Refractive Index

A **refractometer** measures the extent to which light is bent (i.e. refracted) when it moves from air into a sample and is typically used to determine the **index of refraction**(“**refractive index”** or “***n”***) of a liquid sample. The refractive index is a unitless number, between 1.3000 and 1.7000 for most compounds, and is normally determined to five digit precision. Since the index of refraction depends on both the temperature of the sample and the wavelength of light used these are both indicated when reporting the refractive index:

$$n_{\mathrm{D}}^{20}\ 1.3742$$

The italicized *n* denotes refractive index, the superscript indicates the temperature in degrees Celsius, and the subscript denotes the wavelength of light (in this case the D indicates the sodium D line at 589 nm).

In the organic chemistry laboratory, refractive index is commonly determined to help identify pure liquid samples by comparing the experimental value to published values for pure compounds. However, there are many more applications for refractive index:

• Foods and Beverages
– Soluble solids in fruit products
– Rancidity in edible oils
– Moisture in honey and strawberry jam
– Total solids, water and fat in milk
– Oil in avocado and olives
– Fat in chocolate
– Moisture in meat

• Petroleum
– Petroleum in oil sands
– Olefins, aromatics, paraffins
– Ethylene glycol in coolants
• Agriculture
– Oil content of seeds
– Sweet corn maturity
– Salinity

Industrially, it is most often used to determine concentration of a dissolved solute in liquid samples. The most common application is measuring the concentration of sugar dissolved in water, such as in fruit juices and juice concentrates.

Examples of smaller, hand-held refractometers:

Dissolved sugar changes the refractive index of water substantially. Since sugar is the primary ingredient in juices, the “Brix” scale of refractive index was developed.

Degrees Brix (symbol °Bx) is the sugar content of an aqueous solution. One degree Brix is 1 gram of sucrose in 100 grams (% w/w) of the solution. If the solution contains dissolved solids other than pure sucrose, then the °Bx only approximates the dissolved solid content. The °Bx is traditionally used in the wine, sugar, fruit juice, and honey industries. Since temperature can affect refractive index, it is important to control this parameter during a measurement. (One degree Celsius changes R.I. by about 0.0001 unit.)

International Scale (1936) of Refractive Indices of Sucrose Solutions at 20° C.

Index	Per cent	Index	Per cent	Index	Per cent	Index	Per cent
1.3330	0	1.3723	25	1.4200	50	1.4774	75
1.3344	1	1.3740	26	1.4221	51	1.4799	76
1.3359	2	1.3758	27	1.4242	52	1.4825	77
1.3373	3	1.3775	28	1.4264	53	1.4850	78
1.3388	4	1.3793	29	1.4285	54	1.4876	79
1.3403	5	1.3811	30	1.4307	55	1.4901	80
1.3418	6	1.3829	31	1.4329	56	1.4927	81
1.3433	7	1.3847	32	1.4351	57	1.4954	82
1.3448	8	1.3865	33	1.4373	58	1.4980	83
1.3463	9	1.3883	34	1.4396	59	1.5007	84
1.3478	10	1.3902	35	1.4418	60	1.5033	85
1.3494	11	1.3920	36	1.4441	61		
1.3509	12	1.3939	37	1.4464	62		
1.3525	13	1.3958	38	1.4486	63		
1.3541	14	1.3978	39	1.4509	64		
1.3557	15	1.3997	40	1.4532	65		
1.3573	16	1.4016	41	1.4555	66		
1.3589	17	1.4036	42	1.4579	67		
1.3605	18	1.4056	43	1.4603	68		
1.3622	19	1.4076	44	1.4627	69		
1.3638	20	1.4096	45	1.4651	70		
1.3655	21	1.4117	46	1.4676	71		
1.3672	22	1.4137	47	1.4700	72		
1.3689	23	1.4158	48	1.4725	73		
1.3706	24	1.4179	49	1.4749	74		

When a sugar solution is measured by refractometer or densitometer, the R.I. or °Bx value only represents the amount of dry solids dissolved in the sample if the dry solids are exclusively sucrose. This is seldom the case. Grape juice, for example, contains little sucrose but does contain glucose, fructose, acids and other substances. In such cases the °Bx value clearly cannot be equated with the sucrose content but it may represent a good approximation to the total sugar content. For example, an 11.0 %w/w D-Glucose ("grape sugar") solution measures 10.9 °Bx.

When other solids are dissolved in the solution, they can affect the refractive index. For example, many fruit juices contain citric acid that will increase the Brix value. Therefore, the citric acid is usually titrated and the brix value is corrected from values in published tables.

Note the differences in sugar concentrations between orange, grape, and lemon juices. When imported juices arrive (usually as juice concentrates), they are tested by U.S. Customs and the “Brix” value must meet the respective specification in the following table. The values in the lower part of the table are the actual refractometer readings that represent the typical combined citric acid and sugars.

When juice bottlers manufacture a fruit juice beverage, they purchase frozen juice concentrates on the commodities market. The cost of these juices depends on their Brix value. The higher the Brix value, the more concentrated the juice. The concentrates save on shipping and refrigeration costs. The concentrates are diluted with water to the appropriate ratio as determined by the Brix numbers, and the resulting product is pasteurized, filled, and sealed for sale.

US Customs Table of Corrected Brix Values for Selected Juices*			
Degree of Concentration	Orange Juice	Grape [Vitis Vinifera] Juice	Lemon Juice
Unconcentrated (No Citric acid correction) R.I Reading (°Bx)	11.8	21.5	8.9
Unconcentrated	- 17.31	- 30.99	- 13.12
1.5	17.32 - 19.97	31.00 - 35.47	13.13 - 15.18
2.0	19.98 - 25.14	35.48 - 43.95	15.19 - 19.21
2.5	25.15 - 30.09	43.96 - 51.86	19.22 - 23.10
3.0	30.10 - 34.85	51.87 - 59.27	23.11 - 26.87
3.5	34.86 - 39.42	59.28 - 66.23	26.88 - 30.53
4.0	39.43 - 43.83	66.24 - 72.81	30.54 - 34.09
4.5	43.84 - 48.07	72.82 - 79.03	34.10 - 37.54
5.0	48.08 - 52.17	79.04 - 84.95	37.55 - 40.89
5.5	52.18 - 56.12	84.96 - 90.95	40.90 - 44.15
6.0	56.13 - 59.95	—	44.16 - 47.32
6.5	59.96 - 63.65	—	47.33 - 50.40
7.0	63.66 - 67.25	—	50.41 - 53.41

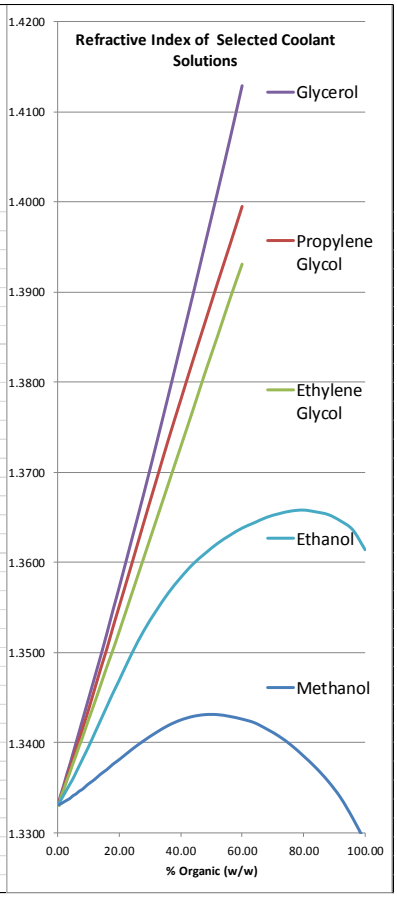
**Note: Brix correction = (0.1775 x % anhydrous citric acid) + 0.1343*

Some industries utilize the Brix scale to measure solute concentrations that contain no sugar at all. Of course, in this case the brix scale is similar to the refractive index… just a number that can be calibrated to the specific analytical method. A series of standards in prepared, measured, and then plotted. When an unknown containing the same solute is analyzed, the reading is compared to the chart to obtain the actual concentration.

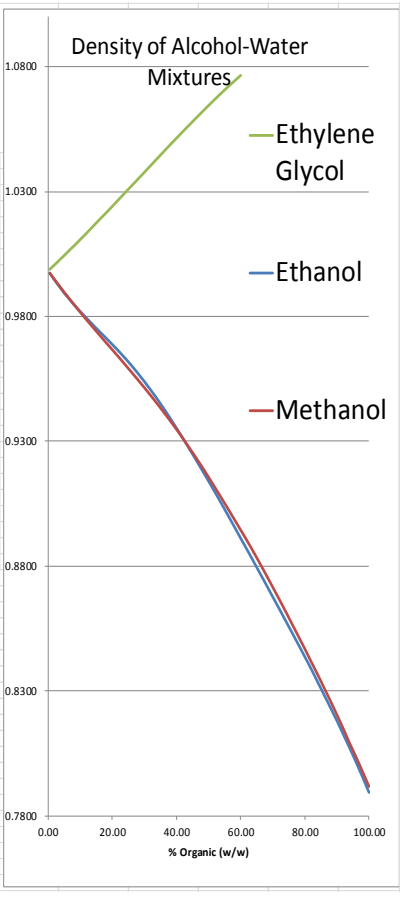
For example, the concentration of salt solutions or antifreeze can be easily measured by refractive index. However, alcohol water mixtures are not as easy. Note the refractive index values of the mixtures in the table below. Also note the density of ethanol and methanol in the same solutions.

Relationship between Salt Solution and Sugar Concentration (Brix) and refractive index at 20°C		
Salt(NaCl) g/100g	Refractive Index	Brix %
0	1.3330	0
1	1.3348	1.3
2	1.3366	2.5
3	1.3383	3.7
4	1.3400	4.8
5	1.3418	6.0
6	1.3435	7.2
7	1.3453	8.4
8	1.3470	9.5
9	1.3488	10.6
10	1.3505	11.7
11	1.3523	12.8
12	1.3541	14.9
13	1.3558	15.1
14	1.3576	16.1
15	1.3594	17.2
16	1.3612	18.4
17	1.3630	19.5
18	1.3648	20.6
19	1.3666	21.7
20	1.3684	22.7
21	1.3703	23.8
22	1.3721	24.9
23	1.3740	26.0
24	1.3759	27.1
25	1.3778	28.1
26	1.3797	29.2

% (w/w)	Methanol	Propylene Glycol	Ethylene Glycol	Glycerol	Ethanol
0.50	1.3331	1.3335	1.3330	1.3336	1.3333
1.00	1.3332	1.3340	1.3339	1.3342	1.3336
2.00	1.3334	1.3350	1.3348	1.3353	1.3342
3.00	1.3336	1.3361	1.3358	1.3365	1.3348
4.00	1.3338	1.3371	1.3367	1.3376	1.3354
5.00	1.3341	1.3382	1.3377	1.3388	1.3360
6.00	1.3343	1.3393	1.3386	1.3400	1.3367
7.00	1.3346	1.3403	1.3396	1.3412	1.3374
8.00	1.3348	1.3414	1.3405	1.3424	1.3381
9.00	1.3351	1.3425	1.3415	1.3436	1.3388
10.00	1.3354	1.3436	1.3425	1.3448	1.3395
12.00	1.3359	1.3459	1.3444	1.3472	1.3410
14.00	1.3365	1.3482	1.3464	1.3496	1.3425
16.00	1.3370	1.3504	1.3484	1.3521	1.3440
18.00	1.3376	1.3528	1.3503	1.3547	1.3455
20.00	1.3381	1.3551	1.3523	1.3572	1.3469
24.00	1.3392	1.3597	1.3564	1.3624	1.3498
28.00	1.3402	1.3644	1.3605	1.3676	1.3524
32.00	1.3411	1.3690	1.3646	1.3730	1.3546
36.00	1.3419	1.3736	1.3687	1.3785	1.3566
40.00	1.3425	1.3780	1.3728	1.3841	1.3583
44.00	1.3429	1.3824	1.3769	1.3897	1.3598
48.00	1.3431	1.3867	1.3811	1.3954	1.3610
52.00	1.3431	1.3910	1.3851	1.4011	1.3621
56.00	1.3429	1.3952	1.3892	1.4069	1.3630
60.00	1.3426	1.3995	1.3931	1.4129	1.3638
64.00	1.3422			1.4189	1.3644
68.00	1.3415			1.4249	1.3650
72.00	1.3407			1.4310	1.3654
76.00	1.3397			1.4370	1.3657
80.00	1.3385			1.4431	1.3658
84.00	1.3372			1.4492	1.3656
88.00	1.3357			1.4553	1.3653
92.00	1.3339			1.4613	1.3646
96.00	1.3316			1.4674	1.3636
100.00	1.3290			1.4735	1.3614



%(w/w)	Ethanol	Methanol	Ethylene Glycol
0.50	0.9973	0.9973	0.9988
1.00	0.9963	0.9964	0.9995
2.00	0.9945	0.9947	1.0007
3.00	0.9927	0.9930	1.0019
4.00	0.9910	0.9913	1.0032
5.00	0.9893	0.9896	1.0044
6.00	0.9878	0.9880	1.0057
7.00	0.9862	0.9864	1.0070
8.00	0.9847	0.9848	1.0082
9.00	0.9833	0.9832	1.0095
10.00	0.9819	0.9816	1.0108
12.00	0.9792	0.9785	1.0134
14.00	0.9765	0.9755	1.0161
16.00	0.9739	0.9725	1.0188
18.00	0.9713	0.9695	1.0214
20.00	0.9687	0.9666	1.0241
24.00	0.9632	0.9606	1.0296
28.00	0.9571	0.9545	1.0350
32.00	0.9504	0.9482	1.0405
36.00	0.9431	0.9416	1.0460
40.00	0.9352	0.9347	1.0514
44.00	0.9269	0.9273	1.0567
48.00	0.9183	0.9196	1.0619
52.00	0.9095	0.9114	1.0670
56.00	0.9004	0.9030	1.0719
60.00	0.8911	0.8944	1.0765
62.00	0.8865	0.8901	
64.00	0.8818	0.8856	
66.00	0.8771	0.8810	
68.00	0.8724	0.8763	
70.00	0.8676	0.8715	
72.00	0.8629	0.8667	
74.00	0.8581	0.8618	
76.00	0.8533	0.8568	
78.00	0.8485	0.8518	
80.00	0.8436	0.8468	
82.00	0.8387	0.8416	
84.00	0.8335	0.8365	
86.00	0.8284	0.8312	
88.00	0.8232	0.8259	
90.00	0.8180	0.8204	
92.00	0.8125	0.8148	
94.00	0.8070	0.8089	
96.00	0.8013	0.8034	
98.00	0.7954	0.7976	
100.00	0.7893	0.7917	

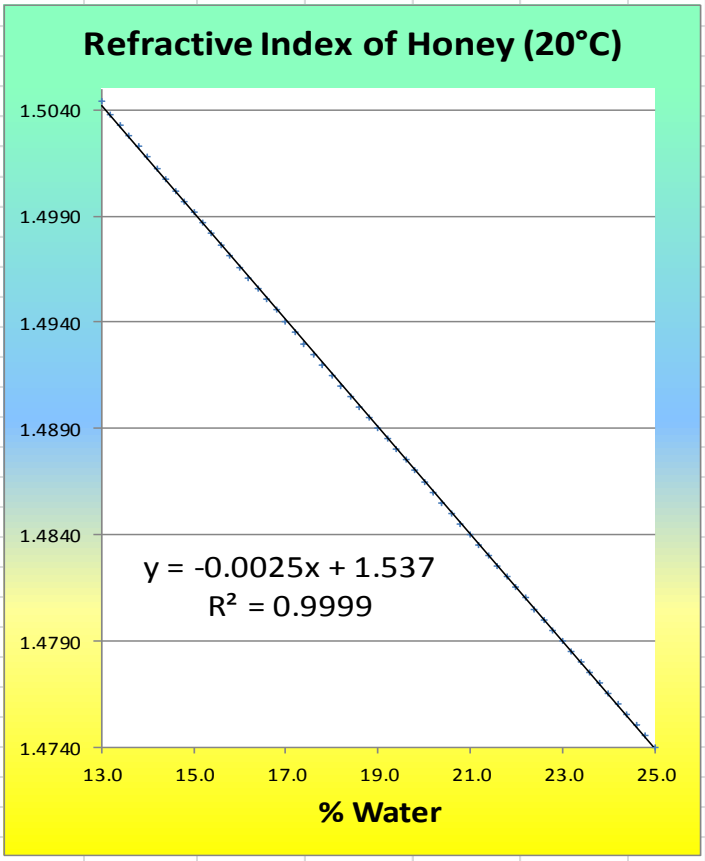


Honey contains a lot of sugar that can be determined by refractive index. Notice that the plot below shows the refractive index as a function of water (not sugar) in the mixture. Hence, a negative slope is observed. The concentration of the sugars is calculated as the remainder (100% - % water = % sugar).

Refractive index and water contents of honey:

%H2O	RI (20°C)	%H2O	RI (20°C)
13.0	1.5044	19.2	1.4885
13.2	1.5038	19.4	1.4880
13.4	1.5033	19.6	1.4875
13.6	1.5028	19.8	1.4870
13.8	1.5023	20.0	1.4865
14.0	1.5018	20.2	1.4860
14.2	1.5012	20.4	1.4855
14.4	1.5007	20.6	1.4850
14.6	1.5002	20.8	1.4845
14.8	1.4997	21.0	1.4840
15.0	1.4992	21.2	1.4835
15.2	1.4987	21.4	1.4830
15.4	1.4982	21.6	1.4825
15.6	1.4976	21.8	1.4820
15.8	1.4971	22.0	1.4815
16.0	1.4966	22.2	1.4810
16.2	1.4961	22.4	1.4805
16.4	1.4956	22.6	1.4800
16.6	1.4951	22.8	1.4795
16.8	1.4946	23.0	1.4790
17.0	1.4940	23.2	1.4785
17.2	1.4935	23.4	1.4780
17.4	1.4930	23.6	1.4775
17.6	1.4925	23.8	1.4770
17.8	1.4920	24.0	1.4765
18.0	1.4915	24.2	1.4760
18.2	1.4910	24.4	1.4755
18.4	1.4905	24.6	1.4750
18.6	1.4900	24.8	1.4745
18.8	1.4895	25.0	1.4740

Slope:	-0.002524
Intercept:	1.5370

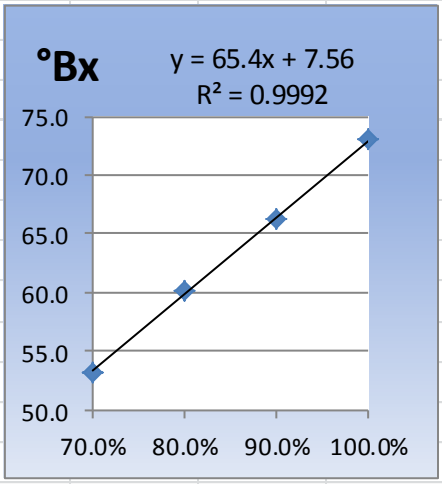


Calibration of the refractometer is important. While published values are helpful, it is critical to insure the instrument is measuring values correctly. Liquid solutions are prepared or purchased that are measured under the same conditions as the samples. Here is an actual example of a test for glycerin (glycerol) in water. Four standards were prepared by weighing out the appropriate masses of glycerin and water, preparing concentrations of 70%, 80%, 90%, and 100%(w/w). These were measured on the Abby refractometer on a cold day in the lab and the values differ slightly from the published values.

Refractive Index Calibration of Glycerin/Water Mixtures (Brix Scale)

%(w/w)	°Bx
0.0%	0.0
70.0%	53.2
80.0%	60.2
90.0%	66.2
100.0%	73.0

°Bx Calibration	
Slope	73.59
intercept	0.482



Unknown Mixture of Glycerin in Water:

	°Bx	% Glycerin
Trial #1	54.8	73.8%
Trial #2	54.7	73.7%
Trial #3	54.8	73.8%

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