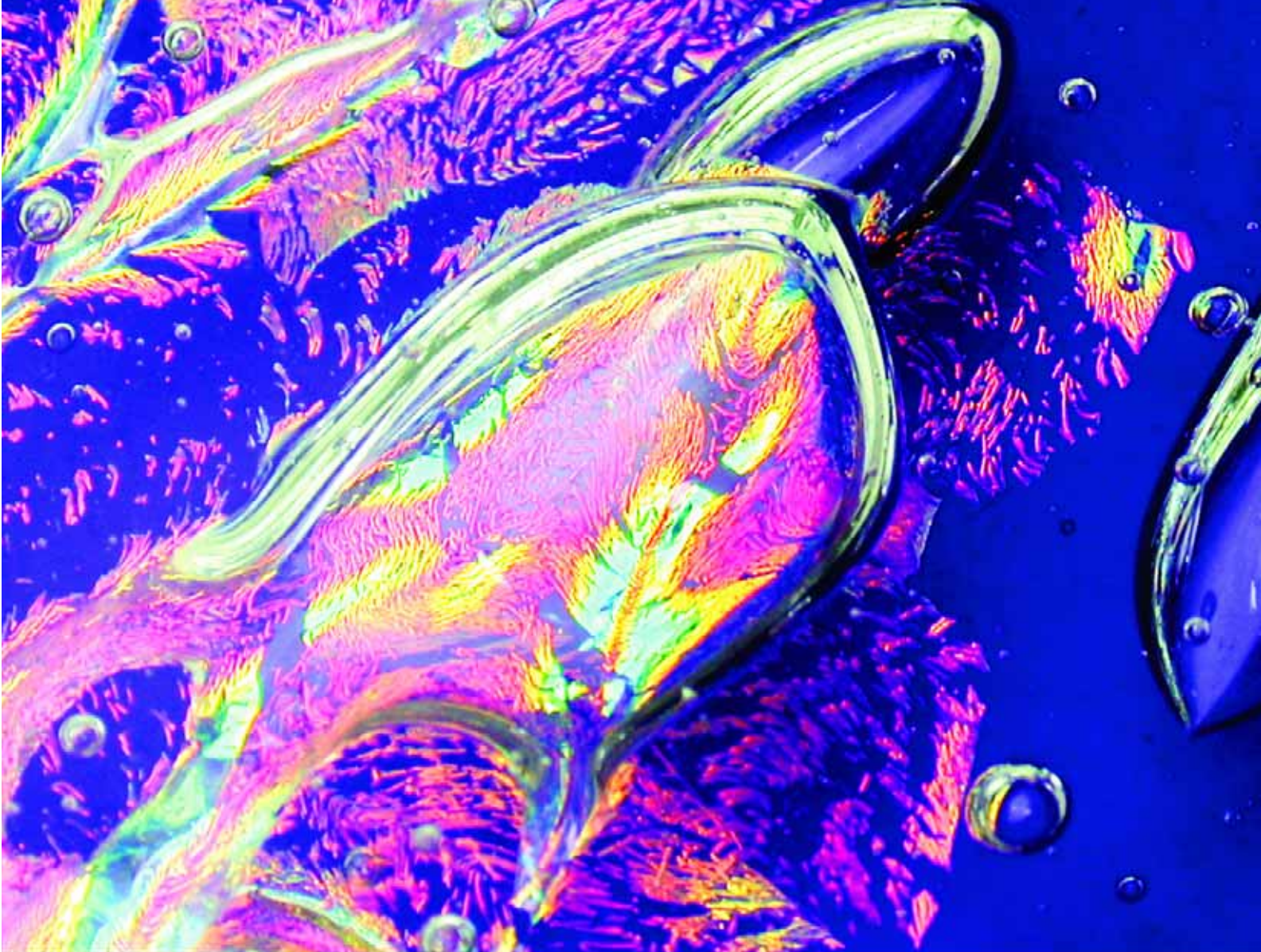
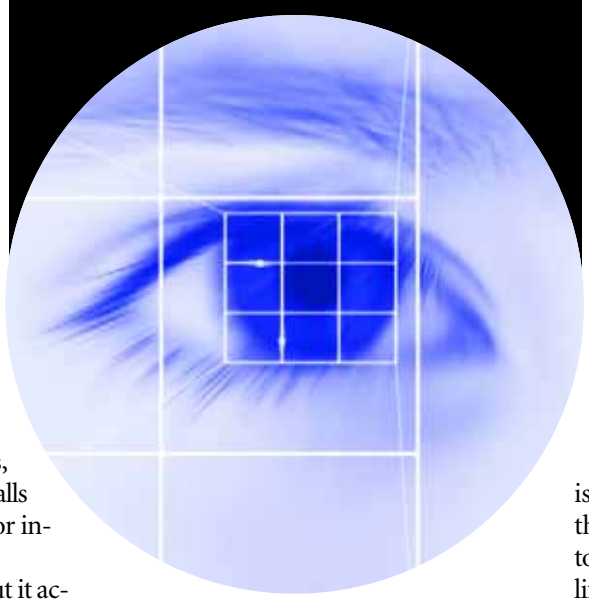


Light Dances

Scientist, artist, inventor and glass-tile manufacturer David Knox knows a lot about the nature of light and how it can be manipulated in the laboratory, in a factory or in a watershape. Here, he explores the subject of light's physical nature, sharing his own experience in applying optical physics to glass-tile production and defining ways in which those same principles apply to the art of shaping water in harmony with the materials that contain it.

By David Knox



When asked what an "optical physicist" does, I sometimes reply that I'm basically a professional choreographer. What I choreograph, of course, is not lithe dancers in leotards and toe shoes, but rather the countless invisible balls of energy whose source, directly or indirectly, is our sun.

That's a colorful description, but it accurately reflects the fact that I've spent my entire professional career coaxing, urging, manipulating and orchestrating light in a completely conscious manner with tools both simple and complex.

Armed with a liberal arts education and majors in art history and American studies, I founded an industrial-laser company in 1983 and spent the next 18 years learning how to choreograph balls of energy into extremely precise line dances. There was nobody out there to teach us what we had to know, so we had no choice but to figure things out for ourselves. In our particular niche, we weren't even able to see what we were working with, because the color of our light was in the near-infrared wavelengths – just outside the visual reach of the human eye.

Having worked with lasers all those years, I became intimately familiar with the fundamental properties of light. That working knowledge now fuels my work in distinctly artistic realms, specifically in the way I apply those fundamental properties in creative ways to influence the design and aesthetics of glass tile.

At the same time, I've also developed a real appreciation for watershaping as its own form of choreography – an exercise in the careful management of light and shadows, colors and contrasts, solids and liquids that plays out before a client's eyes on a daily basis.

Here, I want to discuss just one of the performers you direct as watershapers, using my own experience with glass tile as an example of how principles wielded in creatively manipulating light can be applied across the entire design process.

Ubiquitous Nature

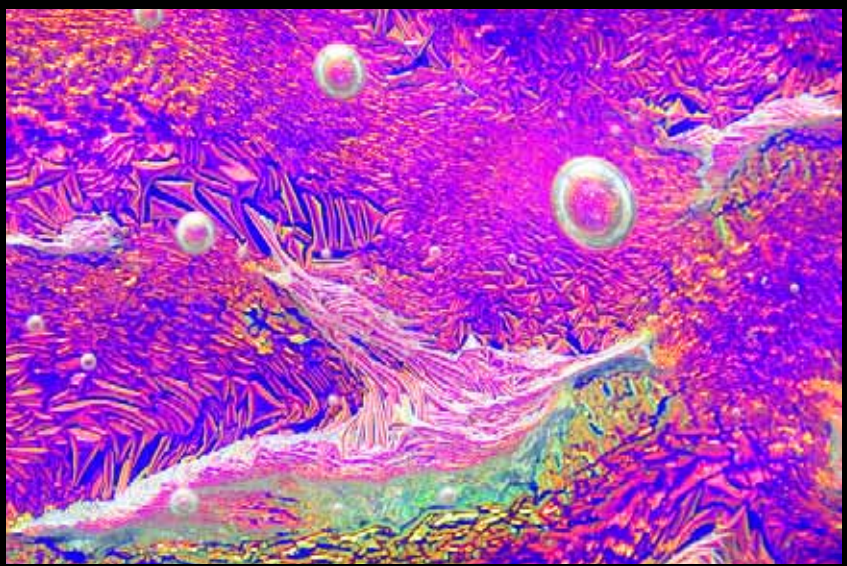
Light is all around us, swimming and swirling, colorless, formless and without scent, taste or mass. It isn't an element or a chemical compound, nor is it biodegradable. It doesn't weigh anything or cost anything (unless we decide to make some on our own).

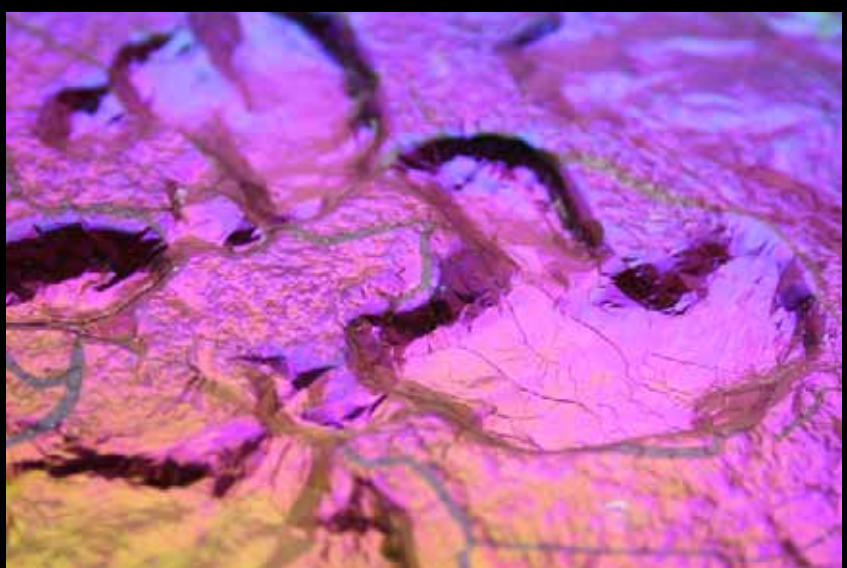
Light is free and, unlike the air, which is constantly being recycled on earth through the biosphere, there is nothing to worry about with respect to its useful life or supply or even the effects of pollution. In fact, it appears that there is no shortage of photons on Earth – and with the ozone layer becoming frail, we might actually have an unwanted glut of them on our hands before long.

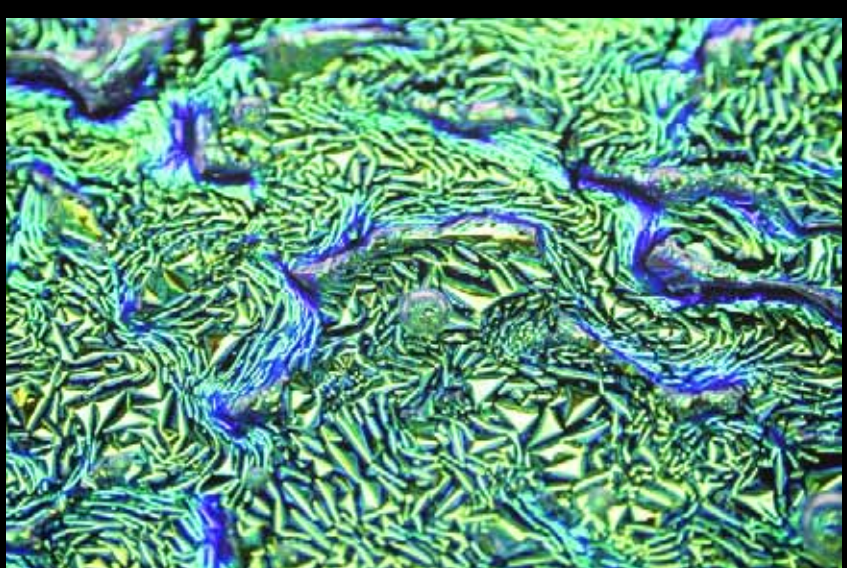
It is my practical understanding of this boundless resource that led me to create the glass tiles I now produce, with optical mechanics always being the primary driver in my designs. These tiles are not just a covering for architectural surfaces: They are instead optical devices of varying complexity that I have consciously designed to manipulate incoming light.

Some are lenses, some are reflectors, some are beam splitters, some are diffusers, some are filters. Some perform well as stand-alone optical elements, others work well optically only when used in an array. Many do a lot of interesting things – and all are deliberately made with specific functions in mind.

The real challenge for me is making







these optical systems "do their thing" in a way that enables people to experience that "thing" (whatever it may be) as beauty. In this way, I am now challenged on a much deeper level than I ever was in building lasers, which don't have to be pretty but which just the same have become devices that just about everyone needs.

But now, no one *needs* my tiles. Nor do they need swimming pools or waterfeatures, for that matter, which makes it our shared challenge to create optical/visual compositions that people desire.

While the perception of beauty is my design goal, that's not even on my mind as I develop a tile design. My approach instead is to create an optical device in the format of a tile – a device that causes the balls of energy that enter into it and strike its surface to dance in a way that perhaps tickles the human spirit.

Form does follow function, but in my case the function is not only the apparent one of being a static object called a glass tile. While the tile must be physically robust and have some dimensional repeatability in order to be properly installed and recognized by people as "tile," its primary function for me is as a device that actively manipulates light that happens to collide with it. In this way, the tiles are truly projectors of light imagery.

Dance Steps

The law that is the cornerstone of my work in choreographing light is this: When light hits any object in space (including gases such as air), there are only four things that can happen – it will be reflected, absorbed, scattered or transmitted. That is all that happens, and I constantly go back to this basic "truth" when I decide to create what I always see as a new and distinct optical component.

Reflections are waves of light that bounce off a surface with a given direction that has a relationship to the direction at which the light

My objective in designing and manufacturing glass tiles is to make each piece a unique optical system. In doing so, I am constantly considering the ways in which light will be reflected, absorbed, scattered and/or transmitted when it hits the tile's surface.

hits the surface. It's just like a tennis ball hitting a backboard: Smack the wall at a severe angle, and the ball shoots off at an equally severe angle away from you. The cool thing is that we can make some pretty sophisticated, wavelength-specific optical reflectors with no more than a can of paint.

It's important to recognize that light is, in fact, colorless and takes on color only when it hits something that reflects it in a way that makes it dance a particular dance we perceive as color – what the scientists call a "measurable wavelength." A bright, red wall appears red because it bounces back only light waves that have a crest-to-crest distance of about 635 nanometers into our eyes. In an optical sense, the paint is a mirror that selectively reflects only red; the rest of the light that hits that wall is *absorbed* by the paint chemistry and turns to heat.

Scattered light occurs when waves get bounced off a surface at random angles. Imagine smacking a tennis ball against a backboard embedded with thousands of golf balls. The tennis ball hitting such an irregular surface would bounce off randomly in almost any direction. Along those lines, a sandblasted sheet of plastic or glass will *transmit* a small amount of light but will *scatter* most of the light that hits it in countless, random directions as a result of the surface's distortions. The light that does reflect back to our eyes is soft and diffuse and sometimes fuzzy.

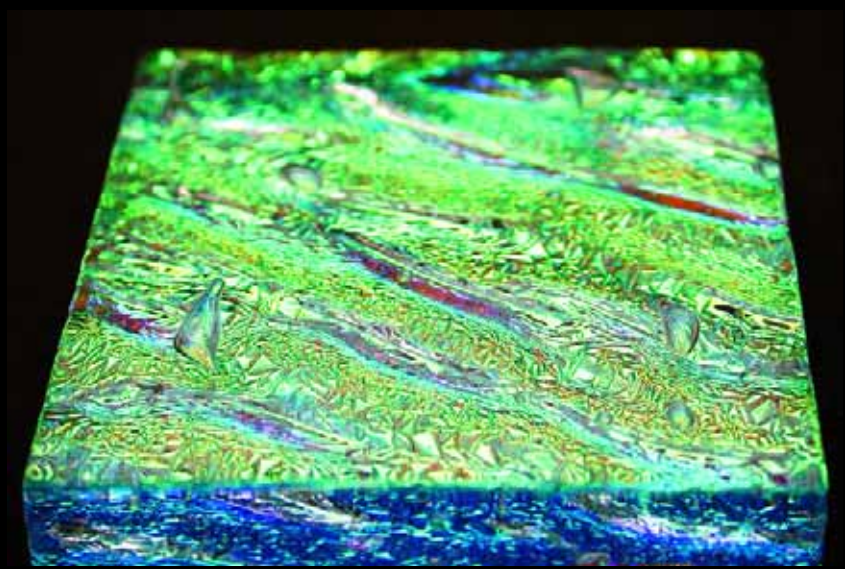
The biggest example of scattered light is the sky above us, although the way the light is scattered is mechanically different from the example given just above. But the result is the same – that is, light shooting out in all different, random directions.

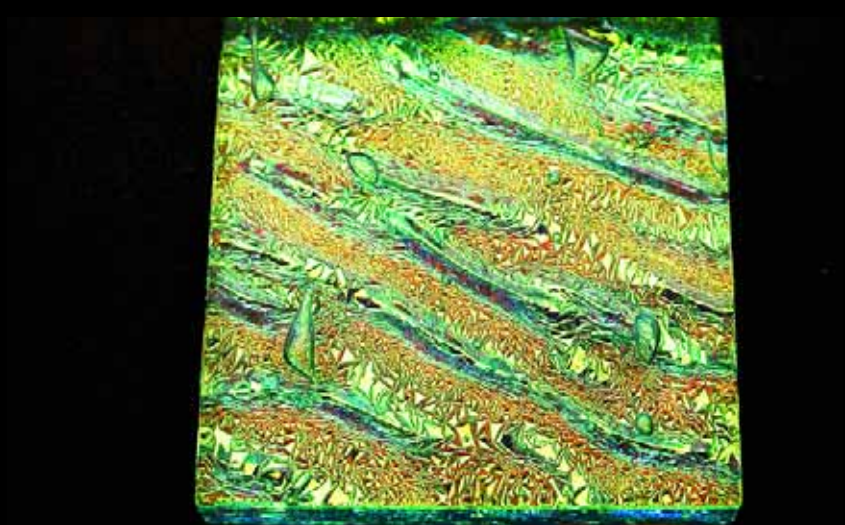
Experts say that the sky is blue because molecules of gas in the atmosphere absorb blue light but let the longer waves of green, yellow and red light pass on by. The gas molecules only hold onto to the blue light for a little while, however, then spit it out randomly in all directions, with collisions occurring everywhere above us like a huge fireworks show.

Some of this scattered blue light is reflected into our eyes and, because of the sheer volume and size of the overhead event on a sunny day (coupled with the complete absence of any green, yellow or red light), the sky appears to be quite uniformly blue.

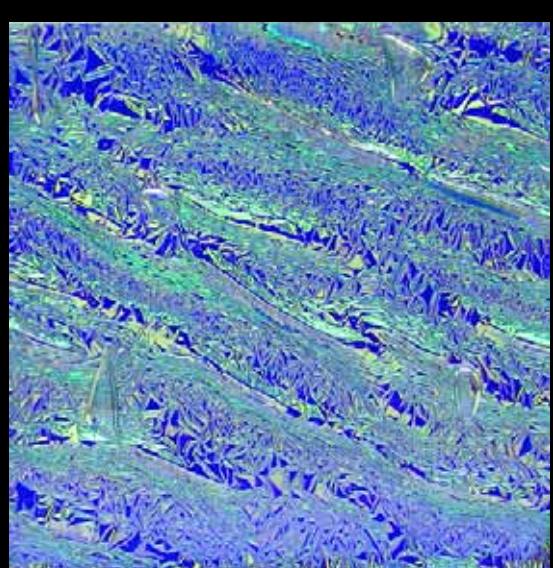
Seeing Through

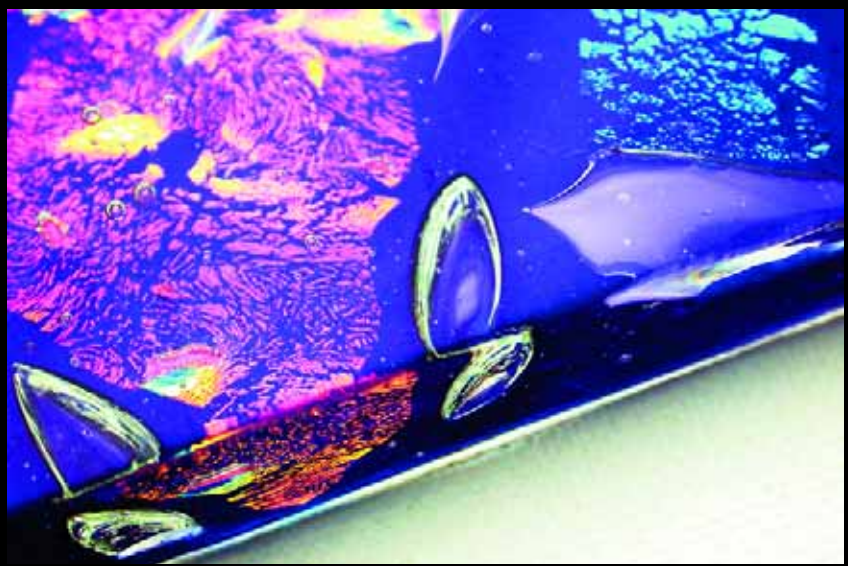
Glass, like water, is transparent, which

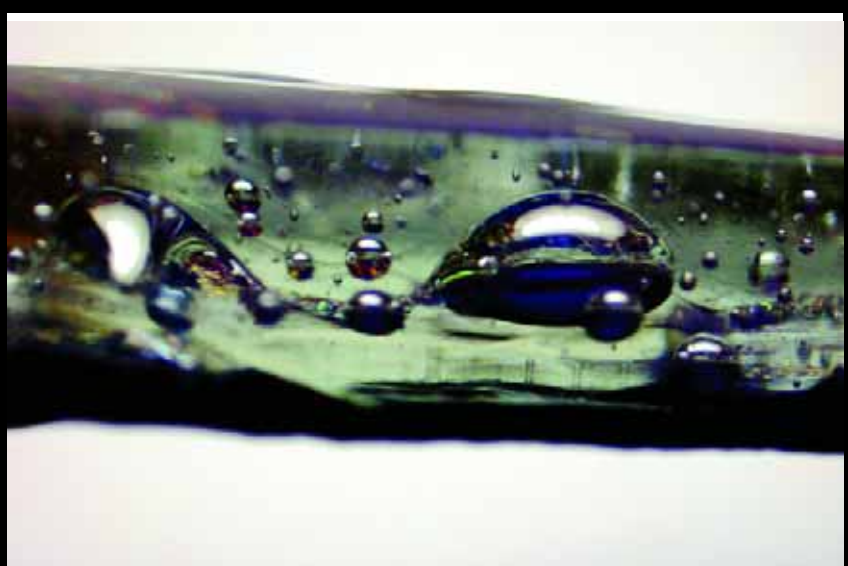


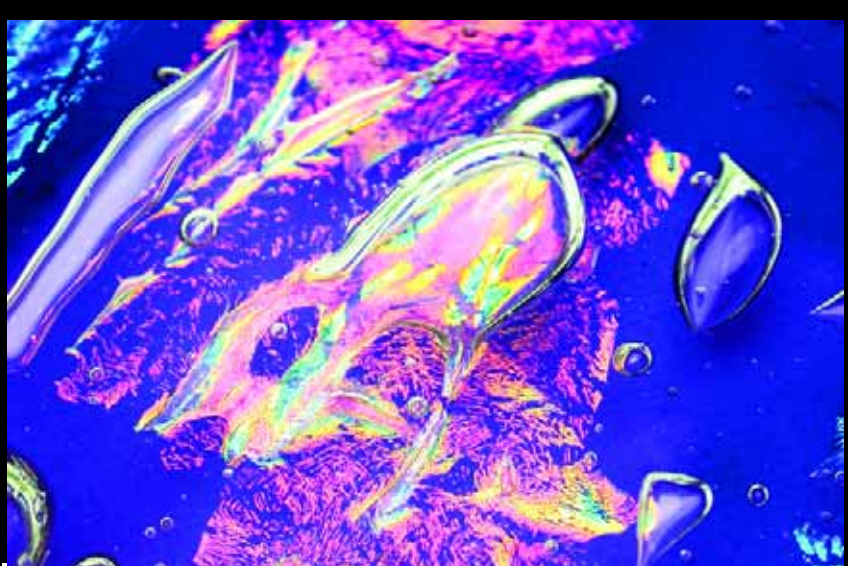


The angle of observation is critical to the observer's appreciation of all that's going on in these tiles. In this case, a single tile is shown at multiple angles, revealing in each photograph a landscape of forms, colors and apparent textures that shifts dramatically as the eye moves along the tile's surface.









means light is able to travel through it.

As I do my design work, I consequently ask myself: What do I want the light that hits this object to do? Which colors do I want to reflect? Which ones do I want to transmit? What do I do with the colors I don't want – transmit them, absorb them or scatter them? How can I make the tile seem different during the day than it does at night? What about angular shifts? Where is the glass going to be installed, and how does the angle of incoming light affect its performance? How do I enhance, compensate or live with that?

(The last question in that series probes the photonic interaction that makes many iridescent glass tiles look very different when mounted vertically than they do when mounted horizontally. In looking at glass tiles for installation, it is therefore always a smart idea to mount samples in the place you intend them to be installed and take a look at them in different light saturations and angles. You can then plan and design specific lighting solutions that will optimize the look you want to achieve.)

As a conscious choreographer of light, I have shied away from making small-format mosaic glass designs. The "optical aperture" of a mosaic tile is quite small and is therefore too limited from the perspective of the art form I pursue. I prefer the larger apertures of bigger tiles and the fact that they enable me to play with more photons and increase the complexity of the device.

In my choreography, I find that the transparency of glass makes it a remarkably appealing medium. This is the primary reason I make very few opalescent glasses: Their opaque/translucent nature limits my ability to choreograph the dance and leaves me few tools and no real internal surfaces to work with.

Accordingly, I see the clarity and quality of the glass I make as being absolutely critical to ensuring that the tile "functions" prop-

The deliberate and careful introduction of bubbles to the material affords me the opportunity to add dozens upon dozens of interior 'lenses' that shift and warp and reflect and magnify the internal structures of the tile.

My tiles have two distinct surfaces, and I often play with the possible contrasts between smoothness on one side and 'roughness' on the other to change the way light plays across large surfaces. With all the tiles oriented with one face up, a visual field results. With random changes in orientation, however, a special sort of luminosity is invoked.

erly as an optical device. The same thing holds true for clear water: The visual system that is a watershape works better when material in the water is not disrupting the movement of light through the "lens" formed by the water.

When everything comes together, the tiles I create usually feature what are, in effect, embedded optical components that interact on different levels within the tile. Inside the tile, for example, different waves of light and color might be removed and then recombined to create shifting landscapes of imagery and color. To achieve this multiplicity of functions requires excellent clarity within the glass: If it is hazy or dull, it simply doesn't function very well (if at all).

Internal Logic

The subtleties and complexities created by the intricate optical design get lost if the volume of light is limited by poor optical quality in the glass material – like listening to a symphony on a tinny portable radio. I purposely seed many of my tiles with bubbles, for example, because they offer a physical frame of reference for the human eye and amplify a tile's sense of depth. If you can't see the reflections these bubbles create within the glass, there would be no point to the exercise!

In transparent glass, however, the bubbles are like little ball lenses that both diffract (spread) and refract (focus in this case) the light, resulting in an internally generated sparkle. If the bubbles are large, they act as magnifying lenses for details within the glass. I also see these large bubbles as metaphorically emphasizing the super-cooled- liquid nature of the glass and the capturing of a moment in time floating in an infinitely slow river of light. This is very similar to what happens when water is entrained with bubbles, the only difference being that in the liquid medium, the bubbles are in motion.

I work with another metaphor in casting my tiles: In running the glass through all its various stages of firing and re-firing, I purposely let gravity play a role in the outcome. Each and every piece is instilled with its own pattern and personality as a result of the way the glass uniquely falls under its own weight during the melt cycles. This is the spiritual aspect of my art, with the Earth's gravity playing a large and meaningful role in the result.

This participation by random forces of gravity is important to me not only because it makes each piece a unique work of art, but also because it ensures that the optical reflecting field is operating in a uniquely random fashion that evokes a

Eye of the Beholder

Why do things we see underwater seem larger and closer than they really are? The mechanism that creates this odd perception is, in fact, the human brain!

It happens because our brains are accustomed to the way light travels in air. We perceive the size and location of objects because our brain knows that the light reflecting off the object comes back to us at a given angle, day in and day out.

In viewing an object underwater, our brain believes that the angle of the light reflecting back off that object should be coming at us at the same angle it does when out of the water. Those angles are different, however, because the speed of the light is different. The brain doesn't compensate for this – and it keeps getting fooled.

The image the brain "sees" is larger than it actually is and, if viewed at an angle, will also be offset from its real location. As a trade-off, I suppose that fish with developed eyesight would have a similar problem adjusting to viewing objects in open air.

– D.K.

Seen with a glorious view in the background, the all-tile finish makes its contribution to the overall impression of luxury. From the reverse angle, however, the tile makes a much more pronounced impression, shifting in color and depth as the angle of the light changes the observer's perception of color and texture. In effect, it looks like an elaborate, shimmering Persian rug draped under the water.

particular, idiosyncratic effect.

That may seem like a small distinction, but it's actually quite profound. Just imagine a series of unique abstract paintings. While each one would appear to be different as you looked at it, each one individually would probably reflect the same image each and every time you viewed it. In the case of the abstract "paintings of light" I create in the form of a tile (or that you create in a watershape), the angle of incidence of the light entering the tile – coupled with the angle of vision of the viewer – will constantly and infinitely shift the image we see.

My tiles (and your watershapes) are metaphorically alive in that sense, different each and every day.

Parallel Purposes

Adding the dimension of water as another optical element into the glass-tile mix makes the visual effects to be achieved even more complex and fascinating.

Like glass, water refracts light. Every material has what is known as an index of refraction, that is, there is a known extent to which the material changes the speed at which the little photonic balls of light travel through it. The index tells us how much the material does so relative to a vacuum.

It's kind of cool when you think about it: We have the power to slow down or speed up the speed of light by putting something in its path.

To see how this works, hold an empty glass jar under water. Light breaks through the upper surface of the water and slows down. It hits the glass jar and slows down even more because the glass has a greater refractive index than the water. Then it hits the air inside the jar and speeds up to the same speed it had before it entered the water. Now it hits the other side of the jar and slows down again before exiting the jar and speeding up just a bit in moving through the water. As all these changes in the speed are occurring, the angle of the light's path shifts.

In the course of that simple passage, the light changed its speed of travel five times. And it's interesting to note that there is no loss of momentum for light: The water and the glass did not *permanently* slow it down, and the slowing that occurred was just a temporary event during the time the light was passing through the materials.

For watershapers, the parallels between what you do with water and what I do with glass extend far beyond the similarities of transparency. Water, when properly shaped, framed and understood, can be consciously optimized as an optical device for light choreography. And when coupled with glass tiles, an even greater optical system may be formed. The effect is like adding another set of lenses into a telescope or camera.

Water also has a very distinct advantage over glass in a photonic sense because water moves a lot faster. It can also be stilled and very cheaply made thicker or thinner to adjust the optical density of the medium.

When you create a watershape, in other words, you are manufacturing a visual and optical system and you use light in all the same ways I do in making glass tiles. By understanding the principles of reflection, absorption, dispersion and transmission, you might be prompted to consider your design work from a different perspective, knowing that you, too, are in command of one of the grandest dances in all of science and nature.

Island Fever

This past year, I've had the pleasure of designing glass tiles for the Anse Chastanet resort on St. Lucia in the Windward Islands – a wonderful project that has allowed me the pleasure of adding a consideration of water to my glass formula as part of the overall optical design. The large facility is just now completing a new "resort within the resort," and each of the 24 guest rooms in this building will have its own vanishing-edge pool in addition to access to a "community" pool on the top floor.

Each of these pools will be surfaced entirely in our glass tiles, which feature a sophisticated, textured iridescent surface on one side and a smooth but undulating surface on the other. The pools are to be lined with the iridescent side facing out, while the bathrooms in each suite will have the tiles mounted in the opposite way, with the smooth, undulating surface facing out.

There are 20 tile colors in all, so most of the rooms will have their own unique color schemes and personalities. The colors are quite bold but work very well in the environment, and I have to say it's been a blast making each and every one. Rather than applying a uniform iridescence to all the tiles, I spread the iridescent patterns randomly over entire *fields* of tile.

The texture is complex in reflective and prismatic qualities, and each piece is unique because of the way I designed the production tooling and manufacturing process. I deliberately optimized the glass and surface structure to operate at their fullest underwater, testing pieces as I went along by running water over them to note changes in appearance and also putting them in still baths to see static effects.

I was also concerned about the integrity of the metal-oxide coating that is folded into the surface of the glass to create the iridescent effect. To make certain all was well, I tested the coating by soaking a tile for 30 days in a bath of pure muriatic acid (31 percent hydrochloric acid). My workbench was completely ruined, but the glass was *perfect*.

– D.K.