

Alcohol Measurements: Chromatography (Gas Chromatography - GC and GC-Mass Spectroscopy, High Performance Liquid Chromatography - HPLC); Densitometry; Enzymatic and Spectroscopic (Near-Infrared - NIR and Nuclear Magnetic Resonance - NMR) Methods: A Brief Review

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On Alcohol, Alcoholic Strength and Measurements

Alcoholic strength is the term used to denote the measure of the amount of ethyl alcohol (ethanol) in solutions such as beer, cider, kombucha, malt-beverages, RTD cocktail mixes, wines and spirits/liqueurs. It may be reported as percent by mass of solution (% weight/weight – w/w or mass/mass - m/m) or as percent by volume (% volume/volume – v/v). These values are expressed at either 60 °F (15.56 °C) or at 20 °C (68 °F) depending on country, regulatory authority or other local requirements.

Over 180 years of research, laboratory practice, and a number of established verified tables of data and extensive algorithms help the alcohol beverage chemist best determine alcohol content in their samples. Many of the methods used to determine alcohol (once only available in well-equipped laboratories) have evolved through new technological developments, with modern instrumentation now simplifying the measurement of alcohol by beverage producers in their own facilities. That said, the grounding principles and theories behind alcohol determinations remain largely unmodified since their discovery, as will be demonstrated.

The Properties of Alcohol and Its Measurement

Ethanol is miscible with water in all proportions, with ethanol molecules fitting within the “spaces” in the three-dimensional structure of water. This “space filling” property means that the final volume of any mixture of water and alcohol is less than the sum of their individual volumes, i.e. there is a volume contraction upon mixing. The volume contraction has to be accounted for when determining alcohol by volume in aqueous mixtures. Solution volumes are temperature dependent and so temperature compensation also has to be allowed for in measurements. More sophisticated instrumentation compensates for temperatures of measurement and can deliver reportable data at specified temperatures. In the US, alcohol by volume is sometimes still reported at 60 °F (15.56 °C) though more frequently 20 °C (68 °F) is the required temperature. The temperature volume change is, however, effectively so small between these two temperatures that the difference in values is

a little redundant for the tolerances allowed for most alcoholic beverages. Most modern instruments and methods are in fact now measuring and reporting values at 20 °C (68 °F) and this will be the value largely discussed here.

Ethanol ($\text{CH}_3\text{CH}_2\text{OH}$; $\text{C}_2\text{H}_5\text{OH}$) has, at 1 standard atmosphere pressure, a boiling point of 78.29 °C (172.92 °F), an ignition or flash point of between 9-11 °C (48.2-51.8 °F), a freezing (or melting) point of -114.14 °C (-173.45 °F), a density (d^{20}_4) of 0.78934 g/ml (or 789.34 kg/L at 20 °C), a density ($d_{20/20}$) of 0.78927 g/mL at 20 °C and a refractive index ($n_{20/D}$: 20 °C measured at a wavelength of 589 nm using the Sodium D-line) of 1.3611.

These properties may be used to determine the concentration of ethanol as outlined below. Density values may be expressed as relative density or specific gravity values as defined elsewhere and will be important numbers expressed throughout this note. Specific gravity values are unit-less numbers as they are defined relative to a standard substance, usually water, and so the unit terms of density g/mL (or kg/L) cancel. For equations expressed herein it is noted that 0.7907 as a unit-less number, or the rounded values of 0.790 or 0.791 are the specific gravity values most commonly used in brewing circles for pure alcohol. The number is derived from the density value of alcohol at 20°C (68 °F) and the density of water also at 20°C (68 °F): 0.998203. [These listed properties of ethanol will be employed in methods for its quantitation as noted throughout this article.]

Outline of Methods to Measure Alcohol

Over the years many physical and chemical methods have been used to determine the amount of alcohol present in solution. These methods relied on measuring some physical or chemical property of ethanol and they evolved in sophistication along with micro-chip technology and micro-scale developments. In general, for the purposes of this article, only the more modern and sophisticated (officially accepted or approved) methods of alcohol determination are covered. As such alcohol may be accurately determined via:

- **Chromatography – Gas (GC) and Liquid Methods (Including High Performance or High Pressure Liquid**

Chromatography (HPLC)

- Density and or Specific Gravity Measurement
- Enzymatically - [Highly specific biochemical tests for analytes]
- Spectroscopy – Near-infrared (NIR) & Nuclear Magnetic Spectroscopy (NMR)

Before detailing the methods listed above, it is to be noted that alcohol was traditionally measured following its separation from samples by distillation. During distillation alcohol is boiled out of the aqueous solution and collected by condensation. Along with alcohol and water some other volatile components of the beverage will be distilled over, sometimes impinging upon the specificity of detection. Such issues if known can be compensated for with careful design of test protocols or by separate measurement of the suspected co-distilling compounds causing such interferences. While often dealt with in the past these issues are largely ignored today or are of only very minor impact on final results. Ultimately the concentration of alcohol in the distillate is estimated and then converted by calculation into alcohol content of the beverage.

The various methods discussed below have all been used to determine alcohol in distillates or were, in fact, designed to circumvent the need for distillation altogether. It will, however, be seen below that most alcohol beverage chemists and the modern instrumentation they use will utilize or rely upon tables and algorithms relating distillate or alcohol-water mixture specific gravity values to their corresponding alcohol values as determined by extensive work done over a century ago. Some of the technologies as used in the laboratory have now also been extended to in-line instruments and measuring alcohol and solids present (extracts) during production of the product. These in-line units rely on the same principles of detection and measurement as the laboratory methods. An international collaboration resulted in the publication of standard tables relating to alcohol measurements by the Organization of Legal Metrology in the 1980's.

The methods used to measure alcohol content and current applications:

Chromatographic methods for alcohol determination (Gas Chromatography and High Performance Liquid – HPLC - Chromatography)

Alcohol has been determined utilizing chromatographic methods, which separate and analyze mixtures of chemical components. These methods often rely on densitometry of distillates for calibration purposes and were initially more frequently used in wine and distilled spirits testing facilities rather than by those producers of lower alcohol-containing beverages such as beer. However, GC systems with a flame ionization type detector (FID, see below) have been used in many laboratories and by producers for several decades for alcoholic products and for non alcoholic and dealcoholized products where target concentration is 0.5% alcohol by volume or less. Furthermore, government bodies around the world

have relied upon GC/FID for routine ethanol analysis in wines, beers and spirits and for the testing of non alcoholic and dealcoholized products.

Gas chromatography.

This method relies on selective adsorption and desorption of volatile components on a stationary phase. Components are carried through a column by means of an inert gas and emerge, depending on their retention times on the column, and pass to a specific type of detector; for alcohol detection a flame ionization detector (FID), as noted above, is used. The detector is linked via an amplifier to record a profile of peaks corresponding to each compound that passes through the detector. Thus alcohol and other components are identified and quantitated by weight (wt/vol) (via calibration with known standard compounds) based on retention (residency) time in or on the column. Clear resolution of each compound of interest is possible, via partitioning between the carrier gas stream and liquid phase supported on an inert solid in the column. When a component is clearly separated from others in the sample the compound will be accurately quantified by the instrument after a calibration curve has been generated. The calibration curve being generated via the use of carefully calibrated amounts of that pure compound across the concentration range expected to be seen in typical samples. Described in some references as an AOAC (Association of Official Agricultural Chemists) approved method accurate to about +/- 0.2% v/v, gas chromatography has been described for measuring ethanol at low concentrations in beer distillates and in beer for example by the US agency TTB. In real world modern practice standard deviation on control samples is more like 0.05% by volume.

GC sees some application in evidential breath and blood analyses and in other forensic applications. Regulatory authorities may rely on GC determinations of alcohol based on both the method's sensitivity and rapid turnaround. As a method in its own right it is fully adequate to the task of measuring most volatile compounds of interest. In this regard it is noted that gas chromatography may also be utilized with detectors other than flame ionization, such as by electron capture, thermal conductivity, sulfur specific detectors and by mass spectroscopy.

Gas chromatography/Mass Spectrometry.

Gas chromatography, through column separation of volatile compounds and detection via specific detectors (see above), is a powerful method when compounds are known, or suspected, to be present in a sample and when the instrument is calibrated to measure those compounds. Where it becomes a more powerful method (mainly for seeking out unknown compounds and identifying them through their mass properties) is when coupled to a mass spectrometer. Mass spectrometry can be used to obtain the formulae and structures of molecules. Yet is overkill for measuring known compounds in routine practice. The use of GC/MS is actually an expensive proposition for the solution to a low resolution problem. If available to a facility it would be valid for use in alcohol measurements but the GC unit itself is all that is needed for routine alcohol beverage chemistry purposes. The GC portion chromatographically

separates the species present in solution. A portion of the separated compounds are siphoned off in turn and introduced to an ionization chamber where the vapor is bombarded with high energy electrons. This generates positively charged ions which can be determined based upon both their mass and electrical charge. Each chemical species can be identified via a peak formed as a function of relative abundance of its formation and at its appropriate relative molar mass (its mass spectrum). Extra information is available regarding how molecules are fragmented (broken down to component parts) during the testing – with the appearance of new mass-spectral peaks. Based on the charge and mass ratios of species produced compounds of interest can be identified and precisely quantitated. Further discussion on the molecular ions formed, the fragmentation patterns and their interpretation which are mathematically complex is beyond the scope of this review. Moreover, the type of internal control compound (for instrument/process calibration) needs to be carefully selected for and understood.

Static headspace testing by GC can be quite tricky. If a headspace GC-MS system is used the partition coefficients of species will affect the subsequent separation and quantitation. Furthermore, the method is reliant on the use of the aforementioned adequate internal standard. It is important to match the matrix of the sample with standards; i.e. the standard should ideally be as close to the analyte of interest as possible (such as deuterated ethanol in this case) and absolutely must not be a compound present in the samples being analyzed. A method of additions technique is suggested as working the best. These latter factors are also topics beyond the scope of this present note. It is, as stated above, a complex and expensive means to quantifying known compounds. The advantage for routine analyses is selectivity in complex matrices where chromatographic interference is inevitable. GC coupled with mass spectroscopy (GC-MS) is better suited for a rapid analysis of complicated mixtures of different compounds (or products from complex chemical reactions) rather than for monitoring a single analyte or two.

HPLC - High performance liquid chromatography.

In general chromatographic techniques are suitable for specific types of separation processes since the principles they employ reflect the physical characteristics of the sample's components. Thus any one technique is limited in its general applicability. However the advent of high performance liquid chromatography overcame many limitations based on the fact it can separate components based on many principles: selective adsorption, partitioning, ion-exchange, exclusion and affinity chromatography (simply put this means relying on different chemical principles and properties to separate groups of molecules). Making for an extremely versatile technique high performance liquid chromatography thus became a most powerful single chromatographic procedure. This chromatographic method uses a liquid mobile phase to transport compounds of a mixture, injected under high pressure, onto a packed column stationary phase. The mixture is resolved into its constituents via adsorption and release from the column matrix (using the principles alluded to above and depending on the desired group separation). The eluting

molecules are then detected and quantified via a suitable detector; for ethanol this is usually a U/V or refractive index detector (see above for the physical chemical properties of alcohol that dictate how in fact it may be detected). Again (like for GC systems) the system must be calibrated using known standards. As HPLC is better suited to less volatile compounds, it is usually used to determine sugars and organic acids in fermentation samples or beverages with ethanol (and glycerol) also coming along for the ride. This method finds more frequent use in the distilling industry than the brewing industry for example but can give very accurate alcohol readings for those using the technology on a regular basis. Ethanol, by its nature can have a much “wider” window of accuracy due to the type of column used and/or the physical and chemical properties of sugars and organic acids vs. ethanol in a so called isocratic system (not further defined here). A much more precise reading can be obtained if the scientist is willing to give up resolution of some sugars and organic acids.

A neat feature of using both types of chromatography (GC and HPLC) is that different chemical properties and physical conditions are used to resolve the species present in mixtures and has certainly helped to confirm that true alcohol measurements can be made using either technology alone.

Density and or Specific Gravity Measurements for Alcohol Determination

Historically, alcohol measurements were grounded in physical measurements of mass and volume through density or mass per unit volume intensive properties. Through density and specific gravity relationships, instruments and devices such as density bottles, hydrometers, densitometers, refractometers and pycnometers were used to establish a recognized and officially accepted body of work. This extensive research effort culminated in the derivation of algorithms and tables which define the relationships between density values and specific gravity readings and alcohol by weight and by volume.

Densitometers.

Modern densitometers have largely replaced the classic methods based on prior distillation of samples and either the use of refractometers or hydrometers for measuring extracts and alcohol in samples. These new density measuring devices are “Oscillating U-tube” density meters and these units are highly sophisticated and expensive instruments for measuring density; they are accurate to 5 or 6 decimal places and can be used to measure the density and specific gravities (SG's) of unfermented and fermented samples and distillates, to obtain original extract (OE) values, final SG (apparent extract) values or the alcohol content of the samples respectively. (The latter via alcohol value specific gravities and reference to tables.)

Oscillating U-tube densitometers work on the principle of electronic excitation of a measuring cell - the U-tube filled with a solution to be measured. Based on a fixed volume within the cell, similar to the older instruments such as the pycnometer (or density bottle), and defining the density as mass per unit

volume, an increase in mass within the same volume leads to an increase in density. The harmonics or oscillation of the tube (frequency of resonance) is affected by solutions of different density and the density is then calculated from the oscillation period. Such instruments will report density and specific gravities of a beverage or, if distillates are used, the percent alcohol by weight at 20 °C based on official tables generated by the Organization of Legal Metrology (The “OIML tables”). The percent alcohol by volume may also be reported based on OIML tables at 20 °C and percent alcohol by volume based on tables by the Association of Official Agricultural Chemists (AOAC). The AOAC tables were also later adopted by the American Society of Brewing Chemists (ASBC) and these tables record the alcohol contents as they would be at 60°F (15.56 °C). (AOAC, 1995, ASBC, 1940, OIML, 2015). These units are easy to maintain and need only to be calibrated on dry-air and pure water (a fluid for which densities are known to the desired degree of accuracy).

Enzymatically Measuring Alcohol (including detection via U/V Spectroscopic Methods)

Enzymatic assays have proven popular and very useful for alcohol determinations. Essentially these assays are in-vitro (“in the test tube”) biochemical assays relying on the natural enzymes and coenzymes (factors) involved in ethanol metabolism in living organisms. In living cells and in the laboratory ethanol can be readily oxidized to yield ethanal (acetaldehyde) or completely oxidized to acetic acid (ethanoic acid) [$\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CHO} \rightarrow \text{CH}_3\text{CO}_2\text{H}$]. In the sensitive and specific enzyme assay the ethanol present from the added sample is first oxidized to ethanal (acetaldehyde – CH_3CHO) using the biochemical compound nicotinamide adenine dinucleotide (NAD) in the presence of the alcohol dehydrogenase enzyme instead of a chemical oxidizing agent (used in earlier test-tube assays). As the reverse reaction is the thermodynamically favored process, the overall reaction is driven to completion by removing the acetaldehyde. This is done in a second step in the presence of aldehyde dehydrogenase which involves the quantitative oxidation of the acetaldehyde to acetic acid, again with NAD involved. The NAD is reduced to NADH (and a proton: H^+) in each reaction (two molecules of NAD are consumed for every ethanol molecule oxidized to acetic acid) which then affords the quantitation of the alcohol spectrally via NADH’s absorbance of energy from wavelengths within the uv/visible spectrum; 334, 340, or 365 nanometers (nm). The use of natural biochemical catalysts and cofactors and the right temperature and pH conditions gives rise to the exquisite sensitivity and precision for measuring ethanol in well-prepared and diluted samples. Full test details and limitations to the assay being described in kit manufacturer specification sheets.

Such assays were originally developed to test for the presence of alcohol in alcohol free or low alcohol products (with anything below 0.5% alcohol by volume considered non-alcoholic). Such assays are often used in such cases due to their extreme sensitivity, specificity and accuracy. However, with suitable and careful dilution, higher alcohol containing beverages and foods can be tested via these very sensitive enzymatic assays. Again, it is to be noted that in order to obtain the true alcohol by volume

from such tests, the sample specific gravity must be known. The methods supplied with test kits make no assumption in this regard and do not give true alcohol by volume values unless a separate sample of the product is tested for its current specific gravity.

Alcohol Measurements Using Spectroscopy

Infrared (IR) spectroscopy is a method which utilizes the energies of the infrared light spectrum to promote transitions within the various functional groups of molecules. Within certain regions of the electromagnetic spectrum, chemical compounds may absorb the infrared radiation and specific vibrations may be measured. The infra-red spectra of molecules are absolutely specific – certain bands which regularly appear near the same spectral wavelength of energy may be assigned to specific molecular groupings. By measuring the vibrations of atoms and bond stretching, those functional groups can be determined. The frequencies and intensities of the infrared bands exhibited by a chemical compound uniquely characterize the material – generating a fingerprint - and thus, infrared spectra can be used to not only identify a particular substance in an unknown sample but can also be used to quantify that substance. As such, the use of the energies associated with the mid-range and near-range of the infrared spectrum may be used to determine the content of alcohol in beverages. Moreover, it is noted that IR spectroscopy in both the mid-infrared (MIR) and near-infrared (NIR) regions is gaining popularity both qualitatively and quantitatively as an analytical technique with potential in other areas of alcoholic beverage and beverage raw materials testing; near-infrared spectroscopy techniques have been implemented for example in malting and brewing since the early 1990’s. Instruments require calibration, but once set up several components in samples can be measured simultaneously with little to no sample preparation needed. However, a major limitation of NIR spectroscopy in alcohol beverage and food analysis is its dependence on less-precise reference methods. Also, once again noting the need to obtain independently the density values of samples to perform subsequent calculations. This measurement of density, alongside the alcohol by volume determination, is covered in brief notes below.

Infrared devices are also finding application within in-line measurements in the brewery and other alcohol beverage production facilities. Most significant to the present discussion is that highly accurate NIR spectrometers are now on the market that can measure the alcohol content of beer and malt beverages in the range of 0-12 percent v/v. These units are often used today along with coupled density meters (see below).

Of Coupled Oscillating Density Meters and NIR Alcohol Meters

As seen above some coupled instruments today rely on two fundamental properties of alcohol; namely its density and its absorption intensity in the Near-Infrared region of the spectrum (often a carbon-hydrogen bond stretching vibration near 1200 nanometers in the energy spectrum). In principle

the alcohol by volume at 20 °C is determined by the NIR instruments based on a specific function of the absorption intensity of the NIR line of alcohol (see above). The specific absorbance of energy being dependent (proportional) to the ethanol concentration. The coupled instrument's software programs' reference the OIML (or other) tables for solving for the percentage of alcohol by weight. The coupled instruments can then determine the ethanol concentration (weight and volume), the specific gravity of the sample, and then, via calculation, the original extract for the alcohol containing sample. The calculation for weight of alcohol relies on the density value for pure alcohol at 20 °C (taken as 0.78924 g/cm³) and the density of the sample measured in the density meter. [The NIR- Alcozyzer method has been extended recently to cover a wider range of alcohol content with high accuracy and precision but the details have not yet been presented for public viewing. The manufacturer, Anton-Paar in Austria might be consulted for the details or to the date and citation when published.]

Nuclear Magnetic Resonance Spectroscopy (NMR)

Another sophisticated method, as yet only available in a few facilities (typically in academic research settings), that can also accurately determine alcohol is nuclear magnetic resonance (NMR). This is a technique for detecting atoms which have nuclei that possess a magnetic moment such as ¹H, ¹³C, ³¹P, ²³Na, ¹⁵N, etc. The nuclear magnetic moments of these atoms interact with the magnetic component of electromagnetic radio-waves giving rise to the phenomenon known as nuclear magnetic resonance. Most studies are conducted using the lightest isotope of hydrogen, ¹H (thus the term proton magnetic resonance or p.m.r. may also be used). This method is being increasingly used to analyze commercial products. In very simple terms the method can chemically fingerprint the bulk solution of an intact beverage with minimal sample preparation. Unlike GC and HPLC methods it is not a chromatographic technique which gives it its own differential way of determining, for example, the true ethanol concentration in a beverage. In ¹H-NMR each chemical component has a unique spectrum based on the different hydrogen chemistry on the molecule. Thus protons in CH, CH₂, and CH₃ groups present in different chemical groups such as olefins, aromatics, organic acids, alcohols, esters, carbohydrates etc., may be detected by the occurrence of particular peaks and multiplets at specific chemical shifts in the NMR spectrum. In addition, the relative number of ¹H atoms in each type of chemical group within the sample is indicated by the relative intensities of the appropriate peaks; that is by the areas under those peaks. A peak unique to a component of interest is chosen and the ratio of its signal intensity to that of an internal standard is determined. The signal intensities are divided by the number of protons they represent in order to obtain a signal intensity on a molar basis. With a knowledge of the molecular weights of the standard and the component, the weight of the standard present and the sample volume, the concentration in milligrams per liter for the component of interest can be determined along with all other components simultaneously. From there the alcohol by weight and by volume can be computed. Thus, NMR is a very powerful and growing method for product analysis.

A quick final note on alcohol calculations

For those instruments and methods that lead the chemist to obtain the alcohol by weight (ABW) the alcohol by volume (ABV) can be calculated if the specific gravity is also precisely known:

$$ABV = \frac{ABW \times SG_{sample}}{SG_{ethyl\ alcohol\ 20^{\circ}C/20^{\circ}C}}$$

Where, SG: specific gravity, e.g., for the alcohol beverage sample or pure ethanol respectively.

This simplifies to:

$$ABV = \frac{ABW \times SG_{sample}}{0.7907}$$

Variant equations are available but alcohol should be reported both % by weight (wt.) and by volume (vol.) to two decimal places. For reporting purposes most alcohol beverage producers are allowed a certain tolerance in readings expressed as some degree +/- a specified amount of alcohol by volume (for beer, for example, that is +/- 0.3% ABV).

A final note on the use of a Coupled Density Meter and NIR Instrument (an Alcozyzer) in resolving issues on simple density measurements

Avoiding the need to analyze distillates the coupled Density meter/NIR instruments measure the alcohol via the ethanol absorption profile. This profile is then compared to and adjusted by the density meter which is described as one of the most accurate concentration meters for binary solutions. Several algorithms can be used for this adjustment. The alcohol by volume is thus obtained which is essentially the equivalent as if obtained from the density of a volumetric distillate. The concentration of ethanol, as percent by weight, is computed as the product of the alcohol by volume, as determined/calculated by the NIR alcozyzer, and the density of pure ethanol divided by the density of the sample, as determined by the density meter (ABW = ABV*0.78924/Sample Density). An apparent redundancy (not detailed here) in determining the ABW with such coupled instruments is actually quite useful as it can eliminate any issues (in this author's opinion and experience) with the density measurement if that is affected in any way with co-distilled components (BDAS, LLC laboratory testing – personal observations and personal communications with the scientists at Anton Paar-USA). In simple terms it means that the coupled density meter/Alcozyzer combination can, in fact, ultimately determine the correct alcohol by volume assuming nothing interferes with the NIR signal in measuring the actual alcohol in the sample. (That is another consideration to take into account in measuring complex samples).

As both density meter and NIR units communicate with each other, a complex series of calculations is performed in order to solve for the correct values of all parameters (Roman Benes of Anton Paar, personal communication). Observations in the

BDAS, LLC laboratory (with what we term direct measurements of samples) show this to be true in measuring the alcohol by volume (in mildly acidic solutions – containing low levels of acetic acid for example) within a tolerance of +/-ca. 0.2% ABV. Further work may be necessary to obtain the finite limits on certain complex-matrix alcohol containing beverages but is in accord with descriptions of earlier published official AOAC methods (for wines containing acetic acid for example). [See AOAC methods: 935.21 and 920.57.]

Concluding remarks

From above it is hopefully clear that, for many types of alcoholic beverage, a number of officially accepted and highly accurate methods/techniques/instrumentation can be used to faithfully, accurately and precisely measure alcohol content in suitably prepared samples within quite tight and allowable regulatory tolerances. For one particularly complex type of alcoholic beverage, not yet classified for testing, a collaborative laboratory project – four independent laboratories/four distinct methods (GC, HPLC, NMR and Density Meter/Near-Infrared Alcohol detection) gave almost identical results (within ca. +/-0.2% ABV) for each method, based on the comparative data on three selected samples. It should be noted that in general all the methods discussed are stated to be capable of accuracy measurements and detection limits of 0.1-0.2% ABV.

References

A detailed set of references is available upon request. This article was adapted in part (and extended in scope regarding the methods) from “Alcohol and its Measurement.” Gary Spedding. In: *Brewing Materials and Processes: A Practical Approach to Beer Excellence* (ed. C. W. Bamforth). Elsevier, Burlington, MA. 2016. [In preparation]. A detailed set of references may be found there. Also recommended reading is “Foundations of Spectroscopy” (Oxford Chemistry Primers). 1st Ed. Simon Duckett and Bruce Gilbert. Oxford University Press. ISBN-10-0198503350. 2000.

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Additional information and references may be requested in relation to this note or other publications from us.

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Tables of data

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ADDENDUM

UV-visible spectroscopy may also provide a useful tool for measuring alcohol concentration. There are instruments on the market to measure both proof and color in whiskey for example (Applied Analytics). Ethanol and water both have unique structural features in their respective absorption spectra (as also noted for the other techniques discussed above). These have stronger or weaker prominence based upon their concentrations in measured alcohol solutions. In such systems the absorbance occurring over the 800-1000 nm region of the visible spectrum is measured. A peak of absorption for ethanol is noted at ca. 907 nm and a broad peak, centered at ca. 988 nm, is noted for water. While the alcohol peak is of very low amplitude it can be used to determine alcohol concentrations as tested vs. known proof samples. Recently UV/visible spectra have been generated in the BDAS, LLC laboratory but data analysis to see if meaningful results from such approaches is only just now underway. It may not be suitable for very low alcohol containing samples but is a powerful technique in its own right and regaining popularity for measuring the “fingerprint” and authenticity, consistency, dilution and adulteration of alcoholic beverages. This topic was discussed in our earlier White Paper: “*Scanning UV-Visible Spectroscopy and Beverage Quality, Consistency and Authentication: Preliminary Fingerprinting Application in the Analysis of a Wide Variety of Alcoholic Beverages – A Brief Application Note*” Gary Spedding. BDAS, LLC WPSP#1. 2015.