angle with the torsional spring stiffness S. The torque is also given as product of current with magnetic induction B, length of wire l, and radius of coil a. The efficiency e, neglecting reactive impedance, is inversely proportional to coil resistance and to current. For a long narrow coil, the length of wire cutting the magnetic lines is nearly equal to cR, where c is conductivity multiplied by cross-section area of wire in the coil. Combination of these relations shows that full-scale angle and efficiency are inversely proportional to each other. In the proportionality constant, the factor a/S is directly related to the time constant of the movement, and hence to its accuracy in following changes. Thus we have here a simple illustration of the general situation, that accuracy, range, and efficiency are competitive factors of merit which must always be compromised in any given design.

In effecting this compromise in design, it would help to have a more definite picture of the relation of information output, reflected in range and accuracy, to the output work required by various methods of indication. During the past year I have been interested, as part of an ONR-sponsored research (*12*), in comparing the common pointer-scale combination with other indicating means. Though it does not seem possible to summarize quantitatively the many factors, some objective, some subjective, entering into such a comparison, I must say that the pointer-scale method stands the comparison very well.

My general thesis has been that the science of instrumentology must be advanced by clarifying the *activities* and *processes* of measurement and control, both in their essence and in their relation to other activities and processes; and by clarifying and organizing our understanding of the *devices* used in these activities. The specific aspects of these two broad objectives which I have touched upon are, of course, only a few of the many interesting questions calling for solution.

References

1. BEHAR, M. F., Ed. *The Handbook of Measurement and Control.* Pittsburgh: Instruments Pub., 1951.
2. DRAPER, C. S., MCKAY, W., and LEES, S. *Instrument Engineering.* New York: McGraw-Hill, 1952.
3. SZILARD, L. *Z. Physik,* **53**, 840 (1929).
4. VON NEUMANN, J. *Mathematische Grundlagen der Quantenmechanik.* New York: Dover, 1943.
5. BOHM, D. *Quantum Theory,* ch. 22. New York: Prentice-Hall, 1951.
6. ASHBY, W. R. *Design for a Brain,* p. 39. New York: Wiley, 1952.
7. BRILLOUIN, L. *J. Appl. Phys.,* **24**, 1152 (1953).
8. TRIMMER, J. D. "Autoradiography Compared to Other Fields of Measurement," lecture to 1953 Summer Course in Autoradiography, Oak Ridge Institute of Nuclear Studies, June 15, 1953.
9. WIENER, N. *Cybernetics.* New York: Wiley, 1948.
10. TRIMMER, J. D. "The Taxonomy of Man-made Objects," paper presented before the Tennessee Academy of Sciences, Chattanooga, November 1952 (to appear in the Academy Journal).
11. ———. *Response of Physical Systems,* ch. 7. New York: Wiley, 1950.
12. Project Nonr-811(01), Office of Naval Research; first annual report, May 1, 1953.

Into a New Century

THE YEAR 1953 marks the one-hundredth anniversary of the Bausch & Lomb Optical Co. At this milestone the company's pride in its achievements is tempered by the challenge of the future. To that future it dedicates its centennial.

Among those who joined the exodus from Europe in 1849 was John Jacob Bausch, founder of the Bausch & Lomb Optical Co. Arriving in New York, he traveled westward to Buffalo where he worked as a cook's helper and carpenter for several months, then borrowed five dollars, and went to Rochester. There he eventually opened the little optical shop that was destined to become one of the world's leading producers of optical glass, scientific instruments, and ophthalmic products.

If John Jacob Bausch had not lost two fingers in a buzz saw accident in 1852, America might never have been the beneficiary of a company which revolutionized the optical industry and provided some of the critically short materials and instruments necessary to win two world wars. After the accident, Bausch found it necessary to continue part-time work at his trade of woodturning for a year, but the real birth of the world-renowned firm, 100 years ago at Rochester, can be traced to that fateful event. It brought the young German immigrant into contact with a fellow immigrant, Henry Lomb, who had collected twenty-eight dollars for his friend to tide him over his convalescence. When Bausch opened his first optical shop, in 1853, it was with the help of sixty dollars borrowed from this same friend. Bausch demonstrated his sincere appreciation by making Lomb a full partner in the struggling business that same year. In 1868, Lomb entered the Union Army and served as a captain in the 13th regiment, New York Volunteers. He sent home his soldier's pay to keep the small business alive. Neither partner, during their long years of association, found it necessary to have a contract with the other—a notable example of faith and mutual trust.

Like most other beginning enterprises, the young business was beset by many difficulties. The first real promise of success came with the development, by Bausch, of a spectacle frame made of hard rubber. The kitchen range in his home served as shop laboratory for this first "plastic" eyewear. From this, the little shop became a successful manufacturing enterprise. Previous to this development, the only plastic frames available were constructed from horn, a material which was difficult to shape and which demonstrated a tendency to split. Experiments proved the hard rubber to be superior in many respects to the horn, but, more important, it readily lent itself to mass production. Spectacles could now be made in quantity and at a reduced cost.

For sixty-nine years, Edward and William, the two sons of J. J. Bausch worked together in the company until their deaths in 1944. Edward Bausch, trained at Cornell University, foresaw the need of science for more microscopes. In 1874, when only fifty such instruments existed in the United States, he set about to develop mass-production machine methods for their manufacture. Such methods, in his lifetime, made microscopes available at moderate cost to laboratories and schools throughout the world—a contribution of untold value to scientific and technological progress. William Bausch was a pioneer in the production of optical glass in America. His earlier successful experiments became of prime importance at the outbreak of World War I, when with the help of the Geophysical Laboratories of the Carnegie Institution, Bausch & Lomb served as the principal source for optical glass, freeing America from dependence on foreign sources for this critical material.

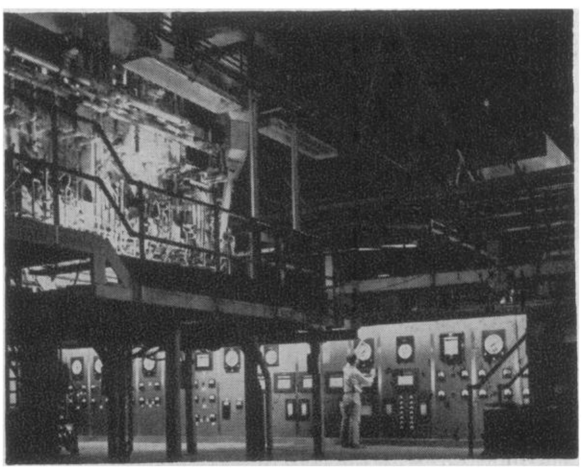

FIG. 1. New processes have been devised and installed for making glass at Bausch & Lomb Optical Company's glass plant which was started in 1913 and was the principal source of supply for the United States during World Wars I and II. Here a glass technician takes a temperature reading of molten, white-hot glass in one section of the huge plant located along the Genesee River bank.

In 1861, Bausch & Lomb further advanced the possibility of better vision by introducing power lens-grinding machinery into the United States. The former laborious manual operation was thus eliminated, and the cost of spectacles was reduced to an even greater extent than it had been by the advent of hard rubber frames.

It is a far cry from J. J. Bausch's first little shop in the Reynolds Arcade to the modern organization and its global affiliation. Besides the main plant in Rochester, totaling 1,500,000 square feet of floor space, there are four other factories in the United States, Canada, and Brazil. Sales outlets include more than 170 branch offices in this country and abroad, and personnel now number over 8000.

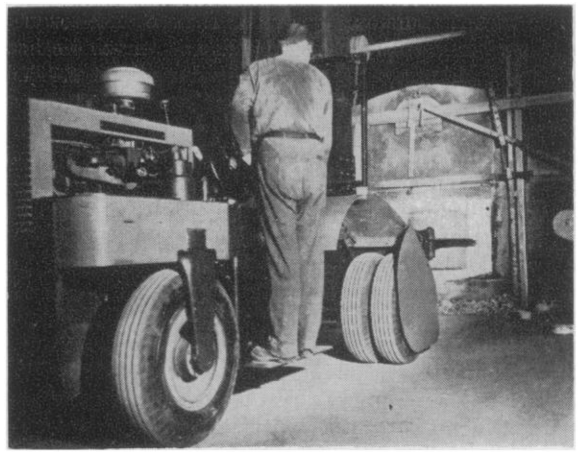

FIG. 2. Approximately 22 hours are needed to complete the melt under accurate control of all furnace conditions. This includes 7–8 hours for the melting process, 7–8 hours for the fining process whereby bubbles are removed and the liquid stirred, and 6–7 hours to cool the molten glass slowly to a temperature suitable for rolling. Here the molten glass, like a giant pot of taffy, is to be poured on a cast-iron table for rolling into a sheet.

Another kind of growth, however, is in the company's concepts of its primary purpose. Simply stated, that purpose today is to make all products that best serve the optical and visual needs of mankind. This calls for an enlarged engineering staff for research and product design, modern manufacturing facilities for efficient quality production, and progressive practices in all other phases of modern management.

Nothing is more important to the manufacturer of optical instruments and ophthalmic products than optical glass, for the performance of any optical part depends on the properties and qualities of the glass from which it is made. Optical glass is as different from ordinary glass as the steel in a fine watch spring differs from that in a tenpenny nail. A fundamental requirement of optical glass is homogeneity. Even a slight departure from a high degree of uniformity in composition is intolerable because of the effect on the performance of the finished instrument. It must have definite refractive indices for different wavelengths and accurate dispersion ratios. It must be free from color, striae, bubbles, inclusions, and cloudiness.

For decades, the Bausch & Lomb Glass Plant has been devoted exclusively to the production of optical glass, a manufacturing operation of considerable proportion. Here, in the year just passed, 2,500,000 pounds of sand, along with sixty other ingredients, went into the manufacture of 3,500,000 pounds of glass, of 120 distinct types. This glass produced 22,500,000 pressings and required 468,000,000 cubic feet of gas.

Foreign labor rates still make it possible to purchase optical glass abroad more cheaply than it can be made here, but the Bausch & Lomb Glass Plant has been continuously maintained since World War I because of the technological advantages which its existence affords the United States. Continuous quality control, from sand to finished product, is an asset of inestimable value.

FIG. 3. Before reaching the finished state, a lens must undergo many hours of grinding and polishing.

Approximately 120 different types of optical and ophthalmic glass are manufactured. Among these are many types pioneered by the company to keep pace with, and in several cases to anticipate, the new scientific developments in many different fields. As the demand for larger lenses in certain applications developed, revolutionary new methods were formulated for making a glass of the particularly high quality necessary in the manufacture of such lenses. The company's chemists assisted U.S. Navy scientists in developing a supersensitive type of glass that can detect the presence of atomic energy. After exposure to high-energy radiation, this dosimeter glass remains unchanged in appearance under ordinary light, but reveals the extent of exposure by the amount of orange fluorescence it emits under ultraviolet rays.

Design of product is a responsibility of the Research and Engineering Division. On its staff of 300 are many scientists and technicians engaged in original research —optical, electronic, chemical. Their specialized knowledge embraces all scientific fields served by the company.

New colors for use in Ray Ban sun glasses and filters have been developed. Revolutionary new types of glass for safety eyewear have been produced. From the very outset, Bausch & Lomb has been particularly concerned with the manufacture and constant improvement of ophthalmic eyewear. Early in the twentieth century, members of the firm suggested to Dr. Moritz von Rohr, of Jena, the development of a scientifically correct series of such eyewear. Von Rohr set himself the task of developing a series that would embody the advantages of all existing types and that would remove their limitations. He followed the work of Wollastow and Ostwalt, making no claim to the invention of astigmatically corrected lenses in the spherical powers, but devoting his investigations to compound lenses that employed toric surfaces. He made thousands of computations of spherocylindrical combinations over the entire range of powers to determine the exact formulas for compound lenses that would give the required powers in the two meridians, and at the same time give equally distinct vision from center to margin. He announced his results in 1911, and in 1914 Bausch & Lomb introduced Punktals to the American market. Thus it continued von Rohr's work by adding eighth and quarter diopter intervals wherever necessary, by recomputing the lenses with reduced center thickness, and by later making Punktal Kryptoks and Punktal Ultex. The attributes of the Punktal received even wider recognition with the introduction of the Bausch & Lomb Orthogon series, which employs group curves, each lens within a group being made with the same base curve and the entire series employing as many base or group curves as the requirements of marginal correction demand.

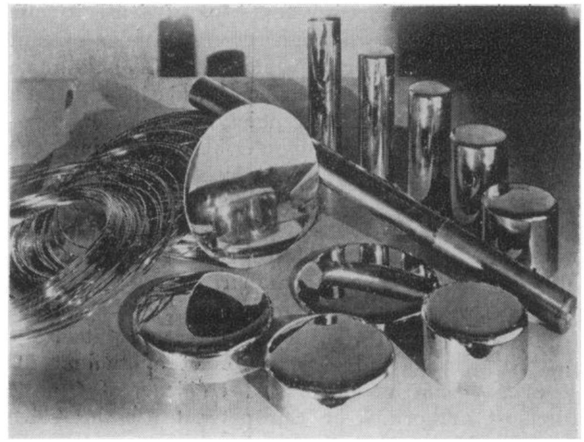

FIG. 4. Over 400 operations are needed in the manufacture of frames and mountings. Shown here are a few steps in the manufacture of gold-filled wire. Sheets of 12-carat gold are blanked into disks, drawn into cups, then into cylinders. Cores of base metal, wrapped with thin sheets of solder, are inserted in cylinders and bonded under high temperature. Cylinders are reduced in diameter by being drawn to desired size. Wire is then ready for use in manufacturing.

For years scientists sought some way of removing the visible dividing line in cemented bifocals. The introduction of fused bifocals remedied this defect; but objectionable color fringes, due to the nature of the glass in the segment, still marred their perfection. Intensive experiments in the glass plant of Bausch &

Lomb finally produced a new type of dense barium crown glass having the high refractive index of flint glass and the low color dispersion of ophthalmic crown glass. At the same time, its coefficients of expansion and contraction, its melting point, and its other physical properties were suitable for perfect fusing. The result was the famous Nokrome lens, a bifocal without noticeable color or dividing line. In the fall of 1930 the successful development of the Hammon patent was achieved. This was the ingenious and justly celebrated Panoptik. It was the first fused bifocal in which a reading segment, with or without prism, of any desired shape or size could be incorporated.

In the design and construction of ophthalmic instruments, Bausch & Lomb has been identified with the foremost authorities of Europe and America since 1890. In this country, the company proposed the new system of lens measuring known as vertex refraction and supplied the vertex dioptrometer for this purpose. In order to insure correct focus, the vertex refraction system of numbering lenses was introduced, so that any two lenses of the same vertex refraction would give precisely the same correcting effect, regardless of their shape.

The blind spot of the eye has been studied for years, since its discovery by Mariotte in 1668. Much more recently, in this country, Dr. Ralph I. Lloyd had given it considerable attention, using hand stereoscopes. Not satisfied with his own progress in this direction, he appealed to Dr. Max Poser of Bausch & Lomb for a stereoscope which would give a field ten degrees above, below, and internally, twenty-five degrees externally, and free from color faults. The instrument must give this field without increasing the lens or prism strength. Lloyd gave this report on the result: "He [Poser] supplied an instrument with a field far surpassing our hopes. It covered the usual field internally, 30° above and below, and 40° externally." This instrument, known as the Lloyd's Stereo Campimeter, combined the advantages of binocular fixation and the tangent screen.

The early success of Bausch & Lomb with the binocular corneal microscope was due to a broad understanding of microscope optics and the application of this science to the study of the eye. Previously, it had been difficult, with monocular vision, to locate slight defects or injuries to the cornea. This deficiency was corrected with binocular vision in which the largest possible field was obtained with a marked stereoscopic effect.

The company also had the privilege of working with Professor Allvar Gullstraud of Upsala, Sweden, on the ophthalmoscope, and later of perfecting an instrument in which the macular area and the optic disk appear in the same field at the same time. The field of view is approximately four times that of the hand ophthalmoscope. In the objective measurement of corneal curvatures, the Keratometer offers the easiest and most accurate method known. Its coincidence system of focusing, a Bausch & Lomb feature, speeds prompt and accurate location of the axis.

Always alert to the requirements of the optical profession, authorities in the ophthalmic field have been encouraged in their search for new or improved instruments. From this collaboration have come such instruments as the perimeter and projector devised by Doctors Ferree and Rand of the Wilmer Institute, the Clason visual acuity meter, Green's refractor, and the Universal and Poser slit lamps.

Probably no single instrument has contributed as much to scientific progress as the microscope. In 1876 there were less than 100 microscopes in the United States. Largely through an improvement in production methods microscopes were made available at modest cost to universities and laboratories. Since that time Bausch & Lomb scientists and technicians have pioneered in the development of more efficient microscopes of all types. The ball-bearing microscope, the variable-focus condenser, the prefocusing gage, and many other new developments, have been introduced.

In our present-day world, spectrography is widely used for the rapid identification and quantitative measurement of substances, both known and unknown. Spectrographic analysis has become indispensable to science and industry. Bausch & Lomb can take particular pride in the role it has played in bringing to the attention of scientists all over the world the advantages offered by the spectrographic method.

In 1953 the company demonstrated, for the first time, a spectrograph that is the culmination of its efforts to date to provide the best tools in the spectrographic field, the Littrow-echelle spectrograph. The new concept employed in this instrument deals with the properties of a new optical element known as an echelle, first conceived by Dr. George R. Harrison, Dean of Science at the Massachusetts Institute of Technology and special consultant to Bausch & Lomb. As used in the new instrument, an echelle is an inch-thick, optically flat glass plate three by five inches, in which grooves have been precisely ground, 200 to the inch. The first and only echelles ever made have been produced since 1949 by Bausch & Lomb. Like the diffraction grating, the echelle disperses light into a spectrum; but its dispersion is considerably greater, thus permitting the distinguishing of spectral lines as separate even when they are only a fraction of an angstrom apart. It makes possible the design of high dispersion spectrographs with focal lengths only one-ninth (or less) of those previously possible with grating spectrographs. Assuming a 200-groove-per-inch echelle and a 15,000 groove-per-inch grating (in the second order), the theoretical resolving power at 5000 A for six inches of ruled width would be 180,000 for the grating and 537,000 for the echelle. In addition, the echelle, in combination with a prism or grating, produces a two-dimensional spectrum, as contrasted to the one-dimensional spectrum produced by the grating or prism alone. Thus, research scientists are able to gain more quickly far more complete information about the substance being studied, and to gain it from a fewer number of photographic plates.

Most people who have some lay knowledge of gratings are impressed by the number of parallel lines cut into the aluminum film with which gratings are coated. A grating recently produced in the Bausch & Lomb Grating Laboratory for the University of California's Los Alamos atomic laboratory was ruled 30,800 grooves to the inch—an impressive number, statistically, but it tells only part of the story. Of equal importance is the manufacturer's ability to shape the grooves so that they are always parallel and reflect light in a specified direction. This is called blazing. Its accuracy depends on the precision of the grating engine, the patience and care shown by the operator in adjusting the ruling diamond, complete freedom from vibration and from temperature and humidity changes during manufacturing, and a storehouse of technical information and know-how. The success of a grating depends then, not only upon the number of grooves but also upon the nature of the grooves. The manufacturing process used in the making of gratings has been brought to a level of precision and accuracy that makes them among the world's finest.

In 1935 Bausch & Lomb entered the photogrammetric field by developing a line of photographic instruments for military engineers. These first instruments were designed around a narrow angle lens (67°), but within a short time the Metrogon lens was developed with an angle of 93°. Soon there was a demand to design multiplex equipment for this lens. Today it is still regarded as one of the finest lenses for this purpose in the world and is used universally.

Not satisfied, the company has recently developed the Cartogon lens, which will reduce distortion by as much as 10 per cent over that of the Metrogon lens. It has also developed the auto focus rectifier to meet the high volume needs of the government services and commercial concerns in the rectification of tilted aerial photographs. This instrument embodies a mechanism that allows a layman with little training to rectify photographs quickly, without the need for complicated computations. It is the only instrument of its type produced in the United States.

At present, Bausch & Lomb is building Twinplex Plotters for the U.S. Geological Survey Service. The development of this instrument will make possible the use of convergent photography and thus considerably reduce the time necessary to complete the task, now in progress, of mapping the United States.

More of the world is being mapped with the use of this company's photogrammetric equipment than with any other. As one of the pioneers in this field its research laboratories are constantly seeking to develop new equipment that will make the task of mapping increasingly simple and more accurate.

Far from being a recent development, the principle of evaporating thin metal films on glass surfaces dates back to the close of the nineteenth century when Thomas A. Edison took out a patent on the process. In 1892, H. Dennis Taylor, a celebrated lens designer, found that certain types of photographic lenses were faster after their surfaces had been tarnished by age, a fact which suggested to him that it might be possible to devise a process by which the same effect could be produced artificially. From these beginnings, thin film technology has matured to a position of scientific importance. Today's thin films are possible only because of the improvements made in techniques and apparatus during the last twelve or thirteen years.

In 1940, when the new Technicolor movie *Gone With the Wind* was first shown, the prints were found to be too dark. Some means had to be provided for throwing additional light on the screen. The solution was reached with Balcoted Bausch & Lomb Super-Cinephor projection lenses. From this point on, Bausch & Lomb assumed a leading position in the field of lens coatings. A few of the major developments since 1940 have been the anti-vignetting filter for wide-angle lenses, the introduction of Ray-Ban gradient density sun glasses, the interference and interference wedge filters, heat-reflecting filters, and a long list of many others. Research in this direction continues at a rapid pace under the direction of Dr. A. F. Turner, a world-wide authority on lens coatings.

The success of the newest cinematographic process, known as Cinemascope, depends in the main on the anamorphic lenses, first invented by Dr. Henri Chrétien of Paris, and improved by Bausch & Lomb, the sole manufacturer of such lenses in this country.

Cinematography, television, astronomy, photography, illustrated magazines, and newspapers require the use of optical systems or processes. The school teacher with a microprojector, the food processor with the refractometer, the forest ranger with a binocular, the master machinist with the contour-measuring projector, the sportsman with a telescopic hunting sight, each reflects one small facet of optical science at work in our modern society. With its tradition of integrity, resoursefulness, and perseverance, Bausch & Lomb, can justifiably be proud of the part it has played in supplying them with the finest of optical tools.

These are but a few of the accomplishments of the past century. More will come as the shaping of new scientific projects is translated into optical needs. New and better manufacturing methods are in the course of development. The past is an inspiration for the future, a future that is viewed with hope and confidence.