The Anatomy of a Liquid-in-Glass Thermometer

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Posted: April 2011

Temperature Measurement: A Fact of Life
Some of my fondest memories from childhood are of working in the kitchen with my mother—canning tomatoes, making candy apples, and baking bread. I still remember how my mother taught me to carefully check the candy thermometer as we made the caramel coating, and how I learned to set the oven to just the right temperature so that the bread would rise and bake correctly. I never thought about it as a child, but temperature measurement played an important role in all of the cooking and baking projects that my mother and I shared.

I can't help but think about what a critical role temperature plays in *everything* that we do. We use temperature to help us decide what to wear, how to prepare our food, diagnose illness, and determine where and when we take vacation. Of course, temperature measurement plays an important role in the laboratory too. The physical properties and characteristics of the materials that we test are influenced, as least in part, by temperature. Inarguably, accurate temperature measurement is one of the most critical components of laboratory testing.

Measuring Temperature in the Laboratory
So, how do we measure temperature in the laboratory? Certainly, the candy thermometer that my mother taught me to use as a kid would not be sufficient for the critical temperature measurements that are required for most laboratory tests. But there is a myriad of temperature measuring products available—liquid-in-glass thermometers, resistive detectors, thermocouples, thermistors, dial-stem thermometers, infrared thermometers… the list goes on and on. Which of these devices should be used, and when? What kind of readability, accuracy, and uncertainty do these instruments provide? With all of the devices available for measuring temperature, it's no wonder thermometry is such a confusing topic. In upcoming posts, I will try to explain some of these different types of thermometers, how and when to use them, as well as the various methods of calibration.

Liquid-in-Glass Thermometers
Let's start our story with one of the most common thermometers used today, the liquid-in-glass (LiG) thermometer. A LiG thermometer, by definition, is a glass capillary tube with a liquid-filled bulb at one end. As the temperature of the liquid in the reservoir increases, it expands and rises into the capillary tube. The level of the liquid in the column corresponds to a specific temperature, which is marked on the outside of the glass. The liquid that is contained within the thermometer may be one of many different substances, but the most common are mercury, toluene (or a similar organic substance), and low-hazard biodegradable liquids.

Dissecting the LiG Thermometer
Ok, so maybe you knew all of that. But, our story doesn't end there.   To truly understand these precision instruments, we first must understand a little bit more about how they work. The glass, materials, and dimensions of a particular LiG thermometer are carefully engineered to provide us with the accurate temperature measurements that we rely upon. Let's take a closer look.

The Bulb
As illustrated in *Figure 1*, the bulb of the thermometer is the thin glass reservoir that holds the liquid.   The bulb is carefully designed to contain a calculated volume of liquid, based upon the length and diameter of the capillary (or stem), as well as the thermal expansion coefficient of the liquid.

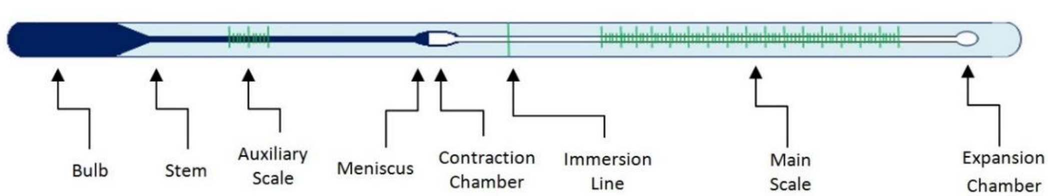

Figure 1: Anatomy of a LiG Thermometer

Stem
The stem, or capillary, of a LiG thermometer is made of annealed glass. The type of glass used is chosen based upon the temperature range of the device so as to minimize the effects of expansion and contraction of the tube. The portion of the capillary above the liquid level is often times filled with an inert gas, such as nitrogen, to prevent separation of the liquid column or vaporization of the liquid at the top of the column.

Auxiliary Scale
Some thermometers, but not all, are equipped with an auxiliary scale, which is located well below the main scale that is employed during normal use. Often times, this scale contains an ice point reference that can be used for calibration purposes if this temperature is not included within the range of the main scale.

Contraction Chamber
Occasionally, a LiG thermometer will have a contraction chamber that is located just below the main scale of the device. The purpose of this chamber is to shorten the total stem length needed to reach the main scale.

Expansion Chamber
An expansion chamber is provided at the end of LiG thermometers, and is used to prevent the buildup of pressure if the temperature of the liquid rises past the top of the scale. Again, the volume of this chamber is carefully designed to contain a certain volume of liquid.

Mercury and Mercury-Thallium Thermometers
For decades mercury thermometers were a mainstay in many testing laboratories. If used properly and calibrated correctly, certain types of mercury thermometers can be incredibly accurate. Mercury thermometers can be used in temperatures ranging from about -38 to 350°C. The use of a mercury-thallium mixture can extend the low-temperature usability of mercury thermometers to -56°C. Traditional mercury LiG thermometers are defined in detail in ASTM Specification E 1, *Specification for ASTM Liquid-in-Glass Thermometers*.

In recent years, concerns over the toxicity of mercury have caused many states to prohibit or limit the use of mercury-containing devices. In fact, one of the world's leading institutions on temperature measurement, the National Institute of Standards and Technology (NIST), recently announced that they will no longer provide calibration services for mercury thermometers. To know more about mercury reduction initiatives, please see my article, "Getting Rid of Mercury: A New Frontier for Temperature Measurement."

Nevertheless, few liquids have been found to mimic the thermometric properties of mercury in repeatability and accuracy of temperature measurement. Toxic though it may be, when it comes to LiG thermometers, mercury is still hard to beat.

Spirit-Filled LiG Thermometers
Spirit-filled thermometers contain toluene, alcohol, butane, or other similar organic liquids colored with a red dye. These devices are not often used for laboratory testing and other precision applications. While the substances contained in these types of LiG thermometers are relatively harmless and safe for laboratory use, they suffer from problems with accuracy and reliability. The low surface tension of these liquids, as well as their propensity for vaporization, makes them improbable candidates for general laboratory use.

Organic liquids generally have inferior performance to mercury, and can leave a film on the glass as the liquid drains down the capillary wall. Separation of the fluid column is also known to be a common problem with spirit-filled thermometers. In addition, they tend to have a greater sensitivity to changes in stem temperature, which is a fundamental limitation in their use. These thermometers also have different capillary and bulb dimensions than mercury LiG thermometers, causing differences in response time and immersion characteristics.

Spirit-filled thermometers are used in some low-temperature applications, as they can be used at temperatures as low as -200°C, which is well beyond the capabilities of mercury or mercury-thallium thermometers. ASTM E 1 covers specifics regarding spirit-filled LiG thermometers. Any thermometers described in ASTM E 1 which should contain toluene or other suitable liquids are specifically designated as such. At the time that this article was written, ASTM E 1 only contains specifications for two spirit-filled thermometers. These thermometers are specifically designed for use at extreme-cold temperatures at which it is not feasible to use mercury.

Low-Hazard Precision LiG Thermometers
Low-hazard precision thermometers have been developed in recent years as an alternative to mercury LiG thermometers. They contain non-toxic, biodegradable fluids of which the contents and chemical makeup are generally proprietary and undisclosed by their manufacturers. Ideally, they can be used as direct replacements for mercury-containing ASTM thermometers. However, these types of thermometers have some serious limitations that should be considered before use as a direct replacement for mercury LiG thermometers, such as those described in ASTM E 1. ASTM has developed a specification for low-hazard precision LiG thermometers, ASTM E 2251, *Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids*. This standard provides specific details on proper use of these devices, the repeatability of their measurements, and other limitations.

The thermal expansion properties of the non-toxic fluids used in low-hazard precision LiG thermometers can be quite different from that of mercury. The bulb and capillary size required to achieve a similar movement along the thermometer scale can vary from that of its mercury counterpart. The surface tension of these liquids varies from mercury, causing differences in the meniscus. In addition, low-hazard precision liquids tend to react to change in temperature at a rate different from that of mercury, and should not be used when rate of rise or other time-temperature relationships are an important part of the test procedure. While these devices are great alternatives for some applications, their range in use is quite limited.

Immersion Depth

As we've learned, LiG thermometers are as complex and intricate as the tests that we use them for. But, the intricacies don't end there. Within the category of LiG, there are three types of thermometers commonly used in laboratory testing—partial immersion, total immersion, and complete immersion. Each of these types of thermometer is calibrated differently and is intended for different uses in laboratory testing. See Figure 2 for a visual explanation of each type of thermometer.

Total Immersion Thermometers

Total immersion thermometers are designed to read correctly when the bulb and the portion of the stem of the device filled with liquid are immersed in the medium to be measured. In other words, this type of thermometer should be immersed to the test temperature. The portion of the stem containing the meniscus should remain outside of the test medium. Immersion of the meniscus can cause an excess of gas pressure that may damage the device, or cause distillation of the liquid, which may cause inaccurate readings (in addition to making the thermometer difficult to read). When using total immersion LiG thermometers, it is acceptable to leave about 1 cm of the liquid column exposed.

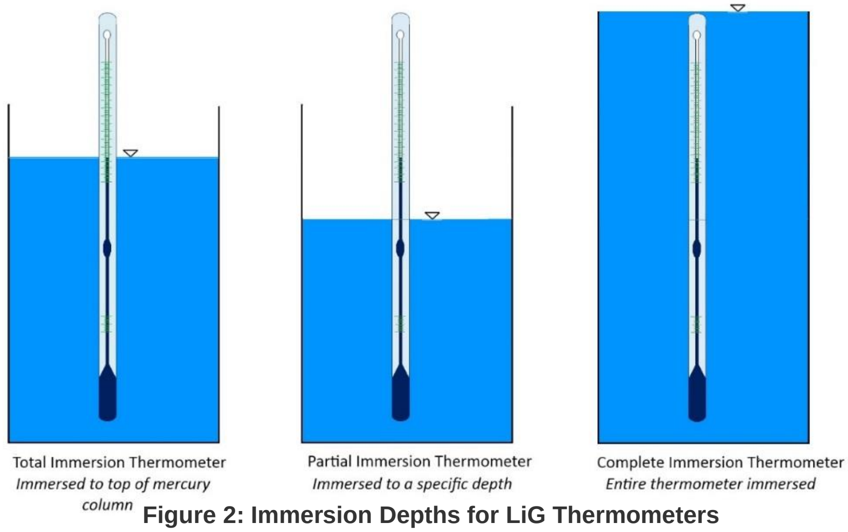

Figure 2: Immersion Depths for LiG Thermometers

Total immersion thermometers are commonly used in constant-temperature baths as a means of monitoring the bath's temperature. For example, total immersion thermometers are used in kinematic and absolute viscosity baths.

Partial Immersion Thermometers

Partial immersion thermometers are designed to read correctly if the stem of the thermometer is immersed to a specific depth. This depth is usually marked on the device. The part of the stem that is not exposed to the test medium, commonly referred to as the emergent stem, is not maintained in a temperature-controlled environment. Therefore, thermal expansion of the liquid in the emergent stem is highly unpredictable, and may lead to inaccuracies in the temperature measurement. Consequently, partial immersion thermometers tend to have a higher calibration uncertainty than their total and complete immersion counterparts.

Partial immersion thermometers are commonly used in applications where total immersion thermometers are impractical or impossible to use. For instance, if the depth of a temperature bath is only 100 mm, a total immersion thermometer with a length of 300 mm is impossible to immerse correctly. In this case, a partial immersion thermometer with an immersion depth of 76 mm is a better choice. In addition, if a rapid, one-time temperature measurement is required, such as in soil specific gravity or hydrometer testing, a partial immersion thermometer works best.

Complete Immersion Thermometers

Complete immersion thermometers are designed to read correctly when the entire device is immersed in the test medium. The use of complete immersion thermometers in the United States is fairly uncommon. There are no complete immersion thermometers described in ASTM E 1 or ASTM E 2251.

What's the Big Deal?

Perhaps you've now realized that you've been using one or more of your LiG thermometers improperly. Maybe you are thinking to yourself "No big deal, how much error could this add to my measurements, anyway? It probably doesn't even make a difference." Think again. People are often quite surprised when they find out just how much error improper use of a LiG thermometer imposes on their measurements. Let me explain.

Immersion depth plays an important role in how the liquid inside of the device will react. If the portion of the thermometer containing mercury is meant to be submerged in the test medium (i.e. a total immersion thermometer), but is left exposed, the liquid will not behave as intended. The error incurred can vary greatly, and is dependent upon the temperature scale of the thermometer, the type of liquid used, and the emergent stem temperature. It is possible to obtain errors as large as several degrees by improper immersion of a LiG thermometer. These errors generally tend to be larger with spirit-filled devices than with mercury-filled ones.

It is possible to apply a correction for intentional immersion of either a total or partial immersion thermometer at a point other than that which it was designed for. ASTM E 77, *Test Method for Inspection and Verification of*

Thermometers, describes procedures that may be used to calculate these corrections. Corrections cannot be made for complete-immersion thermometers that are immersed improperly.

Sometimes Being Wrong is Right
To confuse the issue further, there are several test standards which call for the use of a liquid-in-glass thermometer to be used incorrectly. In these cases, it is important to use the thermometer as described in the test procedure, even if it is technically incorrect. While the thermometer is being used incorrectly, it's important that it is used the same way by everybody that runs the test. In other words, everyone should use the device wrong in the right way. Table 1 shows a list of common ASTM and AASHTO test methods that require the use of liquid-in-glass thermometers.

Parallax
Yet another cause of error in taking measurements from LiG thermometers is due to the effects of parallax. Parallax is a phenomenon that occurs when the thermometer is not viewed with the eyes level with top of the mercury column. Differences in the angle from which the top of the column is viewed can cause the mercury column to appear either higher or lower in the capillary than it actually is (See Figure 3). To avoid parallax, always keep your eyes at the same level as the mercury column. If a thermometer is particularly difficult to read, a magnifying glass, telescope, or similar optical device can assist in avoiding the influence of parallax on temperature measurements.

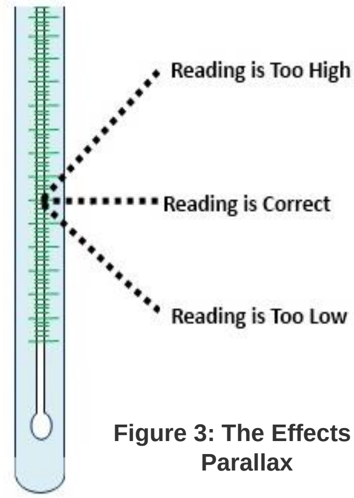

Figure 3: The Effects of Parallax

In Conclusion
From bulb to expansion chamber, LiG thermometers are intricately-made devices that can produce accurate and effective temperature measurements. I hope that you've learned a little about the anatomy of these amazing instruments, as well as how to use them for accurate temperature measurement. In my next post, I will "dissect" some other types of temperature measuring devices and discuss their use in laboratory testing.

What a Minute… What about Calibration???
I knew you were going to ask that question. You're absolutely right— calibration is a critical component of meaningful temperature measurement. However, I cannot do the topic of thermometer calibration justice within the confines of this article. Such critical topic deserves an article all its own. I'll cover this subject in a separate, future post, so stay tuned!

References

- ASTM International, "ASTM E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers," *Book of Standards,* Volume 14.03, 2007.
- ASTM International, "ASTM E 77, Standard Test Method for Inspection and Verification of Thermometers,"*Book of Standards,* Volume 14.03, 2007.
- ASTM International, "ASTM E 2251, Standard Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids," *Book of Standards,* Volume 14.03, 2010.
- Esser, Mark, "End of an Era: NIST to Cease Calibrating Mercury Thermometers," *National Institute of Standards and Technology*, February 2, 2011,<http://www.nist.gov/pml/process/thermometers-020111.cfm> (March 21, 2011).
- Ripple, Dean and Gregory Strouse, "Selection of Alternatives to Liquid-in-Glass Thermometers," *Journal of ASTM International*, Vol. 2, Issue 9, October 2005.
- Webster, John (ed.), *The Measurement, Instrumentation, and Sensors Handbook,"* CRC Press LLC, Boca Raton, Florida, 1999.
- Wise, Jacquelyn, "NIST Measurement Services: Liquid-In-Glass Thermometer Calibration Service," Special Publication 250-23, National Institute of Standards and Technology, Gaithersburg, Maryland, 1988.
- Wise, Jacquelyn, "A Procedure for the Effective Recalibration of Liquid-in-Glass Thermometers," Special Publication 819, National Institute of Standards and Technology, Gaithersburg, Maryland, 1991.