UNIVERSITY OF ZAMBIA
DEPARTMENT OF MINING ENGINEERING

COURSE OUTLINE FOR INTRODUCTION TO GEMOLOGY (MIN 3019)

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Malachite

Malachite and azurite

COURSE OBJECTIVES

Equip students with knowledge in the following aspects:

- To appreciate what constitutes gemstone materials
- Understand the geology and occurrence of gemstones
- Investigate their physical and optical properties (gemstone identification)
- Mining of gemstones
- Gemstone processing
- Gemstone valuation and marketing

COURSE OUTLINE

- What is Gemology?
- Definition of gemstones
- Natural gems
- Synthetics
- Artificial products
- Classification of gems
- Geology of gemstone materials and their occurrences.
- Mining of gemstones

COURSE OUTLINE – cont/d

- Physical and optical properties of gemstones:
  - Physical properties
  - Optical properties
- Gemstone fashioning

  Faceting

  Tumbling

  Caving, etc

COURSE OUTLINE – cont/d

- Synthetic and Artificial Products
- Gemstone enhancement
- Gemstone valuation and marketing

COURSE EVALUATION

Final examination:	60%
2 term tests:	15%
Laboratory	15%
Assignments	10%

References:

Books	
Gemstones of the world	W. Schuman
Gemstones of the world	Webster and Schuster
Hand book of gemstones I.D (R.T.L)	
Gems (sources, Descriptions, I.D)	R Webster
Photo Atlas	E.J Guberin
Gemstone Identification made easy	A.L. Matline
Diamond grading ABC	V Pagel
Gemologists Compendium	R. Webster
Gemology	R.G Read
The Smithsonian Handbook of Gemstones	Cally Hall & John Taylor, Dorling Kindersley, 2002
Simon and Schuster's Guide to Gems and Precious Stones,	Kennie Lyman, Editor, Simon and Schuster, 1986

What is Gemology?

Gemology (or **gemmology**) is the science, art and profession of identifying and evaluating gemstones. It is considered a geoscience and a branch of mineralogy. Some jewelers are academically trained gemologists and are qualified to identify and evaluate gems. Recently, the demand for gemological services has grown, as increasing quantities of synthetic gems such as cubic zirconia and synthetic moissanite are manufactured. Gemologists perform such work as the identification of synthetic and natural gemstones, fracture-filled gemstones, and color-enhanced or treated natural gemstone

INTRODUCTION
Basics

What is a Gem?

A **gemstone** or **gem** (also called a **precious** or **semi-precious stone**, a **fine gem**, or **jewel**) is a piece of mineral, which, in cut and polished form, is used to make jewelry or other adornments.

INTRODUCTION
Basics – cont/d

However certain rocks (such as lapis lazuli), or organic materials that are not minerals (such as amber or jet), are also used for jewelry, and ***are therefore often considered to be gemstones as well***. Most gemstones are **hard**, but some soft minerals are used in jewelry because of their luster or other physical properties that have aesthetic value. **Rarity** is another characteristic that lends value to a gemstone.

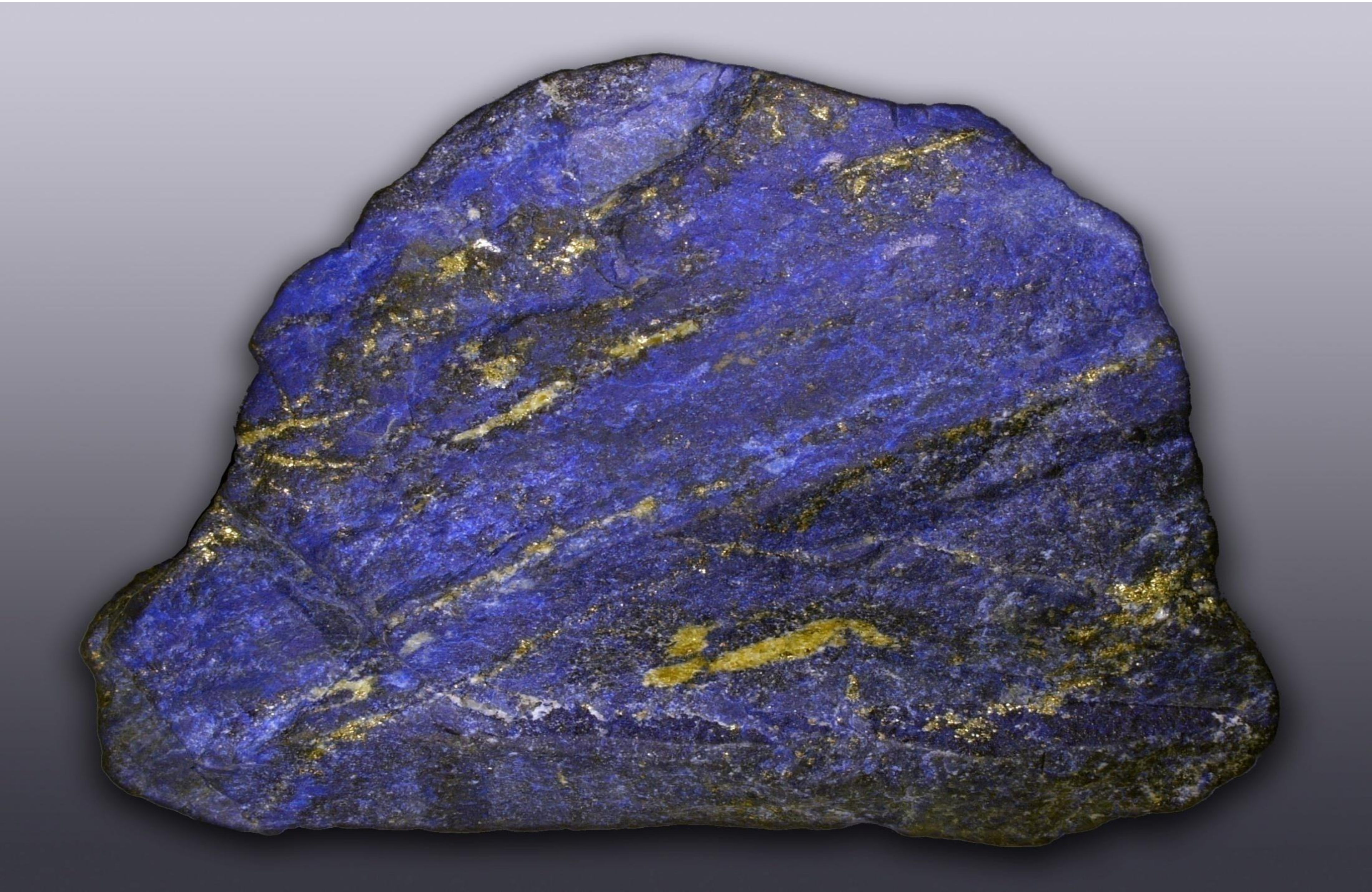
SAMPLE OF JET

JET VASES

INTRODUCTION
Basics – cont/d

Apart from jewelry, from earliest antiquity until the 19th century engraved gems and hardstone carvings such as cups were major luxury art forms; the carvings of Carl Fabergé were the last significant works in this tradition.

LAPIS LAZURI



LAPIS LAZURI

LAPIS LAZURI

LAPIS LAZURI

LAPIS LAZURI

What is a gem?

A gem is a natural, mineral or organic substance, that has substantial beauty, rarity, and durability.

What is a gem? - Cont/d

<u>Natural</u> means that the material was <u>not</u> made, or assisted in its making, by human effort. When such *is* the case, modifiers such as "laboratory grown", "synthetic", "cultured", or "man-made", must, by Federal Trade Commission (FTC) regulations, be used in the descriptions of any such pieces being advertised or marketed. Man-made "gems" have all the chemical, optical and physical characteristics of the natural materials they imitate, but they do not have their rarity or value. You can be certain whenever you see any of the above modifiers that the material in question is *not* of natural origin.

What is a gem? - Cont/d

A <u>mineral</u> can be defined as a crystalline solid with a specific chemical formula, and a regular three dimensional arrangement of atoms. (this definition will be broadened to include "amorphous" materials which have a specific chemical formula but do not have a specific crystalline structure, for example, opal and natural types of glass).

What is a gem? - Cont/d

Mineral Gems

Iolite, which has a specific chemical formula of: $Mg_2Al_4Si_5O_{18}$ and a regular arrangement of atoms which places it into a crystal system, with other minerals of similar structure, known as the *orthorhombic* crystal system is a mineral gem. Another example is emerald, $Be_3Al_2(SiO_3)_6$, a member of the *hexagonal* crystal system. *(The attributes of the various crystal systems will be presented in an upcoming lesson.)*

What is a gem? - Cont/d

Organic Gems

An <u>organic</u> gem is one that was made by living things, present or past. Examples include pearls, coral, jet, ivory, shell and amber. Such gems consist of the molecules formed by the organism, although these molecules may have beem altered somewhat due to compression or other geological or chemical forces.

BLUE AMBER FROM DOMINICAN

AMBER

MOSQUITO IN AMBER

TYPICAL AMBER WITH INCLUSIONS

UNPOLISHED AMBER STONES

Organic Gems

Gems such as "petrified dinosaur bone" and many other "stony" fossil gems, are classified as mineral, rather than organic. Although its true that bone is an organic material: the reasoning involved is that the *original* organic molecules and structures of long ago have been totally replaced with mineral solutions such as silica. (This common geological process is called *petrifaction*).**

What is a gem? - Cont/d

BEAUTY

A gem is beautiful. Beauty, of course, is a subjective concept that has many aspects, and differs from viewer to viewer, but in general, the attributes of gems which excite our sense of beauty include, color, transparency, luster, brilliance, pattern, optical phenomena and, in some cases, distinctive inclusions.

What is a gem? - Cont/d

RARITY

A gem is rare. There are two types of rarity involved: relative and inherent.

- ***Relative*: Many gem minerals occur in various locales and, often, in large deposits, but the vast majority of the material does not approach "gem quality".**
- ***Inherent*: Other minerals occur in only a few locations or in very small deposits. Inherently rare gems are *doubly rare* as the fraction of an already small amount of ore which is gem quality is very, very, small indeed.**

Rarity

The mineral corundum (of which ruby is a gem example) is widespread and abundant. So much so, that an enormous amount of low grade corundum is used in industry for abrasives, due to its hardness (9 on a scale of 10). [Interestingly, very tiny, non-gem grade, corundum crystals have found use in today's beauty industry as the active ingredient in both medical "dermabrasion"agents, and over the counter "exfoliating" products.]

Rarity

Benitoite, on the other hand, is found in gem quality in only one location on Earth: the San Benito River Valley in California. Only a few ounces of cut gems result from each year's mining efforts, almost all of which are quite small in size. Ironically, this ultra-rare, nearly unobtainable stone has been officially designated as the State Gemstone of California.

Rarity

Usually in a deposit of gem mineral bearing ore, the majority is *not* the mineral being sought. From the small portion of the ore which bears the gem mineral, the majority is too low grade to have any gem uses. For example, 80% of the diamond recovered from diamond bearing ore, is industrial grade.

Rarity

Within the small amount of gem grade material, the bulk of it is of lowest quality and useable only for inexpensive beads or trinkets. The even smaller amount of better material which can be extracted, is mostly middle grade, or that which is used for cabochons and better beads and carvings. A tiny fraction is high grade and can be used for faceting. Most of the facet grade material has some defects in color or clarity that limit it to "commercial" quality gems. Only the most miniscule part of the original deposit is top grade: AAA color and flawless clarity.

GEM PRICES

***How valuable are gemstones?* If you ask people at random to name a valuable commodity, many might say gold. And true, we do think of gold as valuable. <u>Consider this</u>:**

- **Good quality amethyst gems sell for about $40/ct**
- **Fine quality aquamarine sells for around $200/ct**
- **Highest gem quality blue sapphire sells for as much as $2500/ct.**

Pure gold, however, is worth *well under $10 per carat!*

Down through the centuries, gemstones have respresented the *ultimate* in portable wealth

DURABILITY

A gem is durable. It must be strong enough to withstand the stresses and forces involved in fashioning it, and its subsequent use as an ornamental object, or in jewelry. Most everyone has heard of "hardness" and knows that harder is better, in terms of using gems for jewelry but in reality, hardness is only the beginning of the story. There are two other aspects of gem durability that are at least as important as hardness.

Three Aspects of Durability

- **1) *Hardness* is the ability to resist scratching. Commonly measured on the "Mohs" Scale of 1 - 10. Talc lowest (1), diamond highest (10). Soft gems, especially those below 7 will tend to become dull through abrasion with harder materials in the environment, and lose their surface polish and their crisp edges over time.**

- **2) *Toughness* is the ability to resist breaking or chipping. This property is measured in relative terms rather than on a numeric scale: sphalerite is fragile, diamond is moderately tough and jade is exceptionally tough. The lower the toughness of a gem the more susceptible it is to damage by the kinds of blows and knocks that are inevitable with frequent wear and use.**

Three Aspects of Durability

- **3) *Stabilty* is resistance to changes caused by environmental factors such as temperature, chemicals and light. Apatite is temperature sensitive, pearls are chemically sensitive, and Kunzite's color is unstable in strong light. Unstable gems exposed to common factors of the natural or man-made environment are likely to break, change color, or lose their luster.**

Classifying Gems

There are any number of ways by which gems can be classified. Most common ways:

- **PRECIOUS OR SEMIPRECIOUS: (HISTORICAL VIEW OF VALUE)**
- **FACETED OR CABOCHON: (CUTTING STYLE)**
- **NATURAL OR SYNTHETIC: (ORIGIN)**
- **ENHANCED OR UNENHANCED: (TREATMENT STATUS)**
- **SIMULANT OR FAKE: (HOW REPRESENTED)**
- **COLORED STONE OR DIAMOND: (GEM INDUSTRY VIEW)**
- **JEWELRY OR COLLECTOR GEM: (WHO WILL BE THE END USER)**

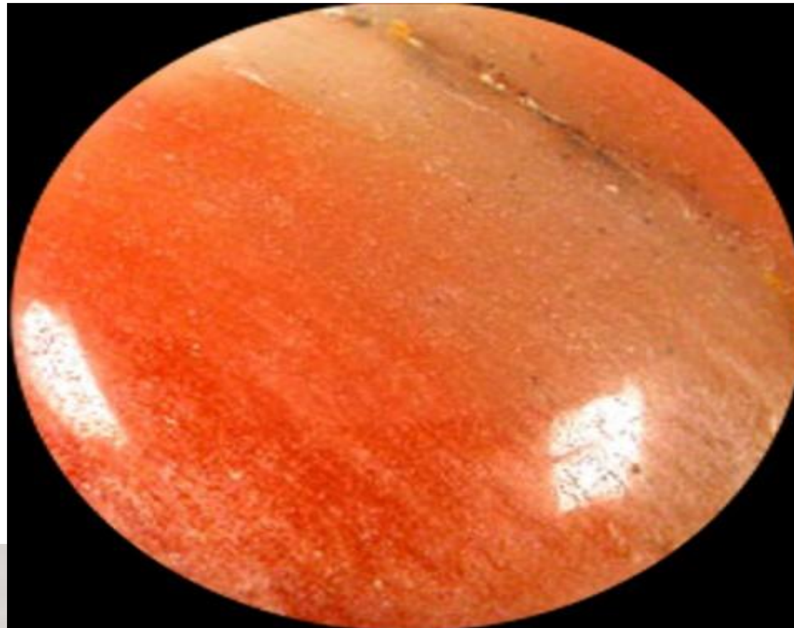

Turquoise
Hematite
Chrysocolla
Tigers-eye
Quartz
Tourmaline
Pyrite
Sugilite
Carnelian
Snowflake
Obsidian
Moss
Agate
Malachite
Rose
Quartz
Ruby
Lapis
Lazuli
Jasper
Amethyst
Lace
Agate

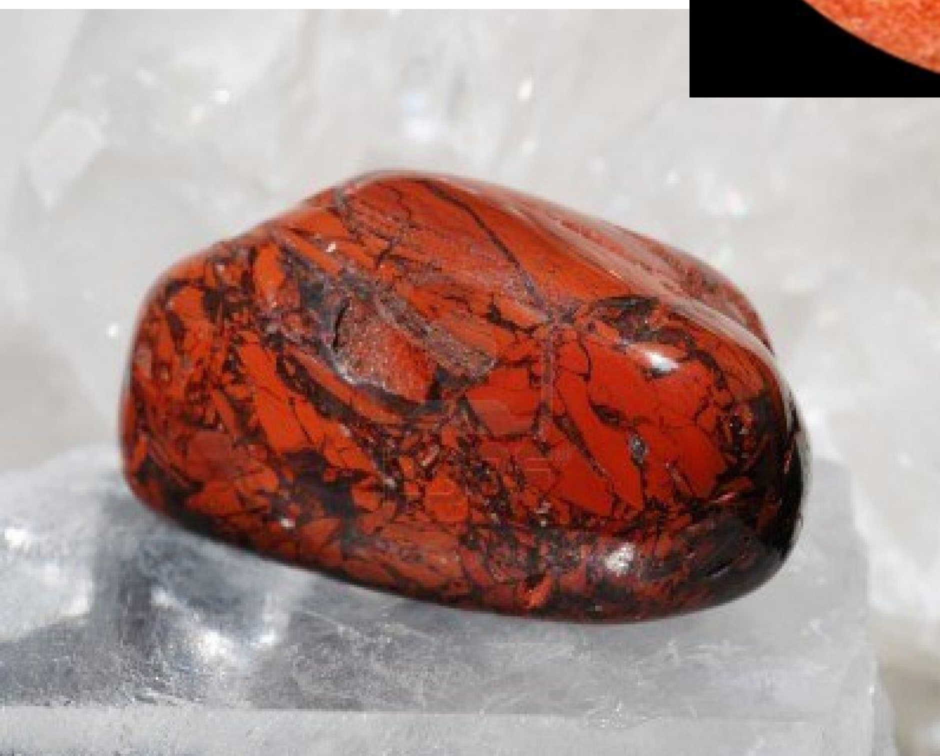
PRECIOUS OR SEMIPRECIOUS: (HISTORICAL VIEW OF VALUE)

"Precious or Semiprecious". These terms were routinely used (until about the 1980's) to separate diamond, ruby, sapphire, emerald and sometimes pearl, from all other gem species such as tourmaline, jasper and amber. Most gemologists no longer use these words and consider them out-moded. *Why?*


Jasper

JASPER





HOPE DIAMOND (45.52 ct.)

PRECIOUS OR SEMIPRECIOUS:

(Historical view of value)

The term, "precious", implies rarity and high value, but, in reality, the individual specimens of each gem species and variety exist within in a full spectrum of rarity, and of value, from very low to very high. Some pieces of <u>"semiprecious"</u> gems are rarer, and more valuable than some individual specimens of <u>"precious"</u> gems.

PRECIOUS OR SEMIPRECIOUS:

(Historical view of value)

So what *<u>should</u>* we call them then? Simple CALL THEM: *gemstones or gems*. These terms will cover them all, regardless of where a given piece lies within the continuum of rarity, beauty, and value for its species.

CLASSIFIED BY CUTTING STYLE

Faceted or cabochon cut: are the two most common ways in which gems are fashioned.

- **<u>Faceted stones</u> are usually cut from transparent rough of relatively high clarity. They are fashioned with a top (crown) and a bottom (pavilion) that have intersecting flat planes called facets, on their surfaces. These facets have shapes that are generally triangular, kite shaped or rectangular.**
- **<u>Cabochon</u> cutting is most often used for translucent and opaque gems and such pieces generally have a flat bottom and a smoothly curved top called a dome.**

Classified By Origin:

Natural or Synthetic (or Artificial)

- **Natural: A natural gem is one produced entirely by geologic and/or biological processes without any human input or assistance.**
- **Synthetic: laboratory grown, manufactured, or "cultured" by human intervention.**
- **A synthetic can be a copy of a natural mineral such as corundum, amethyst, or pearl, or it can be a unique material not found in nature like YAG (yttrium aluminum garnet) or cubic zirconia. In addition to the use of synthetics as gem substitutes, they are also made for industrial, electronic, and research purposes. Examples include synthetic diamonds used as abrasives, and synthetic rubies and garnets used in lasers.**

- ***Strictly – YAG, Gadolinium Gallium Garnet (GGG) are Artificial Products and NOT synthetics!***

CLASSIFIED BY TREATMENT

Unenhanced or Enhanced

Unenhanced: means (except for cleaning and/or fashioning into a useable gem) that the material is *as it was yielded from Nature.* The color, transparency, hardness, or optical phenomena have not been changed by man.

CLASSIFIED BY TREATMENT

Enhanced: an enhanced gem has received some type of treatment to change its characteristics: Ex. irradiation, heating, dyeing, oiling, laser drilling, etc. There are numerous treatments, some of which are routine, have little effect on value, and are considered acceptable as long as they are disclosed to the buyer, and others which are considered extreme and which *dramatically* alter the value of the gem. A treatment may increase, decrease or have no effect on the durability of a gem. (gem enhancement will be covered in detail.)

Classified By Intended Use

Simulant or Fake

- **Simulant: a material, either natural or synthetic, which is being used to imitate another material. Simulants look like what they imitate, but they may or may not share its chemical, physical and optical properties. Not all simulants are synthetics! These mimics are correctly termed either "simulant", "imitation", or "fake".**
- **Ex. synthetic ruby can be used to simulate a natural ruby, but it is also possible for natural red spinel to be used to simulate a natural ruby.**
- **Fake: any material which is represented as something it is not. The fake can be of man-made, or natural origin. ***Whether something is a fake or not, is simply a matter of "truth in advertising***

Not Fakes

- *A synthetic ruby offered as a synthetic ruby.
- *Man-made red glass offered as a "faux" ruby.
- * A cubic zirconia offered as a "diamond simulant".

Fakes

- *** A natural red garnet offered as a ruby.**
- ***A man made Moissanite offered as a diamond.**
- ***An enhanced colored diamond offered as an unenhanced colored diamond.**
- **Simple test: if the material is represented accurately, it is *not* a fake, if it is represented inaccurately it *is* a fake, regardless of whether it is natural or man-made!**

Classified By Industry Terms: Colored Stones or Diamonds

- **Gemologists put all colored stones together into one category and all diamonds into a separate one regardless of their color! The reasons for this is that there are great differences which exist in the systems for fashioning, grading and marketing these two categories of gems. This distinction doesn't divide cleanly, however, between all stones that show color, and all that are diamonds.**
- **Some gems which are classified as "colored stones" are, in fact, colorless. Examples would be white sapphire, white beryl, phenakite and rock crystal quartz. Some diamonds <u>have</u> color, in fact, they are referred to as "fancy" diamonds, amongst which we find the green, pink, blue, yellow, orange, brown, red and black diamonds.**

CLASSIFIED BY WHO WILL BE THE "END USER”

”Jewelry" gems or “Collector" gems:

- **This distinction is not as clear cut as some of the others. Although there are over 3000 species of minerals, of which only 100 - 150 have the characteristics that we associate with gems, and of these, only about 50 species make up a <u>regular</u> part of the jewelry marketplace. In reality, though, the properties of jewelry and collector stones overlap and grade into one another.**
- **In general, a <u>jewelry gem</u> is one that is both *durable* enough to be used for most jewelry applications, and *common* enough to be found in the marketplace in at least moderate amounts. Aquamarine is a good example of a jewelry gem. It is both durable enough and common enough to be readily used, and is widely found in the jewelry marketplace.**
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- **A <u>collector gem</u> is one that is either *not durable* enough to be used in jewelry, or so *rare* that it is not found within the common market channels for jewelry.**
- **Transparent rhodocrostite is an example of a collector gem which, is <u>not</u> durable enough to be set and worn in jewelry, although it <u>is</u> abundant enough to have a place in the jewelry market if it were useable.**
- **Clinohumite is an example of a collector gem which <u>is</u> quite durable enough for most jewelry uses, but so rare that only a few collectors are able to obtain specimens, so it is <u>not</u> found within the normal gem and jewelry channels.**

PHYSICAL PROPERTIES OF GEMS

There are two sets of characteristics possessed by every gemstone, and by which they are studied, identified and evaluated:

1) Physical properties, and

2) Optical properties.

Physical Properties

Physical **properties: those which do <u>not</u> depend on the gem's interaction with light to be expressed or measured**

PHYSICAL PROPERTIES OF GEMS

All properties of gems (whether physical or optical) derive from the underlying <u>three dimensional structure</u> and <u>chemical composition</u> of the gem. Or to put it another way, the chemical elements that make up the gem, and how the atoms of those elements are put together to create its inner structure, determine all those properties that <u>*we can see, feel, and measure.*</u>

PHYSICAL PROPERTIES OF GEMS

Amorphous or Crystalline

The most basic discrimination that can be made, based on internal structure, is that whether gems are amorphous or crystalline

Crystalline gems

These gems have a specific chemical formula, <u>and</u> a well defined, highly predictable internal structure, known as a crystal lattice.

Amorphous Gems

Amorphous gem species also have a specific chemical formula, but their *constituent atoms are not arranged in such regular* and predictable patterns as those of crystalline materials.

Amorphous Gems

"Amorphous" literally means "without form", *<u>but, of course, these materials have a form; it's just not highly regular and predictable, nor is it expressed outwardly by the formation of crystals</u>*. Some examples of amorphous gems are: the natural glasses, amber, jet, opal, and "metamict" minerals.

Amorphous Gems

Natural Glasses: The atoms making up a glass (either natural or man-made) have been cooled from the molten state so quickly that they fail to assume a regular crystalline pattern. A volcanic glass, like obsidian, then, might be formed if a volcano released lava into the air or water such that it was very rapidly cooled. This very same lava could, upon slower cooling, form a crystalline material (like basalt, for example).

Amorphous Gems

Obsidians range in color from light yellow through brown to black and can be transparent, translucent, or opaque. Those of our ancestors, who lived in areas of volcanic activity, made ready use of these natural glasses.

Obsidian glass

In some cases, due to the presence of other minerals with different crystallization temperatures, when the molten material cools, crystal inclusions may be formed. These can give the obsidian an interesting pattern, or affect the structure in such a way as to cause an optical phenomenon, like iridescence. Although most obsidian is drab, single-color translucent material, two interesting and more showy forms of this volcanic glass can be seen below:

Obsidian artifacts

Snowflake obsidian

Velvet obsidian

Tektites

Another group of natural glasses, known collectively as "tektites", are <u>not</u> found associated with volcanic eruptions, but rather in places which are believed to have been sites of meteoric impact. The heat and compression of the impacts are thought to have melted silica sand, and the molten bits which were flung into the air rapidly cooled into their glassy state.

Tektites

Although, like most obsidian, the various types of tektites are dull colors of green and brown, they are still much sought after by gem and mineral collectors. They have a following as well among those who ascribe mystical properties to these gems, perhaps because of their association with celestial events.

Tektite from China

Tektites

The most commonly seen tektite is a green, near transparent type found in the Moldau River Valley in Eastern Europe, known as Moldavite. An intriguing light yellow form of natural glass has been found in several areas within the Libyan Desert, and, to date, has not been associated with a meteor impact, so its origin remains uncertain.

Moldavite cabochon

Faceted Moldavite in jewelry

Libyan desert glass

Amorphous Organics

A number of organic gem materials have an amorphous structure. Species like amber and jet which are composed of organic molecules, (those of evergreen tree resin, and the wood of certain hardwood trees, respectively) which have been altered into a near "plastic" polymeric state by geologic forces and time, are examples.

Reverse-carved amber cabochon

jet carving

Opal

<u>Opal:</u> Although opal is one of the most diverse gem species, with a large number of named varieties, they all share a common structural feature. An electron-microscopic view of opal shows that it is made of row upon row of stacked silica spheres, the exact arrangement, pattern, and size of which determine the body colour, transparency and degree of colour play of the opal.

Opal

Opal forms as a colloidial solution of tiny silica particles in water, and as the water is lost the material solidifies into a microscopically porous, amorphous state

Opals from Australia

Opals from Ethiopia

Metamict Minerals

Most zircon specimens are crystalline gems, but a few pieces (generally a dull olive green colour) have lost some, or all, of their crystalline structure, and have become disorganized internally to a glassy state. *<u>This transformation is due to the effects of radiation, and such a material is said to be "metamict".</u>*

Metamict Minerals

The radiation source is usually from impurities within the zircon itself, but can be from surrounding rocks. *<u>This phenomenon can occur naturally in several minerals, but zircon, and perhaps ekanite, are the only ones of gem significance.</u>* These glass-like zircons (sometimes called "low" zircons) do not have the same super-bright luster and brilliance of the crystalline type, and are mainly sought as curiosities by collectors

Metamict zircon

Crystalline Gems

The highly regular, and sometimes startlingly angular shape of some well formed crystals can seem eerily out of place in the world of Nature, with its more familiar curving and flowing lines.

Single Crystal vs Aggregate Gems

Here a *major distinction is made* between those which are composed of macroscopically visible, single crystal units, and those which occur as a mass of interlocking or intermeshed microscopic or submicroscopic crystals.

Single Crystal vs Aggregate Gems

The pyrite and amethysts, pictured below, are examples of single crystal gems. If, however, you can imagine shrinking the amethyst quartz crystals down to very, very tiny proportions and pushing them together in random orientations such that you'd need ultra-strong magnification to resolve them, you'd have an idea of the internal organization of an aggregate gem, like *chalcedony* (an aggregate form of quartz).

Natural pyrite cubic crystal in host rock

amethyst crystals inside a geode

Chalcedony

A variety of Quartz

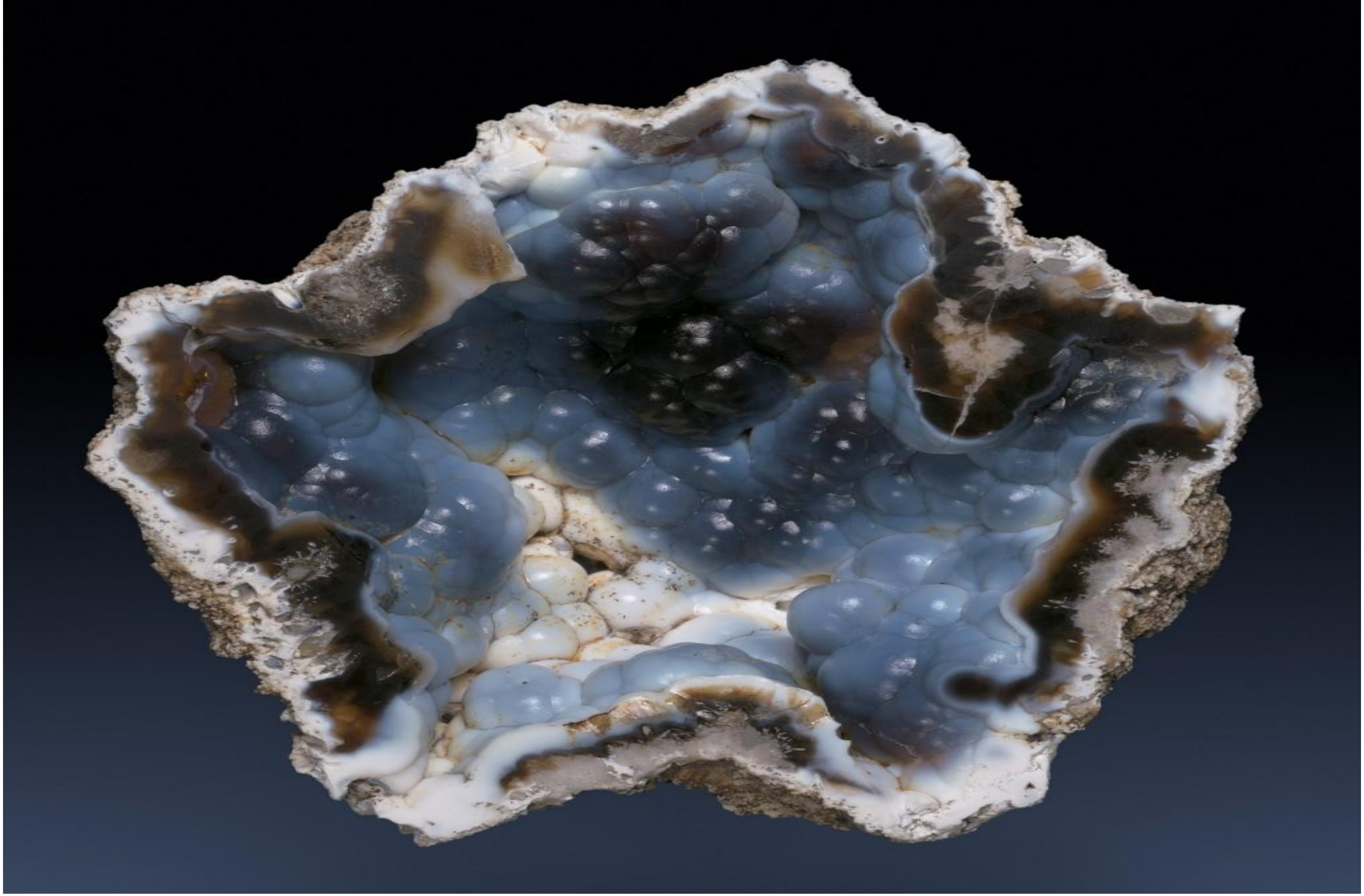
Depending on the context, the term "chalcedony" has different meanings.

A more general term for all varieties of quartz that are made of microscopic or submicroscopic crystals, the so-called microcrystalline varieties of quartz. Examples are the different types of agate, jasper, chert, chrysoprase, onyx, pietersite, etc.

Chalcedony: Agate, Mexico

Chalcedony: Red Jasper, Arizona

Quartz - Agateplate, redbrown-white



Chalcedony: Chrysoprase, Poland

Single Crystal vs Aggregate Gems

Both amethyst and chalcedony are the same species: namely quartz, so their crystals (whatever their size) are of the trigonal system, and their chemical formula is SiO_2, *but the difference in the crystal sizes and arrangement creates some notably different physical and optical properties in the two varieties*. For example, amethyst, and other single crystal quartzes, are commonly transparent and one color, while chalcedonies, agates, and other aggregate quartzes are translucent to opaque and often have complex color patterns. Although single crystal and aggregate types of quartz are equally hard, the aggregates are notably tougher

Single crystal (amethyst)

aggregate (agate) forms of quartz

Single Crystals

Single crystal gems grow in clusters or individually, and they can be formed within, or attached to, another mineral, or loose, as so-called "floater" crystals. Single crystals can be quite small, but they will *still qualify as single crystals (not aggregates)*, as long as they are large enough to be visible as separate entities without high magnification

Aggregate Gems: Micro- vs Crypto-crystalline

Microcrystalline aggregates: **Aggregates with crystals that *can be resolved with a light microscope are called microcrystalline*. The standard way to view the crystals is with a very thin slice of the gem, and about 100 - 200x magnification. The most commonly known gem material that falls in this category is jade.**

Microcrystalline aggregate gems: jadeite jade, nephrite jade

Cryptocrystalline aggregates

Aggregate quartz gems such as: agate, chalcedony, and jasper are generally referred to as cryptocrystalline (crypto, meaning "hidden"). *<u>This is because the minute crystals cannot be resolved with a standard light microscope, but are revealed only with an electron microscope</u>*, or by using specialized polarizing lighting, and very high magnifcation.

agate

jasper

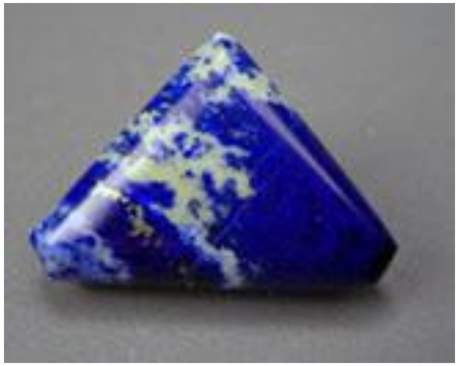
chalcedony

Cryptocrystalline quartzes

Gem Rocks

Although the vast majority of amorphous and crystalline gemstones are composed of a single mineral species (other than their minor inclusions), a few gem materials are classed as rocks. *<u>A rock is a variable mixture of two or more minerals</u>*. Perhaps the most familiar and valuable of the gem rocks is lapis lazuli, a mixture of the minerals lazurite, sodalite, Hauyne, calcite and pyrite. Other gem rocks include unakite (pink feldspar, green epidote, and quartz)

Unakite



lapis lazuli

Chinese writing stone

Popular gem rocks

Crystallography

CRYSTALLOGRAPHY is simply a fancy word meaning "the study of crystals"

At one time the word crystal referred only to quartz crystal, but has taken on a broader definition which includes all minerals with well expressed crystal shapes.

Crystallography is easily divided into 3 sections -- geometrical, physical, and chemical. The latter two involve the relationships of the crystal form (geometrical) upon the physical and chemical properties of any given mineral.

Definition of crystal

A **CRYSTAL** is a regular polyhedral form, bounded by smooth faces, which is assumed by a chemical compound, due to the action of its interatomic forces, when passing, under suitable conditions, from the state of a liquid or gas to that of a solid

Definition – cont/d

A polyhedral form simply means a solid bounded by flat planes (we call these flat planes **CRYSTAL FACES**). "A chemical compound" tells us that all minerals are chemicals, just formed by and found in nature.

Definition – cont/d

The last half of the definition tells us that a crystal normally forms during the change of matter from liquid or gas to the solid state. In the liquid and gaseous state of any compound, the atomic forces that bind the mass together in the solid state are not present. Therefore, we must first crystallize the compound before we can study it's geometry. Liquids and gases take on the shape of their container, solids take on one of several regular geometric forms.

Crystals

Way back in 1669, Nicholas Steno, a Danish physician and natural scientist, discovered one of laws governing crystal formation. By examination of numerous specimens of the same mineral, he found that, when measured at the same temperature, the angles between similar crystal faces remain constant regardless of the size or the shape of the crystal. So whether the crystal grew under ideal conditions or not, if you compare the angles between corresponding faces on various crystals of the same mineral, the angle remains the same.

Smoked Quartz

Crystallization

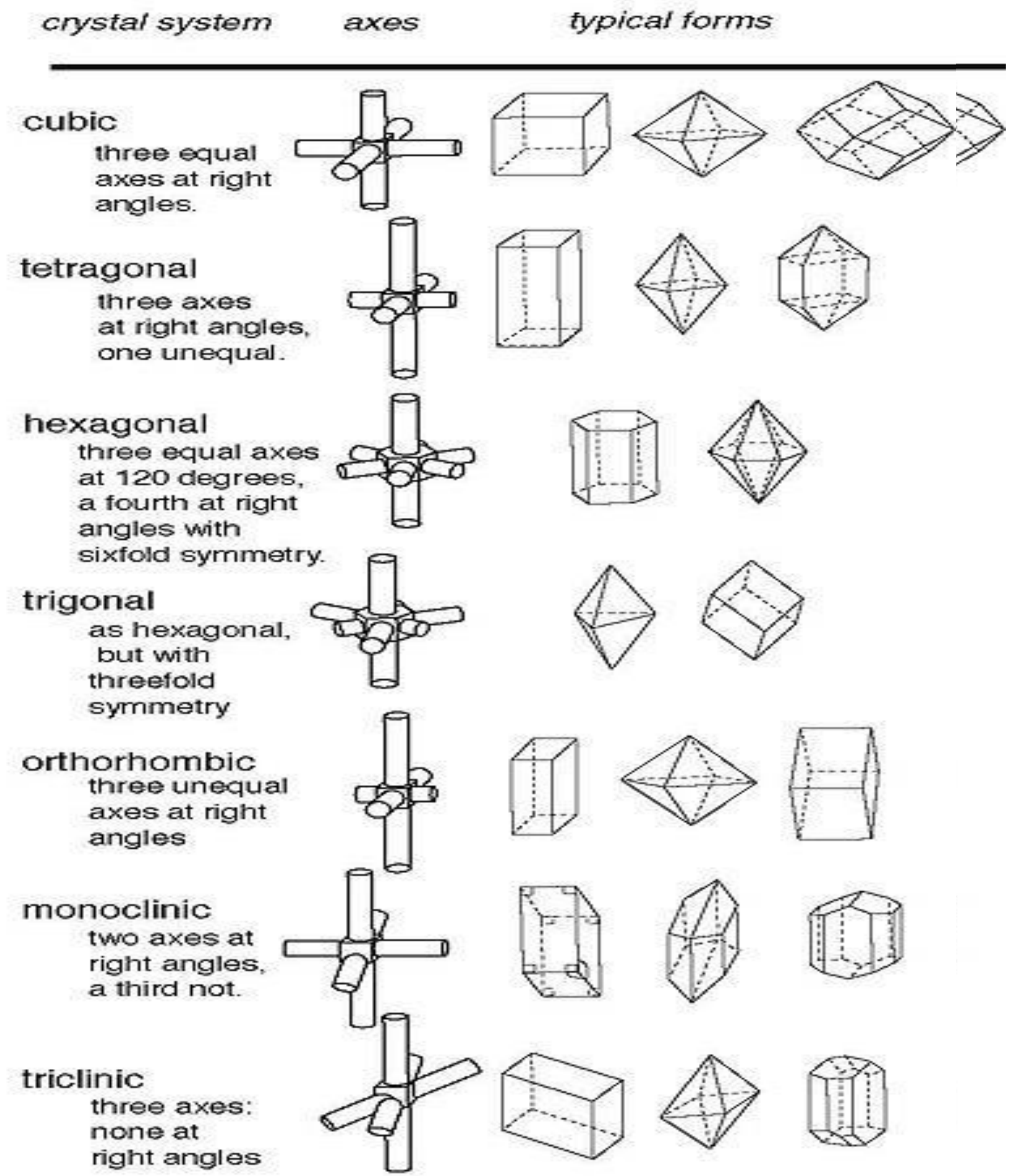
During the process of crystallization in the proper environment, crystals assume various geometric shapes dependent on the ordering of their atomic structure and the physical and chemical conditions under which they grow. If there is a predominant direction or plane in which the mineral forms, different habits prevail. Thus, galena often forms equate shapes (cubes or octahedrons), quartz typically is prismatic, and barite tabular.

Prismatic Quartz crystals

The Crystal Systems

There are six crystal systems

Each of the systems has a unique architecture, based on the lengths, and angles of intersection, of planes through the crystal called "axes", about which there are degrees of symmetry.


crystal system
axes
typical forms
cubic
three equal axes at right angles.
tetragonal
three axes at right angles, one unequal.
hexagonal
three equal axes at 120 degrees, a fourth at right angles with sixfold symmetry.
trigonal
as hexagonal, but with threefold symmetry
orthorhombic
three unequal axes at right angles
monoclinic
two axes at right angles, a third not.
triclinic
three axes: none at right angles

Unit Cells

The innermost structure of each crystal is based upon atomic-scale building blocks that exhibit the symmetries shown in the "axes" column in the diagram above. These tiny building blocks are called "unit cells". The shape of a unit cell is different in each of the crystal systems: a cube in the cubic system, a "brick" for the tetragonal system, etc. These tiny structures assemble themselves as the crystal grows, and build the crystal up to its finished size and shape

Crystal "Habits"

A few of the crystal habits, due to their similarity to common objects, are especially recognizable and have acquired special names, as demonstrated by the specimens below:

<u>Acicular</u> (needle-like)

<u>Acicular</u> (needle-like): golden rutile crystals in quartz

"Puffball-like"mesolite specimen of radiating acicular needles

<u>Prismatic</u> (pencil-like)

Tourmaline crystals

Red beryl crystal in matrix

Quartz with black manganese dioxide crystal inclusions

Sandstone matrix with iron oxide dendritic crystals on surface,

<u>Dendritic</u> (like tree branches)

Dendritic native copper crystals

[Drusy (like sugar or powdery snow on a surface)

Pyrite crystals on matrix

Botryoidal (seen in aggregate gems only, like a bunch of grapes or bubbles): blue chalcedony]

Crystal Growth

Factors affecting crystal appearance

Temperature/Pressure: the effect of rapid versus slow cooling of a melted material has diffrent outcomes. The same molten mass of atoms, or the same solution, or vapor of materials can crystallize differently, depending on the temperature and pressure at the time, and in the place, where crystallization occurs. *This is because there can be more than one stable crystal lattice composed of the same atoms.* The various stable configurations that a particular gem species can crystallize in, are referred to as its "*polymorphs*".

Polymorphs

When two materials have the same chemical formula but have crystallized differently (due to each being subjected to different temperature/pressure conditions at formation), they are called polymorphs. The most famous examples are diamond and graphite. Both have the same chemical formula (just C, pure carbon), but the "lead" in your pencil and the diamond on your finger, obviously exhibit quite different properties. Graphite crystals are formed of sheets of tightly bonded carbons atoms in layers which are very loosely bound to each other, allowing lots of slipping and sliding. Diamond crystals have each carbon atom bonded tightly to four others surrounding it in all directions, so the whole structure is very strong and durable.

Polymorphs of carbon

Diamond (uncut dodecahedral (12 sided) crystal)

Graphite

Space available

Crystals often form in cavities, cracks, bubbles, and other cramped places, the size and shape of which will limit growth possibilities. Some directions of potential growth might be unavailable or limited, while others afford plenty of "growing room". It can also occur that two or more crystals which start growing in a space independently, can contact and/or interpenetrate each other resulting in "*twinning*".

Chemical elements present

Each species requires a particular set and proportion of chemical elements for its basic makeup, and cannot grow without them. Non-required elements, though, which incorporate into the growing crystal in trace amounts can have dramatic effects on the appearance (usually color) of the gem. For example, a very small amount of the element chromium, when present along with the necessary aluminum and oxygen, turns, what would otherwise have been colorless corundum, into red ruby. In addition, fluctuations in the amount or type of growth materials present can lead to color zoning, as well as to the creation of crystal "*phantoms*" and "*negative*" *crystals.*

Presence of other minerals

Minerals do not usually form crystals in complete isolation. As a particular crystal is forming, other minerals, also in the process of crystallization, can be captured by it (to show up as inclusions) or capture it. Exactly how this plays out will depend on the relative crystallization temperatures and pressures required by the materials in the group.

Quartz from Madagascar with fluorite crystal inclusions, inset picture at 10x]

Special Growth Phenomena

Twinning

When growing crystals of the same mineral share one or more faces, the result is a crystal "twin". Depending on the nature of the twinning, which can be on either a visible, or a microscopic scale, the shape of the crystal might be dramatically affected, or the material's properties could be noticeably altered. Sometimes, evidence of twinning can be seen in a crystal or cut gem due to unusual color or inclusion patterns.

Twinned quartz crystals in "rabbit ear" form

Phantoms Crystals

Due to changes in environmental conditions, starts and stops of crystal growth occur. When other minerals, which are favored in the new conditions, start to grow, they sometimes crystallize on the "old" faces of the temporarily inert material. When conditions change, and the host once again starts its growth, evidence of the pauses may now be visibly captured as outlines

Negative Crystals

Likewise, certain conditions may completely block the growth of an interior portion of a crystal leaving a void which is bounded by the sides of the crystal around it at first glance this "negative" crystal looks like a solid crystal inclusion, but it is indeed empty.

Pseudomorphs

The term "pseudomorph" literally means false form. A pseudomorph is, in a way, the opposite of a polymorph. Whereas polymorphs are different crystal forms of the *same* chemical compound, a pseudomorph shows a crystal form which is not one recognized for its species. To put it another way, it's the case of one mineral taking on the outward form of another while keeping its chemistry unchanged. Let's take the example of Goethite which is an iron oxide mineral that crystallizes in the orthorhombic system. A glance back at the diagram for the crystal systems shows us that orthorhombic gems *do not* form in perfect cubes. Pyrite, however is an iron sulfide mineral (in the cubic system) that frequently forms crystals shaped like perfect cubes.

Pseudomorphs occur when environmental conditions occur that cause the replacement of one chemical compound with another <u>without</u> altering the pre-existing three dimensional structure. Mineralogically, the item is named as an "X" pseudomorph (ps.) after "Y".


Protected area!

Chemical Groups of Gems

In addition to categorizing gems by their three dimensional structures, we can also view them as belonging to various chemical groups. Due to their related chemistries, some quite different looking gems share some of their basic properties, while other gems which look rather similar, differ markedly, due to their unlike chemistries

- In the world of minerals, certain groupings occur quite commonly. For example, oxygen frequently occurs bonded to atoms of a metal (like iron or aluminum). We call such compounds oxides, and oxide gems have some characteristics in common. There are dozens of chemical groups which could be listed if all gem species were taken into account, but in this course, you will be required to recognize, and recall, only five major groups, these are:

  - Silicates
  - Oxides
  - Carbonates
  - phosphates and native elements.

Accounting for nearly 60% of gem species, silicates are the most important group, closely followed in prominence by the oxides. These two groups have in common, that their member species tend to be relatively hard and stable, while the carbonates and phosphates are generally softer, and susceptible to attack by acids.

Silicates

Regardless of what other atoms are present (usually one or more metals), gems of this category will have in their chemical formulas some number of Si and O (silicon and oxygen) atoms listed together as a group . For example, as in the polymorphic species from above: Al_2SiO_5--> here we see the group of one silicon atom and five oxygen atoms, which identify the polymorphs Andalusite/kyanite as silicate gems. The numbers of Si and O will vary, depending on the species, but will always appear as a unified group.

In general they tend to be hard, transparent to translucent, and ofmedium density. In this very large class are all the beryls (aquamarine, emerald, etc.), all the quartzes (amethyst, rose quartz, agate, etc.), all the feldspars (sunstone, moonstone, etc.), all the garnets (pyrope, Spessartite, demantoid, etc.) topaz, tourmaline, zircon, and many other lesser known species.

Emerald

amethyst

tiger'seye quartz

Moonstone

white zircon

Blue topaz

rhodolite garnet

Oxides

This group will have one or more oxygen atoms (not grouped with silicon, phosphorus or carbon) in their formulas. Many oxides are important ores of metals or valuable gemstones and tend to be quite hard and rather dense. Amongst the members of this group are corundum Al_2O_3 (ruby and sapphire), spinel, hematite and chrysoberyl.

Ruby *Spinel*

Hematite ***Chrysoberyl***

Carbonates

The grouping CO_3 identifies the carbonate gems such as rhodocrosite, malachite, calcite ($CaCO_3$), and azurite. They are generally soft and often brightly colored. They dissolve readily in hydrochloric acid.

Rhodocrosite

malachite

Calcite

Azurite

Phosphates

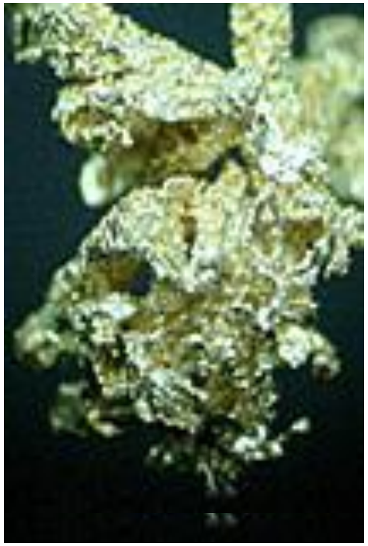
A PO_4 group is the identifying chemical landmark for gems of this class. Many of these gems have very complex formulas, but do not be intimidated, you can still see the phosphate group in there! A highly variable group, in general they are soft, fragile, and brightly colored. Turquoise, and apatite are notable phosphate gems.

Turquoise

Apatite

Native Elements

This is the easiest group of all to recognize, as it consists of one and only one element. All the precious jewelry metals such as gold, silver and platinum belong to this group, as does diamond.



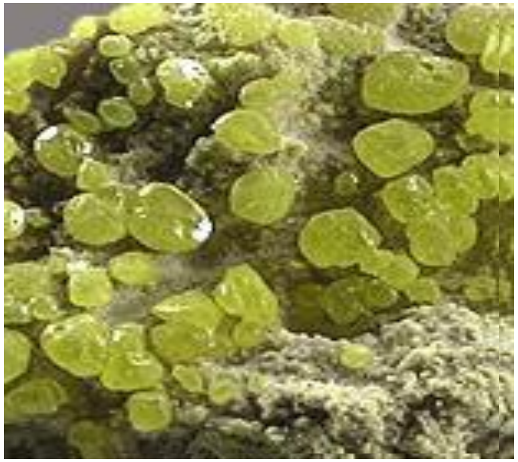
Native gold

platinum nugget

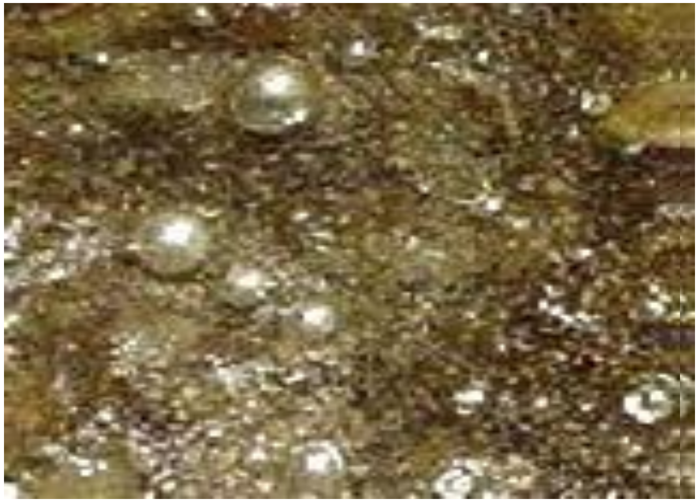
[Diamonds

Native Elements

Two interesting native element examples, not used as gems, but often sought by collectors are sulfur and mercury. Pure sulfur occurs in bright yellow crystals which would tempt the faceter if they were not so heat sensitive that just holding them in the hand causes them to crack, and rare native mercury has the distinction of being the only metal found in a liquid form at normal ambient temperatures.



Crystals of pure sulfur: beautiful to look at but too fragile to touch



Droplets of liquid native mercury in matrix rock

Smoked Quartz

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. Not all gems show cleavage 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.

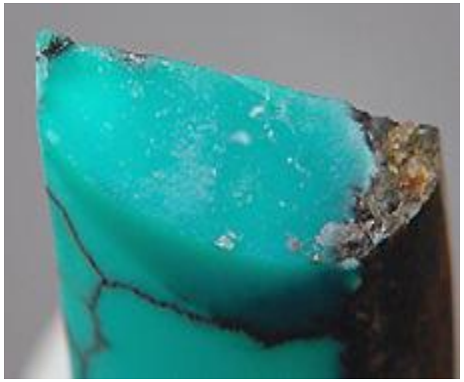
Fracture

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

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).

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.* 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. 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, exquisitely 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 absense 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, <u>but</u> 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

<u>Dehydration</u>: 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

<u>The Effect of Inclusions:</u> 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, and is sometimes suggested as an "evening only" gem. 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. It 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™" (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 th 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!).