Gemstones have a sense of humor. Well, a sense of fun anyway. Who can have seen a colorful opal and doubt it? The colors appear and disappear and change altogether as the stone is turned in the hand. Alexandrite chrysoberyls and other color-change gemstones display the now-you-see-it, now-you-don't legerdemain of experienced magicians. Feldspars are mimics: labradorite imitates the wings of exotic butterflies, while moonstones display the billowing light of the aurora borealis. Pearls, of course, are more refined. In their orient, they exhibit the more discreet frolicsomeness you would expect of a gem with such — ahem — culture.

Play-of-color, color-change, iridescence, adularescence (the moonstone effect), and orient are five of the gemstone effects called *phenomena*. Phenomena, like color, are children of light. These particular phenomena are the result of the interaction of light with a gemstone's intrinsic structure. Light also interacts with the inclusions in a gemstone. Those phenomena will be discussed at a later date.

BUBBLES AND BUTTERFLIES. Iridescence is one of the most common phenomena in the natural world. It causes the rainbow colors in soap bubbles and oil slicks and the intense blues in butterflies' wings. It is also what causes the flashes of color in gemstones such as fire agate, iris quartz, moonstone, and labradorite. It is at least partially responsible for that subtle effect in pearls called orient.

Iridescence is the result of light *interference*. Interference occurs when waves of light, traveling slightly out of step with each other, converge. As the waves overlap, some wavelengths coincide. The colors those wavelengths represent are intensified, and we see bright, spectral hues. Other wavelengths cancel each other out, and their colors vanish (see "And There Was Light," *Lapidary Journal*, December, 1991). Lightwaves can become out of phase with each other through a combination of refraction and reflection.

When light strikes the surface of a gem, part of it is reflected and part of it is refracted into the surface. (Refraction is the changing of speed and direction of

playful COLOR

light when it passes from a medium of one optical density to a medium of another optical density.) Refraction and reflection do not only happen at an exterior surface, the one in contact with air. They can occur at internal surfaces as well. For example, light entering the crown of a gemstone may pass through the stone and be reflected back into the stone from the internal side of the gem's pavilion facets.

Interference and iridescence occur when refraction and reflection take place at ultrathin layers of material called *thin films.* The thin coating of oil on a puddle of water is the thin film that causes interference and iridescence there. But thin layers of minerals, or air in gemstone fractures, can act as thin films, too.

What happens is this: a ray of light strikes the surface of a mineral and is partly reflected and partly refracted. The part of the light that enters the stone strikes another surface inside the mineral: the other side of the thin film. Again, it is reflected and refracted. The reflected ray returns through the thin film and passes through the external surface into the air.

However, its passage into the mineral means this second part of the ray has taken just a fraction of a moment longer to return. It is now out of phase with the part of the ray of light that was reflected initially from the surface. The wavelengths of light overlap, cancelling and intensifying each other: interference occurs.

In iridescent gemstones, there is not only one thin film layer — there are many of them. At each layer, reflection, refraction, and interference occur. But the thin films must be of the right thickness. If they are too thick or too thin, the waves will not be out of phase enough to cause interference and create iridescence.

In fire agate, the thin film causing the green, yellow, red, orange, and violet iridescence is a layer of goethite (an iron oxide mineral) in the botryoidal chalcedony. Iris agate's iridescence is due to interference at fine, air-filled fractures in the stone. Thin layers created by repeated twinning, in which certain alternating directions of crystal growth occur, in labradorite feldspar create the butterfly-wing colors seen in that stone.

Moonstone is an intergrowth of two types of feldspar: orthoclase and albite. Interference of light from those thin layers is believed to produce the floating bluish light seen in the best quality moonstones. (Some of the moonstone-effect may be caused by minute particles in the stone scattering the light.)

Play-of-color in opal is one of the gem world's most intriguing phenomena . . . as if you were holding a rainbow in your hand.

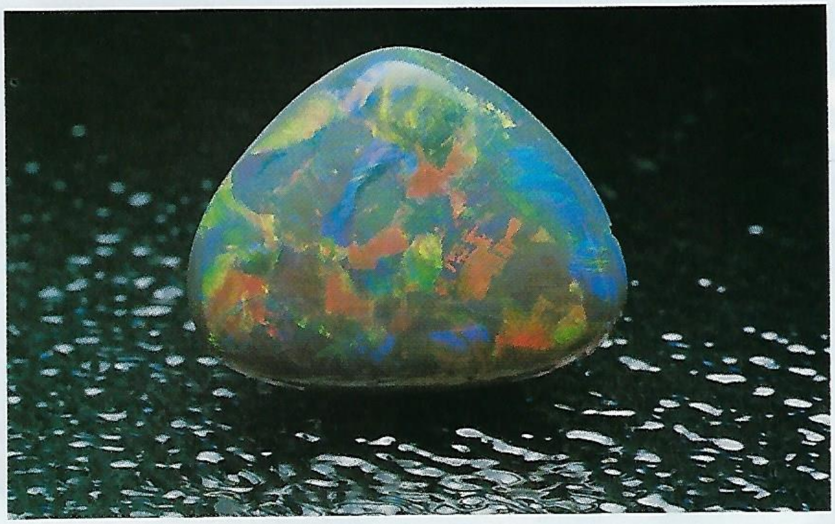
Orient in pearls, that ever-so-faint hint of iridescence, is also due to interference at thin films. The thin films in this instance are the overlapping platelets of aragonite (a calcium carbonate) that form a pearl's nacre, or pearly coating. But orient is also believed to be caused by diffraction that takes place at the edges of the steplike platelets. (This uneven layering gives pearls their characteristic roughness when rubbed lightly along the cutting edge of the tooth.) Diffraction is also responsible for what is arguably the most dramatic gemstone phenomenon — opal's play-of-color.

PLAYING AROUND. Although the term play-of-color is sometimes used for other colorful gemstone phenomena, many gemologists believe it should be used to describe only the vivid, changing colors of opal.

Opal is made up of microscopic spheres of silica (SiO_2) — the chemical composition of quartz without the quartz crystal structure. In precious opal (opal that exhibits play-of-color), the silica spheres range in size from 200 nm (nanometer) to 300 nm in diameter.

At one time, play-of-color was thought to be due to the interference of light at thin films — the layers of silica spheres acting like thin films. The phenomenon is now known to be caused by a combination of diffraction and interference.

Waves of light passing the edge of an object are bent slightly as they pass. This characteristic of light is called *diffraction.* If two edges are close enough to form a narrow opening, the waves fan out — they bend around both edges. When there is more than one narrow opening, the waves of the fan begin to overlap (like the waves of the ocean when they pass through the



The play-of-color for which opal is famous is caused by a combination of diffraction and interference. Peter Secrest collection; 9.5 cts. Photo: Jeffrey Scovil

pilings of a pier). The overlapping causes interference and bright spectral colors appear.

The silica spheres in opal are close-packed, arranged like oranges in a crate. But like oranges, the spheres cannot fill up every micron of space in the opal. There are always some spaces, referred to as voids, between them. These voids are the narrow openings through which light passes and is diffracted. (The “voids” are actually filled with a material with a refractive index slightly different from that of the silica spheres.) As the light is diffracted, the intense spectral colors of opal are born.

The size of the silica spheres in opal determines the size of the voids between them. (The voids in a box of basketballs are larger than the voids in a box of pearls.) If the silica spheres in opal are larger than 300 nm, the voids between them pass light with little diffraction. There is no play-of-color. If the spheres are smaller than 200 nm, light is reflected or scattered from the surfaces of the spheres. Again, there is no diffraction and no play-of-color.

When the silica spheres in precious opal are near their largest limit, they diffract all wavelengths of light, from violet to red. But as the spheres and voids get smaller, only the shorter wavelengths pass through the openings. Longer (red end of the spectrum) wavelengths are reflected and the play-of-color is primarily green, blue, and violet.

Oodles of Opals

No two opals are alike, as any jeweler who has tried to match one will tell you. But opals do fall into rough categories based on the body color of the stone and the size and shape of the color patches. The following are some of the descriptions from “Opal: The Down Under Wonder” by Deborah Ann Hiss (*Jewelers' Circular-Keystone*, March, 1989), and *Australian Precious Opal* by Archie Kalokerinos.

White opal Opal with a translucent to semi-translucent white body color that exhibits play-of-color.

Black opal Opal with a translucent to opaque black, dark grey, blue, brown, green body color (as long as it is dark) that exhibits play-of-color. *Semi-black* opal (grey opal) has a lighter body color.

Jelly opal Opal with a colorless, transparent to semi-transparent body color that exhibits little or no play-of-color.

Crystal opal Opal that is colorless and transparent to semi-transparent and exhibits strong play-of-color.

Black crystal opal Opal with a dark color that is transparent to semi-transparent and exhibits strong play-of-color.

Fire opal Opal with a yellow, red, orange, or brown body color that is transparent to semi-transparent to semi-transparent; it may or may not exhibit play-of-color. Fire opals are often called Mexican opals; red stones may be called cherry opals.

Contra-luz opal A transparent opal that shows strong play-of-color in both reflected and transmitted light. (Most opals exhibit their play-of-color only in reflected light.) From the Spanish for “against the light.”

Boulder opal Opal that has been cut from a thin seam of precious opal so that the ironstone matrix is incorporated into the stone.

Names for opal are also based on the patterns of color found in the stone. The names hint at some of the beauty and mystique of opal and have obviosuly been coined by those who have fallen under its spell: exploding flash, twinkle, Chinese writing, sunflash, rainbow, palette, and peacock's tail. A few of the most common names are:

Harlequin opal Opal exhibiting a broad, angular pattern of close-set patches. Sometimes called mosaic opal.

Pinfire opal Opal exhibiting small patches of close-set color.

Flash opal Opal in which the play-of-color appears and disappears as the stone is moved. — SET

The spheres in opal must be of a uniform size as well as of a particular size range to produce play-of-color. If there is some unevenness in size, light is scattered as well as diffracted. This scattering is what causes opalescence or the milkiness of opal. If there is too much unevenness, more light is scattered and reflected than is diffracted. There is no play-of-color. Like so many things in the Goldilocks world of gemstone color and phenomena, conditions must be “just right” for opals to show off their quicksilver colors.

Opals can display many colors at once. Other gems delight in exhibiting only one aspect of their dual personality at a time. These are the color-change stones.

COLOR CHANGE.

Change of color in gemstones may almost seem to be two different gems depending on the light in which they are seen. The phenomenon is most closely associated with alexandrite chrysoberyls. In fact, color-change is sometimes called the alexandrite effect and stones that exhibit it are often described as alexandrite-like.

Alexandrites can exhibit a distinct color change from green to red. Some people have gone so far as to say the stones are emerald by day and ruby by night. Other gems, such as sapphires, garnets, and spinels, also are known to exhibit color-change. But none is as chameleonlike as the alexandrite.

The phenomena discussed earlier take place at the microscopic level in a gemstone. But color-change takes place at the atomic level. It is the result of the interaction of light with electrons surrounding color-causing ions, such as chromium (see “Painting the Ruby Red,” *Lapidary Journal*, March and April, 1992.)

As light strikes the electrons in a gem material, the energy in the light may be absorbed by these tiny particles of matter. The visible light then usually “vanishes” to be converted into another, usually invisible, type of energy.

The electrons may absorb all the wavelengths of energy in the light or they may be selective about it (which is why this process is called selective absorption). If the electrons absorb only some of the energy wavelengths from the light striking them, only those wavelengths (and as a result, the color sensation they create in our eyes) "disappear" from the light. The remaining wavelengths of energy are transmitted by the gemstone to be perceived as its color. Because rubies absorb strongly in the green wavelengths and transmit mostly red, we see red. In emeralds, it is just the opposite.

The catch to all this is that the wavelengths the stone transmits must be present in the light striking the stone. Otherwise, it has nothing to transmit. "It is the strangest thing in the world to see a magnificent sapphire parure become black in the candle's glimmer," according to a French writer quoted by Emmanuel Fritsch and George Rossman in the first part of their *Gems & Gemology* series on color in gems. Sapphires transmit strongly in the blue part of the spectrum while they absorb most of the other wavelengths. But candlelight is weak in blue wavelengths. There is nothing for the sapphires to transmit. Because they absorb most of the rest of the spectrum, in candlelight, the stones appear black.

What has all this to do with color-change gems such as alexandrites? Although chromium ions make rubies red and emeralds green, they make alexandrites ambivalent. That is because in the chrysoberyls, the chromium ion is bonded to other elements in such a way that the stones transmit both green and red wavelengths. In light that contains generous portions of both red and green wavelengths, alexandrites can look muddy as the stone will transmit both.

However, if the light is richer in green and blue wavelengths (as are daylight and fluorescent light), an alexandrite has more of these wavelengths to transmit, and so looks green. If the light source emits a higher percentage of red wavelengths (as does candlelight or incandescent light), the stone transmits — and looks — red.

This general mechanism creates the color shift in all color-change stones. However, GIA's Emmanuel Fritsch explains that things are really much more complicated. Whether or not a stone changes color depends on which wavelengths the light source emits and which wavelengths the gem material absorbs. He cites a kind of color-change glass that shows no difference in color in daylight or incandescent light. But it is shockingly different in fluorescent light. Fritsch points out that slight variations in a light source's emission pattern can weaken or destroy the color-change effect completely.

Being playful with color is one way gemstones have a good time. But as most collectors and cutters know, play-of-color, iridescence, labradorescence, adularescence, orient, and color-change are not the only gemstone phenomena. Next time we will discuss the stars, stripes, and spangles of the gemstone world.

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