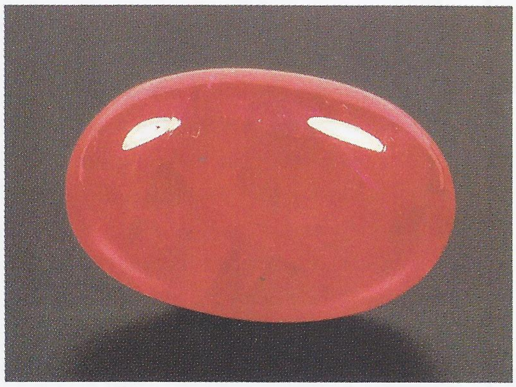
Painting the Ruby Red

FIRST OF TWO PARTS



This is part of a continuing series of articles about gemstone properties. The first appeared in the October 1991 issue of Lapidary Journal.

If rocks and minerals came in shades of black and white and grey, there would be few minerals we would consider gems. Oh, we might value certain minerals such as quartz, tourmaline, or corundum for their industrial properties, but in a world where color is often a criterion for beauty — in the leaves of fall, the fashions of spring, or a friend's eyes — we would almost certainly not treasure rocks and minerals for their beauty. For without color, a gemstone, with the notable exception of diamond, is just another "rock."

For nature to paint the ruby red, an extraordinary set of coincidences must take place. Many gem and mineral fans can recite the fact that

ABOVE: The red in this ruby represents an extraordinary set of coincidences involving light and the atoms that make up the gem. Photo: ICA/Bart Curren

BY SHARON ELAINE THOMPSON

To the Nucleus of the Matter

For those of us whose high school chemistry is shaky at best, here's a short review of atomic structure.

The three most familiar parts of an atom are the *protons* and *neutrons* that make up the nucleus, or center of the atom, and the *electrons* that surround the nucleus. Protons have a positive electrical charge, electrons have a negative electrical charge, and neutrons are, as you might guess, neutral.

Electrons have traditionally been thought of as particles. Today, however, scientists are beginning to regard them as small bundles of energy, not unlike photons. They move around the nucleus in what used to be called orbits (when I was in school) and are now called orbitals. Each electron has its own orbital.

Not all electrons are equal. They may be at different energy levels. Orbitals of electrons that have the same or similar energy levels are clustered into shells around the nucleus. Each shell, representing a different energy level, is a different distance away from the nucleus. Those with higher energy levels are farther away from the nucleus. The farther electrons are from the nucleus, the more weakly bonded they are to the nucleus, just as the farther you pull magnets apart, the weaker the attraction becomes.

You have probably seen the toys, usually dolls or spheres, that nest in each other. When you pull the outer one apart, you find a smaller one inside. Inside that is another, and another, and another. Although not completely accurate, the atom can be imagined as a spherical version of one of these toys. Each sphere represents an electron shell. The smallest sphere in the center would represent the nucleus.

If an atom has the same number of electrons as it does protons, it is electrically neutral. But often electrons in the outermost shell of an atom are knocked off or lured away to another atom. If an atom has more electrons or fewer electrons than it has protons, it is called an *ion*.

Ions can be positively charged or negatively charged. They are positively charged when there are more protons (+) than electrons. They are negatively charged when there are more electrons (-) than protons. In the example Fe^{3+}, we know that the iron (Fe) is an ion with three more protons than electrons; $^{3-}$ would mean there were three more electrons. The number and charge are called the ion's valence. — SET

chromium is the coloring agent for ruby, or some other element accounts for the hue of another gem, but that is just scratching the surface. What do we mean by "agent" or "accounts for" — just *how* does chromium give ruby its prized red? And more puzzling still, how does chromium make a ruby look red but an emerald look green?

Those are big questions and we don't pretend to try to answer them fully here, but we will probe a little deeper and examine not merely the chemical element, such as chromium, but the particles that make up the atoms of those elements and how they interact. For us to see colored stones, the right atoms of the right elements must be in the right places in the right amounts. And on top of that, these minute bits of matter must all be coordinated with the mercurial nature of light. For without light, gemstones, no matter how perfect their atomic recipe, would have no color.

SEEING ENERGY. Light is a part of the continuous spectrum of electromagnetic radiation, which includes everything from very high energy, very short wavelength cosmic, gamma, and x-rays, through short microwave and ultraviolet

Painting the Ruby . . .

wavelengths, down to very low energy, very long wavelength, infrared and radio waves. What interests us here, though, is in the visible light range, sandwiched in between ultraviolet and infrared.

Light such as that from the sun seems to have no color. We call it "white" light. But as Sir Isaac Newton showed in the early 1700s, white light is just chock-full of color. Newton passed a beam of sunlight through a prism separating it into the familiar colors of the spectrum: red, orange, yellow, green, blue, and violet.

This was not remarkable in itself. Newton was not the first to be fascinated with the colors produced by a prism. He was, however, the first to realize that the resulting colors were not generated by the glass prism but were components of the light itself.

Each color of the visible spectrum corresponds to a range of energy, although the ranges overlap. Light, like all energy, is dual in nature, sometimes behaving like a particle and sometimes like a wave, and we can describe colors both ways. In gemology, we commonly describe colors in terms of wavelength. A *wavelength* is the length or distance measured from the crest of one wave of light to the crest of the next.

The short violet wavelengths of light, with crests close together, have the highest energy in the visible light range; the longer (farther apart) red wavelengths have the lowest energy. We can also think of a color as a bunch of *photons*, or particles of light, containing specific amounts of energy.

COLOR IN GEMSTONES is generated when the photons in light interact with the billions of atoms that make up a gemstone. In gemstones, the color-causing atoms that respond to the stimulation of light energy are often *ions* of metallic elements. Ions are slightly out of balance atoms: they either have extra electron(s) or are missing electrons; an *electron* is one of the basic components of an atom. For an instant refresher on the make-up of an atom, see the box "To the Nucleus of the Matter."

Common "color culprits" in gemstones are ions of chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), titanium (Ti), and vanadium (V), which are dispersed throughout the material. When these ions cause color, they may be present as impurities in a mineral, in which case the gemstone is called *allochromatic* or "other colored," or they may be an intrinsic part of the mineral's chemical composition, called *idiochromatic* or "self- colored" gemstones.

As photons of light penetrate a gemstone, they may run into atoms, in particular the electrons in the atom. If conditions are right, the electron absorbs the photon. This boost in energy shoves the electron to a higher energy level. An electron that is temporarily in a higher energy level is said to be in an *excited state.*

In the process of absorbing energy, an electron also absorbs the color or colors that correspond to the energy wavelengths. In effect, that color disappears from the light. The unabsorbed wavelengths of light are left over and are either reflected or transmitted by the gemstone. If we happen to be looking, these leftover wavelengths reach our eyes and give our brains the sensation of color: after all of that, we finally see the red "in" ruby.

Let's run through that now. A ruby absorbs yellow and green wavelengths of light and usually much of the blue. Only red wavelengths are transmitted or reflected to the eye. Because these wavelengths are the only ones we see, rubies appear red. If blue is also transmitted, the ruby becomes purplish.

While the red we see in a ruby is primarily unabsorbed energy, we may also catch a glimpse of "extra" red as a result of some of the absorbed energy as well. An electron excited by light does not stay in its excited state permanently, but almost immediately falls back to its original energy level, or its *ground state.* Since energy can be neither lost nor destroyed, as the electron returns to what is called its ground state, it releases the same amount of energy it absorbed from the light photon in the first place.

However, the energy released is usually of a lower level or longer wavelength, in the infrared part of the spectrum, and we perceive it as heat rather than light. Occasionally, though, some of the longer wavelengths released may still be in the visible light range. That is how rubies may have "extra" red: when they emit heat, they also emit red wavelengths that intensify the color resulting from unabsorbed red wavelengths.

Gemstones can absorb wavelengths of energy outside the visible light region, too. It is not uncommon for minerals to absorb ultraviolet radiation, for example. When the electrons in these materials return to their ground state, they too may emit visible light. This is the phenomenon we call *fluorescence.* Some rubies, in fact, also fluoresce red.

Even though we have seen that Mother Nature's method for painting the ruby red is quite complex, there are other twists yet to come. In part two, we will look briefly at other ways she paints stones red and other colors besides. ◆

To be continued.