MODULE

Major Physical Properties

Major Physical Properties

Although there are a dozen or more physical properties which can be measured, in this course we will concentrate on just a few. In particular, our focus will be on those which are either visible directly, or measurable with minimal equipment, and those which are most important as indicators of a gem's identity, and/or its suitability for particular uses:

Cleavage

- **In the three dimensional structure of certain crystals, atoms are bound more tightly to each other in some directions and more loosely in others. As a consequence, when strong forces are applied, relatively clean breaks may occur in these "weakest link" directions. These breaks, which can sometimes be so smooth as to appear to have been polished, are called cleavages. The number of directions in which a particular material cleaves, the ease with which that happens, and the "perfection" of the breaks are used to quantify this characteristic.**
- **Since cleavage, or lack of it, is a species trait, it also serves as a good gem identification criterion. In the examples below, the number and completeness of cleavage of three species are shown.**

Cleavage

Species with easy or perfect cleavage, particularly when such is the case in multiple directions, are poor risks for most jewelry applications. <u>Not all gems show cleavage</u> however, for example tourmalines, sapphires, and garnets do not.

Cleavage

knowledge of gem cleavage has practical value, both as a means of gem identification, and in the appropriate fashioning and selection of gems for a particular use.

Cleavage

Miners have long used the cleavage properties of gems in trimming the stones they find. "Cobbing" is the act of smacking a piece of rough sharply and precisely with a hammer to break off any unstable (already partially cleaved), or included areas. Knowledge of the cleavage planes in the material being mined is essential to efficient use of this technique.

Fracture

- **Whereas cleavages occur only in some gems, and within those, only in certain directions*, fractures can, and do, occur in all gems, and in any direction*. A fracture is a break which is *not* along a cleavage plane. With sufficient force, any gem will fracture, although some do so more readily than others. The edges of fractures are not smooth like those of cleavages, but they do tend to have one of several basic appearances.**
- **Playing on the resemblances of certain fracture types to well known surfaces and objects, terms like conchoidal (shell-like), splintery, uneven, step-like, and granular are used. Like cleavage, this is a species specific characteristic which has value in the identification of gems**

Citrine quartz: conchoidal

Charoite: splintery

Turquoise: granular

Fracture

Conchoidal fracture is the most common, and is found in corundum, beryls, all the quartzes, opals, and both natural and man-made glasses.

Durability Factors

Gem durability can be described as being made up of hardness, toughness and stability

Durability Factors
Hardness

The tendency to resist scratching in a gem is known as its hardness. Of the three factors comprising durability, it is the most familiar. Hardness is primarily the result of the strength of the chemical bonds between the gem's constituent atoms (how tightly they are bound to one another).

Hardness

The hardness of a gem affects its wearability, luster, and resistance to cutting and polishing. All other factors being equal, harder gems are more useable in jewelry, develop a brighter surface luster, and take more time and effort to cut and polish. They will retain their polish longer than softer gems, given equal wear and tear.

Mohs Hardness Scale

Originator - Frederich Mohs, a 19th century German mineralogist. Scale developed in 1812

The familiar 1-10 Mohs' Scale of hardness, is not an absolute measure, but rather a relative one. Gems ranked at a higher number on the scale can scratch those ranked lower, and will in turn, be scratched by those whose number is higher than theirs

The Mohs Scale of Hardness

1: Talc

2: Gypsum

3: Calcite

4: Fluorite

5: Apatite

6: Feldspar

7: Quartz

8: Topaz

9: Corundum

10: Diamond

Mohs Hardness Scale

You can see that on the list that Diamond is a 10. This is not entirely true. This scale is a simplified scale to show the minerals in order from soft to hard, but in no way does it reflect just how strong the items actually are.

A list showing their true hardness is called the **Absolute Hardness Scale**, and that is shown below

Absolute Hardness Scale

Talc	1		Feldspar	72
Gypsum	2		Quartz	100
Calcite	9		Topaz	200
Fluorite	21		Corundum	400
Apatite	48		Diamond	1600

Now that’s an eye opener! Look at Diamond now. 1600! It shows Diamond is 4 times harder than the next most natural item… Corundum.

Hardness

Corundum is the Parent Gemstone that Sapphire and Ruby comes from. It’s also the type of Watch Crystal that most fine Watches are made of to feature a scratch resistant face.

Hardness - Gemstones

- Knowing the hardness of Gemstones is important because of the wear and tear and longevity that a stone can give.
- The more durable a stone is, the more years you'll have to enjoy it and pass it down from generation to generation.
- Softer stones, like Emerald, Aquamarine and Tanzanite look great, cost a lot of money, but don't hold up well over the long run. They will scratch, dull up, lose their shine and even crack or break easier than harder stones will (like Alexandrite, Sapphire, Ruby and of course Diamond – the Gemstone for April).

Gemstone Mohs Scale

Amber	2.5
Ivory	2.5
Pearl	2.5
Jet	2.5 – 3
Shell	3
Coral	3
Malachite	3.5 – 4
Azurite	3.5 – 4
Lapis	5 – 5.5
Obsidian	5 – 5.5
Hematite	5 – 6
Opal	5.5 – 6
Turquoise	5.5 – 6
Rhodonite	5.5 – 6.5
Fire Opal	6 – 6.5
Moonstone	6 – 6.5
Marcasite	6 – 6.5
Iron Pyrite	6.5
Tanzanite	6.5
Jade	6 – 7
Kunzite	6.5 – 7
Peridot	6.5 – 7
Bloodstone	7
Quartz	7
Rose Quartz	7
Smokey Quartz	7
Milk Quartz	7
Black Opal	7
Ametrine	7
Agate	7
Citrine	7
Jasper	7
Onyx	7
Carnelian	7
Amethyst	7
Tiger’s Eye	7
Garnet	7 – 7.5
Rhodolite	7 – 7.5
Iolite	7 – 7.5
Tourmaline	7 – 7.5
Zircon	7.5
Beryl	7.5 – 8
Aquamarine	7.5 – 8
Emerald	7.5 – 8
Spinel	8
Topaz	8
Smokey Topaz	8
Blue Topaz	8
Yellow Topaz	8
Chrysoberyl	8.5
Alexandrite	8.5
Cat’s Eye	8.5
Cubic Zirconia	8.5
Corundum	9
Sapphire	9
Ruby	9
Moissanite	9.25
Diamond	10

Metals Mohs Scale

Lead	1.5
Tin	1.5
Zinc	2.5
Gold	2.5 – 3
Silver	2.5 – 3
Aluminum	2.5 – 3
Copper	3
Brass	3
Bronze	3
Nickel	4

Platinum	4 – 4.5
Steel	4 – 4.5
Iron	4.5
Palladium	4.75
Rhodium	6
Titanium	6
Hardened Steel	7 – 8
Tungsten	7.5
Tungsten Carbide	8.5 – 9

Metals

Most Metals used for Jewelry are quite soft (2.5 on the Mohs Scale). This makes them malleable and easy to work with.

Looking at this list it’s easy to see how putting a Platinum Ring up against a 14k Gold Ring will scratch the Gold and wear the Gold down.

Hardness

- Metals are not normally rated with the Mohs Scale. They are usually rated with the **Rockwell Hardness Test**.

- But since we’re dealing with Jewelry, Gold and Diamonds, the Mohs Scale is the easiest for most people and consumers to understand. 1-10 is a pretty simple scale.

Hardness

- Diamond may be the most durable Gemstone there is, but that doesn’t mean they won’t Chip or Break.
- Diamonds have Cleavage lines just like trees do. One good whack, hit, or strike and the Diamond could Break, Chip or Shatter.
- The weakest and most vulnerable part of the Diamond is the Girdle (where the Diamond gets the thinnest).

Hardness

In mineralogy, one of the key tests commonly used for purposes of identification is a "scratch" test, which is done with a set of implements known as *hardness points.*

Hardness – cont/d

These, usually steel, "pencils" are tipped with various minerals (or metals) of known hardness. By drawing them across the surface of an unknown mineral sequentially, the tester can determine the sample's approximate hardness.

Hardness – cont/d

In gemology, such tests are rarely used as they are destructive in nature. Exceptions might be in testing the bottom of a carving, or a piece of gem rough, or a bit of material which has broken off. Another drawback of the standard hardness points is that they are not precise, but limited to giving a "ballpark" estimate.

Hardness test

In a laboratory setting, precise measurements can be made with sclerometers. These devices use diamond-tipped, hydraulically operated probes, and can give an absolute reading on the force necessary to penetrate the surface of a material.

The Practical or Field Mohs' Scale

- **1-2: easily scratched by fingernail**
- **3-4: scratched by copper coin**
- **5-6: easily, and not so easily, scratched with pocket knife**
- **7: scratches window glass/scratched by steel file**
- **8-10: scratches window glass, but not scratched by steel file:**

Hardness can be directional.

This is actually quite understandable, as it depends on chemical bonds which can differ in strength, and in distance from each other, depending on which axis of the crystal we are observing. Generally such differences are relatively small and of litttle consequence, but there are two notable cases where they are dramatic and important. 1) Kyanite is notoriously difficult to cut because of its extreme directional hardness differences. 2) Diamond cutting would scarcely be possible unless the cutters could use the directional hardness of that gem to their advantage.

Examples of Soft Gems

- ***[Ivory and jet: 2.5, pearl: 3, sphalerite: 3.5, fluorite: 4]***

Examples of Gems with Intermediate Hardness

Scapolite: 6

Tanzanite: 6.5

Garnet: 7 - 7.5 depending on species

Tourmaline: 7.5

Examples of Hard Gems

Spinel & topaz: 8

Chrysoberyl: 8.5

Sapphire: 9

Diamond: 10

Toughness

The tendency to resist breaking and chipping is known as a gem's toughness. This property is controlled primarily by two factors: the readiness of a material to cleave in single crystal gems, and the presence or absence of certain structural characteristics in aggregate and/or amorphous gems which promote strength and cohesion.

Toughness

All other factors being equal, the harder the gem, the tougher it will be, but all other factors are *not* always equal. Take the case of topaz, for example. At hardness 8 it seems to be a pretty rugged gem, but if we consider its strong tendency to cleave in one direction, in reality, it is rather fragile.

Toughness

Diamond, the "star" of the hardness game, is only ranked as "good" when it comes to toughness because of its cleavage and fracture potential. Diamonds are usually cut with a flat culet facet at the tip of their pavilion, rather than coming to a sharp point as do colored stones. This is due to the likelihood of a fracture (or cleavage) in the fragile culet zone

Toughness

On the other hand, nephrite jade with its hardness of 6.5 might seem to be delicate, but due to the felted, fibrous nature of its aggregate crystals, *it is literally the toughest gem on Earth!* **So it is with pearls, which with their extremely low hardness, would barely be wearable at all, except for their moderately good toughness.**

Toughness

- **Toughness affects both wearability and resistance to polishing. Jade gems thousands of years old are as beautiful today as when they were first made. A well polished jade is a sign of a dedicated and skillful lapidary, as its structural characteristics make it susceptible to "undercutting" and an "orange peel" surface effect if not handled expertly and with patience.**
- **There is no numeric scale on which toughness is measured, rather, relative terms such as: exceptional, excellent, good, fair and poor are used.**

TOUGHESS	EXAMPLES
Fragile Gems	Topaz, sunstone, sodalite, serpentine: all poor
Intermediate toughness	Tourmaline, iolite: fair; chrysoprase (quartz), diamond: good
Tough gems	Sapphire, hematite: excellent; jadeite jade, nephrite jade: exceptional

Stability

Stability in a gem is a measure of its ability to resist changes due to exposure to light, heat and/or chemicals. Not only does stability affect wearability, but it also dictates appropriate ways of fashioning, cleaning and storing the gems. Most gems are stable, but a few (even some quite popular ones) are unstable, and must be handled accordingly.

The Effects of Heat

Dehydration: Heat is a factor that can create problems with certain gems. In some cases, the mineral comprising the gem is "hydrated", that is, it contains water molecules which adhere chemically with varying degrees of tenacity. When the water is rather loosely attached, hot dry air can lead to loss of some of the water, and changes in the color, or transparency of the gem. Even more seriously, its loss can cause a network of cracks to form in the gem, in a process called "crazing". ***Opal is the most well known gem for which this is an issue.***

Thermal Expansion

Another problem that heat creates for some gems is caused by their inherent capacity for "thermal expansion". This is a yet another physical characteristic by which gems differ. Diamond is notably stable to temperature changes (with slow and even rates of thermal expansion), so much so, that jewelers can pour molten metal into molds containing wax models with the diamonds already in place, to cast pre-set jewelry pieces

Thermal Expansion

Gems, such as apatite, expand so rapidly with sharp rise in temperature, that their crystal structure is damaged, and they crack or even shatter. Heat sensitivity of that degree makes it very important for lapidaries cutting such gems, and jewelers working on mountings containing them, to keep the gem cool during these processes.

Thermal Expansion

The Effect of Inclusions: Although a gem might be quite temperature stable itself, inclusions of other minerals within it, could have different degrees of thermal expansion from their host. This situation becomes quite important in the heat treatment processes used to enhance gems. Internal inclusions can literally explode or, less dramatically, expand, and in doing so, create internal "stress cracks" in the gem being treated. (For this reason, it is standard practice among Tanzanite heat treaters to heat only cut stones which have had virtually all the inclusions removed, and to avoid heating rough material.)

Thermal Expansion

There are cases where thermal expansion characteristics of gems are used to deliberately induce cracks or stress fractures. Pieces of amber which have been heated, and then quickly cooled, develop disk-like stress fractures called "sun spangles" which some consider to be attractive.

Other Environmental Factors
Light

Some gems can fade or change color when exposed to light. An extreme example of this phenomenon is seen in the rare mineral pyrargyrite which must be kept constantly under opaque covers or else light exposure quickly renders its originally red color completely black. In the case of gem minerals, there are only a few to be concerned about. Kunzite (pink spodumene) can lighten in color with long term exposure to bright light, *<u>and is sometimes suggested as an "evening only" gem</u>*. Certain brown topazes, notably those from Mexico, can lighten dramatically, even becoming colorless with continuous light exposure.

Other Environmental Factors Chemicals

Exposure to various chemicals can ruin the polish of, and/or discolor certain gems. Two important cases would be carbonate gems, like rhodocrosite*, which degrade due to a chemical reaction when exposed to acids, and amber which can be dissolved by acetone. I*t is doubtful that a drop of lemonade, or vinagrette salad dressing, or a bit of spilled nail polish remover would harm such stones, but acid vapors found in the polluted air of many cities can take their toll over time, as can some intense solvents, such as paint strippers, which might be used in the home or workplace. A dip in certain jewelers' solutions, like the hot "pickle" used to remove oxidation from metals, would be devastating to rhodocrosite, while a few hours spent soaking in "Attack^{TM}" (a solvent used to remove glues used in jewelry making) would ruin an amber gem.

Other Environmental Factors

Care of Senstive Gems

Lightly wiping chemically sensitive gems with a damp cloth after each wearing will help to keep them in good shape. Any gem which is suspected, or known, to be chemical or heat sensitive should be protected from steam or solvent cleaning methods. Such considerations also become a factor in gemological testing in that, turquoise, for example, cannot be placed in the chemicals that would be used to determine specific gravity, or those used in relative refractive index testing.

EXAMPLES OF UNSTABLE GEMS

- ***Apatite and opal:*** ***<u>heat sensitive</u>***
- ***Mexican brown topaz:*** ***<u>fades in light</u>***
- ***Turquoise:*** ***<u>porous and likely to discolor with exposure to various materials</u>***

Specific Gravity

SG. also known as relative density, differs widely among gemstones, and is one of their most important physical characteristics from the viewpoint of gem identification. Specific gravity (SG) is the ratio of the weight of one unit volume of the gem to the weight of the same unit of water. For example, to say sapphire (corundum) has SG = 4.0, means precisely that a cubic metre of sapphire weighs four times as much as a cubic metre of water. In natural gems, SG values range from just over 1 (1.08 for amber) to just short of 7 (6.95 for cassiterite)

EXAMPLES OF SGs

- **LIGHT GEMS: SG < 3.O**

  Amber: 1.08; shell: 1.30, opal: 2.10

- **MEDIUM DENSITY GEMS: SG: 3 - 4**

  Andalusite: 3.16, jadeite: 3.33, chrysoberyl: 3.71, sapphire: 4.00.

- **HEAVY GEMS: SG > 4**

  Zircon: 4.69, scheelite: 6.10, anglesite: 6.35, cassiterite: 6.95

Measuring Specific Gravity

Heavy Liquids

One popular method is based on the principle of bouyancy: "an object will sink in a fluid of lesser SG, remain suspended in one of equal SG, and float in one of higher SG." This technique uses a set of "heavy" liquids with known SGs. By immersing the unknown gem material in the liquids, and observing its behavior, its approximate SG can be deduced.

Heavy Liquids

To give a simple example, consider an unknown gem that floats quickly in the 3.05 bottle, sinks rapidly in the 2.57 bottle, and floats and sinks very slowly in the 2.67 and 2.62 bottles, respectively. That would tell you that the SG was between 2.67 and 2.62 and would allow you to rule out a great many minerals and focus any further tests on a smaller group of "possibles". Corundum (SG = 4.0) would behave quite differently from these observations, and could be excluded, while quartz, whose SG is 2.65 would behave precisely as described, and could not, therefore, be excluded.

Hydrostatic Weighing

By far the most precise technique for SG determination involves use of a specially modified weighing balance that allows a gem sample to be weighed in air (W_a), and also weighed in water (W_w). Using Archimedes Principle: "a body immersed in water weighs less by the volume of water displaced", and a simple calculation, SG can be determined with substantial accuracy.

Hydrostatic Weighing

SG calculation

Weight of gem in air divided by the difference between the weight in air and the weight in water, or:

$$SG = W_a / W_a - W_w$$

Hydrostatic Weighing

SG calculation

Example. We have an unknown gem whose weight in air is 5.10 ct and whose weight in water = 3.20 ct. The difference in the air and water weights is 1.90 ct. Using the formula: SG = 5.10 ct/1.90 ct = 2.68. Looking in the tables at the back of the Hall book we quickly find several gem possibilities close to that SG: quartz (2.65), coral (2.68), aquamarine (2.69), and scapolite (2.70). More importantly, than what it might be, a SG of 2.65 rules out a large number of possibilities that it cannot be. The gemologist, like other scientists, progresses most often by weeding out wrong hypotheses (as opposed to proving right ones!).