Parts Per Million Analysis (PPM)

Randy Sharpe, H_2 Sciences Inc.

What Is "PPM"?

PPM is an acronym for "Parts Per Million", a unit of measure that describes how much of one substance (called the "solute") is dissolved in a sample of water (called the "solvent"). This is a measurement of concentration (or density), which can often be helpful in our daily lives. The PPM can be used to measure the concentration of many substances, such as the minerals in our drinking water or the oxygen in a fish aquarium. Although the PPM is commonly used for concentration measurements, it only provides us with a *ratio* of the solute's mass to the mass of the water, without specifying the water's total volume. But, sometimes, we also need to know the total *amount* (mass) of solute dissolved in the water. This is often important, for example when determining the therapeutic dose for a medicine or the ingested level of a toxin. Without including the size of the container we are testing, which tells us the *amount of water* our solute is dissolved in, the ratio by itself does not tell us *how much* solute the water contains. To convey this information, scientists use a more appropriate unit of measure, one which specifies the solute's concentration in units of "mass relative to volume", rather than the mass-to-mass ratio of the PPM. The unit commonly used is the "milligram per liter", abbreviated mg/L. The mg/L always references the solute's mass *relative to a fixed volume*, one liter.

How are PPM and mg/L related?

We can think of 1ppm as "1 part of a substance (solute) dissolved in 1 million parts of water" (in our case the solute is H_2, hydrogen gas). So, what is a "part"? "Part" represents a unit of measure, in our case the "milligram" (mg). Therefore, 1 milligram of H_2 ("1 part") dissolved in 1 million milligrams of water ("1 million parts") is "one part per million". And, since 1 liter of water happens to weigh 1 million milligrams, one PPM is equal to one mg/L (for dilute concentrations). Note: This relationship is only true when comparing units of mass, not when comparing volumes, the # of moles, or the # of molecules.

What does the PPM measurement tell me about my hydrogen water?

When using the H_2Blue reagent to measure a sample of hydrogen water, each drop represents 0.1ppm of dissolved H_2 gas. By adding together the total number of drops required to reach the titration endpoint (the point at which the next drop does not turn clear, but remains pale blue), the dissolved H_2 level in PPM can be calculated. Because the results of each measurement represent the H_2 concentration expressed in PPM, it is important to understand what the PPM units mean, and how to properly

interpret them. Instead of how many PPM's we have, what we really should be asking is, "how much hydrogen will I ingest if I drink the entire contents of the container from which the test sample was taken"? How the results are interpreted depends, in part, on how the hydrogen water was produced.

Hydrogen water produced using hydrogen tablets:

Hydrogen tablets produce hydrogen gas from the reaction between elemental magnesium (Mg) and water:

$$Mg + 2(H_2O) => Mg(OH)_2 + H_2$$

The production of hydrogen gas bubbles can easily be observed when placing a tablet into a clear container. If the tablet is placed into a sealed container, the pressure will rise as the volume of H_2 gas produced increases. The elevated pressure can help the H_2 to dissolve, although too much pressure may retard the reaction.

Distinguishing between "produced" and "dissolved" hydrogen gas:

Because each tablet contains a fixed amount of magnesium metal, usually in the range of 50 to 80 milligrams, the total amount of H_2 gas which can be produced from each tablet is also fixed. Although the theoretical maximum amount of H_2 gas which can be produced from one tablet (under ideal conditions) can be calculated based upon the amount of magnesium in the tablet (usually indicated on the label), not all of the H_2 gas which can be produced *will be produced* because:
 1) Some magnesium will react with water vapor in the air (humidity) while the tablet is still in the container. Most tablet bottles include a desiccant packet to minimize this effect.
2) Not all of the magnesium contained within the tablet will necessarily react when placed into water because of the formation of oxides on the magnesium particles (passivation).

Regardless of how much H_2 ends up being produced, not all of it will *dissolve* into the water. This is because a portion of the gas will escape into the air and be wasted. The percentage of H_2 *produced* which actually *dissolves* into the water is typically in the 25% to 75% range. This percentage can be influenced (and often improved upon) by altering tablet variables such as magnesium particle size and acid content, and other variables such as temperature, reaction time, and pressure.

Calculating the amount of ingestible H_2 based on the PPM measurement:

In order to convert the PPM measurement to the amount of ingestible dissolved H_2 gas, the size of the container into which the tablet is placed (and from which the test

sample is taken) must be taken into consideration. This is because it takes fewer milligrams of H_2 to produce 1ppm in a smaller amount of water than it does in a larger volume of water. The graphic in Figure 1 illustrates this concept:
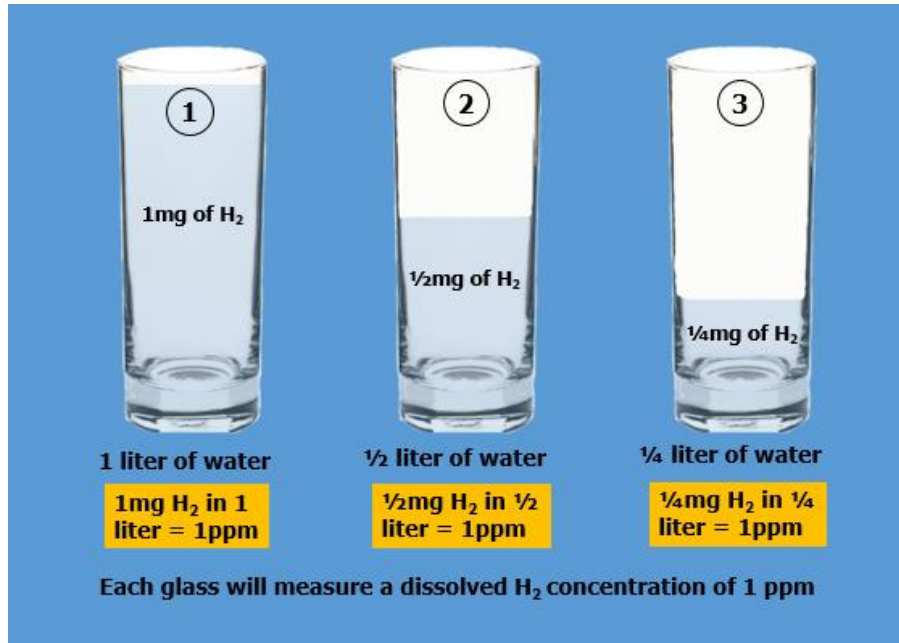

Figure 1

In the above example, samples from each of the containers will measure the *same* concentration of H_2, 1ppm. But, these three containers *do not contain the same amount* of dissolved H_2. This is because, although the volume of water from one to the next is halved, so too is the amount of dissolved H_2, resulting in the *same* concentration and the *same* PPM reading in each container. From this example, it can be seen that the PPM measurement alone does not indicate *how much* H_2 will be ingested when drinking the contents of each container. In order to determine *how much* H_2 will be ingested, the PPM measurement obtained from the test sample must be referenced to 1 liter. This means that we must calculate the *equivalent concentration* of each container if that *same amount* of H_2 was dissolved in *1 liter*. For example, glass #2 (½ liter), which measures 1ppm and contains ½ mg H_2, in fact has an equivalent concentration of 0.5mg/L (½ mg of H_2 dissolved in 1 liter = 0.5ppm). Based on this principle, you will ingest the following amounts of H_2 if you drink the *entire contents* of each of the above containers, all of which measure 1ppm (remember, 1ppm = 1mg H_2 dissolved in 1 Liter):

Glass #1 (volume = 1 Liter): 1 mg of H_2 will be ingested
Glass #2 (volume = ½ Liter): ½ mg of H_2 will be ingested
Glass #3 (volume = ¼ Liter): ¼ mg of H_2 will be ingested

Figure 2 below shows 3 glasses, each of which contains the *same* amount of water, 1 liter, and also the *same* amounts of dissolved H_2 as in Figure 1, 1mg, 0.5mg & 0.25mg. In contrast to Figure 1, now they will each measure *different* concentrations of H_2, 1ppm, 0.5ppm and 0.25ppm respectively.
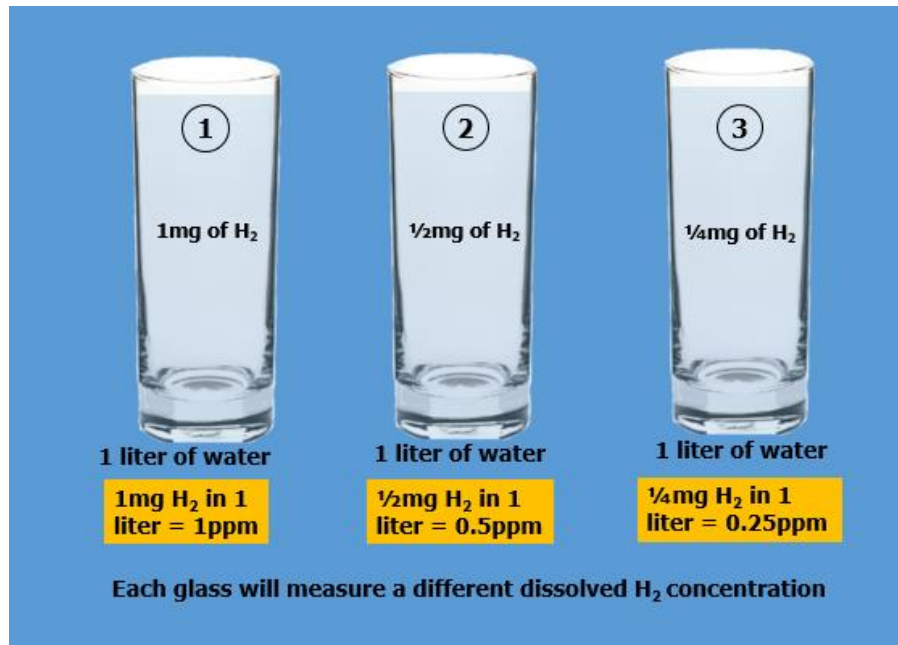

Figure 2

Just as in Figure 1, the three glasses in this example do not contain the *same amount* of dissolved H_2. And, because their concentrations are different, drinking the entire contents *will not* provide the same levels of ingested H_2. In order to receive the same ingested amounts of H_2, you would need to drink *varying* amounts of each as follows:

Glass #1: You must drink 1 liter of 1ppm water to ingest 1 mg of H_2
Glass #2: You must drink 2 liters of 0.5ppm water to ingest 1 mg of H_2
Glass #3: You must drink 4 liters of 0.25ppm water to ingest 1 mg of H_2

From this example, it can be seen that when the PPM reading is referenced to a volume of 1 liter (expressed in terms of "mg/L"), the PPM reading *does* indicate how much H_2 will be ingested when drinking 1 liter from each container. The following example will help to illustrate why the PPM measurement *alone* cannot tell us *how much* dissolved H_2 a sample of water contains.
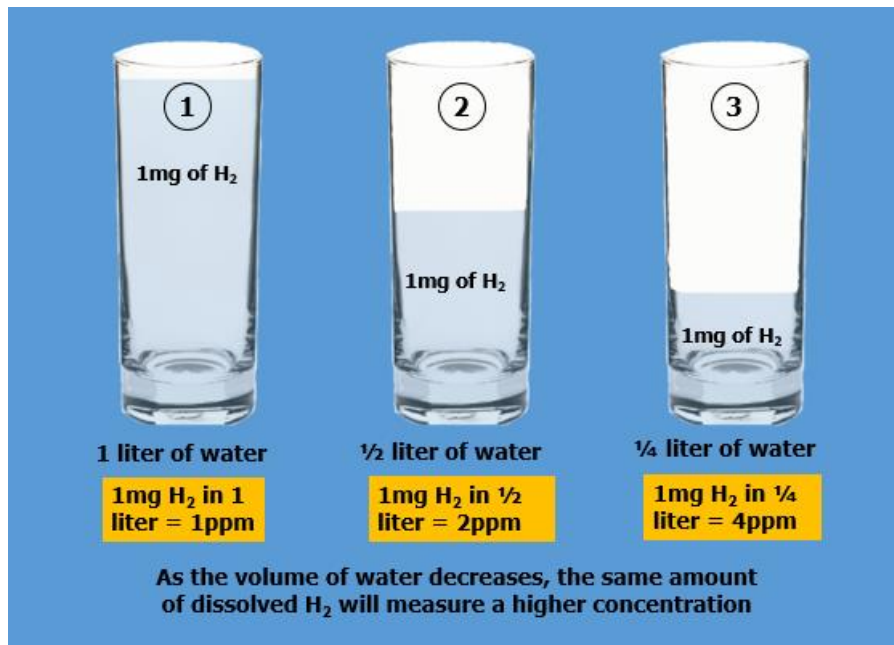
Figure 3

Figure 3 shows the results of dissolving the *same* amount of H_2 into three different volumes of water, 1 liter, ½ liter, and ¼ liter.

If the same amount of H_2 gas is dissolved into half the volume of water, the measured PPM (H_2 concentration) will double. But, this *does not* mean that the *amount* of dissolved H_2 has doubled-in fact, the amount of H_2 *has remained the same*. Therefore, as we have seen in these examples, to determine *how much* H_2 will be consumed, the PPM measurement must be converted to mg/L.

Just to give some perspective on the relationship between PPM and volume, consider the 6mL sample of water used when testing H_2 concentration using H₂Blue. Because the volume is so small (0.006 liters), it takes only 6 µg (6 millionths of a gram) of dissolved H_2 in 6mL of water to produce a concentration in the sample equivalent to 1mg/L!

Marketing trick to elevate the PPM measurement:

In light of our explanation about PPM's and water volume, the following example shows how unscrupulous manufacturers/marketers of batch-type devices can claim a significantly higher PPM/PPB measurement by simply reducing the amount of water used in a device (PPB = parts per billion; 1ppm = 1000ppb).
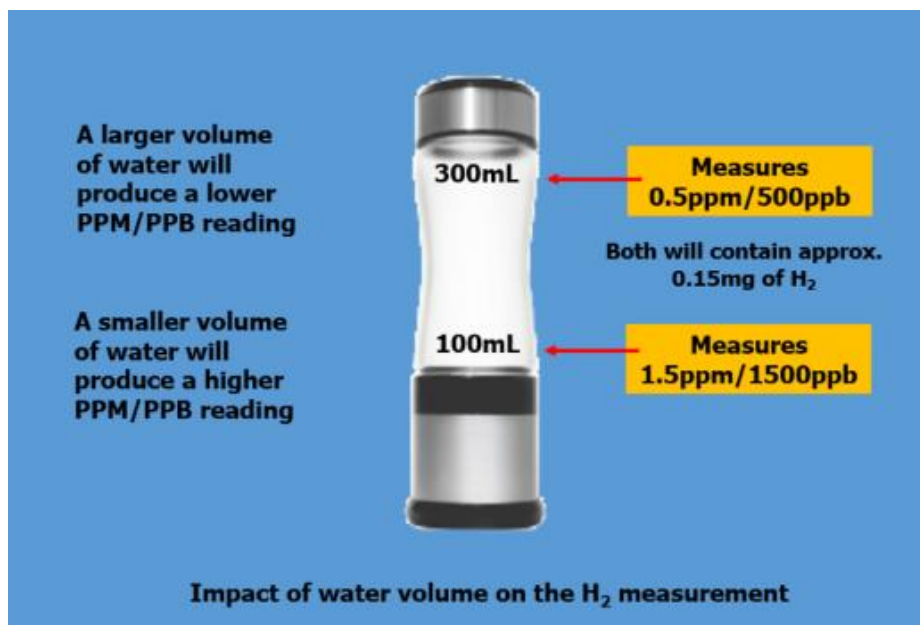
Figure 4

As you can see in Figure 4, the same amount of H_2 gas dissolved in a smaller volume of water will give a *higher* PPM reading. That is because PPM readings are not solely measurements of mass (amount of H_2 in milligrams), but of *mass per unit volume* (H_2 *density* in milligrams per liter). Therefore, both the dissolved mass and the volume of water in which that mass is dissolved must be considered in order to evaluate the amount of H_2 that *together* they represent. Also, although not discussed here, other variables, such as increasing the run time of a single session (if adjustable), or running the device for multiple consecutive sessions, can have a significant impact on dissolved H_2 levels. Therefore, when evaluating the dissolved H_2 performance levels of different devices, make sure that water volume and run times are comparable.

Calculating the theoretical maximum amounts of H_2 which can be produced and dissolved using tablets:

Knowing the number of milligrams of *elemental magnesium* contained in the tablet (not the mass of the whole tablet, which can be much greater), we can calculate the theoretical maximum amount of H_2 which can be produced. Then, knowing the maximum amount of H_2 gas which can be produced, we can also approximate the levels of dissolved H_2 (mg/L) and ingestible H_2 (mg) which can be expected based on using some reasonable values for production and dissolving efficiencies.

When calculating ingested H_2 levels, it is important to remember that we are only considering *dissolved* H_2 gas, not the amount of H_2 *produced*. This is because in any

system, a considerable amount of the H_2 gas produced may never dissolve into the water, and instead escape into the surrounding air. While visible undissolved or "suspended" H_2 gas bubbles may also be of some benefit (if you can ingest them before they escape), it is more difficult to quantify their amount (and therefore the contribution they make to total ingested H_2) using conventional methods such as titration.

A few variables come into play which have an impact on the percentage of H_2 gas which ultimately dissolves into the water. These variables include:

* Whether the container is open or sealed: - Pressure can help H_2 dissolve better, although some tablets may perform better in an open container.

* Materials from which the container is constructed - Less-porous materials hold H_2 better.

* The amount of time the tablet is permitted to dissolve - More time is generally (although not necessarily) better than less time.

* The temperature of the water - H_2 gas will dissolve better in cold water, but the reaction itself will proceed slower.

* The size of the magnesium particles- Smaller magnesium particles can result in smaller, "more dissolvable" H_2 gas bubbles.

*Agitation - Shaking or mixing the contents can encourage more H_2 gas to dissolve.

While a larger container may produce lower PPM readings, the amount of ingestible H_2 will not necessarily be less.

Table 1 shows the maximum possible H_2 production, the levels of measured PPM (mg/L) and ingestible H_2 one can expect, based on two different magnesium tablets (A & B), two different volumes of water, 500mL & 1000mL, and the percentage of H_2 gas produced that ultimately dissolves into the water:

| Tablet Container Volume (mL) [1] | Tablet A - 50 mg Magnesium | | | | Tablet B - 80mg Magnesium | | | |
| | Maximum H_2 Production is 4.2 mg | | | | Maximum H_2 Production is 6.7mg | | | |
	Dissolved H_2 (%) [2]	Measured H_2 PPM [3]	Equivalent H_2 mg/L [4]	Ingested H_2 mg [5]	Dissolved H_2 (%) [2]	Measured H_2 PPM [3]	Equivalent H_2 mg/L [4]	Ingested H_2 mg [5]
250	25	4.2	1.1	1.1	25	6.7	1.7	1.7
	50	8.4	2.1	2.1	50	13.4	3.4	3.4
	75	12.6	3.2	3.2	75	20.1	5.0	5.0
	100	16.8	4.2	4.2	100	26.8	6.7	6.7
350	25	3.0	1.1	1.1	25	4.8	1.7	1.7
	50	6.0	2.1	2.1	50	9.6	3.4	3.4
	75	9.0	3.2	3.2	75	14.4	5.0	5.0
	100	12.0	4.2	4.2	100	19.1	6.7	6.7
500	25	2.1	1.1	1.1	25	3.4	1.7	1.7
	50	4.2	2.1	2.1	50	6.7	3.4	3.4
	75	6.3	3.2	3.2	75	10.1	5.0	5.0
	100	8.4	4.2	4.2	100	13.4	6.7	6.7
1000	25	1.1	1.1	1.1	25	1.7	1.7	1.7
	50	2.1	2.1	2.1	50	3.4	3.4	3.4
	75	3.2	3.2	3.2	75	5.0	5.0	5.0
	100	4.2	4.2	4.2	100.0	6.7	6.7	6.7

Table 1

How to use this Table 1:

*Decide how many milligrams of magnesium your tablet contains, usually found on the label (if using two tablets, double the results shown in columns 3, 4 & 5)

Note: Some tablet labels will indicate *both* the magnesium amounts (typically 50-80mg), and the weight of the tablet itself (typically 500-600mg). ***Be sure to use only the magnesium weight, not the weight of the entire tablet!***

* Select the value in column 1 corresponding to the volume of water into which the tablet is to be dissolved.

* Select the value in column 2 corresponding to the anticipated percentage of dissolved hydrogen. Values will vary depending on preparation method, but will typically be in the 25% to 75% range, depending on the technology & methodology being used.

* Column 3 shows the approximate PPM you would expect to measure based upon the amount of magnesium in the tablet, container volume, and dissolved %.

* Column 4 shows the equivalent mg/L after adjusting the volume to one liter.

* Column 5 shows the approximate amount of H_2 which will be ingested if you drink the entire contents of the container as listed in column 1.

Notice that for any given tablet & dissolved %, only the PPM's change with changing container volumes; the ingested H_2 does not. Also, notice that the PPM, mg/L & ingested H_2 *only agree* when the volume is 1000mL (1 liter).

Example: One 50mg tablet is capable of producing 4.2mg of H_2. If it is placed into a 500mL container, and we assume that 50% of the H_2 gas produced will dissolve into the water (with the remaining 50% escaping into the air), then a concentration of approximately 4.2ppm will be measured, the H_2 concentration in the tablet container (corrected for 1 liter) will be 2.1mg/L, and approximately 2.1mg of H_2 will be ingested when consuming the entire 500mL.

Hydrogen water produced using electric devices, such as alkaline ionizers and hydrogen infusion machines (HIM's):

Alkaline ionizers

Alkaline ionizers produce hydrogen water by reducing (adding electrons to) H^+ ions in the water to hydrogen atoms (H). As the hydrogen atoms "pair-up", hydrogen gas molecules (H_2) are produced at the cathode:

$$2H^+ + 2e^- => H_2$$

The hydrogen gas bubbles then dissolve into the drinking water as it flows across the cathode(s).

HIM's

Recently, a new type of hydrogen water device has emerged on the market, the hydrogen infusion machine (HIM). This type of device does not have the same type of chamber as a conventional electrolyzer, and instead produces H_2 gas in a smaller hydrogen gas chamber (using a proton-exchange membrane containing solid polymer electrolyte, PEM/SPE). Then, rather than depending only on turbulent flow to dissolve the gas into the water, it mixes the H_2 gas into the drinking water stream using a special "dissolver chamber". Because this class of device utilizes specialized, electrically-conductive membranes tightly sandwiched between the anode & cathode, the source water need not contain any level of minerals (TDS), and in fact can produce H_2 water even with distilled or RO water sources. While it is commonly referred to as a "neutral-pH device", the H_2 water produced by an HIM will not necessarily be "neutral"; the final pH will be determined by the pH of the source water, which it typically does not alter.

Electric bottle/pitcher

Another type of electric device now being marketed for producing H_2 drinking water is the hydrogen pitcher, and its smaller counterpart, the portable, battery-powered hydrogen bottle. These are "batch" devices (not flow-through), which typically (but not always) use PEM/SPE membrane technology to produce neutral-pH H_2 water. The levels of dissolved H_2 will vary based on run times and water volumes. Because their run times are typically in the 5 to 15 minute range, they typically do not have the capacity to produce the same volume of water in liters-per-minute as flow-through devices.

Note: Some batch devices utilize electrodes without membranes, commonly referred to as "Brown's Gas" devices. Because there is no membrane to isolate the products produced at the anode & cathode, the mixing of H^+ and OH^- ions tend to cancel out any change in pH that would otherwise occur. Therefore, these devices typically produce water which is close to the source water's pH, although, depending on the source water, they may also add unwanted byproducts into the drinking water, such as chlorine or ozone gas.

Interpreting the results of the PPM measurement for electric flow-through devices

Hydrogen tablets contain a finite amount of magnesium, and therefore can only produce a finite amount of hydrogen gas. They are also placed into a finite amount of water, which dictates (along with other variables) the maximum PPM's which can be measured. But, electric flow-through devices have no such limitations, and therefore have essentially an infinite supply of electrons for producing H_2 gas (as long as there is power available), as well as an infinite supply of water (as long as there is water available). As a consequence, we need not be concerned with the container size from which the 6mL test sample is taken when interpreting the PPM's measured using H_2Blue. We know that, since electric flow-through devices can produce H_2 water continuously, any test sample taken from the machine will likely be representative of its ability to provide any volume of H_2 water at that concentration (within the design constraints of the machine). Therefore, to determine how much H_2 we will ingest, we only need to know two things:

> 1) The H_2 concentration (mg/L) of the water it produces
>
> 2) The total volume of H_2 water consumed (liters).

Table 2 shows the amount of H$_2$ that will be ingested (in mg) when drinking 3 different volumes of hydrogen water, 250mL, 500mL and 1000mL (1 liter), each one calculated for six different H$_2$ concentrations, 0.1 to 5mg/L:

H$_2$ Water Volume (mL)	H$_2$ Concentration (mg/L)	Amt of Ingested H$_2$ (mg)
250	0.1	0.03
	0.2	0.05
	0.5	0.13
	1.0	0.25
	2.0	0.50
	5.0	1.25
500	0.1	0.05
	0.2	0.10
	0.5	0.25
	1.0	0.50
	2.0	1.00
	5.0	2.50
1000 (1L)	0.1	0.10
	0.2	0.20
	0.5	0.50
	1.0	1.00
	2.0	2.00
	5.0	5.00

Table 2

Interpreting the results of the PPM measurement for batch-type electric devices:

Because batch devices contain a fixed volume of water into which the H$_2$ gas is introduced, they are, in terms of PPM interpretation, more like tablets, which also introduce the H$_2$ gas into a fixed volume of water. Because they produce H$_2$ gas electrically, they are not restricted in the amount of H$_2$ gas they can produce, but the total dissolved H$_2$ levels are influenced by the same variables mentioned previously. To interpret the PPM results from batch-type devices, use Table 2 with the volume & H$_2$ readings which most closely match yours, or try the method below.

Passive (non-electric) flow-through countertop devices:

There are flow-through devices available which produce H$_2$ water without electricity, utilizing magnesium similar to the tablets. These devices connect to the faucet with a simple diverter, supply H$_2$ water on demand, and can produce a respectable concentration of H$_2$ water (1ppm or more). But, while electric flow-through devices previously described can produce essentially as much H$_2$ water as the user wants, these passive devices must permit the water inside their chamber to remain in contact with the magnesium for a certain amount of time in order to produce and dissolve the

H_2 gas into the water. Therefore, they can only produce about two liters of H_2 water at the rated concentration before needing to regenerate. After this, the cycle can be repeated. The amount of regeneration time varies with device, source water, etc. As long as this type of device can produce at least two liters of water at the sample concentration, then the H_2 water it produces can be evaluated in the same way as electric flow-through devices described previously.

A simple method for determining H_2 amount:

If you want to use the PPM measurement to calculate the amount of dissolved H_2 in any size container, here is a simple method: Multiply the measured PPM by the size of the container the sample was taken from (in liters). This will tell you how much H_2 is contained within the container.

Example: If you have a 500mL portable bottle (0.5L) which produces H_2 water at a concentration of 2mg/L, multiply: 0.5L x 2mg/L = 1 mg H_2. Therefore, if you drink the entire container, you will ingest 1mg of H_2.

How much H_2 do I need?

Now that we understand PPM's and how to interpret them to determine the amount of dissolved hydrogen gas contained within a particular volume, the question often asked is, **"How much H_2 do I need to ingest everyday"?**
Scientists are asking the same question, and the answer is currently being researched. What we do know is that human studies show significant health benefits when participants consume H_2 water with concentrations in the 1-3mg/L range. This gives us a "target" dosage of approximately 2mg/day. Therefore, if your water has a concentration of 1mg/L, then, by consuming two liters per day, you will ingest 2mg of H_2 per day. Based on the H_2 level of your water, you can use Table 3 below to calculate the volume of water you should drink to ingest about 2mg of H_2 per day.

H_2 Level (mg/L)	Drink This # of Liters to Ingest 2 mg H_2
0.1	20.0
0.2	10.0
0.5	4.0
1.0	2.0
2.0	1.0
5.0	0.4

Table 3

From Table 3 it can be seen that, as the dissolved H_2 concentration falls below 1mg/L, the amount of water which must be consumed to deliver 2mg per day of ingested H_2 becomes prohibitively high. For example, at a concentration of 0.2mg/L, you must consume 10 liters in order to ingest 2mg of H_2. Therefore, it is important to choose a device or technology which is capable of consistently delivering H_2 water at or above approximately 1mg/L.

Summary

PPM is a unit of measurement which provides a ratio of the amount of a dissolved substance to the amount of water it is dissolved in. Therefore, 1 milligram of a substance dissolved in 1 million milligrams of water will have a concentration of "1 part per million". Because 1 liter of water weighs 1 million milligrams, 1 part per million is also the same as 1 milligram per liter. Because flow-through type devices are generally capable of producing a liter or more of the same PPM, the PPM reading of a small test sample will be representative of the number of milligrams of H_2 we will ingest if we drink one liter. When determining how much H_2 is contained in a volume of water produced by technologies other than flow-through type devices (tablets, sticks, cartridges, etc.), the PPM measurement must take into consideration the volume of the container being sampled. Only then can we determine *how much* H_2 we will ingest when drinking the entire contents of the sampled container.

For any questions or concerns, please feel free to contact Randy Sharpe at:

randy@h2sciencesinc.com

rev 2.7

June/2018

H₂Sciences inc
Hydrogen Water Solutions

www.h2sciencesinc.com