Gemstones

What are Gemstones?

Advanced

A few of the many crystals we find in nature are called "gemstones", and most of them are single crystals. But not every single crystal found in nature is a gemstone. We like to have the following properties for gemstones:

- *Rarity*. Things that aren't rare or exclusive but common are never considered noble. Neither feldspar, rock crystals or fluorite crystals are gemstones, nor the rather pretty pyrite or fools gold crystals. They are just not rare enough.
- *Perfection*. It's not enough to be a single crystal, it is important to be as clear and flawless as possible. It is not important in this context that the crystal be free of lattice defects and impurities, it only must appear clear to the eye. A few foreign atoms might even be required to turn an otherwise worthless crystal into a gemstone, as we shall see below.
- *Color*. Rubies are red, sapphires are blue , citrins are yellow, amethysts are violet, and so on. In all of these (and many other) cases the actual pure crystal is colorless and not a gemstone. For attaining color it needs to contain certain impurity atoms that are dissolved in the crystal lattice.
- *Hardness*. Hard crystals are somehow more noble than soft ones, even so women normally go for the soft things (cashmere wool is better than regular wool, ...). Why? Ask your psychologist.
- *Size* counts - at least as far as hard gemstones are concerned. A diamond of **100** carat (1 carat=0.2 g) is far more valuable than 100 stones with 1 carat each.
- Finally, the way the stone is **cut** is of importance. Up to the late 16th century all gemstone "cuts" were *cabochon*, with a smoothly curved surface; just look at old crowns and reliquaries or the picture below. The facetted cut we have today was invented by Jules *Cardinal* **Mazarin** (**1602 - 1661**). Those were the good old times when men (including men like the Cardinal who were not allowed to exercise their manliness [2)]) had no problem to dress elaborately and show their wealth.

Cabuchon cut gem stones in the sail of the "Golden Ship" (12th century) in Uelzen / Germany

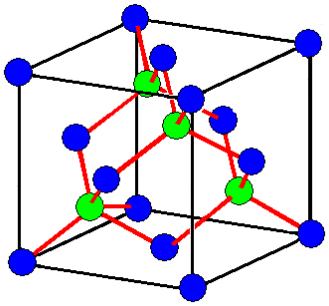
It was, and to some extent still is, common practice to distinguish between the "real" or **precious gemstones** (essentially diamonds, rubies, sapphires and ***emerald***) and semi-precious stones—the rest.

- Nowadays some of us live in a democracy, and we don't discriminate against half-breeds (of the mineral variety) anymore. We just have gemstones or jewels now, including "stones" that aren't true crystals, for example pearls or amber, rather tricky and unusual crystals like opals, or all kinds of things not found in nature but made by man (e.g. zirconia).
- Here I only distinguish between crystalline and non-crystalline jewels. As far as the crystalline stones are concerned, they come in a few basic structures that we will give a first quick look.

Single Crystalline Gemstones

Diamond

- Diamonds are the most precious gemstones (and girls best friends; according to **Marilyn Monroe** [1)]). Diamonds are a metastable phase of carbon. The stable phase is hexagonal graphite; diamond is carbon crystallized in an fcc lattice. Diamonds thus will eventually turn into graphite but not for a long time (roughly infinity) if you keep it around room temperatures.
- It's one of the few crystals that we cannot (yet) grow in big sizes. Pure diamond is colorless and has about the highest index of refraction (that's why it sparkles so nicely) and the highest thermal conductivity (that's why it should feel cold to the touch). Color, like in the Hope diamond shown below, comes from lattice defects, typically impurity atoms.



Diamond crystal lattice

All spheres symbolize carbon atoms. The blue spheres also symbolize the lattice points of the fcc lattice. The red lines symbolize the strong bonds between the atoms, the black lines have no meaning except to show the cubic symmetry of the lattice.

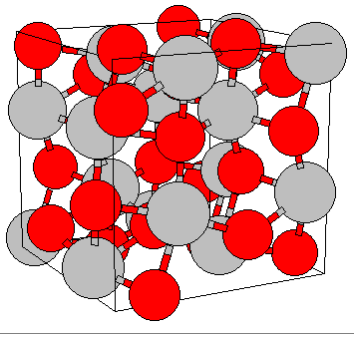
Raw uncut diamond

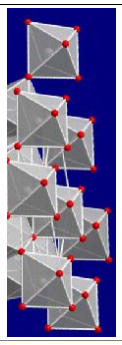
Hope diamond and diamond lover [1)]

Corund(Ruby and Sapphire)

- Corund is an an Indian word for the humble but rather hard aluminum oxide (Al_2O_3) we use in polishing pastes, on emery paper and, in single-crystal form as watch glasses and substrates for microelectronic circuits. For the "cheap" applications, Al_2O_3 "contaminated" with iron (Fe) and looking dirty is used. Its ("trigonal ") crystal lattice is a bit more complicated that that of diamond, see below.
- Now "contaminate" otherwise good single crystals with a little bit of chromium (Cr) or titanium (Ti), and you get very valuable " **rubies**" or "**sapphires**", respectively. Sapphires usually are blue, but they can have all kinds of colors, from yellow to violet, depending on what kind of defect, exactly, sits in the lattice. Of course, the natural rubies and sapphires were contaminated by Mother nature.

  But some of us can also make artificial rubies and so on; and artificial or synthetic ruby was the heart of the very first Laser in 1960. Note also that many (detrimental) defects in natural gemstones can be "healed" by simply heating to a high temperature, causing some question about where, exactly, you find the dividing line between "naturally perfect gemstone"=expensive and "artificial gemstone"=cheap.





Corund lattice, red=oxygen (O), grey=aluminum (Al)

The lattice is often (and correctly) described as hexagonal, but the trigonal or rhombohedral cell given above is simpler. It is not as complicated as it looks - it's just a stacking of O^{2-} octahedra with Al^{3+} inside as shown on the right.

Source: adopted from http://cst-www.nrl.navy.mil/lattice/struk/d5_1.html and Wikipedia

Raw and cut sapphire.

Raw and cut ruby
Rubies / diamonds pendant

- Good rubies are just as expensive as diamonds; sapphires tend to be a bit cheaper. Lesser stones can be rather cheap, however. Both gems had technical uses, e.g. the "ruby" bearings in watches or the "sapphire" pick-ups in old-fashioned record players.

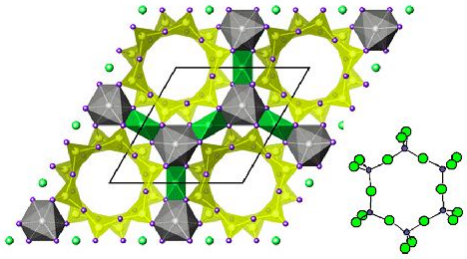
Beryl

- The name Beryl is derived (via Latin: beryllus, Old French: beryl, and Middle English: beril) from Greek beryllos, which referred to a "precious blue-green color-of-sea-water stone". It goes even farther back, ultimately to Sanskrit. The Latin word "berillus" was abbreviated to brill, a word root we find in the Italian "brillare" meaning shine or "brilliant", meaning diamond (and shining) in English and German. The French word "brille" and the English word brilliance means shine or shining once more, and the German "Brille" means **eye glasses**.
- The oldest "Brillen"=eye glasses, one of the key inventions of humankind, were made from beryl that was ground to lens shape. I'm tempted to claim that it was a German invention but something akin to the glasses you wear in front of your eyes was first made and used in Italy, in the 11th century.

Beryl varieties

Source: Photographed in the Metropolitan Museum NYC.

Beryl is basically a beryllium - aluminium silicate with the basic composition $\mathbf{Be_3Al_2(SiO_3)_6}$. The crystal structure is a bit involved. Essentially, $\mathbf{Si_6\ O_{18}}$ rings as shown on the right-hand side in the figure below, are stacked on top of each other, with the metal-oxygen units "in between".



Layer of a beryl crystal lattice

Source: partially from wikipedia

- Beryl is the base for a number of gem stones. Once more, the kind of impurity contained in solution in the crystal defines its color.
  - **Emerald**, the fourth of the four kinds of "precious" stones of old is green because the beryl contains a bit of chromium (Cr), or more precisely, chromium tri-oxide (CrO_3)
  - **Aquamarine**, or spinel, is light blue to greenish. The reason is probably iron, or more precisely Fe^{2+} in, for example FeO. Fe^{3+}, for example in Fe_2O_3, produces a golden-yellow color (see below), and when both $Fe2^{+}$ and Fe^{3+} are present, the color is a darker blue.
  - **Morganite**, or "pink beryl", "rose beryl", "pink emerald", and so on, is a rare light pink to rose-colored variety of beryl. Its color derives from manganese (Mn).
  - **Golden beryl** and **heliodor** range in color from pale yellow to a brilliant gold. Golden beryl refers to pure yellow or golden yellow shades, while heliodor refers to the greenish-yellow shades. The golden yellow color is attributed to Fe^{3+} ions.
  - There are more varieties. The periodic table, as you know, has a a lot of "dirt" left to put into the beryl lattice.

Natural and cut emerald

Natural aquamarine

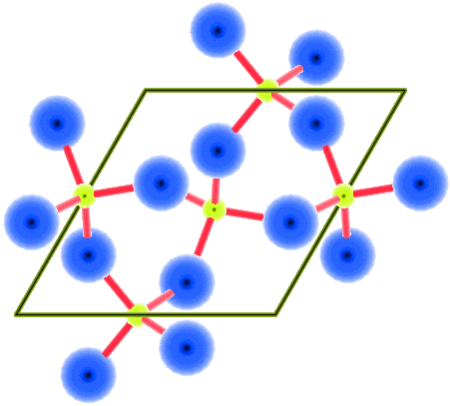
Natural morganite

Golden beryl
Flawless 2054 carat stone on display in the Hall of Gems, Washington, D.C.

Source: (wikipedia)

Quartz
Quartz or silicon dioxide (SiO_2) is one of the most important technical materials. Suffice it to say that there would be no electronic or optical industry without SiO_2. Whenever you look out through a window you're looking through ("dirty") silicon dioxide called **glass**.
Silicon dioxide is also the base material for a long list of gemstones.

- **Rock crystal**, the pure (trigonal) naturally occurring SiO_2or quartz crystal. Rather large, completely transparent and colorless crystals can be found. They were used to cut all kinds of figures, bowls, vessels, etc. for the treasure vaults of the rich.
  Synthetic quartz single crystals are important for the "quartz oscillators" inside digital watches, cell phones and most other electronics.



Rock Crystal lattice (one plane)

Rock crystals and goblet cut from rock crystals

Source: Goblet photographed in: "Landesmuseum Stuttgar", Germany

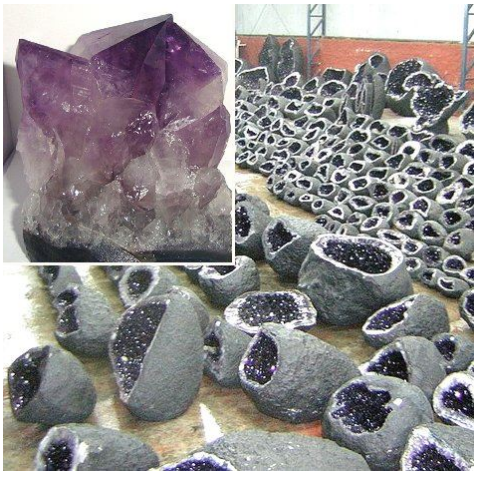
Relatively rare quartz "bipyramids" from Brilon, Germany

Source: Photographed in the Brilon town museum

Amethyst

Up to the 18th century, before the discovery of large amounts of good amethyst crystals in Brazil, amethyst was counted among the really precious stones. Several great properties were attributed to amethyst. Its name comes from Greek, where the word "amethystos" meant: "not drunken". Amethyst was considered to be a strong antidote against drunkenness, which is why wine goblets were often carved from it. It was also supposed to help wound healing, and to prevent theft.

Well - it's just common rock crystal with ionized iron in it. The ionization of the iron "dirt" is crucial, it might have resulted from irradiations by natural radioactivity in the course of a few million years.



Collection of Amethysts Geodes and Detail

- **Rose quartz**
  is the pink to rose-red variety of quartz. The color is due to trace amounts of titanium, iron or manganese, and to more complex inclusions. Rose quartz is typically not clear but at best translucent.
  In transparent form (rarely found) it is called **pink quartz** and its color is thought to be caused by trace amounts of phosphate or aluminium. The color in these crystals is apparently photosensitive and subject to fading. The first crystals were discovered in a pegmatite found near Rumford, Maine, USA, but most crystals on the market now come from Minas Gerais, Brazil.

Then we have **smoky quartz**, gold-yellow **citrine** as single crystals, and **Chalcedony** , **Agate**, **Onyx**, **Jasper** , and plenty more polycrystalline or amorphous ("glassy") stuff.

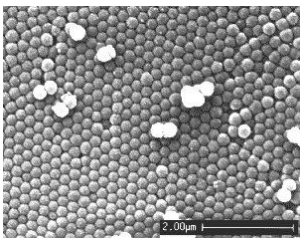
- Of fleeting interest for us is chalcedony. It is an intergrowth of extremely fine crystals of normal quartz and a variety with a different lattice structure called moganite. Since it is almost amorphous it looks glassy or waxy. Ad a little dirt and you get a whole range of minor gemstones like agate, aventurine, heliotrope, onyx and orange-red **carnelian**.
  Carnelian was used quite a bit in antiquity, like in the pectoral below, but also as decoration in one of the earliest iron swords.

Pectoral of Princess Sit-Hathor Yunet, the daughter of
Pharaoh Senusret II (1897 BC to 1878 BC)
Cloisonné inlays on gold of *carnelian* , feldspar, garnet, turquoise, lapis lazuli.

Source: Metropolitan Museum, NYC

But I'm not going to dwell on all those many **SiO_2** forms anymore but turn to one of the most amazing quartz-based gemstone:

- **Opal**
  Opals are crystals (fcc cubic) - but not of *atoms* but of small amorphous quartz spheres or glass beads with diameters around 200 nm; about 100 times smaller than the diameter of a hair. If you think that's so small that it doesn't matter relative to atoms, think again. A 200 nm sphere contains very roughly 300.000.000 atoms.
  The lattice constant of opals thus corresponds to the wave length of visible light and that causes its spectacular optical properties. Nowadays we call structures like that of opals "**photonic crystals**". Synthetically made photonic crystals caused a great stir in the scientific community in the 90ties of the old century and are still pursued for various "high-tech" optics applications.



SEM picture of opal showing the "glass" bead structure

Opal

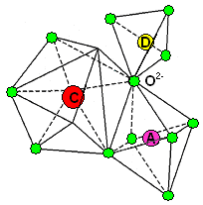
Garnets

Garnets are crystals with a common basic structure of the type $C_3A_2D_3O_{12}$ or $C_3A_2(DO_4)_3$ with:

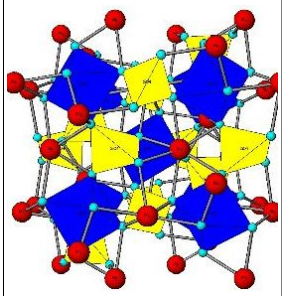
- **C**: *doubly* positively charged metal ion, surrounded by **8** oxygen ions, for example Mg^{2+}, Ca^{2+}, Fe^{2+} , Mn^{2+}.
- **A**: metal ions with *three* or *four* positive charges, surrounded by **6** oxygen ions. Examples are Al^{3+}, Cr^{3+}, Fe^{3+}.
- **D**: mostly ions with **4** negative charges, surrounded by **4** oxygen ions, e.g. Si^{4+}, Al^{3+}, Ga^{3+}, Fe^{3+} .

"*Garnet*" derives either from Middle English " *gernet*"=dark red, or from Latin "*granatus*"=grain; possibly referring to the red pomegranate seeds.

Considering that garnets consists of at least 4 different atoms, their crystal structure tends to be a bit complex. Essentially, you are stacking all those tetrahedra, octahedra, and other "edra" hinted at above; see also the corund example. The general shape is essentially cubic.



The "edra" of the garnet structure (Green=oxygen)



Basic Garnet crystal lattice

The figure on the right shows "Pyrope" with **C=Mg^{2+}** (red); A=**Al^{3+}** (violet);
D=Si^{4+} (yellow). The oxygen ions are light blue.

Source: Adopted from a University of Salzburg page

It is clear that we find a tremendous variety of garnets out there. If they come in nice colors and shapes, they are gemstones.
Some garnets have been used extensively in old times. Not only as a gemstones but also as abrasive. Some major varieties are

- **Almandine**, **$Fe_3\ Al_2(SiO_4)_3$**
  I can't describe it better than wikipedia: "Almandine, sometimes incorrectly called almandite, is the modern gem known as **carbuncle** (though originally almost any red gemstone was known by this name). The term "carbuncle" is derived from the Latin meaning "live coal" or burning charcoal.
  The name Almandine is a corruption of Alabanda, a region in Asia Minor where these stones were cut in ancient times.
  Chemically, almandine is an iron-aluminium garnet with the formula $Fe_3Al_2(SiO_4)_3$; the deep red transparent stones are often called precious garnet and are used as gemstones (being the most common of the gem garnets).
  Almandine occurs in metamorphic rocks like mica schists, associated with minerals such as staurolite, kyanite, andalusite, and others. Almandine has nicknames of Oriental garnet, almandine ruby, and carbuncle." Thanks, wiki!
  Red garnets were the most commonly used gemstones in the Late Antique Roman world, and the Migration Period art of the "barbarian" peoples who took over the territory of the Western Empire. They were often inlaid in gold cells in the cloisonné technique, a style often just called garnet cloisonné, found from Anglo-Saxon England to the Black Sea.

Almandine Garnets in Modern Reproduction of 6th Century Sword
The real thing

From the pages of swordsmith Patrick Bárta

- The rest pales in comparison. We have

  - **Pyrope**, **$Mg_3\ Al_2(SiO_4)_3$**, with magnesium (Mg) instead of iron (Fe) compared to almandine. It's also known as Bohemian garnet from the Czech Republic, and was and is used as gemstone.
  - **Spessartine**, **$Mn\ _3Al_2(SiO_4)_3$**, with manganese taking first place now. It's found in the German "Spessart" and comes red to yellow.
  - And so on. You get the drift.

Garnets

Almandine
From Wikipedia

If you find some "obvious" garnets like those shown in the picture above on the left, it is not all that obvious, which kind exactly they are.

There are plenty more crystalline gem stones, for example spinel, tourmaline, Rhodonite, ... But now let's look at some of the poly-crystalline or amorphous stuff.

Poly-crystalline gemstones

We have

- Light blue to greenish **turquoise** or "Turkey stone" (**$((CuAl_6[(OH)_8[(PO4)_4]\cdot 4H_2O$**); a copper bearing mineral.
- Dark blue **lapis lazuli** (**$(Na, Ca)_8|(SO_4, S, Cl)_2|(AlSiO_4)_6]$**) or lazurite (the "stone of Lazhward"). Lapis was treasured throughout the antique word not only as gem stone but also as a base for (very expensive) blue paint (the ultramarine pigment).
- Greenish **Jade**, coming in several variants based on **$NaAl(Si_2O_6)$**. Jade was highly treasured in the Chinese empire from very early until recently.

Jade Figure; early 1900 century

Source: Photographed in the Metropolitan Museum NYC.

Amorphous an Biological gem "stones"

Essentially we have:

Glass. Of course, fake gemstones are made from glass and that's not what I mean. But cheap glass in all colors as we know it wasn't always around in quantity. The ancients treasured glass things (and used it to fake real gemstones, too). The stained glass windows of old cathedrals were true treasures then and now. Their color derived in part from some nanotechnology (look it up yourself).
Obsidian, a natural black glass of volcanic origin was used more for making tools then for jewelry, just like its more common relative, the flint stone.

- **Amber**, or petrified tree resin. Petrification happens if no oxygen is available (i.e. under water) and if there is enough time like 400 Mio years. Occasionally insects were caught in the resin and then preserved for almost eternity.
  Amber is a polymer consisting of **73,8 %** carbon (C), **9,5 %** hydrogen (H), **10,5 %** oxygen (O) and und **0,1 %** sulfur (S). It is found in quantities right where I live: along the shore of the Baltic Sea.
  Amber is not very precious today but still much in use as gemstone. Already in the stone age it was treasured enough to induce trading over large distances .

	
Jade Buddha	**Amber with enclosed 400 Mio year old flies**

- **Pearls**, shells of slimy animals likes snails or clams, and other "petrified" mollusk snot. Pearls are made whenever mollusks like oysters put the stuff around alien objects in their body (e.g. sand grains) that they can't get rid off. Pearls consist of **nacre** or "**mother-of-pearl**"), something we will encounter in the backbone of the Hyperscript.
  The **luster** of pearls is once more a "photonic crystal" effect as in the case of opals and "pearlite" a (pseudo) phase of steel..
  Perfect round pearls used to be just as expensive as diamonds throughout most of history. They only became cheap after seeded pearls conquered the market. So when you encounter pearls in old jewelry or just in old picture, they heralded great wealth.
- We will encounter *nacre* as a model material for steel, and we will encounter"*pearlite*", as a (pseudo) phase of steel, so pearls are very meaningful for sword lore.

	
A pearl in situ	**Jet mourning brooch**

- **Jet** or **gagat** is "petrified" jet-black coal. Considering that coal is sort of petrified wood, that is a lot of petrification.
  Jet was fashionable on and off, its high point was in the Victorian era. It was never considered to be very precious and sometimes worn as "mourning jewelry". Look a the brooch above and you will feel properly depressed.

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1) "**Diamonds Are a Girl's Best Friend**" is a song first introduced by Carol Channing in the original Broadway production of "Gentlemen Prefer Blondes" (1949), which was written by Jule Styne. **Marilyn Monroe** did the song in the 1953 film version of "Gentlemen Prefer Blondes" and made it famous. The song was listed as the 12th most important movie song of all time by the American Film Institute.
Here is the text:

The French are glad to die for love.
They delight in fighting duels.
But I prefer a man who lives
And gives expensive jewels.

A kiss on the hand
May be quite continental,
But diamonds are a girl's best friend.

A kiss may be grand
But it won't pay the rental
On your humble flat
Or help you at the automat.

Men grow cold
As girls grow old,
And we all lose our charms in the end.

There may come a time
When a hard-boiled employer
Thinks you're awful nice,
But get that ice or else no dice.

He's your guy
When stocks are high,
But beware when they start to descend.

It's then that those louses
Go back to their spouses.
Diamonds are a girl's best friend.

I've heard of affairs
That are strictly platonic,
But diamonds are a girl's best friend.

Marilyn Monroe in "Gentlemen Prefer Blondes"

But square-cut or pear-shaped,
These rocks don't lose their shape.
Diamonds are a girl's best friend.

Tiffany's!
Cartier!
Black Starr!
Frost Gorham!
Talk to me Harry Winston.
Tell me all about it!

There may come a time
When a lass needs a lawyer,
But diamonds are a girl's best friend.

And I think affairs
That you must keep liaisonic
Are better bets
If little pets get big baguettes.

Time rolls on,
And youth is gone,
And you can't straighten up when you bend.

But stiff back
Or stiff knees,
You stand straight at Tiffany's.

Diamonds! Diamonds!
I don't mean rhinestones!
But diamonds are a girl's best friend.

2) Well, Cardinal Mazarin for sure did exercise his manliness, just not quite openly. As Wikipedia knows:
"King Louis XIII died in 1643. His successor, Louis XIV, was only five years old at the time and his mother, Anne of Austria, ruled in his place until he came of age. Mazarin helped Anne expand her power from the more limited power her husband had left her. Mazarin functioned essentially as the co-ruler of France alongside the queen during the regency of Anne, and until his death in 1661 at Vincennes, Mazarin effectively directed French policy alongside the monarch. His modest manner contrasted with the imperious Richelieu, and Anne was so fond of him and so intimate in her manner with him, that there were long-standing rumors that they had been secretly married and that the Dauphin was their offspring."
He was a noted collector of art and jewels, particularly diamonds, and he bequeathed the "Mazarin diamonds" to Louis XIV in 1661, some of which remain in the collection of the Louvre museum in Paris.