Medical and Astronomical Applications of Raman Spectroscopy

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Abstract: The main purpose of this paper is to study the applications of Raman Spectroscopy in the fields of medicine and astronomy. These applications show the involvement of Raman Spectroscopy, rendering qualitative and quantitative aspects of various fields like medicine, astronomy, geosciences, defense etc. These applications have proven to be lucrative in the said fields; such as, by determining the health of an unborn child in the medical field. It has helped many astronomers in uncovering the various secrets of the cosmos as well. The ability of Raman spectroscopy to probe the vibration modes of emission of different molecules either by absorption or emission spectra has innumerable applications which will be discussed further in the paper, in order to give the readers a complete panorama of the field with respect to its applications

Keywords: Raman Spectroscopy, Applications, Medicine, Astronomy

I. INTRODUCTION

The principal of Raman spectroscopy is that once the vibration mode of an electron is configured, different molecular bonds present in any sample can be deciphered. Therefore, Raman spectroscopy has innumerable applications, as it uses Raman Effect. “Raman spectroscopy utilizes the inelastic scattering of monochromatic light to determine these molecular modes.”

Raman Effect takes place when a sample such as a blood sample, is exposed to monochromatic light. In this event, it absorbs the light, while transmitting majority of the portion of light right through the sample. However a part of light is scattered by the sample in all the directions. This is called Raman scattering, which takes place when the incident frequency of the photon is different than the scattering frequency of the photon. Therefore, Raman scattering involves two photons of different frequencies. Meaning, electrons have different vibration levels.

When the electron in a sample interacts with the light, it will absorb energy from its photons and rise to a hypothetical level before falling back to an energy state which may be different than what was occupied by it prior to rising to the hypothetical level. In this case, the energy lost by the electron is not equal to the energy absorbed from the incident photon. As a result, the photon emitted by the electron has energy different from incident photon. This gives rise to Raman Scattering. Depending upon the final energy of the electron or final vibration level of the electron, Raman scattering is separated into Stokes line, where an electron absorbs energy and Anti-stokes line ($V_s > V_i$), where energy is released by electron.

Therefore, a Raman spectrum gives us the whole spectrum of properties of a molecule. And it is different for each molecule. This has proven to be of utmost importance in the applications studied hereafter. The spectrum gives the rotational levels of a molecule. Raman spectroscopy gives the quantitative, as well as qualitative analysis of a molecule in a sample. It also helps to find out the constituent particles in a sample.

Raman spectroscopy has gained recognition in the medical field, non-invasive probing of cervix to determine the changes during pregnancy, in the diagnosis and treatment of cancer, in studying the orientation of molecules and their rotational levels, in studying the crystal structure of molecules, etc.

II. SPECTROSCOPY TECHNIQUES

Raman Spectroscopy is a common approach used to observe rotational and fluctuations in other lower frequency mechanism in a system. Using this technique the structural fingerprint of a molecule can be identified with ease. The Raman scatters monochromatic light through a laser consistently in the visible, near infrared region or even adjacent ultraviolet region, the laser light is responsible for interacting with the molecular vibrations of photons or any new excitations in the system, which results in the energy of the system being shifted up or down. This energy shift gives us the required data about the frequency modes of the arrangement. Similar but complementary information is obtained using infrared spectroscopy. Some of the main techniques used to get the Raman spectra have been discussed below:-

2.1. Raman Spectrometers - A Raman scattering is very weak typically and spontaneous as a result of which it is quite a tedious task to separate the feeble inelastic light from the acute Rayleigh scattered light, as high degree of laser rejection is needed so multiple dispersion stages and holographic gratings are used. In dispersive Raman setups photomultipliers were the preferred detectors in the past, but it had downsides too it had long acquisition times. However, as the technology advances notch or edge filters are universally employed for laser rejection.

2.2. Czerny-Turner Monochromators - A visual device which disseminates thin bands which are mechanically selectable consisting of light or other radiation selected from a wider range of input wavelengths. It is based on the aspect of optical scattering in a prism, or that of diffraction grating, using which the different colours of light are spatially separated. It is based on the mechanism that selected colour of light is directed to the exit slit, it is usually used in reflective mode. The light enters the reflective prism through a single mirrored side at right angles. The light enters past the hypotenuse face and is reflected back. The total dispersion and refraction have the same results that we would obtain if an equilateral prism was used in transmission mode.

2.3. Fourier Transform Spectroscopy- In this type of spectroscopy the spectra are collected by measuring the coherence of radiation source, space domain or time-domain measurements of the electromagnetic spectrum is used. It is applied in various types of spectroscopy including optical spectroscopy, nuclear resonance, infrared spectroscopy, magnetic resonance spectroscopic imaging and mass spectrometry. The Fourier Transform Spectrometry states the case that in all these techniques, in order to obtain an accurate spectrum we need to turn raw data and in many cases using of Interferometers.

2.4. Charge-Coupled Device (CCD)-This device is used to track flow of electrical charge, usually from inside the device to an area where the manipulation of charge can be done. It is also used to convert data into digital values. This technology has been used extensively for digital imaging. Due to the high quantum efficiencies of CCDs, ease of use and linearity of the output as in comparison to photographic plates, so CCDs were extensively adopted by astronomers across the globe.

III. APPLICATIONS OF RAMAN SPECTROSCOPY

3.1. **Raman Spectroscopy to detect Head and Neck cancer**

In this decade there has been a lot of research about the use of Raman Spectroscopy in the diagnosis of head and neck cancer and the best chance of curing this disease is during the early stages. This method works when the photons interact with the target material producing a biological fingerprint, which can be analysed to detect presence of any cancer causing material. With this type of process being successful in detecting cardiovascular diseases and in dental and as the population is ever growing the urgency of rapid cancer detection has never been more. In the recent years there has been much argument about the use of optical diagnosis in cancer detection. At present the diagnosis of cancer is based on the histological evaluation with a possibility of cytological evidence of the same. In order to revolutionize cancer diagnostics the ability to detect early carcinogenesis prior to the changes a pathologist identifies would change the way we diagnose cancer. Some of the techniques involved are infrared spectroscopy and many other approaches as well such as; differential path-length spectroscopy, elastic scattering spectroscopy, optical coherence tomography and fluorescence are few of the techniques being used for the detection of head and neck tumours. These all techniques have been providing encouraging results for quite some time now, Raman spectroscopy is still in development in related to its application in life sciences but it has some great potential in the future.

3.2. **Astronomical Spectroscopy**

Astronomical spectroscopy is the study of our universe using the various spectroscopic techniques to measure the electromagnetic spectrum radiation, which includes radio and visible light from the heavenly bodies in the solar system. One of the most essential tools that can astronomer has to study the universe is spectroscopy. Using this technique various properties of astronomical sources can be determined such chemical composition, radial velocities and physical properties. One of the main means of means of measuring the dark matter content of the various galaxies in our universe, masses of two or more stars in an orbit around each other, rate at which the universe is expanding or the mass of a cluster of galaxies all are accomplished using the Doppler shift. Using the quantitative analysis of spectral features it is possible to discover the physical conditions of the far-off stars and galaxies, find their chemical compositions and temperature as well. In almost all the astronomical spectrographs and the disperser of the grating is dependent on the total sum of the grooves/mm usually of the order of 100-1000. If a person would see from the camera the wavelength of light would depend on the angle i, as a result of the incoming beam the grating would be set relative to it and the angle that the person sees through the camera normal to the grating. The amount at which we will have to change the angle in order to change the wavelength is called dispersion, and as higher the number of grooves/mm greater is the dispersion, all other conditions being equal. This relationship governing the wavelength and grating is called Grating Equation.

3.3. **Detecting Preterm Labour with Raman Spectroscopy**

Raman spectroscopy can make itself useful in detecting preterm labour, which can be intimidating, both for the doctors and the at-risk women. Right now, there is no way to detect preterm labour, which is the cause of premature delivery, and it causes a lot of other difficulties during delivery too. Since, Raman spectroscopy can analyse changes in the molecules of a blood sample, it analyses these changes in the cervix during Pregnancy, hence the Raman spectra can be observed and preterm labour can be detected. There are various other changes during pregnancy such as hormonal levels, water-content, changes in collagen, biochemical changes, which can be analysed by Raman spectroscopy. To detect the onset of labour, changes in the hormones can be observed and softening of the tissue or ripening of the cervix, which happens during gestation can also be taken into account. Though the reason for preterm labour is not yet set in stone, but once the molecular changes and the Raman spectra are analyzed, they are bound to be of help to detect preterm labour at least before a day. A day before labour can prove to be invaluable for the doctors, to help the mother and yet-to-be-born baby to an innocuous procedure, injecting proper drugs and medicine which can only used when preterm labour is diagnosed. Diagnosing it before time can prove to be of gigantic help for the baby, as it gets more time to develop inside the womb.

There has been research done on pregnant mice, to study the changes in the cervix using Raman Spectroscopy. The gestation period of mice is found to be19 days. During the research, they were kept in a temperature of 22 degree Celsius and their Raman spectrum was observed, with full care. The same was done for pregnant women, as they came for prenatal check-ups with their full consent, but the probing couldn’t be continued. Therefore, not a lot of information could be gathered due to lack of participation of patients. But a conclusion that could be drawn from the research is that changes were observed in the Raman spectra in the form Raman shifts, and these changes were significant during pregnancy. These were changes in DNA, lipids, collagen, amide, etc.

Therefore, by predicting preterm labour, infant mortality rate can be improved; better therapeutic drugs can be introduced and taken up by researchers as motivation. Since these drugs can prove to be life changing and act as stepping stones in making lives of at-risk women, ten-fold better. It is imperative that at-risk mothers are identified for preterm labour. Raman spectroscopy has been able to detect subtle changes during pregnancy, and it is still a research that is to be dug in, involving participation of patients in large numbers. Hopefully, if compensation is granted to the patients, and they are made aware of the benefits of the research, they will be able to participate and prove to be a catalyst for the research.

3.4. **Raman Spectroscopy for Clinical Oncology**

Cancer is the most lethal disease of all, and the most common and prominent cause of death, all over the world. Though there are several detection techniques, they have their disadvantages as well, such as delay in getting results. Raman spectrum of a cancer cell gives us its molecular fingerprint. The vibration level of the electron proves to be a defining trait of a molecule, so biochemical properties of a chemical bond can be noted from the spectra. This information is gained by using Raman spectroscopy, which can be performed by a non-invasive probing, without disturbing or harming the cells. Pairing such biomedical tool as Raman Spectroscopy and Machine learning, large sets of data can be deciphered and a cancer cell can be distinguished from a normal cell in less time than the normal.

Therefore, Raman spectroscopy can reduce the time at which cancer is diagnosed and treated. It can reduce the cost of operation, surgery and lab-tests. It can give certain, to-the-point and reliable information about the disease than what is ascertained by histopathology techniques.

For cancer studies, the data cannot be analyzed manually because if the peaks of the spectra are selected manually, it can lead to unreliable information. Therefore, the commonly used techniques to analyze data for cancer cells are Principle component analysis (PCA) and Fisher's Linear discriminate analysis (LDA). These techniques are used to analyze the data of Raman Spectroscopy. Here, machine learning can be paired with Raman spectroscopy as well. The machine can be made to "learn" by introducing such an algorithm which helps it to distinguish between a cancerous cell and a normal cell.

Similarly, Raman spectroscopy is found to have distinguished between a cancerous cell lesion in breast and a normal tissue. It is known, that breast cancer is the most lethal disease in women apart from skin and lung cancer, and it can only really be detected through biopsy of the suspected tissue. "Several other recent studies have been completed in which Raman spectroscopy was used to successfully classify excised breast tissue as cancerous, benign or normal with the results correlating closely to conventional histopathological findings". Thus, application of Raman spectroscopy in the treatment of cancer has proven to shown tremendous potential as an emerging technology.

IV. FUTURE SCOPE OF RAMAN SPECTROSCOPY

At present the technology is touching millions of lives, be it astronomers, scientists, doctors and many other people of this planet, thereby improving the quality of life. It has been responsible for saving many lives as well. In the coming future, Raman Spectroscopy is going to grow at a rapid rate.We can hope to see Raman Spectroscopy coupled together with Artificial Intelligence, being an amalgamation of an approach to solve complex problems. Therefore, machine learning combined with Raman Spectroscopy has some great prospects. Still a lot of work needs to be done in its research and development, but it sure has a bright future ahead.

V. CONCLUSION

Raman spectroscopy as seen in all the mentioned applications is definitely a scientific tool that can be of help in foretelling any foreboding in the medical field, by analyzing the molecular spectra of different samples, therefore, better preparing the doctors for appropriate procedures. For research purposes, as is analyzed, more patients need to come on board so that proper conclusions can be reached and significant progress can be made. This will therefore motivate several researchers to come up with better drugs and medicine to ensure the safety of the mother and the baby during preterm labour, or for early diagnosis and treatment of cancer. It can be said that Raman spectroscopy, when paired with advanced data analysis tools and machine learning, will give ultra fast results, which will be accurate in determining the root cause of a complex problem. Raman laser does not damage the substance or the cells, therefore it has also proven to be more advantageous than Fourier-transform infrared spectroscopy.

It can be concluded that the horizon overlooking the bright future of Raman spectroscopy in the advancement of data analysis and diagnoses is very wide, open to more investigation, research and experimentation, owing to the acceptance of Raman Spectroscopy in the medical procedures, defence and even astronomy.

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