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# 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

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

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. He achieved this by employing a spouted container filled to the brim with water. When a stone was added to the container, the displaced water would fall into the pan of a balance, where it was weighed.

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

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 method most commonly used today, in which a stone is weighed whilst suspended in water (whether from a 'weigh below' hook at the bottom of a scale, or 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.

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

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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 overcome with the 'Betts method' of hydrostatic weighing. John Betts' insight was that, whilst a stone would weigh less when suspended in water (due to the upward force of buoyancy), the container of water would simultaneously weigh more (due to the equal and opposite force of the stone's weight pushing downward through the water). The Betts method therefore involves weighing the container and water, rather than the gemstone suspended in the water.

$$SG = \frac{\text{Weight of stone}}{\text{Increased weight of container and water (when a stone is suspended in it)}}$$

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

An alternative approach to avoiding the unwieldy equipment normally associated with hydrostatic weighing is to use 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 by the weight of the stone minus the weight of water displaced. The formula for specific gravity therefore becomes:

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

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 device 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 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:

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

**A Nicholson Hydrometer.**

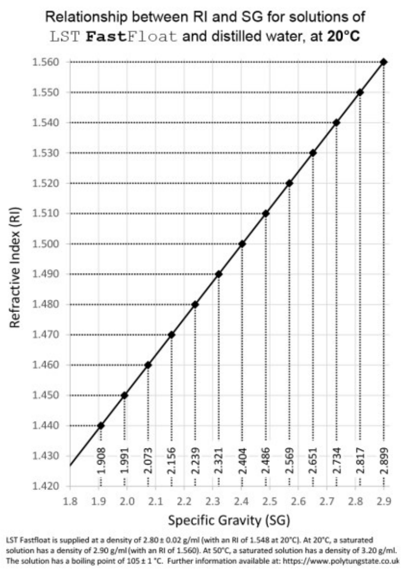
Whilst hydrometers are rarely used today, the method is noteworthy in relation to an entirely different approach to measuring specific gravity; that of heavy liquids.

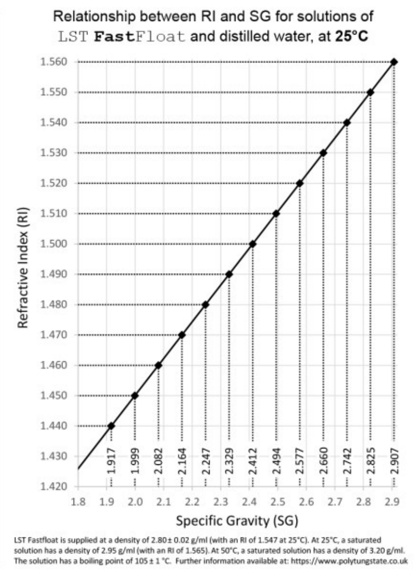
## Heavy Liquids

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.

Today's gemmologists have better options: saturated solutions of sodium heteropolytungstate, sodium polytungstate, and lithium metatungstate all have specific gravities above 2.9 (at 20 °C), have minimal toxicity, produce no fumes, and are not flammable. The former 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 contact with metals other than stainless steel or titanium can degrade the liquids, whilst the use of tap-water (rather than distilled water) can turn the solutions cloudy.


**LST FastFloat, sold by Lustre Gemmology.**




**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).**

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## Weight Estimation Formulae

A final method of determining specific gravity, for gemstones cut into standard shapes, is to estimate SG from a stone's weight and physical dimensions. Formulae are readily available to calculate 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 SG. For example, the weight of a round, brilliant-cut diamond can be estimated as: Carat weight = 3.52 x Diameter$^2$ x Depth x 0.00173. This can be rearranged to estimate specific gravity as:

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

Almost a millennium after al-Birūnī's treatise, the measurement of specific gravity remains a significant tool of the gemmologist's trade. Indeed, Max Bauer presented specific gravity as the predominant test in distinguishing gem species within his influential work *Edelsteinkund* (*Gemmology*, published 1895-1896). Bauer recommended the heavy liquid methylene iodide (diluted with benzine) for this test. More recently, hydrostatic weighing has become the primary method of quantifying specific gravity; with the Betts method becoming increasingly popular due to the avoidance of unwieldy equipment. Pycnometers offer still greater convenience for use in the field. A faster approach, for stones cut as standard shapes, is to use weight estimation formulae. But heavy liquids still provide the most accurate measure – especially for smaller stones. In summary, there is no one best method for measuring specific gravity in all situations, but a range of solutions are available for a well-resourced gemmological toolkit.