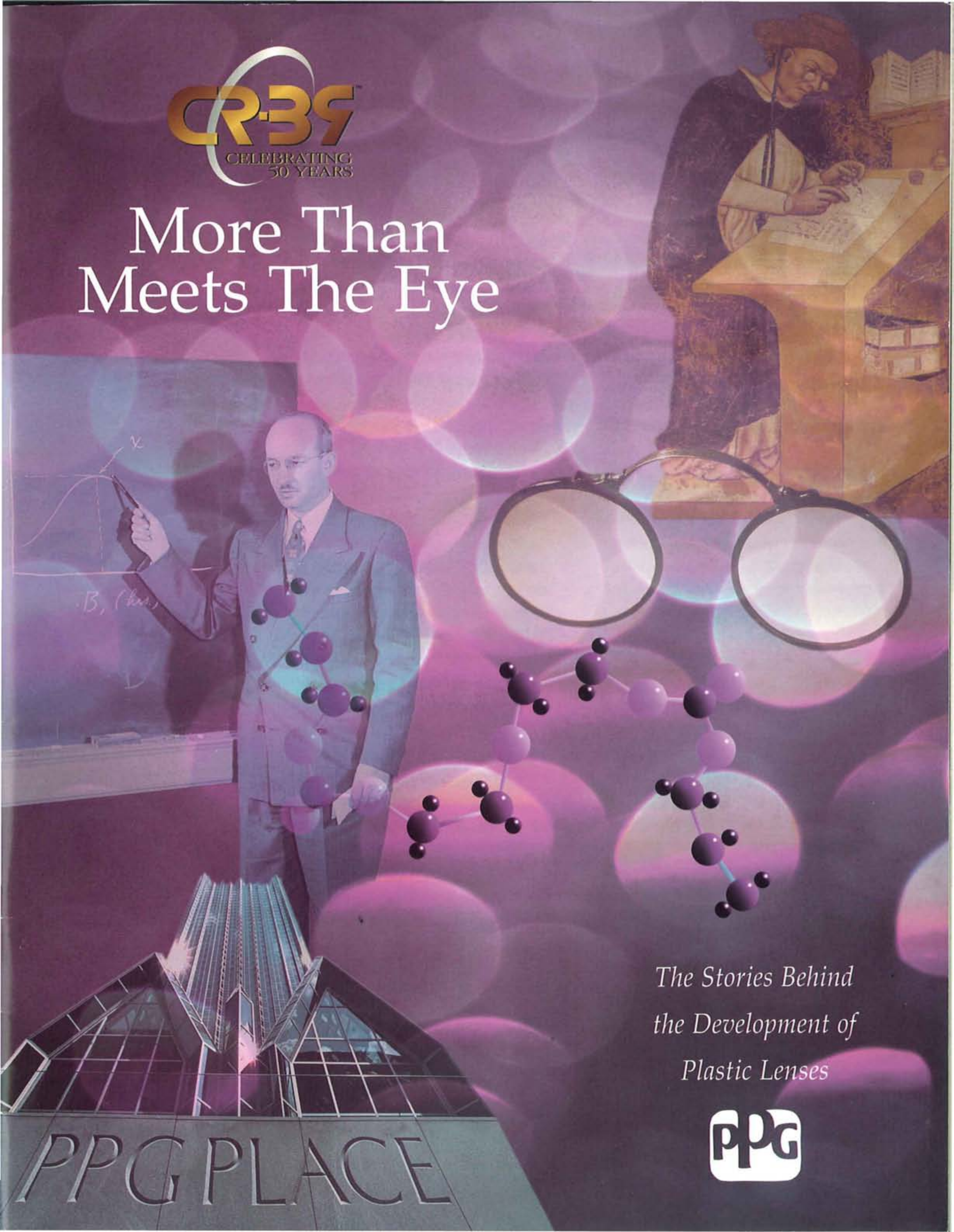

More Than Meets The Eye

The Stories Behind the Development of Plastic Lenses

PPG

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About the Author

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On the Cover

The cover illustrates key elements in the development of ophthalmic lenses.
Upper right: This is the first known painting to show someone wearing eyeglasses. It was painted in the year 1252.
Directly below: Pince-nez glasses were in vogue around the turn of the century. They often featured a chain or ribbon to catch them when they fell off the nose.
At left: Frank Strain was one of the two inventive chemists at PPG who developed and patented allyl diglycol carbonate (CR-39® monomer) in 1940. Due to the war, the patent was not issued until 1945.
Center: A model of the atomic structure of CR-39 monomer.
Bottom left: This energy-efficient landmark glass tower in Pittsburgh, Pa., serves as international headquarters for PPG Industries, a global manufacturer of coatings, glass, fiber glass, and industrial and specialty chemicals.

The Beginning

By the time World War II began, the plastics revolution was already well underway. Polystyrene resins had been produced commercially since 1937 and nylon, the first high-performance engineering plastic, was also a product of the 1930s. As the war began, both the Allies and the Axis powers faced severe shortages of natural raw materials. The plastics industry turned out to be a rich source of acceptable substitutes. Realization of this fact led to concentrated efforts by the industry to develop other new plastics.

With this heightened interest in plastics, PPG Industries—known as Pittsburgh Plate Glass Co. until 1965—began searching for a way to create an allyl resin with low-pressure thermosetting properties. Rohm & Haas had already developed Plexiglas® resin and DuPont chemists had invented Lucite® resin, both of them thermoplastic materials. Pittsburgh Plate Glass Co. owned a subsidiary company in Barberton, Ohio, called Columbia Southern Chemical Company where a research team was assigned responsibility for investigating clear resins. The term "Columbia Resins" was chosen to serve as the name of this project.

As a compound was isolated and worked on by the team, it was identified by a code number. By May 1940, one of the compounds showed real promise. This particular resin was an allyl diglycol carbonate (ADC) monomer that Pittsburgh Plate Glass Co. trademarked under the material's batch name "CR-39." In future years, more than 180 different compounds of this clear resin were individually researched and investigated.

The 39th Compound

The 39th attempt was the most promising because it offered some unique characteristics. Among them was the fact that the resin could be combined with multiple layers of cloth, paper and other materials to produce exceptionally strong laminated products capable of being molded into a variety of reinforced shapes. This discovery marked the beginning of what would come to be a major new industry called "reinforced plastics."

The first commercial use for Pittsburgh Plate Glass Co.'s new monomer involved combining the resin with fiberglass (another Pittsburgh Plate Glass Co. product) to form a molded fuel tank for the B-17 bomber, the famous Army Air Force plane that saw service in every theater of operation during World War II. The fuel tanks were molded of materials laminated with CR-39® resin and lined with a special rubber compound that became self-sealing when the tank was pierced by bullets or shell fragments. Replacing conventional fuel tanks with tanks laminated using CR-39 resin made it possible to greatly reduce the plane's weight, extending the bomber's range and contributing substantially to the war effort.

Fuel Monitors

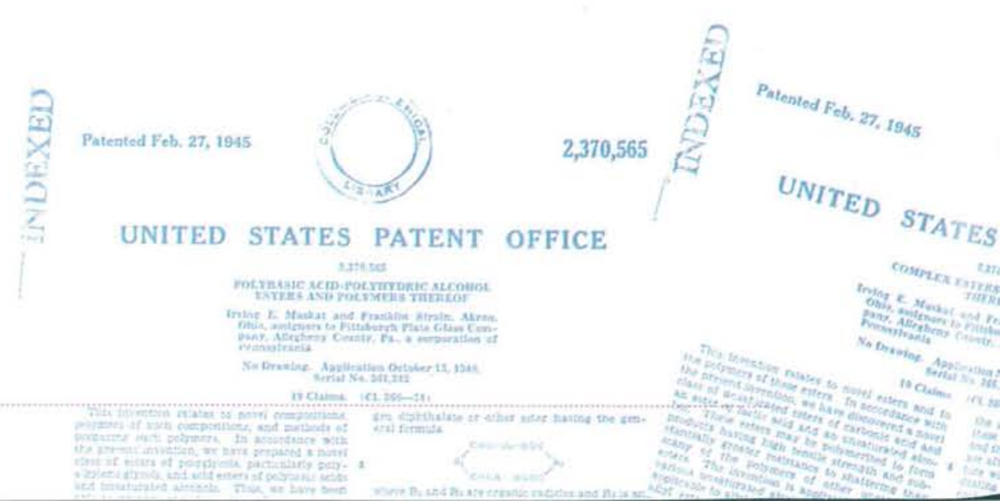
Another innovative use for the new CR-39® resin in aircraft was production of transparent tubes that were embedded in fuel lines running through the flight engineers' compartment, providing the crew a visible gage to indicate fuel flow to each engine. These tubes made of CR-39 resin replaced tubes made of glass which were often shattered during combat, spraying gasoline throughout the cockpit. There was also some minor use of transparent CR-39 resin for making lenses during the war but the lenses produced were ½" to ¾" thick and primarily used for reflector and searchlight applications.

The War Ends

When the war ended in 1945, all government contracts were cancelled, and Pittsburgh Plate Glass Co.'s Barberton plant ended up with a railroad tank car full of allyl diglycol carbonate (CR-39® resin), all that was left from wartime production. The 38,000 pounds of resin remaining in the tank car represented a costly investment for the company, so a search was launched for civilian markets that could use this transparent resin. PPG old-timers involved during that period remember how time-sensitive this project became. CR-39 resin remains a liquid until a catalyst is added. Eventually, however, the material polymerizes, or hardens, without a catalyst. In those early days, no one knew how long that self-curing process would take. They did know that when it happened, instead of an expensive railroad tank car, they would end up with a useless steel-encased slab of plastic.

The Search for Peacetime Uses

A variety of industries were contacted in a search to find customers for the left-over CR-39® resin. A few individuals in the ophthalmic industry indicated some initial interest, particularly because of the material's resistance to impact. One company was interested enough to set up a special research department to try to develop plastic eyeglass lenses. The company was Univis Lens Company, at that time located in Dayton, Ohio. Univis was a leading lens producer investing large sums in an attempt to produce plastic lenses from CR-39 resin. Their efforts are explained in greater detail in Robert Graham's story (see page 14). Eventually Univis abandoned the project. It's interesting to note that, following successful production of plastic lenses by Armorlite, SOLA and Essilor, Univis did eventually become a major plastic lens producer.



Franklin Strain, standing at the right, was the co-developer of allyl diglycol carbonate (CR-39® monomer) along with Frank Muskat. He is seen here discussing the optical properties of CR-39 monomer with several PPG marketing executives. Muskat and Strain's original patent application, dated October 15, 1940, stated, "Thus, we have been able to prepare complex esters of various polyglycols such as diethylene, triethylene, tetraethylene, pentaethylene, dipropylene, tripropylene, tetrapropylene, dibutylene, or other polyglycol." Who could have predicted how such an exotic chemical combination would impact eyewear in the years to come?

FLAT SHEET MARKET

Until 1960-61, PPG's primary CR-39® resin sales were for flat sheet applications. These sheets of transparent plastic were used for personal safety equipment and clothing such as welding helmets, industrial goggles, gas masks, etc. Another widespread use of CR-39 resin during those post-war years was for windshields of industrial crane cabs and other vehicles used in industrial plants. Much of the early work in developing optical lenses was concentrated on strong correction lenses, primarily high plus lenses used for post-cataract patients. This was an important segment of the lens industry in those days before development of the inter-ocular lens.

As the optical industry gradually learned how to cast lenses from CR-39 resin, and how to edge and surface these new lenses, sales to the optical industry grew slowly but steadily until 1975, when more than 90 percent of PPG's CR-39 resin sales were to the optical trade. In 1975, PPG's marketing experts predicted that plastic lenses—at that time representing 15 percent of all eyewear in the U.S.—would grow to 30 percent by 1978. Few people outside of PPG believed that optimistic prediction. Today, plastic lenses represent more than 80 percent of the U.S. market.

THE TANK CAR

Looking back to that tank car of CR-39® monomer sitting forlornly on a siding in Barberton, Ohio in 1946, the PPG employees who tried to sell the contents before the resin solidified uncovered two important facts. The first was that CR-39 monomer was remarkably stable with an amazingly long shelf life. The solidifying they feared never came to pass. Their other discovery was that there was indeed a viable market for a stable, transparent, impact-resistant material for producing spectacle lenses.

PPG—The Company

The company known today as PPG Industries, Inc. was founded by two very dissimilar men. John Pitcairn was a conservative railroad official. In 1880, he linked up with Captain John B. Ford, a flamboyant entrepreneur. For some reason, now forgotten, these two men came to the conclusion that they could produce and market plate glass. This was an ambitious undertaking because, at that point in time, plate glass for the United States was almost entirely imported from Europe. More than a dozen U.S. companies tried to compete in this market but all ended as financial failures. Belgium, England, France and Germany monopolized both the machinery and the skilled technicians required to produce plate glass.

Pittsburgh Plate Glass Company

With Pitcairn as major stockholder, Captain Ford founded the New York City Plate Glass Company in 1880 and began building a plant in Creighton, Pa. It didn't take long for the pair to run out of money. To get needed capital, the company was reincorporated in 1883 as the Pittsburgh Plate Glass Co. This also marked the year the company produced their first plate glass. Success soon followed those early efforts and by 1895, the company moved their corporate headquarters to Pittsburgh, Pa. By this time, the company produced 20 million square feet of plate glass annually.

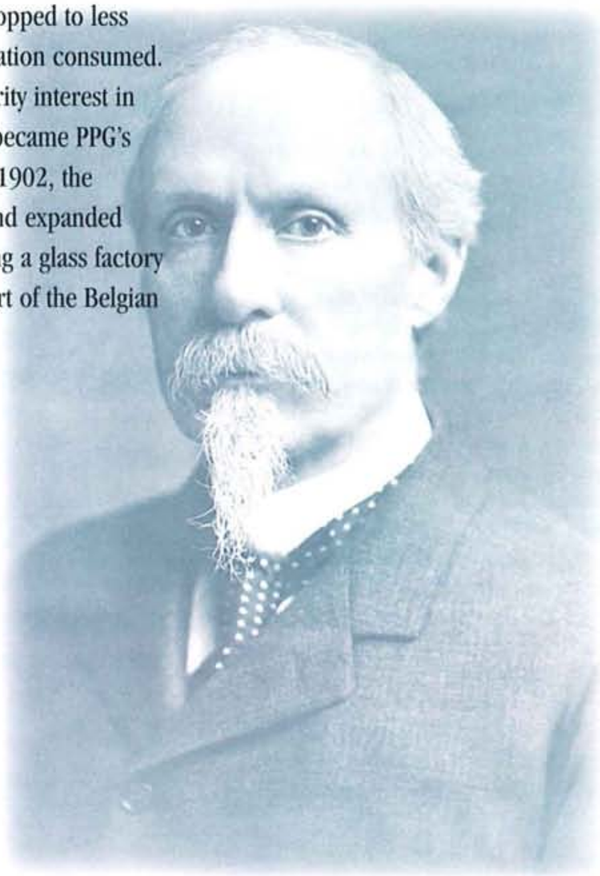
Ford and his sons had a disagreement with Pitcairn in 1896 and sold their interest in Pittsburgh Plate Glass Co. They left to found the Edward Ford Plate Glass Company in Toledo, Ohio. In 1930, this company merged with the Libbey-Owens Sheet Glass Company, forming the well-known Libbey-Owens-Ford Glass Company.

Pitcairn Takes Over

With Ford gone, Pitcairn took over as president and, in 1899, established an independent company called Columbia Chemical Company, based in Barberton, Ohio. This new operation was created to assure PPG a constant supply of soda ash, a major component of glass. The Columbia Chemical Company was responsible for inventing CR-39® resin during World War II. In 1951, Pittsburgh Plate Glass Co. became the sole owner of Southern Alkali and merged it with Columbia, forming the Columbia-Southern Chemical Corporation. This company ultimately became PPG's chemical division.

By 1900, Pittsburgh Plate Glass Co. was selling 13 million square feet of plate glass annually. The company had become the country's most successful producer of plate glass. Imported plate glass dropped to less than 15 percent of what the nation consumed. That year, PPG bought a majority interest in Patton Paint Company which became PPG's coatings & resins division. In 1902, the company reversed tradition and expanded operations to Europe by buying a glass factory in Courcelles, right in the heart of the Belgian glass industry.

PPG founder Captain John B. Ford



PPG founder John Pitcairn

Today

PPG Industries, Inc. is a diversified global manufacturer and a leading supplier of products for manufacturing, construction, automotive, chemical processing and numerous other world industries. The company produces protective and decorative coatings, flat and fabricated glass products, continuous-strand fiber glass, and industrial and specialty chemicals. They operate 70 major manufacturing facilities in Australia, Canada, China, England, France, Germany, Ireland, Italy, Mexico, the Netherlands, Portugal, Spain, Taiwan and the United States. The company conducts research and development at eight facilities worldwide.

The Evolution of Ophthalmic Lenses

The word "lens" comes from the Latin word "lentil," a species of bean that rather vaguely resembles the shape of a lens. Single pieces of convex-shaped glass or rock crystal have been found in ruins dating back thousands of years. These primitive lenses were used as magnifiers but it wasn't until the 13th century that anyone thought of combining them into spectacles.

Reading Stones

The first mention of magnifying lenses is found in a famous treatise on optics written by Arab physicist, al-Hazen (996-1038). Al-Hazen observed that a segment of a glass sphere, in effect a plano-convex lens, would magnify images. Later, Italians would call magnifying lenses lapides ad legendum which translates to "stones for reading," most likely because they were made from rock crystal rather than glass.

The very earliest spectacle lenses were made of quartz crystal and were given the name "pebble lenses" in the optical trade. Other early lenses were created from hand-blown glass. As the optical industry grew, hand-blown glass was gradually replaced by more easily-formed lens blanks made from flat sheets of glass. These were called "dropped" lenses because of the process in which flat sheets of glass were heated until they softened enough to drop into cavities that shaped the blanks to a rough curve.

The earliest origin of eyeglasses is a matter of some dispute. In his famous "Opus majus," Roger Bacon described how a convex lens magnified and offered a suggestion that such a lens might help those with vision problems. While Bacon did not invent glasses, it is strongly believed that their first use undoubtedly started during his time (1214-1294).

Ich mach gut Brillen / klar vnd liecht/
Auff mancherley Alter gericht/
Von viertzig biß auff achtzig jarn/
Darmit das gsicht ist zu bewarn/
Die gheuß von Leder oder Horn/
Dreyn die gläser Poliert sind worn/
Dadurch man sicht/gar hell vnd scharff/
Die find jhr hie / wer der bedarff.

This Middle Ages woodcut shows a customer trying on eyeglasses from a street merchant. Woodcut, Werke G. Rodenstock, Munchen.

Early Lenses

Contemporary writers tell us that the Roman Emperor Nero viewed sporting events in his coliseum through an emerald lens. The emerald was probably chosen because of its pleasing green color. This was undoubtedly the world's first tinted sun lens. It's also believed that the stone cutter accidentally produced a slight concave shape to the stone which may have helped a near-sighted Nero see better.

Crystal Lenses

The earliest spectacles were produced by glaziers in Venice, Italy. Lenses in these first eyeglasses were made from quartz or rock crystal and produced by gold craftsmen experienced in working with rock crystal when producing jewelry. Artisans at that time were closely governed by individual statutes that applied to everyone engaged in a specific craft. The Cristallieri, as these craftsmen came to be called, received their own code in the fall of the year 1284. This seems to indicate that spectacles must have been common by this period if they required their own regulations.

One of the regulations governing spectacle makers involved substituting rock crystal lenses with inferior glass lenses. This was strictly forbidden. Rock crystal was very expensive while glass was considered a less desirable material for lenses. Early artisans were permitted to make lenses out of glass but only if they promised they wouldn't claim them to be quartz. On June 5, 1301, the city of Venice changed the rules and permitted persons to make reading spectacles from glass, providing they first took an oath in front of judges that they would never represent the lenses to be rock crystal.

Bishop Ugone da Provenza, shown in this 13th century painting is the first historical figure known to wear glasses. The painting can still be seen in the church of St. Nicolo in Treviso near Venice. His glasses are simple magnifiers with short handles, riveted together so they could perch on his nose. Painting copy, Werke G. Rodenstock, Munchen.

The First Evidence of Eyeglasses

The earliest historical figure documented who wore glasses was Bishop Ugone da Provenza. This Dominican priest was portrayed in a painting by Tomaso da Modena in the year 1252. The painting can still be seen in the church of St. Nicolo in Treviso, a city near Venice. His glasses were really nothing more than simple magnifying lenses with short handles, riveted together so they could perch on his nose (see illustration).

Glasses and the Printing Press

Spectacles did not come into common use until some time after Guttenberg invented the printing press during the mid-1500s. That event marked the real beginning of the need to correct vision with eyeglasses. Lenses used during that period were biconvex in form and used primarily to correct presbyopia. Some time later, it was found that biconcave lenses would help nearsighted persons see more clearly in the distance. It wasn't until 1500 that lenses were graded by their focal power. This was the idea of a man named Johannes Kepler. Prior to Kepler, lens powers were defined by the age of the person wearing them.

By the time the 19th century began, most glasses were sold in hardware stores. Gradually, gold and silver were used as frame materials, and jewelers became logical successors to hardware merchants. Merchants selling glasses purchased them as ready-made glasses, usually one dozen to the box, and sold them under an "inch-number" system. Away from large cities, itinerant eyeglass peddlers were the primary method of eyeglass distribution. Most of their wares were produced by European sources. People who thought they needed glasses would try on ready-made glasses, one after another, until they found a pair that helped. The lenses in these factory-made glasses were always the same power for each eye.

Lenses

Bausch & Lomb and American Optical were the first American companies to initiate mass production of glass spectacle lenses. Prior to that time, most lenses were imported from Europe, either as rough blanks or in uncut form. No optical glass was manufactured in the United States until World War I cut off traditional import glass sources for this country.

Pebble Lenses

Lenses made of rock crystal were originally introduced in England under the name of Scotch Pebble and later as Brazilian Pebble, names indicating their country of origin. Crystals are found all over the world, but those large enough to make into eyeglass lenses are

During the eighteenth century when wigs were commonly worn by persons of substance, eyeglass frames featured special spatula type temples that would fit under the wig, as seen here. During this period, many lenses were made of natural rock crystal (pebble). The stones were only found in small sizes and opticians often inserted the lenses in circular shells made of leather, horn or wood so the frames could be larger, as seen here.

only found in a few countries. During the period when pebble lenses were popular, spectacle lenses were about the size of a half dollar coin. The best crystals were found in Brazil, and interestingly, no rock crystals in paying quantities were ever found in the United States. Pebble lenses normally cost considerably more than glass lenses. They were much harder than glass and, as a consequence, much more difficult to grind and polish. Their harder surface made them last longer without accumulating scratches. This was highly valued by consumers.

Even when glass lenses became plentiful, pebble lenses continued to be sold as superior lenses because of their longer wearing qualities. It wasn't uncommon for eyeglasses to be passed on from one generation to another. The cost for pebble lenses kept rising as the supply of rock crystal diminished, but they were still being sold well into the 1920s.

Flat Lenses

Early lenses, whether made of pebble or glass, were all made in flat form, or biconvex for plus powers/biconcave for minus. Flat lenses were easier to manufacture, and no one thought to make them any other way. Flat lenses were still widely used into the 20th century.

The next evolution in lens form came about when lens designers tried to eliminate visual problems created with flat optics use. Lens makers found that lenses ground with a concave curve on the back side and convex on the front surface were positioned further from the eye and, as a consequence, would provide a considerably wider field of view. This had the additional benefit of reducing contact between the lens and the wearer's eyelashes, something that had always been a problem with flat lenses. Meniscus lenses were described as early as 1645 but not used for eyeglasses until the periscopic lens was introduced in 1804. These lenses had a standard -1.25 back curve for all powers. Conventional six base meniscus lenses first became available around 1890.

Lens Tints

Early in the evolution of ophthalmic lenses, lens producers looked for ways to increase profits, for them and for their retailers. The first lens "add-on" was simply adding color to raw glass. Some of the early uses of color in lenses included treatment of disease and even claimed improvement of vision. Early in the 19th century, blue, pink and green lenses were introduced. Later, Dr. William Crookes, an eminent British scientist, developed a special color that filtered infra-red rays and was named "Crookes" after the inventor. This cool blue/gray shade was quite effective but unfortunately gave wearers a rather ghastly look, with unattractive shadows beneath the eyes. American Optical produced a more attractive pink shade called "Cruxite." Between the two World Wars, pink lenses became very popular. Soft-Lite® lenses by Bausch & Lomb ultimately became the top-selling premium lens. Later B&L developed Ray-Ban® and G-15® proprietary sunglass lenses. Ray-Ban is today one of the ten best-known trademarks in the world.

Corrected Curve Lenses

Lens designers found that changing a lens design from biconvex or biconcave to a 6.00 diopter curve provided a wider field of view for the wearer. They also found other inherent optical distortions that cropped up as eyeglass lenses grew larger with increasing frame size. It was determined that changing front curves as lens powers changed would minimize marginal distortions, producing better acuity for the wearer.

This led to the development of corrected curve lenses. These modern lenses changed base curves for every one to two diopters of lens power. Before long every lens manufacturer was producing standard six base lenses, called "toric lenses," along with a separate line of corrected curve lenses.

The tough job then became convincing eyecare professionals to prescribe corrected curve lenses rather than the less desirable toric lenses. To provide an idea of the difference in cost between toric and corrected curve lenses, American Optical's 1935 prices listed a +0.50 +0.50 compound corrected curve uncut lens at $1.80 per pair. The same lens in toric form (non-corrected curve) was $1.55 a pair. The difference was only 25 cents, but it was more than thirty years before old-fashioned toric lenses were totally eliminated.

Minus Powers

As fused multifocals gradually took over the multifocal market, replacing old-fashioned one-piece lenses like the Ultex, a new problem arose. Fused multifocals were surfaced on the back side which meant labs surfaced them with the cylinder on the back surface. Single vision stock lenses at that time were all produced with plus cylinders on the front side. As patients aged and went from single vision lenses to bifocals, they often experienced difficulty adjusting to visual differences created in switching from plus cylinders to minus cylinders.

This was also a time when labs first started using automatic bevel edgers for finishing lenses. One of the major benefits of bevel edgers was the ability to apply a special "hide-a-bevel" to high minus lenses. This is an automatic way of applying most of the bevel to the back side of the lens, hiding the lens thickness behind the frame. Plus cylinders, especially in higher cylinders, produced an unattractive bulge in the front rim of the frame, following the axis of the cylinder. When

The use of colored glass lenses for implied therapeutic purposes or simply for the visual comfort they provided was the first enhancement for ophthalmic lenses. One of the most exciting aspects of lenses made from CR-39® resin was their ability to be tinted to any color of the rainbow, an impossibility with glass lenses. Best of all, the tinting could be done in a retail office, offering new profit opportunities for everyone.

cylinders are ground on the back side of the lens, this cylinder bulge is completely hidden by the frame. This provides a considerable cosmetic advantage for minus cylinders, in addition to their visual advantages.

Minus cylinder lenses were more expensive to produce than plus, but their advantages were too obvious to ignore. Lens manufacturers, facing the heavy costs of converting production equipment to minus cylinders decided to convert their lenses to corrected curve form at the same time. This conversion to single vision minus cylinder stock lenses effectively doomed toric lenses, to everyone's great relief. Today, all single vision lenses are produced in minus cylinder form and are also considered corrected curve.

PLASTIC LENSES

A great deal of work was done in England before and during World War II in an effort to develop a lightweight, shatter-proof plastic lens. Most of this work resulted from the British experience working with acrylic (polymethyl-methacrylate), a material widely used in Great Britain before and during the war for aircraft windshields. IGard, a division of Combined Optical Industries, Ltd., a prominent British lens manufacturer, began producing prescription lenses made of acrylic. These enjoyed modest distribution in the United States before World War II. After the war, McLeod Optical of Providence, R.I., began distributing imported acrylic lenses to other labs located in the United States. These IGard® lenses were produced only in finished uncut form and could not be surfaced. They were lightweight but proved to be brittle, subject to scratching and prone to yellowing after a few months in inventory.

There were other attempts to utilize acrylic materials but the plastic lens revolution was virtually dormant until Pittsburgh Plate Glass Co. came up with CR-39® resin. That event eventually made lightweight plastic lenses a reality.

During the scramble to find peacetime uses for CR-39® resin, some innovative PPG scientists proposed that colorful, long-lasting fishing lures could be made from the material. Fortunately, wiser heads concluded that ophthalmic lenses offered greater opportunities.

The Quest for Plastic Lenses

PART ONE

As the country came out from the depths of the depression, popular magazines of the day were filled with stories of the wonders of new plastic materials that promised to create a whole new world for consumers. Housewives began discovering the benefits of sturdy, lightweight housewares made from Bakelite® synthetic resin, the convenience of cellophane food wrappings and the ease of self-stick Scotch® tape. The 1939 World's Fair in New York carried the theme "World of Tomorrow," and much of the world they predicted involved the benefits and glories of plastics.

One familiar plastic developed during the thirties was polymerized methyl methacrylate (PMMA), introduced in 1937 as Lucite® and Plexiglas® resins. This material had excellent optical properties and was considered suitable for eyeglass and camera lenses, and for producing special effects in highway and advertising illumination. Another plastic was polytetrafluoroethylene, first made in 1938 and eventually produced commercially as Teflon® resin in 1950. Also developed during the 1930s was the synthesis of nylon.

There were a few far-sighted people in the optical industry who were convinced that one of these exciting man-made materials would eventually prove to be a suitable material for ophthalmic lenses. Two basic factors motivated this desire for a plastic lens. One was the safety issue (greater resistance to impact). The other was comfort (lighter weight lenses).

SAFETY ISSUES

Auto manufacturers faced a similar safety issue with automobile windshields. The auto-driving public grew concerned over the serious cuts and injuries that were the inevitable result of broken car windows, often in the most minor of traffic accidents. A clever glass maker found that laminating thin sheets of plate glass over a strong inner layer of plastic minimized injuries from broken glass. The first laminated automobile windshields had an interlayer of cellulose acetate. Pittsburgh Plate Glass Co. produced a superior windshield with a polyvinyl butyral interlayer which was more yielding, and therefore safer, than cellulose acetate. When laminated windshields broke, shards of glass were held together by the plastic core. Laminated glass windshields worked so well that someone in the optical industry decided to adapt a similar laminated process to ophthalmic lenses.

Called "Motex," these safer laminated lenses were moderately successful during the thirties and forties. They were widely advertised as a "non-shatterable" lens and used mostly for children's eyewear. Each pair of lenses came with a $15,000 insurance policy against eye damage. Since there were two layers of glass in each lens, the layers were kept thin in an effort to keep down the weight. Unfortunately, these thin wafers made the lenses considerably more fragile than conventional lenses, and they often cracked under normal handling. The important thing, however, was that their construction prevented pieces of glass from entering the wearer's eyes, making for less danger to the wearer.

Plastic Lenses

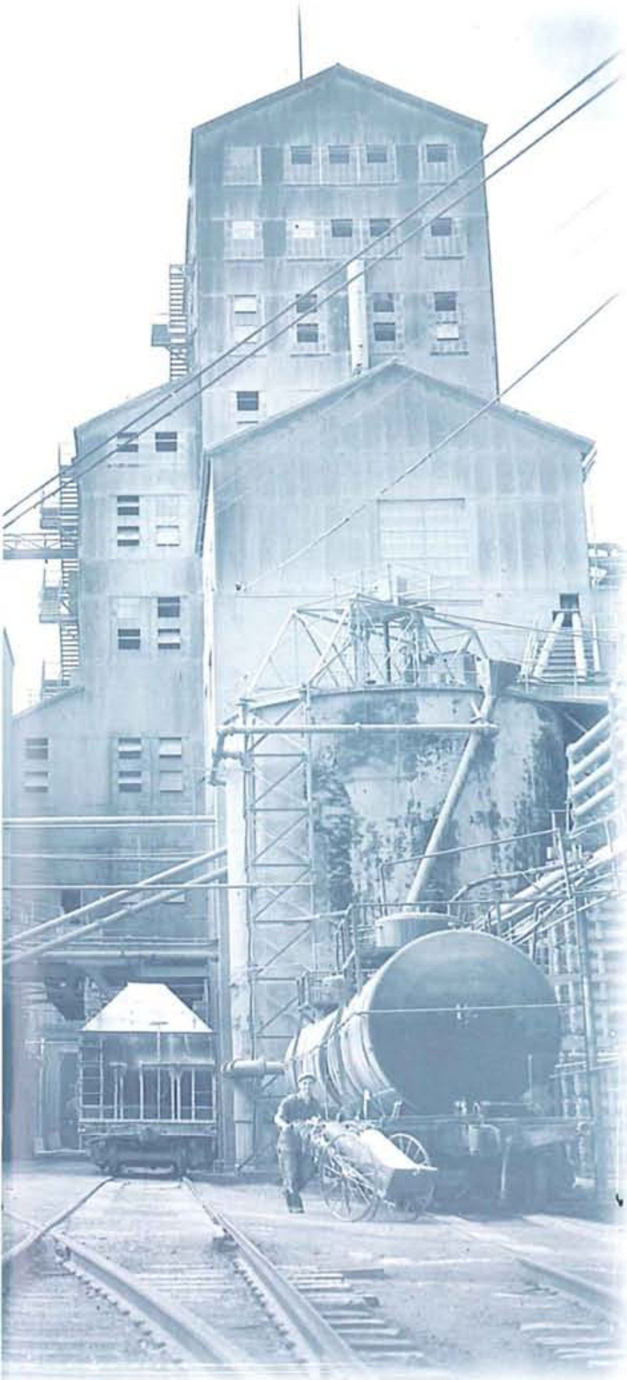
The first serious work in developing an ophthalmic lens made from lightweight plastic was undertaken by an English company, Combined Optical Industries Limited (COIL). COIL developed a plastic lens made from PMMA in the 1930s. A few of these early lenses were distributed in the United States under the name IGard® prior to World War II. Following the war, COIL decided there were real opportunities in the States and attempted to market their lenses in this country. They met with little success until 1949 when McLeod Optical in Providence, R.I., was established as the exclusive distributor in the U.S. for IGard lenses.

Norm McLeod knew most lab owners in the country, so his company enjoyed moderate success in selling IGard lenses to major independent labs. It turned out to be a hard sell, primarily because the lenses were so easily scratched and relatively expensive. Another unfortunate attribute of these early lenses was a tendency to turn a rather ghastly shade of yellow, even when stored in stock drawers.

During that earlier pre-war period (1938), another company in the United States was working on development of a plastic lens. Located in Beverly Hills, Calif., the company name was "The Unbreakable Lens Company of America," later shortened to "TULCA." The company was acquired by the Univis Lens Company and moved to Dayton, Ohio, in hopes that TULCA's research would give Univis a lead in development of plastic lenses.

TULCA followed the same path as COIL by utilizing PMMA for their lenses. In November 1938, M. H. Stanley, president of Univis, sent three letters to McLeod Optical, one of the first American labs to offer plastic lenses to their accounts. McLeod was advised that TULCA lenses were not available for general distribution, but Univis was prepared to provide TULCA lenses for "emergency cases where the safety factor predominates." First division spheres, cylinders and compounds were priced at $4.00 (with a 15 percent discount for McLeod) with a suggested minimum retail price to consumers of $10.00 to $11.00. TULCA was never able to solve the scratching problem, and Univis ultimately closed the company when they abandoned their research and development efforts to produce plastic lenses.

In spite of these disappointments, many in the industry were fascinated by the crystal clear properties of PMMA and continued struggling to make ophthalmic lenses from the material. Ironically, PMMA would later prove to be the ideal material to use in fashioning corneal contact lenses (prior to the development of soft contacts).



The famous railroad tank car filled with 38,000 pounds of CR-39® monomer that prompted the search for civilian uses for allyl diglycol carbonate (ADC) can be seen in this 1945 photograph of the shipping yard at PPG's Barberton, Ohio, plant. These marketing efforts led to the successful development of lightweight plastic ophthalmic lenses.

Worldwide Development of Plastic Lenses

Development of what led to today's plastic lenses came primarily from the efforts of three manufacturers. The earliest pioneer was Robert Graham, first with the Univis Lens Company and later with Armorlite, the company he founded in California. For a period of six years, Graham was the only source for plastic lenses made of CR-39® resin. Later, SOLA in Australia began experiments for producing plastic lenses, and during that same time frame, Essilor in France began working to produce a lightweight organic lens.

The story of how each of these innovative companies solved the problems of producing plastic ophthalmic lenses follows.

PART TWO

DR. ROBERT GRAHAM & ARMORLITE

Graduating from Ohio State University with a degree in applied optics, Robert Graham took a position with Bausch & Lomb, at the time, the second largest optical manufacturer in the world. On learning that Univis was conducting experiments to make ophthalmic lenses out of PMMA, Graham was asked to visit Univis and report back to B&L on the progress of the Univis project. Several months following his Univis visit, Graham was contacted by Univis President Jack Silverman and offered a job in the sales department. Largely because of his strong interest in the company's experiments in the field of plastic lenses, Graham joined Univis.

UNIVIS LENS COMPANY

Univis was a fast-growing multifocal manufacturer. Their product line of Flat top multifocals had become the industry's leading products and were much favored by independent laboratories, always in fierce competition with the industry giants, Bausch & Lomb and American Optical. Univis Lens products had become the industry's premier multifocal line. Graham was attracted to the company because of what he heard about their interest in developing plastic lenses. Six years after joining Univis, he advanced to the position of company sales manager. The project in which he was most interested, however, was simply having no success in achieving marketable plastic lenses. By this time, Univis had spent a third of a million dollars—a considerable sum for that time—and the company had virtually nothing to show for their investment.

TULCA

In their quest for a practical lightweight lens, Univis acquired a company in Beverly Hills, Calif., called TULCA (The Unbreakable Lens Company of America). This company had been compression-molding lenses made of Plexiglas® resin, using metal molds. Univis purchased TULCA for their technology but six years after taking over the company, Univis discovered they were being sued by Combined Optical Industries, Ltd. (COIL), the English company that produced IGard® lenses. COIL claimed to have conceived the TULCA production method which involved injection molding. This process used high chrome-content steel molds, necessary because of the extreme heat and high pressure created during the molding process. Highly discouraged by the whole experience, Univis turned their back on the entire plastic lens project.

Robert Klark Graham founded the Armorlite Company in Pasadena, Calif. For a period of six years, he and his company were the world's only source for lenses made of CR-39® monomer.

THE MOVE TO CALIFORNIA

This was a bitter pill for Graham. He believed Univis was giving up too easily. The technicians who had been working with Graham on the plastic lens project felt the same way. When Univis shut down the project, these technicians lost their jobs. Bob Lanman had been involved with casting lens research and anti-reflection coating technology at Univis and was one of the ones who was let go. Graham suggested he and Lanman set up a lab of their own to work on the plastic lens project. Both men moved their families from Dayton, Ohio, to California, taking all but one of the Univis lens researchers with them. They set up their new company in Pasadena. Graham and Lanman agreed to each draw a salary equivalent to what they had earned at Univis. Whenever there were no dollars to pay them, they would take the equivalent in shares. Initially the new company was called Plastic Lens Company, but the name was later changed to Armorlite.

The terms of their agreement also permitted Graham to fit contact lenses on the side when there was no money for salaries. For several years, the Graham family was supported primarily by contact lens fees (Graham was a consultant to Kevin Tuohy, inventor of plastic corneal lenses). Graham's accumulated stock ownership and his cash investment eventually made him Armorlite's largest stockholder.

The first plastic lenses produced by the Armorlite Lens Company were made of polymethyl-methacrylate (PMMA), a material better known by the trade names Lucite® and Plexiglas® resins. Injection-molding of PMMA lenses had also been tried but was never satisfactory because of striae introduced during the injection process. The required metal molds were expensive and had a short life.

Graham's team developed a different process which involved machining discs made of PMMA to the approximate desired curves on a lathe. These turned blanks were polished by pressing them between highly polished glass molds, using moderate heat and pressure. This minimum-flow process produced a fine-looking lens that was optically clear with no machining grooves or residue marks. Unfortunately, the lenses enjoyed only moderate success. The company had earlier tried making lenses out of styrene but abandoned that material because it was too soft and prone to scratching. The new PMMA lenses had the same problem. Excessive scratching had become the insurmountable problem.

CR-39® Resin

For some time Dr. Graham had known about CR-39® resin, the allyl resin initially developed by PPG as a bonding solution for war planes. CR-39 resin had first been used during World War II for fuel tanks in bombers. Sheets of this new plastic had also been sandwiched between thin pieces of glass and used for bomber windows, strengthening the glass sheets and, in effect, reducing their weight. This lowering of gross weight extended the bombers' flight range. CR-39 resin had been classified as a military property during the war and, as a consequence, was unavailable to Univis. Graham (still at Univis) managed during the war to gain access to five gallons which he used for experimental purposes. With the war at an end, and Pittsburgh Plate Glass Co. sitting with a railroad tank car full of the material, word of its availability reached Pasadena where Graham jumped at the opportunity to try it once again for ophthalmic lenses.

Like PMMA, CR-39 resin was optically clear but turned out to be thirty times more abrasion-resistant than Plexiglas® or Lucite® resin. There were, however, certain inherent problems in casting lenses with CR-39 resin. The first one is easy to understand. The original design function of CR-39 resin was to act as a bonding agent for gluing together laminated multi-ply materials. This proved to be a less than desired property for lens casting because the resin tended to bond to the mold, particularly when the mold was made of metal. Fortunately, Graham's group favored glass molds.

Shrinkage

An equally serious problem was that lenses cast from CR-39® monomer experienced a 14 percent shrinkage as the material cured. This wasn't a problem when casting plano lenses, since the shrinkage merely made the lens edges retract slightly. When lenses were cast with corrective power, however, a variance in thickness between the center and the edge was created. This resulted in a differential shrinkage which inevitably created optical distortions in the finished lens. Graham's answer to this innate property of CR-39 resin was to cast thick blanks in which the back curve matched the finished front curve. This form allowed uniform shrinkage during curing with no induced distortion. Armorlite would then grind and polish the back surface to the required curve and thickness.

Graham would later write about those traumatic days. "We will never forget those nights, month after month, when we sat by the ovens listening to the sound of cracking glass molds!" Breaking of glass molds resulted from the combined action of the resin's shrinking factor (14 percent) and its adhesive properties (sticking to the mold). Eventually, after a great deal of trial and error, Graham's persistence

Most of those involved in casting lenses made from CR-39® monomer during the first several years were fully convinced that no one would be able to cast bifocals in this new lightweight resin. As a result, everyone concentrated on single vision blanks. Here, a portion of the day's production is seen on it's way to packaging.

paid off when his team found a better glass for making molds and was able to add a release agent to the monomer. Finally, they successfully casted lenses with CR-39® resin.

The Start-Up

ARMORLITE LENS CO., INC.

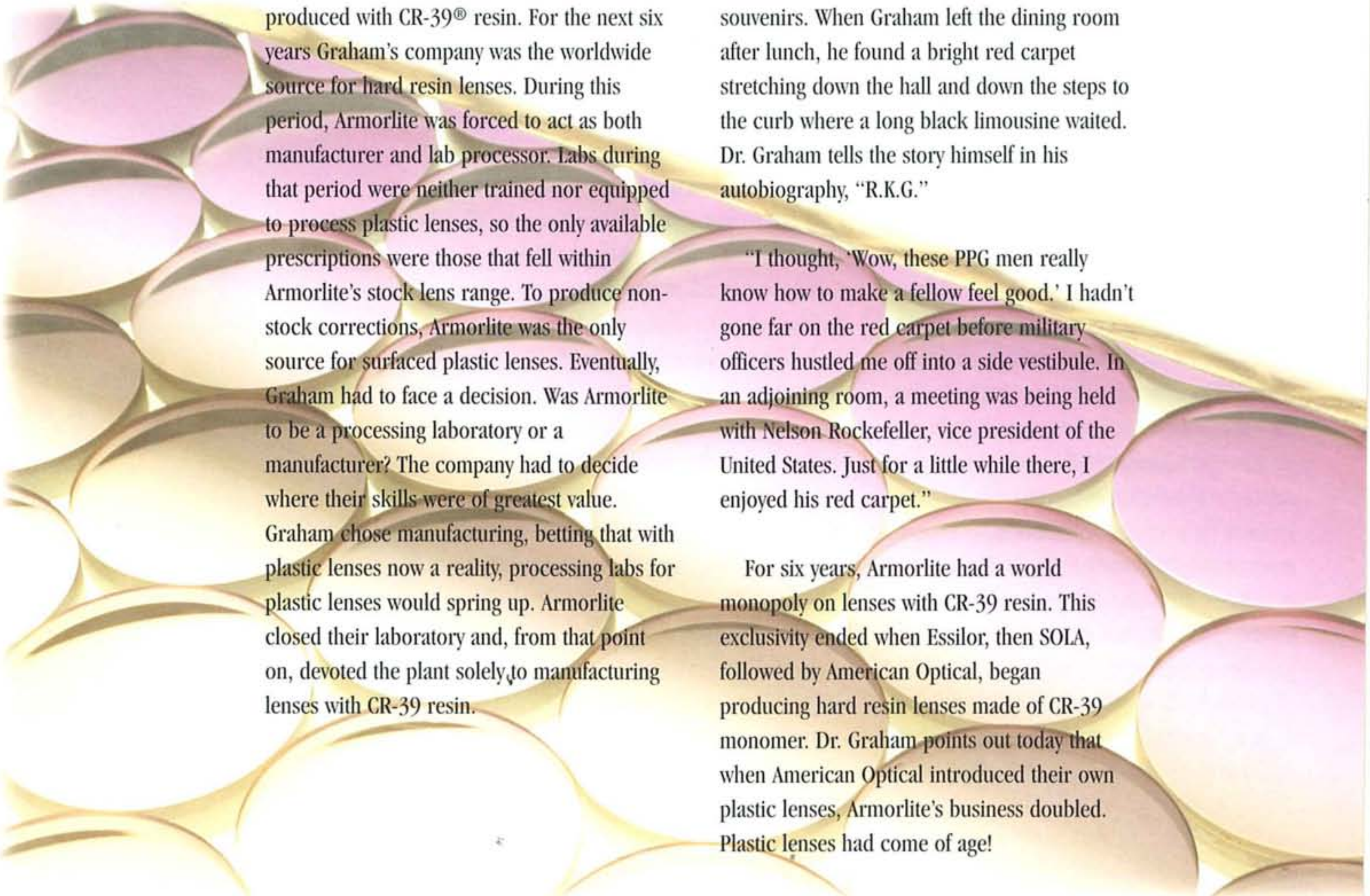
The year 1947 saw the Armorlite Company incorporated and the beginning of lenses produced with CR-39® resin. For the next six years Graham's company was the worldwide source for hard resin lenses. During this period, Armorlite was forced to act as both manufacturer and lab processor. Labs during that period were neither trained nor equipped to process plastic lenses, so the only available prescriptions were those that fell within Armorlite's stock lens range. To produce non-stock corrections, Armorlite was the only source for surfaced plastic lenses. Eventually, Graham had to face a decision. Was Armorlite to be a processing laboratory or a manufacturer? The company had to decide where their skills were of greatest value. Graham chose manufacturing, betting that with plastic lenses now a reality, processing labs for plastic lenses would spring up. Armorlite closed their laboratory and, from that point on, devoted the plant solely to manufacturing lenses with CR-39 resin.

A Trip to Pittsburgh

During this period, PPG invited Graham to visit the Pittsburgh office in appreciation for helping them find a major peacetime use for CR-39® resin. Dr. Dial, one of the original patent-holders of CR-39 resin, hosted a luncheon at Pittsburgh's Duquesne Club. There were many flattering speeches about Graham's ingenuity, accompanied by awards and souvenirs. When Graham left the dining room after lunch, he found a bright red carpet stretching down the hall and down the steps to the curb where a long black limousine waited. Dr. Graham tells the story himself in his autobiography, "R.K.G."

"I thought, 'Wow, these PPG men really know how to make a fellow feel good.' I hadn't gone far on the red carpet before military officers hustled me off into a side vestibule. In an adjoining room, a meeting was being held with Nelson Rockefeller, vice president of the United States. Just for a little while there, I enjoyed his red carpet."

For six years, Armorlite had a world monopoly on lenses with CR-39 resin. This exclusivity ended when Essilor, then SOLA, followed by American Optical, began producing hard resin lenses made of CR-39 monomer. Dr. Graham points out today that when American Optical introduced their own plastic lenses, Armorlite's business doubled. Plastic lenses had come of age!



Scratches

The only down side in comparing plastic lenses to glass was plastic's susceptibility to scratching. Armorlite's scientists tried everything to improve scratch resistance, reviewing more than 2,000 patent abstracts in their quest for a suitable abrasion-resistant treatment. The basic problem was the difference in thermal-coefficient of expansion between coatings and lenses made with CR-39® resin. This usually resulted in crazed surfaces after exposure to temperature variations.

In the early 1970s, the famous Minnesota Mining and Manufacturing company (3M) came to the conclusion that they had the answer. Coatings had always been one of 3M's technological strengths, but finding the right coating for lenses made from CR-39 resin was eluding even these innovative scientists. Among their researchers' discoveries was that the cleanliness requirements for production coating of ophthalmic lenses exceeded anything the company had previously experienced. The ultimate answer to the cleanliness problem turned out to be a production facility that reduced airborne particles to a minimum.

From 1974 to 1976, 3M refined their coating process. They set up special test laboratories to evaluate treated lenses. Lenses that looked fine to the 3M chemists working on the project were totally unacceptable to lab technicians who had a better understanding of what was required. Eventually 3M offered the coating service they developed to labs in five states on a test market basis.

More than 25,000 pairs of hard resin lenses with the new 3M treatment were sold in the test market from April 1978 to December 1979. At the end of the 20 month test, 3M found that all the test labs wanted to continue selling the coated lenses. Just prior to this time, 3M, concluding they had a real handle on the optical business, bought the Armorlite Company and transferred the scratch-coating technology to Armorlite. The 3M coating technology was introduced nationally under the trade name RLX Plus®.

When Armorlite was sold to 3M, the original investors who had paid $1.00 per share for their stock received $4,164.88 per share under the terms of the sales agreement.

Final inspection of semi-finished blanks made from CR-39® resin as they pass out of the annealing oven following the manufacturing process.

Signet Uptown

Signet Uptown was an all-plastic wholesale laboratory, a rarity at the time the company was formed. They also casted lens blanks and soon became a major lens manufacturer. By 1971, they produced single vision, bifocal and trifocal lenses, as well as an innovative new post-cataract lens design called hyperaspheric.

In 1976, the company was sold to American Hospital Supply Corporation who sent Richard Ormsby to serve as general manager. In 1981, Ormsby, along with Robert Jepson, purchased Signet from American Hospital Supply Corporation. Later that same year, Ormsby and Jepson also purchased Armorlite from the 3M Corporation. The two companies were merged to form Signet Armorlite, Inc. From that point on, the company was an affiliate of Jepson Corporation. Signet Armorlite was later purchased from Jepson by the Eagle Corporation. In 1993, Signet Armorlite formed a joint alliance with Industrie Ottiche Europee. Each company continues to operate independently.

SOLA Optical

Today, SOLA Optical is recognized as one of the world's major manufacturers of spectacle lenses, but the company evolved from humble beginnings. The first experiments of casting lenses made of CR-39® resin in Australia began in 1956. The company founders were a group of men led by Noel Roscrow who worked for a prominent optometric practice named Laubman & Pank in the city of Adelaide. Roscrow and his associates began their efforts in a garage by using a gas ring and a saucepan, experimenting in an effort to produce plastic lenses. Hard resin lenses were just beginning to make inroads in other countries, primarily the United States and France. This small group of Australian entrepreneurs was determined to cast lenses in this new CR-39 material.

By 1960, Noel Roscrow convinced the owners of the optometric practice to let him spin off his small group and form a new company they would call Scientific Optical Laboratories of Australia (the company now known as SOLA). As a means of producing cash flow during those early years, the employees also performed a number of other tasks. They did binocular repairs for the Australian army, vacuum coated ophthalmic lenses, made optical instruments and, somewhat incidentally, manufactured all rear vision mirrors used for cars produced in Australia. Whenever they could steal some time away from these tasks, they worked on casting lenses with CR-39 resin. They established a branch in Melbourne in 1965 for manufacturing and repairing instruments but later converted that plant for the purpose of prescription surfacing and glass mold-making.

Plano Lenses

Initially, the company concentrated on casting to prescription completely finished lenses. They found surfacing and polishing lenses made with CR-39® monomer difficult, if not impossible, so casting finished lenses seemed to be the way to go. Gaskets for separating the molds were made by hand, and the lens molds were hand filled individually by syringe. It was a very slow process. Needing another product, the company began mass-producing plano lenses for sunglass and industrial use. Manufacturing lenses with CR-39 resin was still a new process, and Roscrow and his team had no one to tell them how to do it.

SOLA concentrated on plano lenses for two reasons. First, planos were easier to manufacture, and the owners believed producing planos would provide training to help their people solve the greater problems of casting prescription-power lenses. At that time, the common opinion of most casters was that manufacturing semi-finished blanks was 10 times more difficult than planos and making finished prescription lenses 10 times more difficult than semi-finished. The second reason, and perhaps more important reason for producing planos, was their belief that broad distribution of plano plastic lenses by SOLA would help convert the world to the benefits of these new, lightweight lenses.

Marketing Lenses with CR-39® Resin

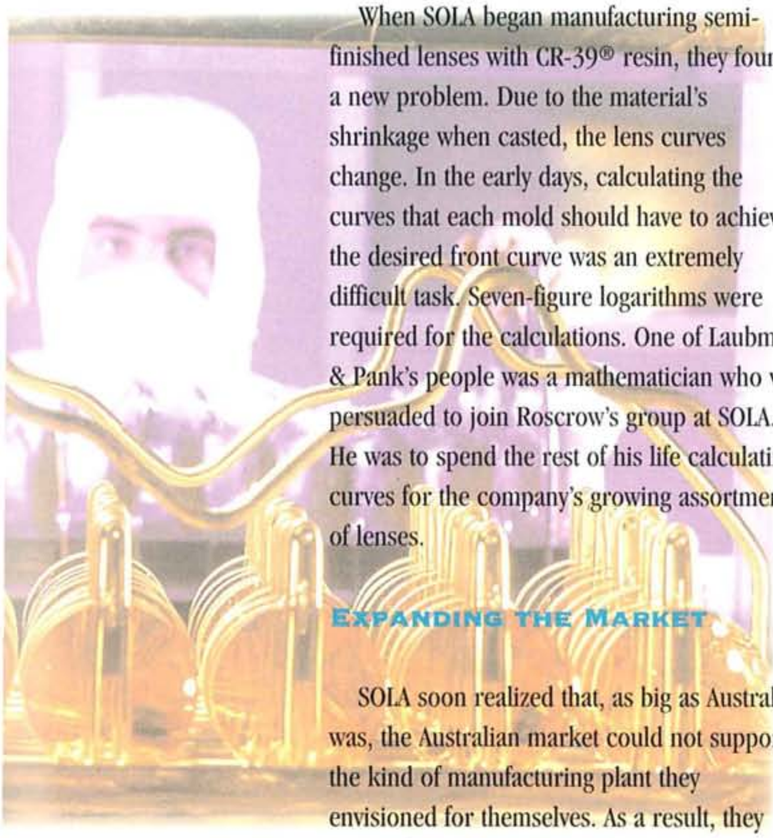
To establish plastic lenses as a viable alternative to glass, SOLA first had to convince the eyecare professionals in Australia. One of the early marketing promotions the company implemented was making thousands of clip-on sunglasses with plano lenses and bundling them into batches of five. These bundles were shipped out to hundreds of opticians and optometrists throughout Australia. One pair was free, and the other four were billed at a special low price. Seventy percent of the retailers receiving these bundles kept and paid for the sunglasses, 15 percent kept them and didn't pay, and five percent wrote to SOLA to say how impressed they were with the company's positive attitude regarding plastic lenses. The balance complained bitterly about the use of such "cheeky" sales tactics. The end result, of course, was a steadily growing acceptance of lenses with CR-39 resin in Australia.

World Production

At this time, there were only three companies worldwide making any serious attempt to manufacture plastic lenses. These were Essilor in France, Armorlite in the United States and SOLA in Australia. For reasons that no one has ever determined, each company carved out their own niche in concentrating production efforts. Essilor's efforts were aimed at producing finished lenses, Armorlite

Casting lenses from CR-39® resin requires meticulous cleaning and care for the precise glass molds in which they are cast. Many steps in the process are accomplished in a "clean room" environment. In this photograph, trays of finished stock lenses are removed from the oven following curing of the lens coating.

concentrated on semi-finished blanks and SOLA zeroed in on plano lenses.



When SOLA began manufacturing semi-finished lenses with CR-39® resin, they found a new problem. Due to the material's shrinkage when casted, the lens curves change. In the early days, calculating the curves that each mold should have to achieve the desired front curve was an extremely difficult task. Seven-figure logarithms were required for the calculations. One of Laubman & Pank's people was a mathematician who was persuaded to join Roscrow's group at SOLA. He was to spend the rest of his life calculating curves for the company's growing assortment of lenses.

Expanding the Market

SOLA soon realized that, as big as Australia was, the Australian market could not support the kind of manufacturing plant they envisioned for themselves. As a result, they focused on export sales. In 1968, a foreign operation was opened in Japan, expanding in the early 1970s to the United Kingdom, Italy, Brazil and finally, the United States in 1975. By this time SOLA had evolved into a global network of companies. Their semi-finished line was manufactured with a 68 mm diameter, at that time, the largest available blanks in the world.

Opening the U.S. Market

When SOLA came to the United States, they opened a 15,000 square foot facility in Sunnyvale, Calif. At this time, the U.S. lens market was still dominated by glass lenses, representing 70 percent of the market at the time SOLA's American plant opened. As a result, the company's marketing efforts during the '70s were devoted to aggressively converting the market to lighter, more impact-resistant lenses. Growing rapidly, the company moved their U.S. manufacturing operations to a much larger facility in Petaluma, Calif., and broadened the product line. An additional production site was set up in Mexico in the mid-1980s.

One of the main limitations in SOLA's growth was the lead time for expanding and maintaining the wide range of precision molds required for casting. In 1975 a specialist center was established in Singapore to supply glass molds to plants in Italy, Brazil, the United States and Australia.

Pilkington Group

In 1979, SOLA was acquired by the Pilkington Group of the United Kingdom. One of the reasons for SOLA's remarkable growth was the U.S. market's shift from glass to plastic lenses. By 1983, the U.S. market was over 50 percent plastic and by 1992, more than 80 percent. SOLA took every advantage of this growing market.

In 1987, SOLA's parent company, Pilkington, acquired the vision care business owned by Revlon, including Coburn Optical. The former Revlon operations were operated separately from SOLA. One exception was the Coburn glass lens business which was added to SOLA's organization.

New owners

In 1993, the SOLA Group was purchased by AEA Investors, Inc. This privately-held company, founded in 1968 as American European Associates, Inc., invests in successful, industry-leading companies for long term growth.

Today, SOLA's operations span the globe, operating 12 manufacturing sites on five continents with sales offices in 16 countries. Every week, SOLA customers, located in some 70 nations, order more than one million lenses. The company estimates that more than one hundred million people around the world are wearing SOLA lenses today. Even those optimistic dreamers in Adelaide couldn't have foreseen what would result from those primitive attempts to make plastic lenses in a garage.

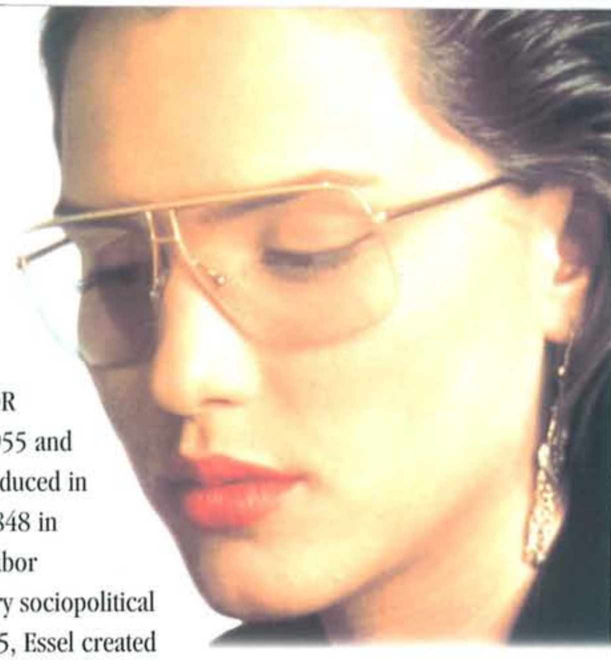
Essilor International

To understand Essilor's role in the development of plastic lenses, it's necessary to review the origins of what has become the largest optical company in the world.

Essilor Family Tree

The Lissac Company was founded in 1931 by George Lissac, an entrepreneur who introduced marketing to the conservative European optical industry. Lissac later created SIL (Societe Industrielle de Lunetterie) in 1946 and a separate company, LOS (Lentilles Ophtalmiques Speciales), in 1948. These two companies included frame and lens research and development, manufacturing and distribution operations. SIL, the frame division, created the revolutionary AMOR rimless frame in 1949. "AMOR" is a condensed version of the French word "amortisseur" which means shock absorbing.

Rene Grandperret, with LOS, developed an early interest in plastic lenses, dating back to the late 1940's. In 1952, LOS introduced the



ORMA® 500 lens made from Plexiglas® resin, marking the beginning of plastic spectacle lenses in France. Lenses made from Plexiglas resin were only marginally successful because of the familiar problem of scratching. LOS eventually found what they decided was the ideal resin in the United States and began experimenting with PPG's CR-39® monomer.

After years of continuing research, LOS eventually mastered the difficulties of casting lenses from CR-39 monomer and introduced the ORMA® 1000 lens with CR-39 resin in 1956. This lens was patented and introduced worldwide in 1959. The following year, the name of the lens division was changed from LOS to LOR (Lentilles Ophtalmiques Rationnelles). By 1961, SIL had introduced the polymil frame. In 1966, the Lissac group merged with Telegic, a company specializing in the production of corrective lenses. Then in 1969, Lor-Telegic joined the other division of the Lissac group, SIL (Society Industrial de Lunettegy) to form a French company with the now familiar name of Silor. ORMA 1000 lenses made with CR-39 resin were introduced in the United States by Silor's American subsidiary, La Lunette de Paris.

ESSEL

Meanwhile, another significant French company, Essel, began to use the company's name in marketing Nylor® frames, an improved version of the AMOR frame created by Lissac in 1955 and Varilux® optical lenses, introduced in 1959. Essel was formed in 1848 in France during the Spirit of Labor Cooperation, the revolutionary sociopolitical worker's cooperative. In 1955, Essel created the Nylor frame which enjoyed huge success. The cash flow generated by Nylor frames helped finance the Varilux® I optical lens.

The "marriage" of these two companies (Silor and Essel) brought together recognized ophthalmic brand names (Nylor, AMOR, Varilux I and ORMA 1000), research and development teams, and major manufacturing and distribution networks. The two most important optical companies in France merged to become Essilor International.

PLASTIC LENSES

The company's first successful corrective lenses were cast on April 29, 1954 by Bernard Mignen when he successfully polymerized lenses with CR-39® resin in glass molds. His experiments took place in the kitchen of a factory in St. Maur, France, which had been recently purchased by Georges Lissac. Early efforts were unproductive, primarily because of problems with breakage of the glass molds and great difficulty in separating lenses from their glass molds. Eventually, in 1959, the company successfully launched commercial

The introduction of lightweight lenses made from CR-39® resin had a major impact on eyeglass frame fashions. As the lenses grew in popularity, so did the size of frames and before long, stylish oversize eyeglasses became the leader in eyewear fashions. Attractive eyewear like that worn by the model would have been impossible with glass lenses.

production of lenses made with CR-39® resin under the trade name ORMA® 1000. That became possible when Jean Boudet and Bernard Mignen developed an improved molding process.

Early Attempts

In 1941, Rene Grandperret, 20 years old and a new employee at Lissac Brothers, visited a laboratory in Colombes, France, where two engineers with the National Conservatory of Careers were trying to produce lenses made of Plexiglas® resin cast in molds instead of using heat compression. They used spring-actuated molds that allowed the mold walls to follow the retraction of the Plexiglas resin as it solidified (the material shrank 22 percent during polymerization).

Second Attempt — Sunglass Lenses

Following World War II, Georges Lissac began producing sunglasses using lenses made of Plexiglas® resin. In 1946, Sovis, a branch of Saint-Gobain, transformed sheets of colored Plexiglas resin into sunglass lenses by cutting the sheets into circles which were then heated and pressed into plano lenses. Because the lens surfaces were parallel, this was a relatively easy way to produce lenses made of Plexiglas resin.

Third Attempt — Plexiglas® Resin Molded Through Heat

The IGard® lens process involved sheets of Plexiglas® resin that were compressed in heated iron molds. A license for this process was granted in 1937 to Peter Koch of Goreyn. This was the process used by COIL in England. In 1946, another license was requested by Arthur Kingston who also experimented with Plexiglas resin and polystyrene. Georges Lissac was initially in favor of negotiating a license for molding lenses made from Plexiglas resin but changed his mind after talking to engineers who described the process used by COIL. He didn't believe the COIL process was sufficiently innovative. In 1950, a mechanic named Bonnion received approval from Lissac to begin production of lenses made from Plexiglas resin. The lenses were reasonably impact-resistant but very susceptible to scratching and yellowing with age. These early plastic lenses, called ORMA® 500 lenses, were used primarily for children.

CR-39® Resin — Military and Optical Uses

One day Grandperret received a transparent sheet that seemed to have interesting mechanical and optical properties. The material had good transparency and resistance to scratching 40 times that of Plexiglas® resin. The commercial name was Homalite®, and it was made of CR-39® resin. The material had been used as windows for American tanks during the war. In 1953, Grandperret ordered a half liter of CR-39 resin for experiments.

The Men Who Made Lenses With CR-39® Monomer A Reality

Robert K. Graham grew convinced that plastic lenses were possible while working for Univis Lens Company. That vision became a reality but only after years of heartbreaking failures and countless nights of listening to the sound of breaking molds caused by heat from the polymerizing process.

Noel Roscrow was making plastic lenses on a gas ring in a garage when he and his group formed Scientific Optical Laboratories of Australia, the company known worldwide today as SOLA. Upon his retirement, Chairman David L. Pank credited Roscrow's mix of knowledge, entrepreneurial drive, energy and sheer cheek as contributors in helping achieve the company's success.

Rene Grandperret was 20 years old when he first became involved in an attempt to produce lightweight lenses from Plexiglas® resin in 1941. Twelve years later, he discovered some interesting sheets of transparent material that had been used in American tanks during World War II. The material was made of CR-39® resin, and he immediately ordered a half liter of material from PPG. Two years later Lissac was making sun lenses from CR-39 monomer.

The First Lens Made with CR-39® Resin

Saint-Gobain accepted an order to deliver circular blanks made of Pyrex® glass for use in building molds. Plastisol was used for making gaskets to hold the molds. The process of polymerization was new to Grandperret's people, and initially, all the cast lenses broke during polymerization due to lack of ventilation. They soon discovered they had to find a way to control the rise in temperature during polymerization. If the temperature rose too much, the lenses turned yellow and broke. On April 29, 1954, for example, they produced three good lenses and one broken lens. Pittsburgh Plate Glass Co. referred them to two people who had been working on plastic lenses for several years. One was a man named John O. Beattie; the other was Robert Graham in the United States. In June of 1954, Grandperret spent three weeks in the United States learning the methods being used by Graham.

Solar ORMA® 1000 Lenses

In 1955, Lissac, Inc. decided to make sun lenses of CR-39® monomer. The resin was ordered and production methods similar to those observed in the United States were initiated. There were still problems controlling polymerization, but eventually these were resolved. Unfortunately, they had homogeneity problems in the first batch of sun lenses. The result was a variation in color.

ORMA® 1000 Lenses — The Ultimate Goal

In the meantime, many production methods for casting lenses with CR-39® resin were tried. One was suggested by John O. Beattie which involved partially polymerizing the lens and removing it from the mold to continue polymerization in a large pan. Later, polymerization in the mold was tried. General consensus deemed that molding lenses with CR-39 resin would never be adaptable to bifocals. By this time, both the English and the French were convinced that the ultimate answer would be a lens made of Plexiglas® resin covered with a veneer of CR-39 resin for scratch protection. Grandperret tried a radiochemical process for linking Plexiglas and CR-39 resins but the resulting lenses were unsatisfactory.

By 1959, however, the company successfully produced ORMA® 1000 lenses with CR-39 resin. In the early 1960s, the company began exporting lenses to Germany, Spain, Italy and Switzerland. In Great Britain, ORMA Optical opened in 1965 to produce prescription organic lenses. The company's major success, however, was in the United States. A production plant under the name Silor opened in Florida in 1972. This facility would eventually become the largest producer of organic lenses in the world.

PART THREE

Optical Laboratories

Converting lens production from glass lenses to casting lenses from CR-39® monomer involved a variety of new technologies for lens manufacturers. It also required new equipment and new employee skills. For a number of years, most lens manufacturers maintained two diversely different production lines, one for glass and one for plastic. As lenses made from CR-39 resin came to dominate the market, lens manufacturers began dropping out of the glass market altogether.

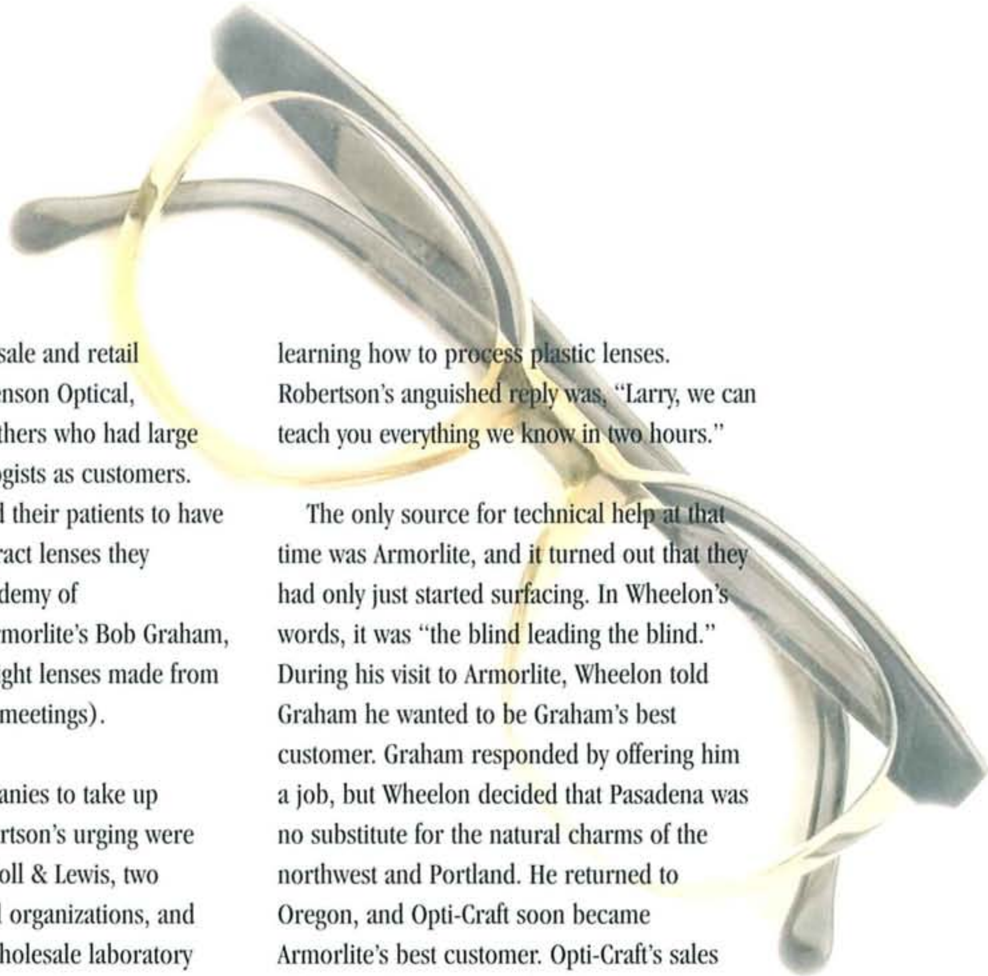
This changing market impacted optical laboratories in even more dramatic ways. At the time Armorlite began producing lenses made from CR-39 resin, no labs had the ability to surface plastic lenses. During the late 1940s and 1950s, a few progressive laboratories distributed I-Gard® acrylic stock lenses purchased from McLeod Optical (see "Plastic Lenses," page 10). Labs learned to edge plastic lenses, but they had no experience with grinding and polishing them. Armorlite, the first successful manufacturer of plastic lenses, eventually (and secretly) set up a surfacing laboratory to provide practitioners with surfaced lenses. Armorlite was convinced this was the only way they could create a market for their new plastic lenses.

The Pied Piper

By now, laboratories began to receive occasional orders for post-cataract lenses made from CR-39® resin. It seemed obvious that labs would eventually have to surface this new material. As it turned out, the role of convincing and teaching labs to process lenses with CR-39 resin fell in the unlikely hands of an ex-Canadian Air Force World War II pilot named Forbes Robertson. Robertson was hired by Armorlite in 1959 to sell the company's lenses. Initially, his job consisted of detailing doctors for ordering plastic lenses. The fact that many of the lenses Armorlite sold were surfaced in their lab was, for the most part, a dark secret. Robertson grew convinced that the only way to build national demand for lenses made from CR-39 resin was to get labs surfacing plastic lenses as quickly as possible. His was a minority opinion at Armorlite, but eventually he prevailed and was authorized to show lab owners how to process lenses with CR-39 resin. Soon he began calling on every major laboratory in North America, trying to establish a market for Armorlite semi-finished lenses. First, he had to teach labs how to surface plastic lenses. His sample bag consisted of a few semi-finished blanks and a box of tin oxide.

It was the desire for lightweight, high plus, post-cataract lenses that created initial interest in lenses made from CR-39 resin. This came

Forbes Robertson was convinced the only way to make lenses with CR-39® resin successful was to get laboratories involved. The hundreds of sales trips he made carrying few lens blanks and a can of tin oxide resulted in many major wholesale laboratories biting the bullet and becoming involved in plastic lens production.



mostly from large wholesale and retail organizations such as Benson Optical, Uhlemann Optical and others who had large numbers of ophthalmologists as customers. Ophthalmologists wanted their patients to have the new lightweight cataract lenses they learned about at the Academy of Ophthalmology (from Armorlite's Bob Graham, who lectured on lightweight lenses made from CR-39 resin at Academy meetings).

Among the first companies to take up plastic surfacing at Robertson's urging were Uhlemann Optical and Boll & Lewis, two prominent Chicago retail organizations, and White Haines, a major wholesale laboratory chain based in Ohio. Around that same time, Robertson heard that the three partners at Paramount Optical in San Francisco were breaking up, and one planned to set up a laboratory in Portland, Ore. He flew to Portland and called on Lawrence "Larry" Wheelon. He gave Larry and his partners, Otto Wagner and son Robert Wheelon, his standard pitch on the advantages of processing plastic lenses, and left town without knowing whether his sales efforts worked.

Two weeks later he received a call from Wheelon with the astonishing news that the partners decided their new lab, called Opti-Craft, would process only plastic lenses. Larry announced that he and his partners wanted to come down to Pasadena and spend a week learning how to process plastic lenses. Robertson's anguished reply was, "Larry, we can teach you everything we know in two hours."

The only source for technical help at that time was Armorlite, and it turned out that they had only just started surfacing. In Wheelon's words, it was "the blind leading the blind." During his visit to Armorlite, Wheelon told Graham he wanted to be Graham's best customer. Graham responded by offering him a job, but Wheelon decided that Pasadena was no substitute for the natural charms of the northwest and Portland. He returned to Oregon, and Opti-Craft soon became Armorlite's best customer. Opti-Craft's sales efforts, in effect, opened up the whole West Coast for Armorlite. Other wholesale laboratories began surfacing plastic lenses in the hopes of salvaging business they were losing to Opti-Craft. (See "The First All-Plastic Lab," page 30)

LENSES MADE FROM CR-39® RESIN INTRODUCED AT THE OLA

The 1961 Optical Laboratories Association (OLA) convention in Chicago was a major event for Robertson. This would be the labs' initial introduction to lenses made from CR-39 resin. Since Armorlite hadn't sold semi-finished lenses before, there was a mad scramble to get lens boxes printed so the lenses could be displayed at the OLA in a reasonably professional way. On the way to the Los Angeles airport, Mrs. Robertson hung over the back of the car seat trying to match and insert lens blanks into the proper printed boxes. She managed to sort the lenses and box them by the time they reached the airport. That OLA convention paved the way for the industry's slow transformation from glass lenses to lenses made from CR-39® resin.

Other Lab Experiences

Another early convert who responded to Robertson's sales efforts in a positive way was Bill Lowry of Lowry Optical in Florida, a lab later acquired by Milroy. Aggressive labs across the country began experimenting, trying any way they could think of to surface plastic (some ways were rather bizarre). William C. Seibert, owner of Three Rivers Optical Company in McKees Rocks, Pa., remembers those days well. In the mid-1950s, he worked for American Optical as a lab supervisor. Most machinery used in American Optical labs was manufactured by AO but was hardly considered state-of-the-art, even for that day. As demand for lenses made from CR-39® resin increased, American Optical fell behind independent labs in processing plastic lenses. Seibert remembers the tortures of trying to develop techniques for grinding plastic lenses.

Wire mesh pads were tried with 145 grit emery, resulting in 30 minutes fining for each lens. Polishing was done on white felt pads. Seibert's American Optical branch never did reach a point where they could produce plastic lenses with the ease of glass. Problems continued in one form or another until 1975-76 when American Optical installed Coburn surfacing equipment. Even with the new equipment, they were still plagued with waves and distortion. Eventually they discovered a yellow felt pad from Econ-o-cloth that worked. They tried one-step pads, two-step pads and even diamond pads. It was a common experience to produce one good lens and discover they were unable to repeat the process for the other eye. Lenses ended up with gray edges or swirl marks. It wasn't at all unusual to produce a good-looking lens that couldn't be read in the lensometer.

Difference Between Glass and Plastic

Most surfacing problems were created, in Seibert's opinion, because labs wanted to process plastic the way they did glass. Surfacing blocks were small in diameter and designed for glass, offering no support beyond the center of the lens. Plastic lenses flexed during surfacing, creating multiple waves and distortion. Sales engineers at Coburn Optical were helpful during this period, but even Coburn was feeling their way in this new field, much like their customers. Eventually, Coburn came out with larger blocks and eliminated one cause of distortion.

Lenses made from CR-39® resin were the major influence on eyeglass fashions during the seventies and eighties. Their light weight made stunning oversize frames a reality. The profusion of solid and gradient tints of every shade and hue that could be produced through artistic tinting of the lens made those years unforgettable to those who lived through them.

Forbes Robertson was convinced that plastic lenses would only succeed if labs could process them on equipment they already owned. The problems came in convincing labs that to do this, they had to completely clean the existing equipment and maintain a degree of cleanliness they weren't used to. Labs in the early 1960s looked far different than today's labs. Robertson's greatest problem was simply their dirty condition. He undoubtedly offended some labs when he told them, "The first thing you have to do is clean up." Another issue was that heat created many problems related to surfacing plastic. Air conditioned labs were comparatively rare at that time, and Robertson continually urged that plastic production lines had to be air conditioned. Eventually, this was accepted by experienced labs. They began to process glass and plastic on separate production lines with air conditioning for the plastic line.

One day Forbes received a call from Allan Kosh, father of Jeff and Stuart Kosh. Kosh Optical (then in New York City) had been an early convert to CR-39® resin. Allan called complaining about a rash of surfacing problems that had recently cropped up. Forbes saw on TV that morning that a heat wave had hit New York City. He asked Allan if he air-conditioned the lab as he had promised. The answer was, "Not yet. We have the equipment ordered but it's not installed." Forbes reminded him how heat affected plastic surfacing. Needless to say, Allan quickly had the air conditioning equipment installed.

POST-CATARACT LENSES

Initially, labs concentrated their plastic production on producing post-cataract lenses. Plastic lenses were too new and too prone to scratching for most patients. With post-cataract patients, it was a different story. During that period before the development of inter-ocular lenses, two factors made lenses casted from CR-39® resin an ideal lens for post-cataract patients. The first was weight. Strong plus lenses of 10 to 14 diopters were extremely heavy when made up in glass, a situation that concerned every wearer of these awkward lenses. The second factor was the recent development of sophisticated aspheric post-cataract designs that proved extremely difficult and costly to produce in glass.

A good set of glass molds, however, could replicate the most sophisticated aspheric curves over and over in CR-39 resin. It was comparatively easy for labs to convince doctors and consumers of the advantages of lightweight plastic lenses for cataract patients. Labs found this a ready market and before long, labs were scattered around the country that routinely surfaced plastic cataract lenses. Expertise gained with cataract lenses helped establish plastic lenses for all patients.

THE FINAL STRAW

The fate of glass lenses was largely sealed when the Food and Drug Administration (FDA) decreed in 1972 that all glass lenses sold in

THE FIRST ALL-PLASTIC LAB

In June, 1962, Lawrence Wheelon, an experienced lab man with more courage than most lab people of that day, decided there was a rosy future for plastic lenses. Wheelon had an aunt who underwent cataract surgery at the University of Washington. Her new plastic cataract lenses were ordered from Armorlite. It took three months to get them. Wheelon decided anything that difficult to obtain would be a good business to get into. Along with his wife; his son Bob; Steve Whitman, an experienced lab man who had worked for Riggs Optical; and Otto Wagner, an experienced surface man, Wheelon set up a new laboratory in Portland. Equipment was purchased from a recently-closed lab in Montana.

Wheelon initiated a relationship with PPG and investigated the possibilities of casting lenses. By the time PPG engineers pointed out all the ramifications required to cast lenses, Wheelon decided it made more sense to fabricate lens blanks cast by someone else. Following a sales call from Armorlite's Forbes Robertson, he flew to Pasadena and met with Bob Graham. When the Opti-Craft lab opened, they made history by becoming the first plastic-only laboratory.

Footnote: Customers liked Opti-Craft's service and wanted to order all their lenses from the same source. These doctors weren't, however, ready to switch from glass to plastic for conventional lenses. Within a year, Opti-Craft faced reality and set up a separate division for processing glass lenses. As the years passed, however, Opti-Craft eventually convinced customers of the advantages of lenses made from CR-39® resin, and the company became a leading laboratory on the West Coast. They are presently part of the Omega Laboratory Group, a division of Essilor of America. For slightly less than a year, however, Opti-Craft was the only all-plastic lab in the world.

the United States would have to be a minimum of 2.2 mm at their thinnest point, be heat-treated or chemically tempered and pass a drop ball test performed by the lab or the person edging the lenses. Previously, most glass lenses had centers or edges (depending on the power) well under 1.5 mm, some with centers as thin as 1.0 mm. This new ruling effectively meant that glass lenses would be 30 to 50 percent heavier than in the past.

This couldn't have happened at a worse time for glass because frame styles were just starting to grow in size. These factors effectively combined to give lenses made from CR-39®monomer the boost that would ultimately make CR-39 resin the dominant lens material in the United States. The rest, as they say, is history.

During the seventies and eighties, the one item on everyone's "optical wish list" was a lightweight photochromic lens that would work. Several promising photochromic plastic lenses showed up during the eighties but none of them satisfied the professions' expectations. It took the introduction of Transitions® lenses in 1991 to satisfy the need. Instead of replacing glass photochromic lenses (less than 10 percent of the market), Transitions lenses replaced cosmetic tints, ushering in a totally new category of premium lens for the eyecare professions.

The Story of Photochromic Plastic Lenses

The Continuing Evolution of CR-39® Resin

Almost from the day photochromic glass lenses were first introduced, lens manufacturers received requests for a photochromic lens made in a lightweight plastic. From the mid-sixties on, every gathering of optical people would usually include discussions of, "When are we going to have plastic photochromic lenses?" During the entire fifty years CR-39® resin has been used for ophthalmic lenses, PPG researchers have continually searched for ways to increase its versatility. The most dramatic result of this continuing research was the development of an effective photochromic process based on a variation of CR-39 resin called CR-307™ monomer. The story of how the Transitions® lenses process evolved is best told in timeline fashion, beginning in 1973.

1973

The first reported work on photochromics by PPG takes place at the company's Barberton Technical Center in 1973. From then until 1980, photochromic research & development became part of a number of different CR-39® monomer projects. These efforts remained comparatively low-key, and no synthesis of new compounds was involved.

1981

American Optical introduces their Photolite lens. The industry excitement prompted by this product release galvanized the scientists at PPG into another flurry of photochromic research. The American Optical lens turns out to be a commercial failure because of poor properties, short lifetime and an unattractive blue color. A new specialist with a background in photochromics is added to PPG's staff, and synthesis of new photochromics combined with testing of known photochromics in matrix from CR-39® monomer begins.

1983 - Pyridobenzoxazines

This year is a photochromic milestone because of the discovery of a new family of photochromics called pyridobenzoxazines. This year also marks the discovery of the unique imbibition process for incorporating photochromic properties in polymers and copolymers made from CR-39® monomer.

1984

PPG starts a joint venture with Intercast-Europe to manufacture and sell photochromic sunlenses called Attiva. These are still manufactured by Intercast, using PPG's blue photochromics. Research in this technology continued, and by 1985, production of Attiva lenses reached 3,150 per day. In 1986, marketing of the Visenza lens, an all-PPG venture, begins. A variety of prototype lens systems were produced and tested on PPG employees and consumers during the next three years.

1986 - Transitions

PPG authorizes $1 million for testing the technical and marketing feasibility of plastic photochromic lenses. Between July 1987 and May 1988, the company assesses the acceptance of prototype lens systems through employee and consumer use tests. In the fall of 1987, 30 persons wear the lenses for one month. A typical comment about those primitive lenses comes from one wearer, "They worked pretty well... could get a lot darker, and, boy, are they an ugly yellow in the bleached state." In 1988 a pair is given to another employee to wear on a trip to Hawaii. His comment: "If you can't make them get any darker, you're out of business." Additional consumer-use tests are conducted in Minneapolis, Miami and San Diego, and gradually, the consumer responses improve.

1988

On May 1, PPG gives the go-ahead to proceed to the next step which consists of setting up test markets for the new photochromic lenses. This is considered a milestone by the company's ophthalmic photochromics group, and a special picnic is held at Lake Dorothy, Ohio, near PPG's Barberton Technical Center. Eighty-eight people show up for a special catered meal of barbecued ribs. Shortly after the picnic, PPG Project Director John Crano hand-carries 100 lenses to Vermont and southern New Hampshire for the first tests. Later, additional test markets are established in Memphis and Pittsburgh.

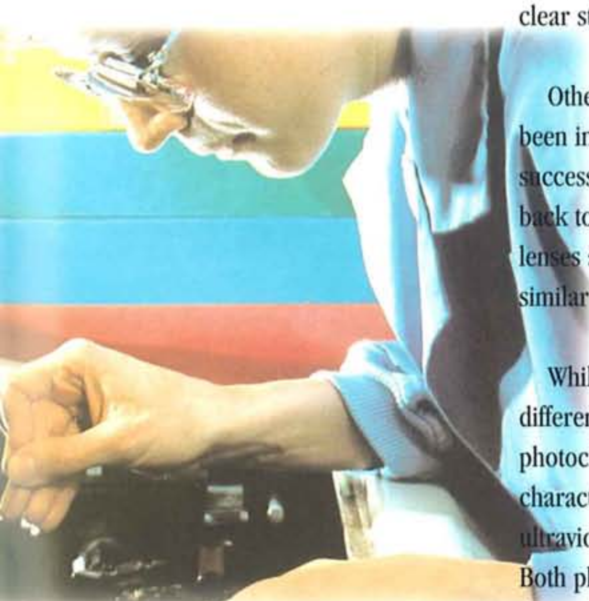
1990

Substantial progress is made, and by 1990, Transitions Optical Inc. (TOI) is formed and a manufacturing facility established in Pinellas Park, Fla., for producing photochromic lenses. By this time, PPG invested more than $8.5 million in developing the new Transitions® photochromic lens.

To firm up the industry's shaky confidence in such a new technology, TOI wisely decides to offer a patient satisfaction guarantee on

their new lenses. During the first three years of distribution, their return rate runs less than one percent, a remarkable record for such a new technology.

The technology used to produce photochromic plastic is totally different from photochromic glass. The chemistry is based on organic, rather than inorganic, compounds. When Transitions® lenses are exposed to the ultraviolet rays in sunlight, the photochromic compound is activated to a form that absorbs visible light, causing the lens to darken. When sunlight is removed, the photochromic compound converts back to its colorless form, and the lenses return to their original clear state.



Other plastic photochromic lenses have been introduced, but none have enjoyed the success of Transitions comfort lenses, dating back to their introduction in 1990. Transitions lenses are made of a lightweight polymer, similar to CR-39® resin.

While their technologies are completely different, photochromic glass and photochromic plastic share certain characteristics. Both are activated by the ultraviolet component of the solar spectrum. Both photochromics are temperature-dependent. Another distinct advantage of photochromic plastic compared to photochromic glass is that Transitions lenses darken uniformly, regardless of the prescription of lens design. Thicker portions of photochromic glass lenses darken more than thin areas, creating an unattractive, uneven density.

1992

The first Transitions® lenses formulation is replaced by the new Transitions® Plus. This second generation provides greater activation speed, darkening more and faster than the original lens. In 1993, Transitions Plus lenses receive the prestigious Optical Laboratories Associates (OLA) Award for Best Lens Treatment.

1996

The newest generation of Transitions® lenses is unveiled to the eyecare profession through a series of galas held in major U.S. cities. The result is overwhelming approval of Transitions® III lenses which darken faster, darken more and achieve a true gray color that most consumers prefer. This newest TOI product is also available in a mid-index, opening a totally new market for photochromic plastic lenses.

The Importance of Positioning

At the time Transitions® comfort lenses were introduced, the lens market in the United States was approximately 80 percent plastic and 20 percent glass. Half of all glass lenses sold were photochromic. With the introduction of Transitions lenses, many doctors and dispensers assumed the market for these new lenses would be those patients who had been wearing heavy photochromic glass (10 percent of the market).

Marketing people at TOI thought differently. "Go after the consumers who already wear plastic lenses (80 percent of the market), and go after those who wear fixed tints (60 percent of the market)" was their advice. That huge untapped segment of the market turned out to be exactly right for Transitions lenses. Further, offering these consumers photochromic lenses opened up a completely new premium lens market for the eyecare profession. The rest is history. Transitions lenses turned out to be the most successful and fastest-growing segment of the entire premium lens field, all made possible because of proper positioning of a brand new technology.

The End (Not Yet in Sight)

With the experience of fifty years of major participation in the ophthalmic lens industry, what does the future in this important segment of the health care industry hold for PPG?

Some industry observers have tracked the steady growth of alternative plastic lens materials such as high index and polycarbonate, and have predicted a gradual decline of market share for lenses made of CR-39® monomer. Executives in PPG's optical products business are quick to point out that the market for lenses made of CR-39 resin has never been stronger. While usage in the United States has flattened somewhat, continuing conversion from glass to CR-39 resin is rising dramatically worldwide. They remind listeners that major highly-populated countries such as India and China are just at the threshold of a major conversion from glass to plastic. The general expectation is that this trend, added to all the third-world countries entering a similar conversion phase, predicts healthy increases in worldwide sales of lenses cast from CR-39 resin for years to come.

John Crano, PPG's associate director of optical products, was asked recently what he sees in PPG's future for the optical products business. "Our initial major contribution to the ophthalmic industry was the development of CR-39® monomer—chemistry that ultimately

The one individual at PPG who was personally involved in the quest for a photochromic plastic lens from the very start was John Crano. Once his research chemists were convinced that they had found the answer, a primitive production line was set up, and John personally carried the first 100 lenses produced to Beta Site Labs in Vermont and New Hampshire.

became the major substrate for ophthalmic lenses in every developed country. PPG's continuing investment in technology led to the development of photochromic Transitions® lenses. This new technology has already proved to be a major profit contributor for the eyecare professions."

To quote Peggy Lee, Dr. Crano was asked, "Is that all there is?" He laughed and proceeded to project some of the areas in which he believes PPG will play a major role. Dr. Crano contemplates higher index materials for Transitions lenses and suggests those could include polycarbonate. There is a viable market for more easily cured high index substrates, utilizing ultraviolet (UV) light for curing. This is an area that will certainly be considered. Development of UV-cured high index resins will lead to more cost-effective manufacturing, and this will ultimately benefit everyone in the supply chain, from manufacturer to consumer. The development of modified CR-39 resins that will produce thinner lenses in 1.50 index with improved impact resistance are definitely under consideration.

Whether Dr. Crano's predictions come to pass or not, PPG Industries has proven the value of their contributions to the eyecare professions and the spectacle-wearing public during the past fifty years. It would be fascinating to have the ability to project into the year 2047 and observe how PPG celebrates the 100th anniversary of their major contribution to mankind and the field of ophthalmic optics.

PPG's headquarters are based in the world-famous six-building glass complex located at One PPG Place in Pittsburgh. Opened in 1983 and designed by renown architect Philip Johnson, this totally energy-efficient building has become a Pennsylvania landmark.

The Evolution of Lenses Made With CR-39® Monomer

1937	Combined Optical Industries Ltd. (COIL) starts production of IGard® lenses made from Plexiglas® resin.
1938	TULCA (The Unbreakable Lens Company of America) begins producing injection-molded lenses made from PMMA.
1940	CR-39® monomer developed by research team at Columbia Southern Chemical Company, a wholly-owned subsidiary of Pittsburgh Plate Glass Co. (now PPG). PPG researchers discover CR-39 resin and apply for patent. They discover the material can be combined with paper, cloth, pigments and other materials, and molded into finished, shaped, laminated products. CR-39 resin used for producing transparent gauge tubes in aircraft to prevent breakage and fuel spills associated with glass tubes.
1941	France's National Conservatory of Careers tries casting Plexiglas resin in spring-actuated molds.
1943	CR-39 resin first used for reflector and searchlight applications.
1946	CR-39 monomer patent awarded to PPG's Irving E. Muskat and Franklin Strain. Univis closes their plastic lens division. Robert Graham and ex-Univis team move to California. Lissac produces sunglass lenses from flat circles of Plexiglas resin pressed into plano lenses.
1947	Armorlite Corporation forms and begins experimenting with CR-39 resin.
1949	McLeod Optical becomes exclusive U.S. distributor for IGard lenses.
1950	Lissac sets up to produce lenses made from Plexiglas resin in France.
1952	LOS introduces ORMA® 500 lenses made from Plexiglas resin in France.
1953	Lissac's Rene Grandperret orders a half liter of CR-39 resin for experiments.
1954	Grandperret spends three weeks in the U.S. with Robert Graham. Lissac's Bernard Mignen successfully polymerizes lenses made from CR-39 resin.
1955	Lissac, Inc. makes sun lenses from CR-39 monomer.
1959	ORMA 1000® lenses made from CR-39 resin introduced worldwide.
1960	First plastic bifocals are cast. SOLA Optical formed and begins producing lenses made from CR-39 resin in Australia with 10 employees.
1961-66	SOLA begins exporting lenses made from CR-39 resin to Japan, England, France, Italy, India and other countries.
1968	SOLA's Japan operation opens (the first totally foreign-owned operation in Japan following World War II). SOLA introduces Spectralite® optical lenses, the first photochromic high index lens.

1969	La Lunette de Paris introduces ORMA® 1000 lenses to the United States.
	Lenses made from CR-39® resin tested on U.S. pilots.
1970	SOLA's UK operation opens.
1971	Food & Drug Administration passes impact-resistance regulations for eyeglass lenses.
	Signet Uptown begins casting bifocals, trifocals and post-cataract lens blanks.
1972	Silor opens lens casting plant in Florida.
1973	PPG's Barberton Technical Center conducts the first photochromic experiments with CR-39 monomer.
1974	3M develops scratch-resistant coating for lenses made from CR-39 resin.
1975	Lenses made from CR-39 resin now account for 15 percent of all lenses in the U.S.
	SOLA opens operations in U.S.
1976	SOLA begins casting lenses in the United States.
1978	Armorlite Corporation sold to 3M.
1979	SOLA is acquired by England's Pilkington.
1981	Signet and Armorlite are merged into Signet-Armorlite.
	American Optical introduces Photolite photochromic lenses.
1983	PPG discovers new family of photochromics, the blue pyridobenzoxazines.
1984	PPG forms joint venture with Intercast-Europe to manufacture and sell photochromic sunlenses called Attiva lenses.
1986	PPG starts a one year $1 million program to test technical and marketing feasibility of plastic photochromic lenses.
1987	PPG launches employee and consumer use test of prototype photochromic lenses.
	SOLA acquires Coburn lens business.
1988	PPG researchers at the company's technical center in Monroeville, Pa., produce a prototype of a plastic photochromic lenses, a precursor to Transitions® comfort lenses.
1989	Transitions lenses introduced in test markets - Vermont, New Hampshire, Memphis and Pittsburgh.
1990	Transitions Optical Inc. (TOI) is formed as a joint-venture between PPG Industries and Essilor International, and begins manufacturing Transitions lenses.
1992	Researchers in Monroeville develop Transitions® Plus comfort lenses, a faster acting photochromic lens.
1993	TOI opens sales and marketing office in Paris.
1994	Transitions Optical, Ltd. opens a new plant in Tuam, Ireland, to supply the European market.
	SOLA introduces Spectralite® optical lenses, the first photochromic high index lens.
1995	TOI begins construction of manufacturing facility in Australia and opens sales office in Brazil.
1996	The third generation, Transitions® III lenses, is introduced in Spectralite lens and 1.56 high index.
1997	PPG celebrates the 50th anniversary of lenses made from CR-39 resin.

CR-39™

CELEBRATING
50 YEARS

PPG

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