Gemmology Bulletin

Measuring Specific Gravity

By James Evans, EG

The hydrostatic measurement of specific gravity is famously attributed to Archimedes, following his naked dash around Syracuse (Sicily) in the 3rd Century BC. More than a millennium then passed before the Arab scholar Abū Rayhān al-Birūnī used specific gravity as a quantitative test for precious stones – a test that is still employed today.

Hydrostatic Methods

Al-Berūnī calculated the specific gravity (SG) of various precious stones by dividing their weight (in air) by the weight (and thus the volume) of water they displaced.

Measuring specific gravity with a Tanita KP-601 scale and a specific gravity kit from Mineralab.

$$SG = \frac{\text{Weight in air}}{\text{Weight of water displaced}}$$

The method employed by Archimedes is disputed, for the story of Heiron's crown is absent from his known works. Galileo later suggested that Archimedes had used a hydrostatic balance. If so, his approach would have been similar to the modern method, in which a stone is weighed whilst suspended in water (whether from a 'weigh below' hook at the bottom of a scale, or from an SG kit above the scale). A stone will weigh less in water than in air – a result of the upward force of buoyancy. And the extent of this weight loss will equal the weight (and thus the volume) of water displaced. The formula for specific gravity therefore becomes:

$$SG = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

Two problems arise from this method. Firstly, the apparatus is unwieldy. Secondly, the minimum size of stone that can be tested is dependent on the sensitivity of the scale.

The former problem can be solved by replacing the SG kit with a pycnometer (also known as a 'specific gravity cup'). These devices enclose a fixed volume of water. Adding a stone to the pycnometer increases the total weight of the device and its contents by the weight of the stone minus the weight of displaced water. The formula for specific gravity therefore becomes:

A pycnometer, manufactured by GARDCO and sold by Lustre Gemmology (postage stamp for scale).

$$SG = \frac{\text{Weight of stone}}{\text{Weight of stone} + \text{Weight of cup with water} - \text{Weight of cup with stone and water}}$$

Whist a pycnometer is convenient, its use adds to the potential measurement error of the scale (and thus increases the minimum size of stone that can accurately be tested). But if accuracy is the primary concern, one solution is to set aside both the pycnometer and the scale and turn instead to a direct-reading specific gravity balance. Dr Hanneman produced one such balance in the late 1960s, having realised that the calculation of SG could be performed mechanically on the beam of a customised balance scale. With no manual calculations to be made, there was no need for standardised weights. Instead, Hanneman could use weights as fine as salt grains. And with a fine nylon thread employed as a fulcrum, his balance could achieve an effective sensitivity of just 0.002 carats!

A Nicholson Hydrometer.

A final hydrostatic method employs a hydrometer, such as the Nicholson Hydrometer (invented by the English instrument-maker William Nicholson in the 1780s). To use this device, the hydrometer is first lowered into a water-filled cylinder. Weights are then added to the hydrometer's top platform until the mark on the instrument's stem meets the waterline. This process is repeated with a stone placed first on the top platform (in the air), then on the lower platform (in the water). The stone's specific gravity can then be calculated, to a reported five decimal places, with the following formula:

$$SG = \frac{\text{Weights without stone} - \text{Weights with stone in air}}{\text{Weights without stone} - \text{Weights with stone in water}}$$

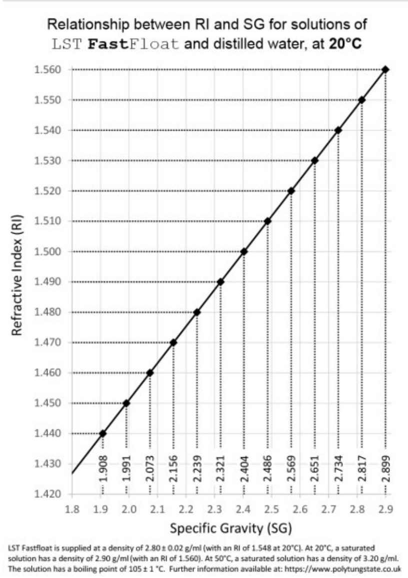
Whilst hydrometers are rarely used today, the method is noteworthy in relation to an entirely different approach to measuring specific gravity; that of heavy liquids.

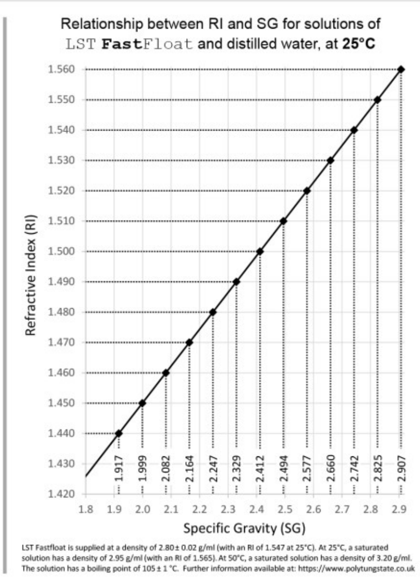
Heavy Liquids

By adding weights to a hydrometer, the device's effective density is adjusted. But what if we set aside the hydrometer and instead adjust the density of the water to match the gemstone? There was a time when the Gemmological Association of Great Britain sold the highly toxic, yet water-soluble, Clerici solution. This heavy liquid consisted of equal parts thallium formate and thallium malonate and had a specific gravity of 4.25. To accurately test a stone, it would be placed in a concentrated Clerici solution. Distilled water would then be added; progressively lowering the SG of the solution until the stone displayed neutral buoyancy. At this point the SG of the solution (and thus the stone) could be calculated from the liquid's refractivity (as measured by a standard gemmological refractometer). Alternatively, several pre-prepared concentrations of the heavy liquid could be used to differentiate particular gem species on the basis of float-sink tests.

LST FastFloat, sold by Lustre Gemmology.

Today's gemmologists have better options: saturated solutions of sodium polytungstate, lithium metatungstate, and sodium heteropolytungstate all have specific gravities above 2.9 (at 20 °C), have minimal toxicity, produce no fumes, and are not flammable. The latter solution, marketed as 'LST FastFloat', is to be preferred, for it has half the viscosity of the alternatives – meaning water dissolves quicker, and stones react faster. One note of caution, however, is that only tools made from glass, plastic, stainless steel, or titanium should be used with these liquids. Contact with most other metals will degrade the liquids, whilst tap-water is liable to turn the solutions cloudy.





Using LST FastFloat to separate two violet gems: a beryl (morganite) and a scapolite. Both stones have an optical character of U- and ranges of RI and DR that overlap. However, the beryl has a higher specific gravity. At the start of the test both stones were floating. Distilled water was added to the solution until one of the gems displays neutral buoyancy. At this point the RI of the solution was found to be 1.540, corresponding to an SG of 2.73 (calculated with the charts provided on the 'Measuring specific Gravity Instruction Card' – Sold by Lustre Gemmology). 2.73 is between the values of specific gravity expected from blue and pink beryls. After further distilled water was added to the solution, the second gemstone displayed neutral buoyancy whilst the first had sunk (pictured). At this point the RI of the solution was found to be 1.529, corresponding to an SG of 2.64 (between the values expected from blue and pink scapolites). Following the test, the LST FastFloat was left uncovered; allowing excess water to evaporate until the solution returned to its original SG of 2.9 (with a corresponding RI of 1.560).

Weight Estimation Formulae

A final method is to estimate a stone's SG from its physical dimensions. Such calculations are frequently used to estimate the weight of set diamonds (with a known SG of 3.52). But if a stone can be weighed, the calculation can be run in reverse to estimate its specific gravity. For example, the weight of a round, brilliant-cut diamond can be estimated as:

$$\text{Carat weight} = \text{Diameter}^2 \times \text{Depth} \times 0.00173 \times 3.52$$

The specific gravity of a round, brilliant-cut stone can therefore be estimated as:

$$SG = \frac{\text{Carat weight}}{\text{Diameter}^2 \times \text{Depth} \times 0.00173}$$

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Almost a millennium after al-Birūnī's treatise on specific gravity, its measurement remains a significant tool of the gemmologist's trade. Hydrostatic weighing is now the primary method of quantifying specific gravity; with SG kits offering a reasonable compromise between accuracy and convenience, and pycnometers offering greater convenience for use in the field. A faster approach, for stones cut as standard shapes, is to use weight estimation formulae. A more accurate approach, especially for smaller stones, is provided by heavy liquids. In summary, there is no one best method for measuring specific gravity in all situations, but a range of solutions is available for a well-resourced gemmological toolkit.