MAGNETIC SUSCEPTIBILITY OF GEMSTONES Part 3

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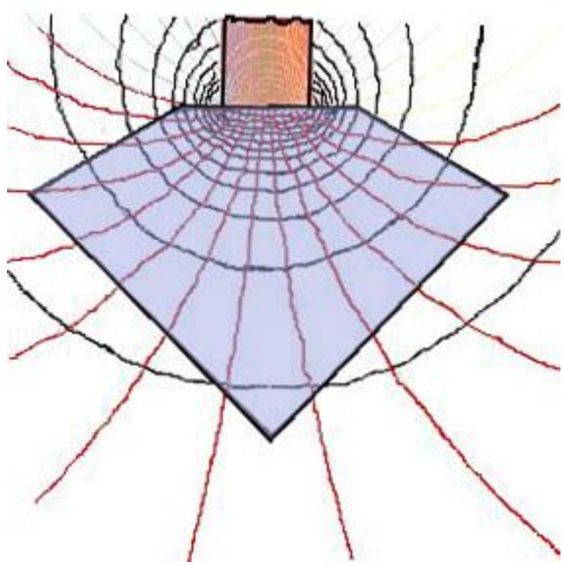
MEASURING SUSCEPTIBILITY

In part one of this discussion, on the history of magnetic volume susceptibility measurements for gemmological purposes, it was noted that B. Anderson developed a purely empirical formula to obtain a “susceptibility” measure for gemstones. Also, that Prof. Haralyi used a rather elaborate scheme to correct a measured loss of weight to give susceptibility, and that this scheme apparently had problems.

To understand what the problem is in measuring susceptibility from a measure of the loss in weight of a material, one needs to look at the formal expression of the force equation given in Figure 1.



The Force Equation

$$F=1/2 \text{ grad} \int k H^2 dv$$

Fig. 1 The Force Equation

This nasty looking equation is the formal expression for the force of attraction between a magnetic field, as from a permanent magnet, and the volume of an unknown represented by the gem with a volume susceptibility of k (Kittel, 1956).

You don't have to understand this formality, for I hope the illustration will explain what is happening.

What the equation tells us is that the attraction is proportional to the volume susceptibility, k, and the gradient of the magnetic field, integrated over the volume of the unknown.

In general this equation can't be solved by simple means, so the physicist looks for a simple solution.

One simple solution is if the sample is in the form of a long cylinder. This is used in magnetic balances such as the Gouy and Evan's type which are used in the physics lab to measure susceptibility.

Obviously this is not practical for the gemmologist whose gemstones are seldom of the proper shape.

What is required is another simple solution which can be applied to gem measurements. After some thought, there is one solution to the equation which can be used. If the magnet which supplies the magnetic field is small compared to the sample size, then the force equation reduces to:

$F = Ck$ where C = a constant

If this condition applies, then all one needs to do is measure a material of known susceptibility to get the magnet constant, C:

$C = F_{kn}/k_{kn}$

where Fkn is the force measured for the known material and kkn is the known susceptibility.

An unknown susceptibility is simply given by:

$k_u = F_u/C$ where Fu is the unknown susceptibility

With this understanding our task was to determine just how small the magnet had to be.

But before we go on, look at the illustration in Fig 1 above showing a faceted gem on whose table a small magnet is placed.

You can get some appreciation of what is happening from this illustration. The red lines are the magnetic field lines and the force of attraction or repulsion is directed along the lines. Note how the direction of the attractive forces change with position within the gem.

The black curved lines are lines of constant magnetic potential. You can see that the field is strongest right at the face, or pole of the magnet and drops off rapidly with distance away. Thus, the gradient; the change of field with distance; is greatest at the magnet pole face.

You can also see that for these proportions of gem and magnet sizes, that the magnetic field gradient, and hence the force, at the pavilion edges of the gem is rather small compared to the field gradient just below the magnet and within the gem.

Thus, the distant parts of the gem contribute much less attraction. If the attraction from the parts of the gem distant from the magnet pole face are small enough, then, for practical purposes, our condition is met.

Of course, the gem surface must be flat, and clean, and the magnet must be as close as possible. Another result is that if the magnet pole area changes size, and the strength of the magnet remains the same, the force of attraction will be proportional to the area of the magnet pole face.

Realizing this, we then had to determine just how small and strong our magnet had to be. We then purchased very strong NIB magnets with diameters of 1/4, 3/16. 1/8, and 1/16 inch diameters. (Total cost about U.S. $2.00) and experimented with an old analytical two-pan balance.

If our analysis was correct, then the force of attraction should be proportional to the magnet's pole area, or the square of its diameter, for a very large stone. This assumes the strength of each magnet is the same, which the manufacturer claimed.

So we used a 20ct Brazilian almandine to check for a square law response.

To measure the force of attraction we simply measured the force it took to pull one of the small magnets off of the table of the gem we were measuring. Initially, the magnet was at balance on the scale, the gem positioned just below the magnet, and just touching the table facet.

Figure 2. shows the magnet pull, or attraction, plotted against the magnet diameter, plotted on a log-log scale. The force should plot on a line following a square law, which it can be seen to do. I've also shown an ideal square law line, and a line for the manufacturer's pull or lift in pounds on steel. Note that the 1/4 inch magnet will lift about 4 pounds of steel and the attraction for the 20ct almandine is 15 carats! Thus, for the 20ct almandine our assumption was valid.

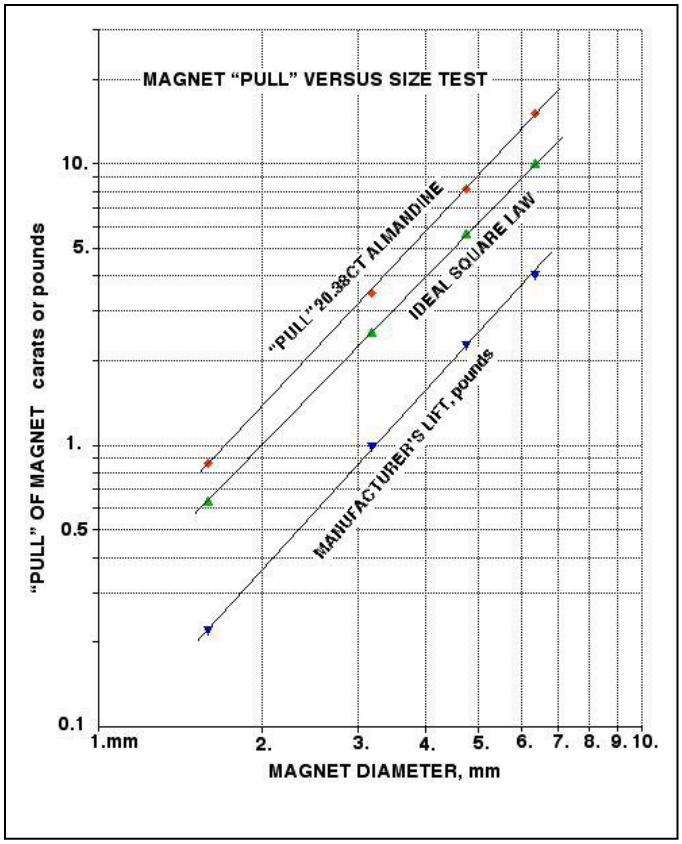


Figure 2
Pull v Magnet Size

Next we needed to determine the largest magnet we might use in order to get the most "pull" possible for the measurement. The larger the magnet the more precision we will have in our readings. Figure 3. shows the force of attraction, the "pull" against magnet diameter for two different table sizes. Again we used garnets for the tests. You can see that when the magnet diameter is the same size or larger than the table, the force begins to fall away from a square law. Fortunately we don't have to use magnets much smaller than the table diameter. Thus the 1/16 inch magnets will let us measure stones down to about 1/2 carat.

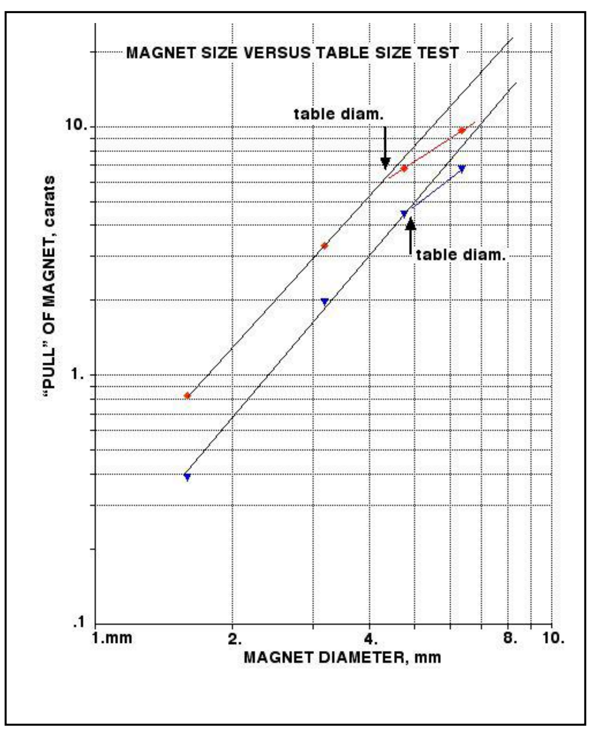


Figure 3.
Magnet Size
v
Table Size

Our initial work was with an old analytical balance and it was a bit tedious to do the measurements, so we worked on devising other ways of manipulating the magnet and stone to get measurements (Hoover and Williams, 2007; Hoover et al., 2008). Our latest version is next shown in Figure 4.

Fig 4. Scope with Scale and Gem

This shows a discarded biological microscope stand without the optics. Where the lenses once stood, we have placed an insert with a short steel post. We simply stick what ever size magnet we will use to the steel post.

On the mechanical stage of the scope we place a small digital scale measuring to 0.005cts, and a gem is placed on a support and in a small blue tac or similar doughnut, then onto the scale.

One needs to check that all materials used near the gem under test are not magnetic.

The x-y positioning of the mechanical stage lets us easily position the gem directly below the magnet.

A key point in this setup is the fine focus mechanism of the microscope which permits very precise vertical positioning of the magnet and gem.

Initially the magnet is pushed onto the gem’s table facet in order to align the surfaces parallel this is an important point.

When doing this a bridge is placed over the active portion of the scale so as not to overload the weighing mechanism.

Next the bridge is removed, the gem placed back on the scale, and the interface between the magnet pole face and gem table visually checked to see if they are parallel.

Then the gem is dropped a cm or so below the magnet, and the scale turned on and tared.

The gem is next brought up to the magnet and the maximum “pull” recorded.

This is of course a negative reading for paramagnetic gems.

I won’t go into details of the manipulation, but interested people may contact me for more information.

The total operation is comparable to a hydrostatic density determination, and should be done two or three times to check repeatability. We encourage others to try alternate ways to measure the force of attraction in hope of finding even better ways to measure susceptibilities.

Initially we used copper sulfate with 5 H2O as a standard for susceptibility, but it’s volume susceptibility is rather small (169x10exp-6(SI)). We now use cobalt chloride crystals with 6 H2O which we grow with k=986x10exp-6(SI). Any other well described salt could be used for calibration.

References

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