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Study of Doppler Broadening by Using Four Beams of Light

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ABSTRACT

In this work we study of Doppler broadening by using four beams of light. The measurable velocity (m.s-1) was in the range of -5.2x107 to 5.2x107. The maximum measurable velocity (m.s-1) was found to be limited by the signal-to-noise ratio. The intensity spectrum broadened linearly when velocity (m.s-1). At the same time, the spectral amplitude decreased and eventually approached the noise level. Increasing the laser power or improving the transducer sensitivity can extend the maximum. In contrast, the minimum measurable velocity (m.s-1) increased. Immediate, which represents the velocity sensitivity of the system, was limited by the frequency resolution of the system (-1.5x1014 Hz). Increasing the number of piezoelectric transducer cell (PZT) points can improve the minimum.

1. Introduction

In this work we study Doppler effect is the change in the observed frequency of a source due to the relative motion between the source and the receiver. The relative motion that affects the observed frequency is only the motion in the Line-Of-Sight (LOS) between the source and the receiver [1]. When the source of the waves is moving towards the observer, each successive wave crest is emitted from a position closer to the observer than the previous wave. Therefore, each wave takes slightly less time to reach the observer than the previous wave. Hence, the time between the arrivals of successive wave crests at the observer is reduced, causing an increase in the frequency. While they are travelling, the distance between successive wave fronts is reduced, so the waves "bunch together". Conversely, if the source of waves is moving away from the observer, each wave is emitted from a position farther from the observer than the previous wave, so the arrival time between successive waves is increased, reducing the frequency. The distance between successive wave fronts is then increased, so the waves "spread out"[2]. Doppler first proposed this effect in 1842 in his treatise "Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels" (On the colored light of the binary stars and some other stars of the heavens).[3] The hypothesis was tested for sound waves by Buys Ballot in 1845.[4] He confirmed that the sound's pitch was higher than the emitted frequency when the sound source approached him, and lower than the emitted frequency when the sound source receded from him. Hippolyte Fizeau discovered independently the same phenomenon on electromagnetic waves in 1848 (in France, the effect is sometimes called "effet Doppler-Fizeau" but that name was not adopted by the rest of the world as Fizeau's discovery was six years after Doppler's proposal).[5] In Britain, John Scott Russell made an experimental study of the Doppler effect (1848).[6], and the Application of Doppler Effect in Sirens, The siren on a passing emergency vehicle will start out higher than its stationary pitch, slide down as it passes, and continue lower than its stationary pitch as it recedes from the observer. Astronomer John Dobson explained the effect thus, "The reason the siren slides is because it doesn't hit you. “In other words, if the siren approached the observer directly, the pitch would remain constant until the vehicle hit him, and then immediately jump to a new lower pitch. Because the vehicle passes by the observer, the radial velocity does not remain constant, but instead varies as a function of the angle between his line of sight and the siren's velocity $v_r = v_s \cos\theta$ where θ is the angle between the object's forward velocity and the line of sight from the object to the observer, the other application of Doppler Effect is Astronomy, The Doppler effect for electromagnetic waves such as light is of great use in astronomy and results in either called red shift or blue shift. It has been used to measure the speed at which stars and galaxies are approaching or receding from us, their radial velocities. This may be used to detect if an apparently single star is, in reality, a close binary, to measure the rotational speed of stars and galaxies, or to detect exo planets. Note that redshift is also used to measure the expansion of space, but that this is not truly a Doppler effect.[7]This redshift and blue shift happens on a very small scale, if an object is moving toward earth, there would not be a noticeable difference in visible light [8,9]. The use of the Doppler effect for light in astronomy depends on our knowledge when the spectra of stars are not homogeneous. They exhibit absorption lines at well-defined frequencies that are correlated with the energies required to excite electrons in various elements . The Doppler effect is recognizable in the fact that the absorption lines are not always at the frequencies that are obtained from the spectrum of stationary light source. Since blue light has higher frequency than red light, the spectral lines of an approaching astronomical light source exhibit blue shift and those of a receding astronomical light source exhibit a redshift. Among the nearby stars, the largest radial velocities with respect to the sun are +308 km/s (BD-15°4041, also known as LHS 52, 81.7 light-years away) and -260 km/s (Woolley 9722, also known as Wolf 1106 and LHS

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64, 78.2 light-years away). Positive radial velocity means the star is receding from the Sun, negative that it is approaching, the Doppler effect is used in some types of radar, to measure the velocity of detected objects. A radar beam is fired at a moving target as it approaches or recedes from the radar source. Each successive radar wave has to travel farther to reach the car, before being reflected and re-detected near the source. As each wave has to move farther, the gap between each wave increases, increasing the wavelength. In some situations, the radar beam is fired at the moving car as it approaches, in which case each successive wave travels a lesser distance, decreasing the wavelength. In either situation, calculations from the Doppler effect accurately determine the car's velocity. Moreover, the proximity fuze, developed during World War II, relies upon Doppler radar to detonate explosives at the correct time, height, distance, etc [10]

2. Experimental Procedure

Experimental had done to eliminates Doppler broadening in measurements made and will allow for Doppler-free saturated absorption. Four beams of light are derived from the same laser using piezoelectric transducer cell (PZT) and (USB 2000) spectrometer, which pass the beams through a cell. The laser then passed through the piezoelectric transducer cell. The piezoelectric transducer cell incident beam into four beams, the (USB 2000) spectrometer were placed one behind the incident beam. The subtraction of the overlap and reference beam circumvents Doppler broadening, leading to Doppler-free laser-saturated absorption spectroscopy.

3. Results and Discussion

3.1 Results

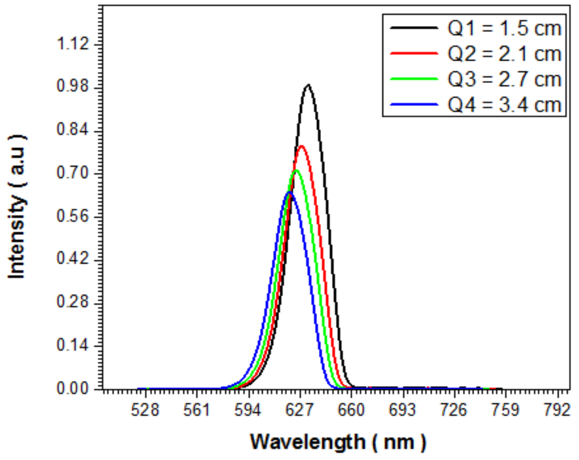

Figure 1. Wavelength verses intensity Spectra of piezoelectric transducer cell(PZT).

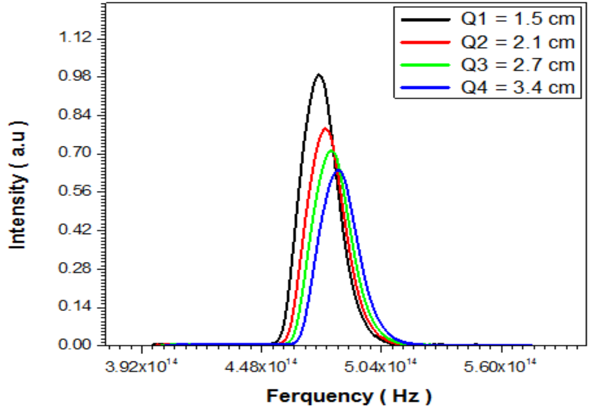

Figure 2. Frequency verses intensity Spectra of piezoelectric transducer cell (PZT).

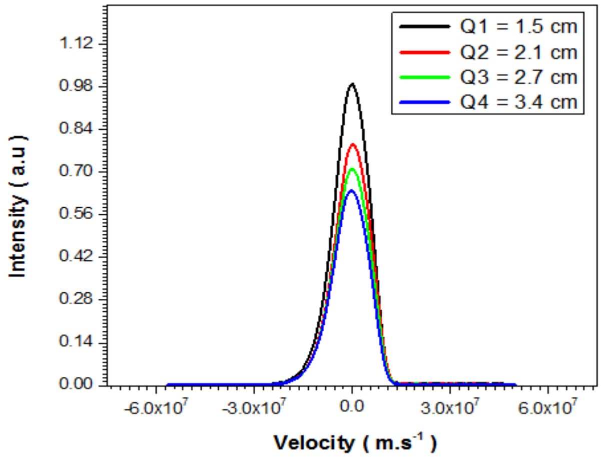

Figure 3. Maxwell-Boltzmann velocity distribution. The Intensity vs. their velocity component in one direction for room temperature He Ne laser.

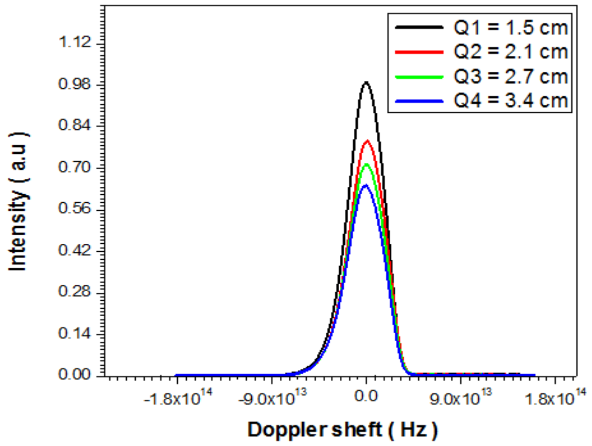

Figure 4. Doppler profile. The Intensity vs the laser frequency offset from resonance has a Gaussian line shape.

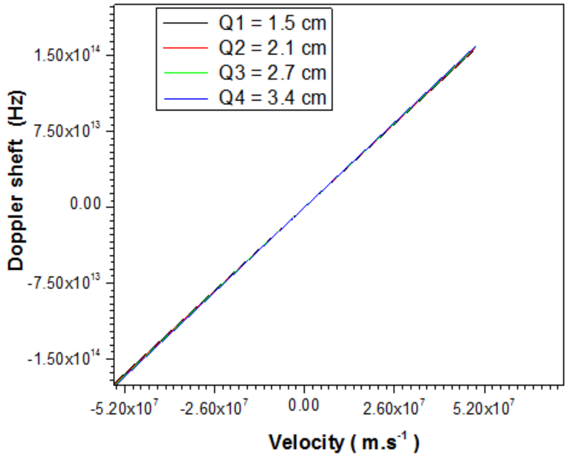

Figure 5. Doppler frequency shift as a function of average flow velocity.

3.2 Discussion

In Fig (1) and fig (2) a laser beam passes through the piezoelectric transducer cell (PZT) and its intensity is measured by (USB 2000) spectrometer as the laser (wavelength and frequency) is scanned through the natural resonance wavelength. When a laser beam propagates through piezoelectric transducer cell (PZT), the two stimulated transition processes change the intensity of the laser beam and (wavelength and frequency). Moreover, Doppler shifts associated with the random thermal motion of the absorbing atoms must also be taken into account. here is an interplay among these effects which is critical to understanding saturated absorption spectroscopy.

We begin with the basic equation describing how the laser intensity changes as it propagates through the piezoelectric transducer cell (PZT) and then continue with the effects of Doppler shifts and population changes.

Atoms in piezoelectric transducer cell (PZT) cell move randomly in all directions with each component of velocity having a distribution of values. Only the component of velocity parallel to the laser beam fig (3) Maxwell-Boltzmann velocity distribution. The intensity of laser beam vs. their velocity component in one direction for room temperature. Direction will be important when taking into account Doppler shifts. The intensity of laser beam in the velocity group between ($3x10^7$ $m.s^{-1}$ and $-3x10^7$ $m.s^{-1}$) is given by the Boltzmann velocity distribution this is just a standard Gaussian distribution with a mean of zero indicating the laser beam are equally likely to be going in either direction.

In fig (4) Intensity moving with a velocity *v* see the laser beam Doppler shifted by the amount $v(v/c)$.We will take an equivalent, alternate view that intensity moving with a velocity *v* have a Doppler shifted resonance frequency in the lab frame. The sign has been chosen to be correct for a laser beam propagating in the positive direction so that the resonance frequency is blue shifted to higher frequencies if*v* is positive and red shifted if *v* is negative. The intensity from a velocity group at a laser frequency *v*is then obtained by adjusting the Lorentzian so that it is centered on the Doppler shifted resonance frequency v'.

As also shown in Fig (5) the measurable velocity ($m.s^{-1}$) was in the range of $-5.2x10^7$ to$5.2x10^7$.

4. Conclusion

The maximum measurable velocity ($m.s^{-1}$) was limited by the signal-to-noise ratio. When velocity ($m.s^{-1}$) increased, the intensity spectrum broadened linearly with velocity ($m.s^{-1}$). At the same time, the spectral amplitude decreased and eventually approached the noise level. Increasing the laser power or improving the transducer sensitivity can extend the maximum. In contrast, the minimum measurable velocity ($m.s^{-1}$), which represents the velocity sensitivity of the system, was limited by the frequency resolution of the system ($-1.5x10^{14}$ Hz). Increasing the number of piezoelectric transducer cell (PZT) points can improve the minimum.

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