More research into what is causing the interference with the signal could make this instrument more consistent; the leading theory from the June experiments suggested that the interference could be from the electromagnetic field generated by the exposed wires on the levitator. Future experiments should focus on rewiring the instrument with shielded cable. There also might be some interference coming from the room conditions; setting the instrument up in an atmospheric control box could help rule out any error coming from the room conditions. While these initial results are promising, there is significant work still required to develop a precise instrument.