J Integr. Sci. Technol, 2013, 1, 1, 13-18 Article

Journal of Integrated
Science and Technology

Application of He-Ne laser to study the variation of refractive index of liquid solutions with the concentration

Vivek Kumar Singh[a], Brij Bir Singh Jaswal[a], Vinay Kumar[a], Ram Prakash[a], and Priyanka Rai[b]

[a]*School of Physics, Shri Mata Vaishno Devi University, Katra -182320, J&K, India*
[b]*Department of Mathematics, Patna Science College, Patna University, Patna-800005, Bihar, India*

Received: 21-03-2013 Accepted: 21-05-2013 Available Online: 22-05-2013.

ABSTRACT

In the present paper, we have presented the variation of the refractive index of liquid solutions with the concentration at the He-Ne laser wavelength 632.8 *nm*. The measurements of the present experiment were carried out using the conventional minimum deviation method of an equilateral hollow glass prism. We measured the refractive indices of sugar solutions, sodium chloride (NaCl) solutions, and sodium (Na) for a range of density varying from distilled water to a saturated condition and their variation with the concentration is presented. Our results reveal that the refractive index of liquid solutions varies linearly with the concentration of sugar and sodium chloride at low concentrations. For the higher concentrations of sugar solution we found a slight curvature from the plot of refractive index *vs* concentration of solution. For the quantitative measurements of sugar, NaCl and Na present in different kinds of samples we drew the calibration curves. We have verified our results with the results reported and obtained from atomic absorption spectroscopy (AAS). We have also used this method to determine the salinity of the water sample of Adriatic Sea.

Keywords: Sugar, Salt, Sodium, He-Ne laser, Minimum deviation

Introduction

The refractive index or indices of a substance describe an important part of its interaction with electromagnetic radiation. The refractive index is a basic optical property of materials. Its accurate measurement is often needed in many branches of physics and chemistry and it has several applications to many industries and materials. Refractive index is measured for many reasons. It is clearly important to know the refractive index of materials used for their clarity, such as glasses and solid plastics. In complex fluids such as drinks or foods, the refractive index is a measure of dissolved or submicronic material. The Brix scale relates refractive index to sugar concentration. Common industrial applications are to microemulsions to measure their oil/water ratio, to antifreeze to check the glycol/water ratio, and to inaccessible liquids such as the electrolyte of rechargeable cells[1].

Address:
Dr. Vivek Kumar Singh
School of Physics, Shri Mata Vaishno Devi University, Katra-182320, Jammu and Kashmir, India.
Tel: 01991-285699, Ext. 2520 (O)
Email: singh_vivekkumar2005@yahoo.com

Cite as: *VK Singh et. al. J Integr. Sci. Technol., 2013, 1(1), 13-18.*

Numerous methods for measuring the refractive index of a liquid solution are well documented in textbooks[2], however the most suitable and easiest method was also reported[3, 4]. The authors have reported that the use of an equilateral hollow prism would allow measurement of the refractive index of most ordinary liquids. It opens the possibility of studying small variations in the refractive index of a solution with concentration. In the present paper, we have discussed an experimental technique using He-Ne laser to determine the refractive index of transparent liquid samples making the use of Snell's law. We have utilized He-Ne laser as a light source to measure the refractive index of different kinds of standard and unknown sample solutions and hence to determine the concentrations of the sugar and salt in unknown samples.

Materials and Methods

Experimental Setup

The theory and method have been discussed in well manner in the reported literature and textbooks[3-6]. However, in brief we have discussed the method to measure the minimum deviation to measure the refractive index of liquid solutions making use of Snell's law. Regarding Fig. 1, a collimated light beam *AB* is incident on a prism of apex angle α. The angle of deviation δ is found to be minimum (δ_m) if i_1 and i_2 are equal. In this position the refracted ray is parallel to the base of the prism. Then the refractive index of the material filled inside the prism or solid prism can be determined by using Snell's law which is given by:

$$n = 2.00056\sin(\alpha + \delta_m)/2 \qquad (1)$$

To derive Equation (1), the value α = 60° and n_{air} = 1.00028 is being used.

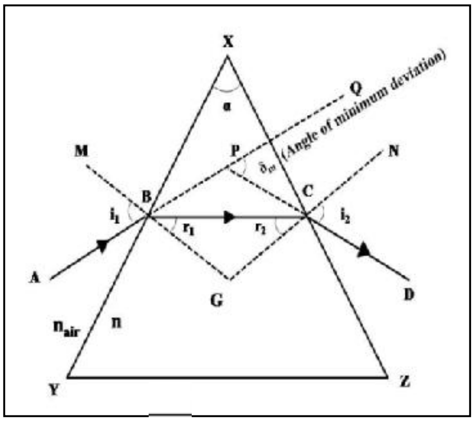

Figure 1: Refraction through prism at the position of minimum deviation (δ_m)

To perform the experiment, an equilateral hollow prism is fixed on a spectrometer table. A 2 mW He-Ne laser at 632.8 nm was used as the light source. A schematic representation of the apparatus setup is shown in Fig. 2. At first we have set the laser pointer in such a way so that the laser beam (light ray AD) fall perpendicularly to a nearby wall. We have attached a big piece of paper to the wall for marking and measuring where the beam hits. We have also adjusted the height of the laser pointer so that it hits about half-way up the side of the prism. The laser pointer is fixed and in place and we have checked periodically to make sure that the beam is still hitting its original spot. When the prism was empty (filled only with air), then we placed it in the path of the laser beam. We marked the laser spot on the wall when the prism was empty. When we filled the prism with liquid, the laser beam refracted within the prism. To find the angle of minimum deviation the position of minimum deviation is required. To find this position we changed the angle of incident by rotating the prism table in that direction where the deviated laser beam spot move towards the undeviated laser spot.

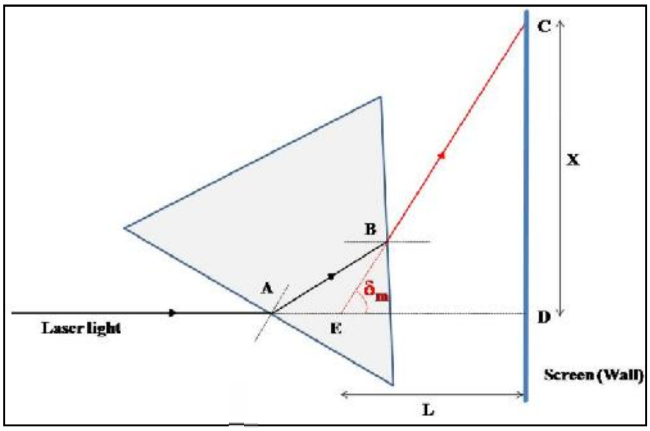

Figure 2: Experimental setup to measure the angle of minimum deviation ($\boldsymbol{\delta_m}$)

At a particular incident angle the laser beam spot stops and the laser spots reverse its direction. At that point where the laser spot stops is the position of minimum deviation. By theory and experiments, it is proved that at this position the angle of incident and the angle of emergence are equal and the refracted ray (light ray AB) is parallel to the base of the prism which can be seen in Photographs 3. The emerging beam (light ray BC) hits the wall some distance away from the original spot (point D) of the undiverted beam. Thus, the angle of minimum deviation can be measured easily using the formula:

$$\delta_m = tan^{-1}(X/L) \tag{2}$$

Finally, the index of refraction is calculated using Equation (1). To check the validity of this experimental setup we calculated the index of distilled water which came 1.333 and validate our experimental setup and procedure.

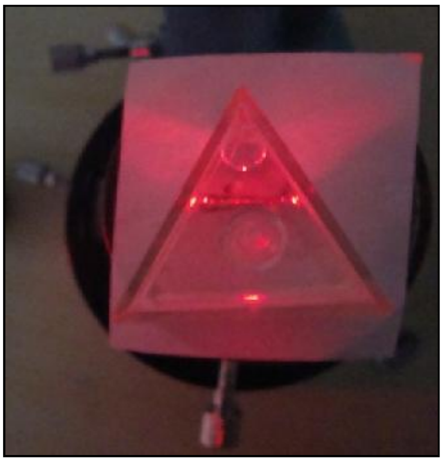

Figure 3: Photographs of the experimental setup in the laboratory at the position of minimum deviation

Preparation of standard samples of varying concentration of sugar and sodium chloride for calibration

For the quantitative analysis of sugar and NaCl present in the unknown sample solutions, we have to draw proper calibration curves. Thus, for the calibration curve (a graph between refractive index and the concentration of sugar or NaCl in the matrix), different liquid samples having a known concentration of sugar and NaCl are required.

In this work, a standard solution method[7] was preferred for the preparation of the standard samples, to maintain the homogeneity of the liquid samples. The standard sugar solutions having sugar concentration of 2%, 4%, 6%, 8%, 10%, 15%, 20%, 30%, 40%, and 60% were prepared. A 2% sugar solution is meant by 2 gm of sugar is dissolved in 100 ml of distilled water i.e. $(2\% = 2\ \mathrm{gm}/100\ \mathrm{ml})$. In the present experiment, distilled water is used to avoid any type of contamination error. Similarly, the standard solutions having different concentrations of sodium chloride (NaCl) i.e. 2%, 5%, 10%, 15%, and 20% were prepared. A 2% NaCl solution is meant by 2 gm of NaCl is dissolved in 100 ml of distilled water. Since the percentage equivalent of Na in NaCl is 39.3371%, then 1 gm of NaCl contains 0.39 gm of Na. Thus, the equivalent percentage of Na in these standard NaCl solutions is given by 0.78% ($0.78\% = 0.78\,\mathrm{gm}/100\,\mathrm{ml}$), 1.95%, 3.9%, 5.85%, and 7.8% respectively. These solutions have been used to calculate the refractive index of the solutions.

Collections of different types of samples containing Sugar and Salt

We have collected different types of samples containing sugar and different kinds of salt samples. We have also collected the water from an "*Adriatic Sea*" to analyze their salinity. The Adriatic is the northernmost arm of the Mediterranean Sea, extending from the Strait of Otranto (where it connects to the Ionian Sea) to the northwest and the Po Valley. Its coasts are part of (in decreasing order of coastline length without islands) Croatia, Italy, Albania, Montenegro, Slovenia and Bosnia–Herzegovina[8]. These solutions then finally used to determine their refractive index and hence to determine the sugar content, salt content and the concentration of Na in these samples.

Results and Discussion

Study of the Variation of Refractive Index of Sugar Solution with the Concentration of Sugar

Using Equation (1) we have calculated refractive index of sugar solutions of varying concentrations and the variation of the refractive index of the sugar solution with the concentration sugar is plotted and shown in Fig. 3.

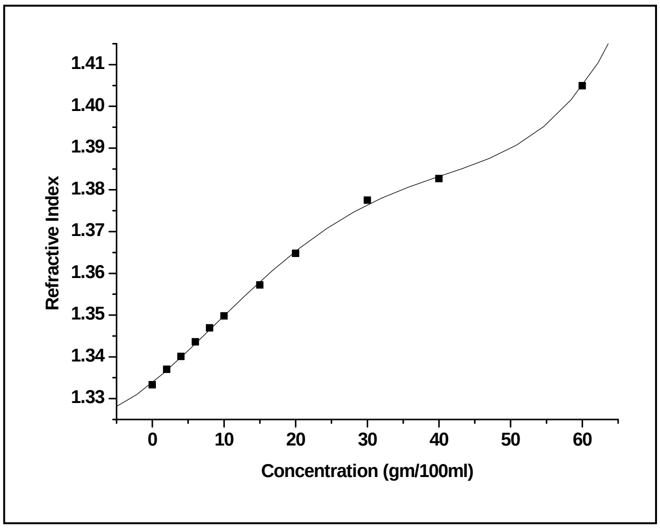

Figure 4: Variation of index of refraction with concentration of sugar

All the data points on the graphs represent five independent measurements carried out at a particular concentration of solution. From the Fig. 4 it is clear that the variation of refractive index with sugar concentration is linear for lower concentration but at higher concentrations a slight curvature can be seen. For the sugar solutions containing sugar upto 30% one can figure on a linear relationship between the refraction and sugar concentration. Our result is very close to the results reported by *W. Mahmood bin Mat Yunus*[9]. They have found the linear part of the graph for the solution concentration upto 24 gm/100 ml which is 24%. From the literature[10] the report says that the linear relationship was found upto 40%.

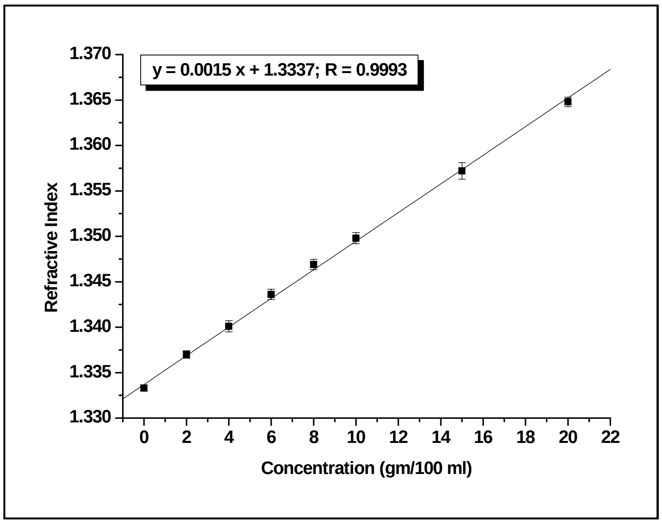

Figure 5: Calibration plot for the variation of index of refraction with concentration of sugar solution up to 20%

For more accuracy, we drew the calibration curves for different concentration of sugar solutions by plotting refractive index *vs* concentration of sugar upto 20% only, using ORIGIN software. It is because that the linear regression coefficient of the linear fitted data for the concentration upto 20% is much more better than that of the linear fitted data concentration upto 30% (Figure not shown here). Therefore, the calibration plot as shown by Fig. 5 is better than that of obtained from the concentration upto 30%. Five measurements were carried out separately to determine the refractive index of the solution and, finally, the mean relative standard deviation (RSD) of the refractive index is calculated and shown as $\pm y$ error bar. We obtained the slopes of these calibration curves by fitting data in the linear regression functions concentrations upto 20%.

Using this calibration curve we have determined the sugar content of different payable liquids of different brands available in the markets. The refractive index of these liquids has been determined using the calibration curve and tabulated in Table 1. From the Table 1 it is clear that the calculated sugar content is in good agreement with the sugar contents reported in these liquids. Thus, we can explore the possibility of using this method to determine the sugar content in complex fluids like orange juice, apple juice etc. We have also used this calibration curve to determine the sugar content in sugar cane juice. The calculated value of the sugar in sugar cane liquid was approximately 22% for the particular sugar cane juice which is good agreement with the reported literature[11]. High quality cane has a good juice content with high sugar levels (20% plus)[11]. Poor quality cane or cane that has been harvested early may have similar juice content but the sugar levels will be reduced. From the literature, it is clear that our result is in close agreement with the results reported in literature. From the above results it is clear that the present method is very useful to determine the refractive index of transparent liquids and finally to determine the sugar content in complex fluids.

Study of the Variation of Refractive Index of Sodium Chloride (NaCl) Solution with the Concentration of NaCl

Using Equation (1) we have calculated refractive index of NaCl solutions having different concentrations of NaCl and the variation of the refractive index with the concentration is plotted and shown in Fig. 6.

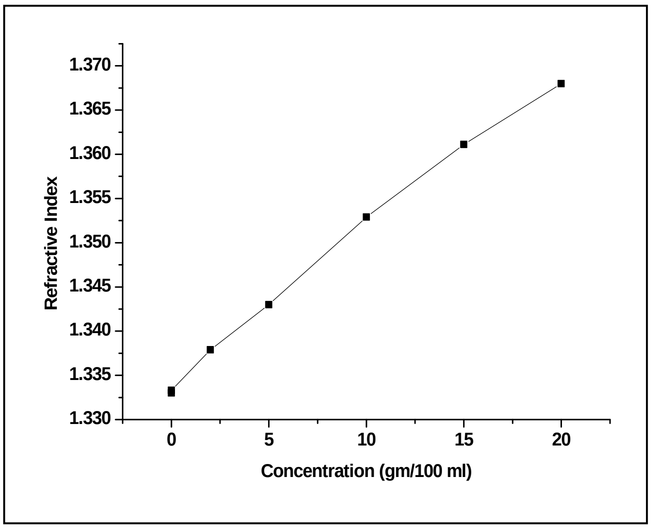

Figure 6: Variation of index of refraction with the concentration of NaCl

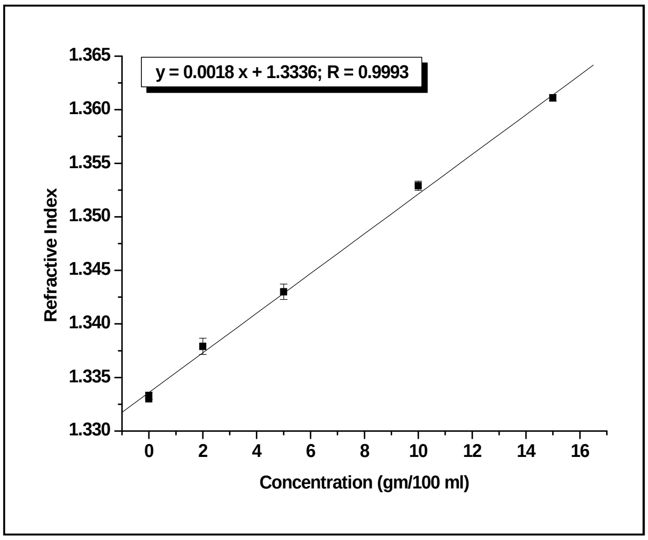

Figure 7: Calibration plot for the variation of index of refraction with concentration of NaCl upto 15%

From this plot (Fig. 5) it is clear that the refractive index varies linearly with the concentration of NaCl. For better accuracy, we drew the calibration plots upto the concentrations 15%. We obtained the slopes of these calibration curves by fitting data in the linear regression functions for the concentrations upto 15%. We have seen that at low concentration less than 20%, the variation of the refractive index is linear with the concentration. This is in good agreement with the results reported by *W. Mahmood bin Mat Yunus*[9]. They have found the linear part of the graph for the solution concentration less than 10 gm/100 ml which is 10%.

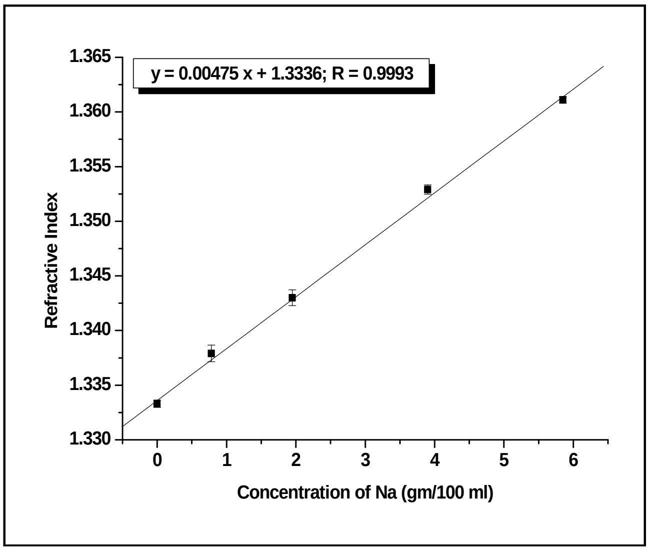

Figure 8: Calibration plot for the variation of index of refraction with concentration of Na

We have used this calibration curve to determine the salinity of the water collected from "*Adriatic Sea*". The content of NaCl is determined which was approximately 4%. Generally, the salinity of sea water is reported[12] from 3%-5%.

Quantitative Study of Na in different kinds of Salts Using Calibration Curve

There are several types of salts that are easily available in the market place for daily use and they contain different proportions of Na. The Na contents in the salts are directly related to high blood pressure and kidney diseases. The levels of Na in these salts can help to make the choice of low Na, which are the requirement to manage these diseases. So it is very important to know the Na concentration in these salts. To know the Na content in different kinds of salts four different types of common edible salts taken in the present study are described below.

(i) Black salt: *Black salt*, containing Na, is available in purified form in the Indian markets.

(ii) Tata salt: This is a refined iodinated salt widely used as a table salt and easily available in the Indian markets.

(iii) Saindha salt: It is commonly known as rock salt[13].

(iv) Ordinary salt: This is an o*rdinary type of salt*, which is not refined and can be obtained easily in the Indian markets.

The solutions of these salt samples were prepared which are finally used to determine the refractive index and hence to calculate the concentration of Na in the salt samples. To prepare the solution we dissolve *10 gm* of *Tata salt*, *Saindha salt*, *Ordinary salt* and *8 gm* of *Black salt* in *100 ml* of distilled water and filled these solutions in hollow prism to calculate the refractive index of these solution.

The refractive indices of these solutions were measured and finally the concentrations of Na in these salt samples are given in Table 2. The calculated value of the concentration of Na is in good agreement with the results reported. We have also determined the concentration of Na in *Ordinary Salt* and *Saindha Salt* using atomic absorption spectrometry (AAS) which is in good agreement with our results reported here.

Table 1: Concentration of sugar content in different liquids

Salt Samples	Calculated concentration of Na (gm/100gm of salt)	Reported concentration of Na (gm/100gm of salt)
Black Salt	35.7	33.1
Tata Salt	39.7	38.7
Saindha Salt	36.04	35.8 (Results of AAS)
Ordinary Salt	39.9	39.7 (Results of AAS)

Table 2: Concentration of Na content in different kinds of salts

Common drinks	Calculated concentration of sugar (gm/100 ml)	Concentration reported (gm/100 ml)
Brand A	11.80	12
Brand B	12.81	12.4
Brand C	11.95	13.2

In the *Saindha salt*, the concentration of Na is in comparable to *Black salt* but is lower than that of *Tata salt* and *Ordinary salt* (Table 2). It is difficult to use daily *Black salt* in daily food so keeping this point in view *Saindha salt* is more beneficial to use especially for the blood pressure and kidney patients. The presence of a reasonable amount of Na in the human body helps with nerve activity, muscle contraction, and fluid balance. Thus, one needs some sodium, but since Na is found naturally in foods, most people consume more Na than they need. When kidneys fail to work properly, the extra Na is not removed from the body. With extra sodium in the body one will feel thirsty and drink more fluids. Drinking a lot of fluids is dangerous for chronic kidney disease patients. Too much fluid can also cause high blood pressure, difficulties in breathing, and swelling of hands, feet and legs. Thus, the best way to control thirst is to limit Na. This means that one need to select the proper use of salt containing low Na, thus, *Saindha salt* is suitable for this purpose.

Thus, we can say that the present experimental setup is very useful to calculate the concentration of Na and other minerals of the salt which affects the human being directly like K, Ca, and Mg etc.

Conclusion and Further Prospects of the Research

In the present paper, we have studied the variation of refractive index of liquid solutions with the concentration dissolve in the liquid at He-Ne laser wavelength 0.6328 µm. We have successfully determined the sugar content in common drinks. We have also determined the concentration of Na in some different kinds of salts. In summary, we have demonstrated that this method is quite capable to determine the solute content dissolved in a solvent which is transparent. Our results reveal that this method can also be application for the determination of the content of the other major and minor elements like Ca, Mg, Na and K which directly affects the human health.

References and notes

1. Geake, J. E.; Smalley, C. A; Simple linear hand-held refractometer. *J. Phys. E: Sci. Instrum.* **1983**, *16*, 608-610.
2. Longhurst, R. S. *Geometrical and Physical Optics*, Wiley: New York, 1967.
3. Grange, B. W.; Stevenson, W. H.; Viskanta, R.; Refractive Index of Liquid Solutions at Low Temperatures: An Accurate Measurement. *Appl. Opt.* **1976**, *15*, 858-859.
4. Jenkin, D. D.; Refractive Index of Solution. *Phys. Educ.* **1982**, *17*, 82-83.
5. Cariou, J. M.; Dugas, J.; Martin, L.; Michel, P.; Refractive-Index Variations with Temperature of PMMA and Polycarbonate. *Appl. Opt.* **1986**, *25*, 334-336.
6. Bass, J. D.; Weidner, D. J.; Method for Measuring the Refractive Index of Transparent Solids. *Rev. Sci. Instrum.* **1984**, *55*, 1569-1573.
7. The article can be found at: http://www.ltss.bris.ac.uk/coursegenie/pharmacy_calculations/page_05.htm.
8. The article can be found at: http://en.wikipedia.org/wiki/Adriatic_Sea.
9. Yunus, W. M. B. M.; Rahman, A. B. A.; Refractive index of solutions at high concentrations. *Appl. Opt.* **1988**, *27*, 3341-3343.
10. Lide, D. R. *CRC Handbook of Chemistry & Physics*, 90^{th} Edition, CRC, 2009-2010.
11. The article can be found at: http://practicalaction.org/docs/technical_information_service/sugar_production_from_cane.pdf.
12. The article can be found at: http://en.wikipedia.org/wiki/Salinity.
13. The article can be found at: http://www.answers.com/topic/salt.

Dr. Vivek Kumar Singh obtained his M.Sc. (Physics) and D. Phil. Degree from the University of Allahabad, Allahabad, India in 2004 and 2010 respectively. Currently, Dr. Singh is an Assistant Professor of Physics at the Shri Mata Vaishno Devi University (SMVDU), Katra, J&K, India. His research interests are in the field of Lasers and Spectroscopy. Dr. Singh is currently working in the field of Laser-induced breakdown spectroscopy (LIBS) for the study of biological samples like gallstones, kidney stones, teeth, bones etc. He has published more than 15 International research papers. He is also working in the field of Theoretical Physics and published several article in the field of Cosmology. He is also life member of Indian Laser Association, Modular Labs, BARC, Bombay; Laser and Spectroscopy Society of India, BHU, Varanasi, Indian Science Congress Association, Kolkata, Indian Society of Atomic and Molecular Physics, Ahmedabad, and Indian Association of Physics Teachers, Kanpur.

Dr. Priyanka Rai has completed her M.Sc. degree in 2007 from Patna University, Patna, India and received several University Gold Medals. She completed her Ph.D. degree from Veer Kunwar Singh University, Ara, Bihar, India in 2010. Her research interests are in the field of Cosmological Models in Scalar-Tensor Theories of Gravitation. She has published her research work in the Journal of International repute like International Journal of Theoretical Physics. Currently, she is involved in theoretical as well as experimental Physics.

Mr. Brij Bir Singh Jaswal has completed his M.Sc. (Physics) degree in 2012 from Shri Mata Vaishno Devi University (SMVDU), Katra, J&K, India. His research interests are in the field of Laser and Spectroscopy. He has attended National level conferences to present his research work.

Dr. Vinay Kumar received his M. Sc. Degree in Physics from Jiwaji University Gwalior in 2002. He obtained his Ph.D. from K.U., Kurukshetra in 2007. His research interests are in fluorescent nanomaterials in powder and thin film forms, and their applications in lighting, displays, and latent finger-print development. He did his first Post-Doctoral Research from UFS, South Africa and second PDF from Panjab University, Chandigarh, India. He has published more than 38 international research articles. Currently, Dr. V. Kumar is an Assistant Professor of Physics at the Shri Mata Vaishno Devi University, Katra (J&K) India. He is also a Life member of Luminescence Society of India. He is also a recipient of DST-Young Scientist Award in 2011.

Dr. Ram Prakash received his Ph.D. Degree in Physics from DAVV, Indore. He has also post doctoral experiences from IIT Kanpur and South Korea. His areas of Specialization are Magnetic oxide thin films, DMS, Materials science, Experimental Techniques and area of Interest are Materials Science, thin film & nanostructures, spintronic materials and optical materials. He has published more than 20 International research papers. Currently, He is an Assistant Professor of Physics at the Shri Mata Vaishno Devi University, Katra, J&K, India. He is also a Life member of Indian Science Congress Association, Kolkata, MRSI, and Indian Association of Physics Teachers, Kanpur.