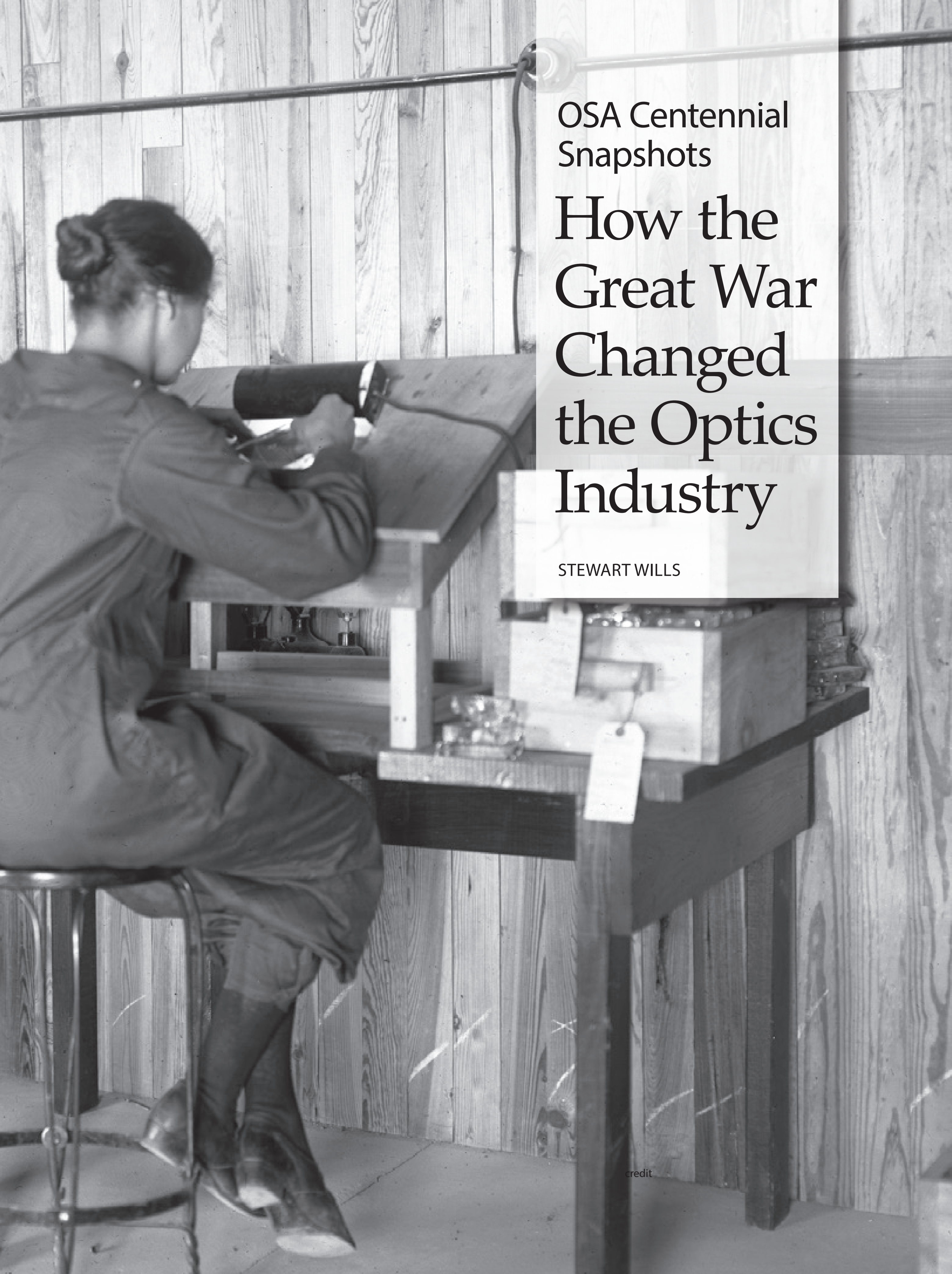
Workers at the Spencer Lens Company, Buffalo, N.Y. (USA), 1918, inspect optical-glass samples, under the watchful eye of a war bond poster.

Courtesy of Geophysical Laboratory Archives, Carnegie Institution of Washington

OSA Centennial Snapshots

How the Great War Changed the Optics Industry

STEWART WILLS



credit

In a 1915 essay, the British writer H.G. Wells memorably—and unflatteringly—characterized the "Great War" then raging in Europe as the first "scientific war." A long-time pacifist who nonetheless staunchly supported the British government's war effort, Wells heaped scorn on science and technology's destructive role in enabling Germany's mechanized artillery and ordnance. Yet World War I also tapped the best scientific minds of Germany's foes. And it boosted scientific progress in unexpected ways.

The optics industry offers a case in point. Both Britain and the United States entered the war utterly dependent on imports of fine German optical glass, with little scientific or manufacturing expertise in what had become a vital strategic material. Yet warfare's demands sparked intense efforts that transformed those countries into self-sufficient suppliers with a sophisticated lock on glass science. And in the United States in particular, a key player in the drama was a versatile young staffer at the Geophysical Laboratory of the Carnegie Institution in Washington, D.C.—who would, coincidentally, later become the second president of the newly formed Optical Society of America.

The demands of World War I transformed the optical-glass industries of the Allied countries from small-scale, trial-and-error crafts to volume enterprises informed by science.

Before the war

We live in an era rich in exotic, engineered optical materials, from photonic crystals to metasurfaces. But for most of optical science's history (and, arguably, today as well), *the* essential material has been high-quality glass. And in 1914, when the Great War broke out, most of the world's glass for precision optics came from Germany.

It hadn't always been that way. For much of the previous 100 years, optical glass had come mainly from two other countries: the United Kingdom, through the firm of Chance Brothers in Birmingham; and France, through the company Parra Mantois et Cie in Paris (where the domestic industry had ramped up during the British blockades of the earlier Napoleonic wars). The quality of the glasses these firms supplied, while reflecting the best technology of the time, was nondeterministic and quite variable.

All of that changed abruptly with the work of Carl Zeiss, Ernst Abbe and Otto Schott in Jena, Germany, in the late 1800s, which culminated in 1886 with production of technical glass of unprecedented, highly dependable optical quality. The "Jena glasses" proved so superior that the center of gravity for quality optics quickly shifted to Germany, and other countries began to rely on German optical-glass imports. By 1912, as *Nature* reported in a 1915 issue, Germany was annually exporting 176,400 kg of "other optical glass"—with more than 25 percent shipped to Britain and the United States alone.

War and the Allied optical-glass quandary

Other countries besides Germany could boast well-developed, diverse commercial capabilities in fashioning optical instruments—including military optics. But the *glass* for those instruments came almost entirely from Germany. Meanwhile, in the half century leading up to the Great War, steady increases in the range and accuracy of field guns and artillery had made high-quality optics—for aiming, rangefinding and reconnaissance—an essential element in waging war. Thus, by the time hostilities broke out in August 1914, dominance in optical glass left Germany with a significant, perhaps underappreciated strategic advantage.

It also left Germany's adversaries, Britain in particular, with a huge problem. Dependent on Jena for 60 percent of its optical glass when the war commenced, Britain initially scrambled to make up the shortfall in what had suddenly emerged as a strategic material. (It even made, a year into the war, a secret effort to negotiate a supply of optical instruments from … Germany.) Eventually, however, the British government cut a deal with the leading domestic supplier, Chance Brothers, to ramp up production, and by war's end

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Chance had built up an impressive optical-glass operation. (For more on the British glass scramble, see the online edition of this article.)

The United States didn't enter the European war until 6 April 1917. When it did, however, it faced its own day of reckoning in optical glass.

Europe's war had already cut off U.S. imports of optical glass both from Germany and from other countries. By spring 1917, several U.S. firms had made some effort to build their own optical-glass capabilities—with mixed results. One company, Bausch & Lomb (B&L), was turning out a ton of glass each month described as "of fair optical quality," mostly for its own optical-instrument business. Efforts by other glass manufacturers and the U.S. Bureau of Standards, though, had been much smaller in scale and mainly experimental.

Thus, when war came to America, only one firm was producing optical glass in quantity, at a rate of around 2,000 pounds per month. The problem was that the U.S. General Munitions Board had estimated that it would require optical glass at a rate of 2,000 pounds *per day* to fill the needs of the wartime Army and Navy.

The U.S. optical industry, even B&L, was ill-positioned to make so great a capacity jump so quickly. B&L and other manufacturers in that era (outside of Jena) treated the making of optical glass more as craft than as science, relying largely on trial and error to reach correct formulations and procedures. Those methods, although adequate for small-scale experimentation and distribution, couldn't hope to meet the suddenly ballooning demand for military optics. Clearly, in April 1917, the United States faced daunting, seemingly insoluble problems in optical munitions.

Enter Fred Wright

Just over eleven years earlier, in 1906, a young scientist joined the staff of the recently founded Geophysical Laboratory (GL) at the Carnegie Institution in Washington, D.C. His name was Frederick Eugene Wright. And, along with colleagues at the GL, Bausch & Lomb, and elsewhere, he would play a key role in solving the optics problems that confronted the U.S. armed forces in 1917.

Wright's background made him virtually ideal for that role. Although born and raised in Michigan, he had attended Heidelberg University in Germany, an experience that had put him in close touch with European and German science and technology. (He'd even done a short stint assisting in the shop of a noted local optical-instrument maker, Peter Stöe.) Wright also had a military connection; his November 1916 application for a commission in the U.S. Army's Engineer Officers Reserve Corps was finally approved only a few days after America entered the European war.

Fred Wright, c. 1906, captured by Geophysical Laboratory colleague E.S. Shepherd. A handwritten note on the back of the photograph describes Wright (or, perhaps, the item he's working on) as "a difficult subject."
Courtesy of Geophysical Laboratory Archives, Carnegie Institution of Washington

And Wright was steeped in optics. By profession a petrologist, he had developed a worldwide reputation as an expert on petrographic microscopes, and as a zealous advocate for their continual improvement. They formed the topic of his first book, in 1911, and of an article that he contributed to the very first issue of the *Journal of the Optical Society of America* in January 1917.

In his prewar years, Wright's microscope work also put him in frequent correspondence with B&L—particularly with Hermann Kellner, the director of the firm's scientific bureau. Often, these exchanges dealt with resolving problems when the company's microscopes didn't quite meet Wright's exacting standards (and, after 1914, with Kellner's difficulties in obtaining optical glass in the face of dwindling supplies from Europe).

In general, however, Wright seems to have regarded B&L's work highly. As a renowned expert, he frequently fielded (and cordially answered) requests from other scientists for information and advice on specific microscope purchases. To one such correspondent, he wrote that Bausch & Lomb manufactured "a research model petrographic microscope which is satisfactory in every respect." Wright's good relationship with B&L would pay dividends in spring

1917, when the company emerged as another of the main *dramatis personae* in the unfolding optical-glass story.

The Carnegie Institution steps in

By March 1917, with America's entry into the European war apparently inevitable, the shortage of military-grade optical glass finally captured the U.S. government's attention, and it reached out to scientific institutions for possible solutions. By mid-April, the National Research Council had formally asked the Carnegie Institution to step in, a request that the director of the Geophysical Laboratory, Arthur L. Day, immediately accepted.

One reason for zeroing in on the GL was that the lab was, scientifically speaking, in the business of melting rocks. A March 1917 letter from the Institution to L.H. Baekeland of the U.S. Naval Consulting Board noted, "it is probably true that we have wider and more thorough experience with molten silicates than any other institution, whether commercial or scientific." The lab also had connections through its work with a number of the nation's large glass manufacturers, including B&L and Corning.

Indeed, Fred Wright had, a week earlier, sent a confidential letter to his B&L contact Hermann Kellner, informing him of Carnegie's pending involvement, and laying the early groundwork for a cooperative arrangement between the lab and the company. Apart from the patriotic inducements, Wright shrewdly noted that "your firm would get, in a short time, information which it cannot at present buy," and that would put it in a favorable position for postwar profit.

Once the cooperative arrangement was in place—and after applying to have his just-granted military commission transferred to the more appropriate Bureau of Ordnance—Wright, along with a team of GL scientists under his direction, embarked from Washington to Rochester, N.Y., where B&L was headquartered. By 27 April 1917, he had taken up residence at the Fitzhugh Apartments in Rochester. He would remain holed up at the Fitzhugh, pushing forward operations on the ground in the B&L theatre, for much of the next year, while Arthur Day managed the broader optical-glass campaign from the GL in Washington.

> Another vast and persistent problem, even before the war, was the composition of the clay pots used as melting vessels.

An exacting material

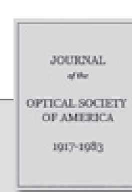
On arriving in Rochester, Wright deployed the GL team across B&L's glass-manufacturing operation. The team faced a formidable technical challenge—reverse-engineering, within a few

OSA Centennial Timeline

www.osa.org/100

OSA HISTORY

1916
OSA Chooses Its Name; First Annual Meeting



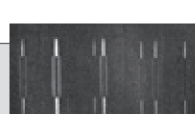
1917
First JOSA Issue

POLITICAL/ SOCIAL

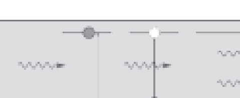
1917
Russian Revolution; U.S. Declares War on Germany

1918
War in Europe Ends; Flu Pandemic Begins

SCIENCE/ ENGINEERING



1916
Quantum Theory of Spectral Lines



1917
Einstein Predicts Stimulated Emission

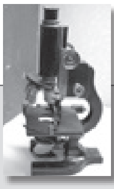
Workers at Bausch & Lomb, c. 1917, building up clay pots used for glass melting. Improving the design and composition of the pots proved an important factor in eliminating imperfections from optical glass.

Courtesy of Geophysical Laboratory Archives, Carnegie Institution of Washington

months, decades of European progress in optical-glass design and manufacture.

Accustomed as we are today to ready supplies of excellent optical glass, it's easy to forget how exacting a material it is—especially from a 1917 perspective. Military optical glass needed to be both chemically and physically uniform—free from striae (lines due to chemical variations trapped when glass melt cooled), bubbles (volatiles trapped during cooling) and inclusions (then called "stones") of foreign material in the melt. The glass also needed to be free from internal stress that could cause variations in optical properties. It needed to maintain a correct, uniform refractive index and dispersion ratio (Abbe number) throughout. It required high transparency, and had to be free of colors and stains introduced by chemical impurities. And it needed to be durable and stable.

1920
Fifth Annual Meeting; Membership Reaches 200



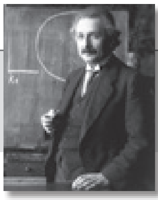
1922
First Optical-Instruments Exhibit at OSA Meeting

1925
OSA Publishes Helmholtz Translation

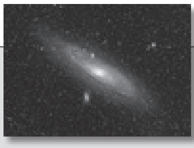
1920
Prohibition Begins in the U.S.

1922
Mussolini Seizes Power in Italy; Birth of the BBC

1925
Scopes "Monkey" Trial in U.S.



1922
Albert Einstein Wins Nobel on Photoelectric Effect



1924
Hubble Describes Andromeda Galaxy

1925
Leica I Camera Introduced; Patent Application for Television

Fred Wright: The OSA connection

Fred Wright's professional papers, housed at the Carnegie Institution, are peppered, especially in the mid and late 1910s, with correspondence bearing the neat signature "P.G. Nutting," and seeking Wright's involvement in a professional society and journal in applied optics that the writer was trying to get started. Perley Gilman Nutting's tireless efforts, which had stretched over a decade, led at the end of 1916 to the formation and first meeting of the Optical Society of America.

Nutting attempted to enlist Wright as the first editor of the *Journal of the Optical Society of America*, but Wright demurred—apparently to Nutting's "intense disappointment." Nonetheless, Wright, an OSA charter member, did not turn down the presidency of the organization when elected to the post for the 1918-1919 term.

Wright's papers include correspondence not only from Nutting, but from a variety of other professionals whose names are associated with the society's founding and early history, including Floyd Richtmyer, who would follow Wright as OSA's third president, and Wright's long-time Bausch & Lomb contact Hermann Kellner, who became the first JOSA editor after Wright declined. And Bausch & Lomb itself was, with Eastman Kodak, a crucial early corporate supporter of OSA.

By April 1917, British and French firms had made significant progress in meeting those requirements, and in building their own optical-glass capabilities. But, even in wartime, specific recipes and techniques were viewed as closely guarded trade secrets. And, while sympathetic to the Americans' plight, France and Britain refused to divulge those details, for fear of jeopardizing their own suppliers' business. For optical glass, at least, the United States would need to go it alone.

Science trumps craft

Not surprisingly, the Carnegie team attacked the problem by proceeding, as Day later wrote, "much as a scientific man is accustomed to proceed in other unknown fields." The team began by focusing, laser-like, on the six varieties of optical glass from the Schott catalog actually found in U.S. military instruments. Those included two types of lead-rich flint glasses (largely used in gunsight systems and rangefinder eyepieces), and four types of crown glasses (used in varied applications, including field glasses and telescope objectives).

The scientists set to work on the puzzle of these glasses' composition. Wright later wrote that it was his "good fortune," soon after arriving at the plant, to "deduce certain relations which enabled us to write down at once the batch-composition for glasses of desired optical constants." Wright's modest statement obscures the reality: a statistical study of published analyses of some 110 German glass samples, over an intense period of several weeks, to work out the equilibrium curves for the three-component oxide systems making up the crucial glasses.

It was perhaps the most vital single step in putting U.S. optical glass manufacture on a scientific footing—and a huge timesaver over the previous trial-and-error methods. Now, using the equilibria deduced by Wright and the team, a glass with predetermined optical constants could be designed and made in the course of one or two trials—compared with, as Day later wrote, as many as 150 trials "in the days of rule-of-thumb glass making."

Sand, furnaces, pots and diplomacy

Beyond the compositional breakthrough, the Carnegie team also had to navigate a mare's nest of basic production issues, including ensuring a steady supply of adequately pure raw materials, such as sand and potash, and working with B&L to boost the company's furnace capacity to a war footing. Another vast and persistent problem, even before the war, was the composition of the clay pots used as melting vessels, which contained impurities that reacted chemically with the melt to create striae in many glass batches. Day, Wright, and others worked obsessively to find clay compositions and pot suppliers to overcome this problem.

Wright also spent his long days handling administrative burdens. As the "man on the spot," he issued detailed weekly, quarterly and semiannual progress reports, periodic statistical summaries for the U.S. Inspector of Ordnance, and regular typed missives, sometimes more than daily, to Arthur Day. While Wright's communications with the Ordnance Department stressed the patriotic response of the companies participating, his communications with Day paint a more complicated picture, hinting at personality conflicts in the plant and corporate concerns about leaking trade secrets.

Both Wright, on the scene, and Day, who occasionally visited (and who emerges from the correspondence as a manager of impressive skill), had to diplomatically smooth over these issues. Wright also sometimes found himself, as an officer in the Ordnance Bureau, caught between the priorities of the Army and the Navy, as they competed for scarce supplies of optical glass.

Somehow, Day, Wright and the rest of the team made it all work. By November 1917, according to Wright's reports, the B&L plant was churning out optical glass of "A"

During the war, nearly 660,000 pounds of usable optical glass was produced for the U.S. war effort—an incredible achievement in light of prewar production levels.

quality at a rate of more than 20,000 pounds per month—a tenfold production increase in seven months. By the following March, he reported, the plant was producing some 35,000 pounds of glass usable for optical instruments—and, except for negligible differences in transparency, "the quality of the glass [was] equal to the best European glass in every respect."

Toting up

While the effort at B&L was the most fruitful, the Rochester firm was not the only company enlisted to meet the U.S. shortfall in military optical glass. The U.S. Bureau of Standards undertook a parallel effort at the Pittsburgh Plate Glass Co. (PPG) in Pennsylvania, but proved unable to produce any significant quantity of optical glass.

Arthur Day, whom the War Industries Board ultimately designated as "in charge of optical glass production," sent a GL team in January 1918 to consult at PPG; Wright himself spent a week at the plant to help iron out some persistent problems with striae in the glass output. After Carnegie became involved, the PPG plant ended up being the second-biggest U.S. producer of optical glass during the war. GL personnel also worked during 1918 to boost production at a third plant, the Spencer Lens Company in Buffalo, N.Y.

Wright's summary report to the U.S. Chief of Ordnance showed that, between 7 April 1917 and the 11 November 1918 armistice, the combined efforts of the companies, workers, and scientists produced nearly 660,000 pounds of usable optical glass for the U.S. war effort—an incredible achievement in light of prewar production levels. More than 68 percent had come from the B&L plant, where Wright had managed the effort. (Wright's careful recordkeeping proved valuable when, after the war, the Bureau of Standards attempted to claim credit for solving the optical-glass problem itself. Wright's numbers showed that the Bureau's efforts had actually produced only 2.9 percent of the total wartime supply.)

After the war

With the war over, Wright and the other Carnegie scientists returned to their work at the GL. "After we get back into civilian activities it will probably take six months to train our brains back into the channels of scientific research," Wright wrote to Arthur Day soon after the armistice, "but that is part of the price we pay for the experience we have had. Personally, I have enjoyed it greatly."

After a short period as a vice president of the Corning Glass Works, Day returned to the helm of the GL until his retirement in 1936. Wright likewise spent the rest of his career at the GL, where his scientific journey was varied and rich. Beyond petrology, he contributed to studies of the Earth's gravitational field and of the moon's surface features. In addition to serving as OSA president from 1918 to 1919, he held high offices with the Geological Society of America, the Mineralogical Society of America, and the U.S. National Academy of Sciences.

But his work during the war (as well as subsequent work on optical munitions during World War II) has always loomed large in his reputation. One appreciation, after his death in 1953, summed up Wright's World War I contribution this way: "He supervised the removal of mystery and alchemy and introduced science and control into the production of more than 600,000 pounds of optical glass that met the most exacting requirements."

Bausch & Lomb, meanwhile—still operating today as a division of Valeant Pharmaceuticals—had built new and powerful capabilities in its optical business. And it found its wartime experience useful in other ways. In a February 1920 *Popular Science* advertisement, the company trumpeted its part in helping the United States break free of the "foreign monopoly" in optical-glass production. The ad includes words about optical glass that—in light of all that optics and photonics have wrought since then—sound prescient:

"Events have shown its immeasurable value in wartime. And it will prove no less a factor in the arts of peace." OPN

Sincere thanks to Shaun Hardy of the Geophysical Laboratory, Carnegie Institution of Washington, for his help with research on this article.

A complete reference list appears in the online version of this article at www.osa-opn.org/january_2016/optical_glass.

Stewart Wills is the editor and content director of *Optics & Photonics News*.