When Snow Melts, Where Does the White Go?

The riddle-like nature of this question tickles me. How can something so bright leave no trace? (Grape juice won't do that.) We'll see the answer soon, and we'll have some fun in the kitchen.

Let's first ask, "Is white a color?" In a sense it is, for it is all colors added together. That makes it a unique color, but it still obeys the color laws of addition and subtraction. Some nice experiments suggested in earlier "Light Touch" columns help illustrate these rules. White does give two unique results: A white object will return the color of any light shined on it unchanged, and white dilutes any pure colors mixed with it rather than creating a new color.

Two interesting riddles remain: How is white different from "silvery," which also reflects any color unchanged? And how is white different from "clear," which passes any color unchanged? The words "shiny" and "transparent" might come to mind.

Here it is in one big gulp. Younger children probably should take smaller bites:

- A white object scatters all colors in all directions.
- Clear objects let all colors pass through.
- Colored objects absorb some of the colors inside them.
- Silvery objects are always shiny—they reflect all colors, but scatter light less than white objects.

Surface reflections are one key to whiteness. Any object, even a clear one or a black one, reflects some light at its surface. Some things with special optical properties (such as mercurochrome, iridescent sunglasses, or butterfly wings) reflect some colors better than others. But many surfaces reflect all colors about equally.

This is easiest to see with smooth, shiny surfaces. Look carefully at the reflection of a light bulb from shiny surfaces like a blue lake, red jello, coffee, or a black car. Regardless of what color is underneath, the color of the light bulb's reflection is unchanged. Of course, the light bulb may *be* any color, but the color of its *reflection* is unchanged, which was a property of white objects.

So why don't those things look white? Because we can only see their surface reflection of the light source when we look in exactly the right direction. Beneath their surfaces, light is absorbed. Red jello absorbs everything but red. Coffee absorbs all colors eventually. Black paint absorbs all colors in a thin layer.

Rear surface reflections are another key to whiteness. In the right conditions for total internal reflection (TIR), essentially all the light is reflected. See how white a clear diamond looks in diffuse light.

Scattering is another key to whiteness. When a strong reflection shows us surrounding details, we call it silver. When we can't see those details, we call it white. A mirror looks silvery, but a diamond looks white because the tiny facets confuse the reflected details. A metal paper clip looks silvery due to its glints and highlights. One big bubble looks silvery but countless tiny ones look white.

What happens if we jumble many tiny surfaces together? Light bounces in all directions. Any light not absorbed is eventually scattered or reflected. Many reflections (some TIR) in many directions means lots of scattered light of all colors. Have you noticed that many powders are white or nearly white? Powders have many surfaces. White paint contains a powder that reflects very well and absorbs very little.

Now that we're experts, let's have some fun in the kitchen. We can do some real science—testing a theory by checking its predictions and using a theory to learn what we can't see directly. Let's see if we can apply the principles of surface reflection and scatter to explain what we see in the kitchen.

The water coming out of an aerated faucet has lots of bubbles, the surfaces of which reflect in all directions. How does this look? Where does the white go when we fill a glass with this water?

Salt looks very white at first glance. Actually, each crystal is clear, but we're seeing lots of surfaces. If we get up really close with a magnifying glass, we can see how clear and shiny each crystal is. What happens when we put salt in water and stir it up? What happens if we let salty water evaporate?

What about milk? If we put milk in water, the white doesn't go away. Why? Milk contains scattering particles that don't dissolve in water.

If we roughen a clear ice cube by hitting it with the back of a spoon or scraping it with a key, we will make lots of irregular surfaces. How will this look? What would happen if we dripped some water on it?

When many shiny surfaces are put together smoothly, all the reflections come out together. How should a new roll of clear plastic kitchen wrap look on the roll? Silvery? Look and see.

This one is magical: Put a little liquid dish soap in a large bowl, fill it quickly with water from the faucet to get lots of suds, and leave it alone for about 20 minutes. The top will look ghostly and sky blue. Those bubbles have ***(Continued on page 60)***

Strong theoretical background and experience on electromagnetic modeling and system analysis. Demonstrated skills in FORTRAN, MATLAB, and BASIC. Familiarity with C and PASCAL. Outstanding academic records. Nearly 30 publications. Fluent in Chinese, Japanese, and the languages of the former Soviet Union central Asian republics. Willing to start as a post-doc and to relocate. U.S. permanent resident.

11-L—Medical systems physics and engineering. Over 15 years experience. Project teams have successfully completed each project through a business plan, proof-of-principle, engineering prototypes, manufacturing prototypes, concurrent engineering, quality assurance, and market introduction. A team was led that obtained FDA pre-market approval in just 85 days. 13 issued U.S.A. patents.

12-A—Ph.D. (1991) in Physics. Seeking postdoctoral or R&D position in industry or academia. Specialized in atomic and molecular laser spectroscopy and applications. Experience in design and fabrication of laser cavities for using intracavity laser spectroscopy in plasma diagnostics. Fluent in C, Pascal, Fortran, and applied mathematical methods for creating codes for computer simulations. Demonstrated ability in supervising students; three years university teaching experience.

12-B—M.S. (1993) in Health/Medical Physics, M.S. (1992) in Physics, B.S. (1990) in Optical Science. Seeking a junior physicist position in medical imaging research, instrumentation R&D, or clinical medical physics (interested in residency program). Graduate. research experience: 1.83 years in medical imaging (publication/presentation experience), 1.67 years in optics (thesis). Computer system experience: IBM/DOS, Apple/Macintosh, SUN/UNIX.

12-C—Ph.D. (1995) in Electrical Engineering. Seeking industrial research, development, or engineering position in optoelectronics and microelectronics. Dissertation carried out extensive investigations on optoelectronic implementation of neural networks. Strong background in electron trapping materials, lasers, VLSI and discrete-element circuit design, smart pixel devices, spatial light modulators, liquid crystal and a-Si technology, flat panel display (liquid crystals and field emitters), integrated optics and diffractive optics, image intensifiers, phosphors, and electron beam devices. Co-authored grant proposal to NSF and reviewed papers. Computer skills: C, Fortran Basic, Unix, X-Window System, MATLAB, IMSL, SPICE, Cadence, LaTeX, MS-DOS, MS-Window. U.S. permanent resident. Will relocate.

12-D—M.S. (1994) in Applied Physics, B.S. (1990) in Mechanical & Optical Engineering. Seeking R&D or industrial position. Three years optomechanical and software engineering experience in Japan and China. Experience in magneto-optical disk system design, mechanical design and manufacturing, hologram and digital image processing, interferometry, and optical metrology using SLM. Strong computer skills and programming experience in C, C++, AutoLisp, Fortran, Assembly on PC & SunSPARC/X-window. Fluent in Japanese, English, Chinese. Innovative. Published; willing to relocate.

1-A—Ph.D. (1985) in Physics. Interested in product development in photonics or related area. Experience in analysis, specification, design, and implementation of complex electro-opto-mechanical systems, sub-angstrom motion measurements, interferometers, laser heterodyne systems, low noise measurements, noise analysis, single frequency operation of lasers and laser frequency noise suppression (active and passive), servo systems, vibration isolation, vacuum systems, and measurements.

1-B—Ph.D. (1991) in Applied Physics/Electrical Engineering. Strong background in guided wave optics, photonics, and electromagnetic theory. Experience in design and fabrication of $LiNbO_3$ integrated optics, fiber optic communication systems, wavelength division multiplexing, computer modeling of electromagnetic fields, and electronics. Seeking R&D position, industry or academic.

1-C—Ph.D. (1993), B.S. (1990). Interdisciplinary education and experience in ultrasonics, optics and fiber optics, electronics, and mechanical engineering. One year industrial and seven years research experience. Principle investigator of industry founded project. Project planning, budgeting, and managing experience. Fluent in Chinese and English. Seeking a challenging liaison position or overseas assignment in a U.S. company that has or plans to establish business (manufacturing or marketing) in China. Can relocate. U.S. permanent resident.

1-D—Ph.D. (1992) in Physics. One year industrial, one year government lab post doc experience. Background in quantum optics: fiber optics, solitons, atom laser cooling. Seeking R&D position.

1-E—Ph.D. (1988) in EE/Optics. Three years teaching experience, three years postdoc experience. Seeking academic or research/development position. Unusually interdisciplinary interests including optics (statistical, beam propagation, acousto-optics, signal processing), physics (special relativity, Doppler effect, squeezed states), and mathematics (matrix and determinant theory, Fourier theory, Lie Theory). Pioneer in three-dimensional effects in optics and Fourier transform theory. U.S. citizen, willing to relocate.

Light Touch

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gotten so thin that light from the front and back surfaces interfere and you can barely see them. Now take your finger and draw a trail through the bubbles. What happened? You broke some thin bubbles and their soap slipped down to thicken some others and change their optical properties. Are they silver or white?

Based on our discussion, when snow melts, where does the white go? Snow is made of countless clear crystals jumbled in every direction. Each front surface reflects a little bit. The crystals are clear and many rear surfaces reflect totally. There are so many surfaces that almost everything is reflected, so snow is very white. When the snow melts, all those surfaces join together until there's only one surface on the top of the water, which reflects only a little bit in a certain direction. So now you know.

Ray Williamson is the quality and engineering manager at Virgo Optics in Port Richey, Fla.

Books

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lacking in applications, the book emphasizes the basic principles of EDFAs. It goes into great depth analyzing and clarifying all the complicated concepts involved and facilitates an in-depth understanding of EDFA characteristics. Surely the book will be of great help to all scientists and engineers working in the field and are struggling with the properties and the understanding of EDFAs. The unified and in-depth presentation of the subject will benefit, in particular, researchers and post-graduate students dealing with problems involving optical amplification in general. Certain parts of the book, especially the modeling section and the entire second section, could well be used to supplement undergraduate courses. I thoroughly recommend it to everybody interested in EDFAs.

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