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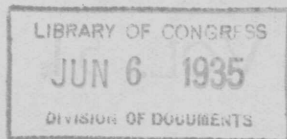
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UNITED STATES DEPARTMENT OF LABOR

FRANCES PERKINS, Secretary

BUREAU OF LABOR STATISTICS

ISADOR LUBIN, Commissioner

**BULLETIN OF THE UNITED STATES }
BUREAU OF LABOR STATISTICS } No. 593****EMPLOYMENT AND UNEMPLOYMENT SERIES****TECHNOLOGICAL CHANGES
AND EMPLOYMENT IN THE
ELECTRIC-LAMP INDUSTRY**

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of the
United States Bureau of Labor Statistics



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LETTER OF TRANSMITTAL

UNITED STATES DEPARTMENT OF LABOR,
BUREAU OF LABOR STATISTICS,
Washington, October 1, 1933.

Hon. FRANCES PERKINS,
Secretary of Labor.

MADAM SECRETARY: I have the honor to transmit herewith the results of a study of technological changes and employment in the manufacture of electric lamps. This is one of a series of studies made by the Bureau for the purpose of determining to what extent technological changes in industry are affecting the output per worker and the opportunity for employment.

The Bureau takes this opportunity to acknowledge the cordial cooperation of representatives of the electric-lamp industry. Through the courtesy of Mr. A. E. Allen, Mr. J. L. Thomas, and various other officials, both the technical and the statistical staffs connected with the industry devoted much time and effort to the inquiry.

Respectfully submitted.

ISADOR LUBIN, *Commissioner.*

BULLETIN OF THE U. S. BUREAU OF LABOR STATISTICS

NO. 593

WASHINGTON

OCTOBER 1933

TECHNOLOGICAL CHANGES AND EMPLOYMENT IN THE ELECTRIC-LAMP INDUSTRY

Summary

In 1920 approximately 362,140,000 electric lamps were made in the United States. The number fell off sharply in 1921, then increased to 643,957,000 in 1929, and thereafter declined to 503,350,000 in 1931.

In 1920 about 59 percent of all labor engaged in the industry was employed in assembly plants, in which are combined the filament, the lead-in wires, the glass parts of the mount, the bulb, the base, and the other parts. In 1920 the average number of workers in lamp-assembly plants was 17,283; by 1931 the number had declined to 5,817.

On account of a reduction in the average number of hours per employee, the total number of man-hours declined somewhat more sharply than the average number of workers—from 36,145,000 in 1920 to 11,448,000 in 1931. This was a reduction of 68.3 percent. On account of the increased production the amount of labor required per lamp declined more rapidly than the total number of man-hours. The time required per lamp in 1920 was 0.099809 man-hour, and in 1931, 0.022743 man-hour—a reduction of 77.2 percent. Stated reciprocally, in terms of the number of lamps produced per man-hour, the number in 1920 was 10.019 lamps, and in 1931, 43.968 lamps. With 1920 as the base, or 100, the index of productivity of labor increased to 438.9 in 1931.

In plants for making parts (the filament, the lead-in wires, the bulb, the base, etc.) the amount of labor employed was less than one fourth of all labor engaged in the industry. There have been varying increases in the productivity of labor in plants for making parts. In the case of bulbs for large lamps, as distinguished from miniature bulbs, the increase in productivity exceeded the increase in lamp-assembly plants, but for all of the parts plants combined the estimated index of productivity was lower.

For the entire industry, including the nonmanufacturing divisions, the index of productivity ranged from 100 in 1920 to approximately 340 in 1929 and 329 in 1931.

The changes in the total volume of employment in terms of man-hours were due in part to changes in the number of lamps produced, a decrease or an increase in production being accompanied by a similar change in the amount of labor, especially in the lamp-assembly and the parts-manufacturing plants. The other principal factor affecting volume of employment was the saving of labor by means of technological improvements. During the period from 1920 to 1931 earlier technological researches were continued and even intensified. Among hundreds of innovations there were two outstanding changes. One of these was the development of the group or unit system of coordinating, and when possible synchronizing, the various related operations of a production unit. An illustration is a high-speed lamp-assembly machine in five sections, for (1) stem making, (2) stem inserting (placing the filament-support wires in the stem), (3) filament mounting, (4) sealing the mount in the bulb and exhausting the air, and (5) attaching the base. A second outstanding change was the perfecting and extensive adoption of cam-operated mechanisms for performing a large proportion of the operations formerly requiring manual labor. An instance of the intricate and delicate operations made possible in this way is the automatic mounting of the filament of both large and miniature lamps on the lead-in wires and the support wires of the stem.

Origin and Growth of the Industry

The first commercially successful incandescent electric lamp was the carbon filament lamp invented by Thomas A. Edison in 1879. This was the beginning of the incandescent electric-lamp industry, but its growth depended primarily on the development of economical sources of current. Edison realized this, and it was largely through his efforts that the first central station for the supplying of electric current was constructed in New York in 1882. The success of this station led to the installation of similar power stations in other cities, and the central-station industry developed rapidly. The transition from direct current to alternating current resulted from the successful use of the latter by George Westinghouse in lighting the World's Fair at Chicago in 1893.

The carbon-filament-lamp industry grew with the central-station industry until nearly 50,000,000 carbon-filament lamps were sold in the United States during 1906. The rapid growth of the industry since that time is traceable to other inventions. One of these was the pressed-tungsten-filament lamp invented by Just and Hanaman and introduced in 1907. This was followed in 1910 by the drawn-tungsten-filament lamp developed by Dr. W. D. Coolidge, and in 1915 by the gas-filled drawn-tungsten-wire filament lamp invented by Dr. Irving Langmuir. These and many other inventions, together with the further development of central power stations since 1906, have so stimulated the growth of the incandescent-lamp industry that more than half a billion incandescent lamps were sold in the United States during the year 1931.

Inventions often have far-reaching results. The electric lamp is an outstanding example of this. This lamp was largely responsible for the early development of the central-station industry, because the first central stations depended almost entirely upon the revenue

which they obtained from the sale of current for the operation of electric lamps. It is possible that there would have been no central-station development if it had not been for the invention of the electric lamp; and it is certain that there would have been no extensive electric-lamp industry if it had not been for the development of the central station. The great central-station industry, which thus owed its origin to the electric lamp, has become more important in employing labor and in changing our modes of living and working than the lamp industry itself.

Thus the electric-lamp industry has contributed indirectly to employment in central power stations. On the other hand, the use of electric power has restricted the development of other sources of power; and the use of the electric lamp has limited the development of lighting by other agencies, such as kerosene and gas. A specialized investigation of a limited field, such as the present study of technological changes and employment in the electric-lamp industry, must eliminate these intangible factors while recognizing that they qualify in a measure the conclusions reached in the more limited field of inquiry.

The activities of industrial organizations seem naturally to divide into two main phases: (1) The manufacturing and marketing of a product which meets present-day needs and existing demands; and (2) the development of the industry so as to enable it to anticipate the needs and possibilities of the future. The electric-lamp industry has been distinguished by unusual emphasis on the second phase. The organization of the industry has provided large sums and engaged the services of many of the foremost engineers and scientists for carrying on research and for putting into effect new knowledge and new ideas. The industry has exhibited an emphatic trend toward continuous improvement of lighting facilities.

These policies of the industry have had a number of important results. For most purposes, and where current is available at moderate cost, the incandescent electric lamp provides the most efficient and most economical form of lighting. The light output of the tungsten-filament lamp in 1920 was 10.6 lumens per watt, and in 1931 was 13.4 lumens per watt. These figures apply only to the ordinary large lamps operating on standard central-station circuits. Between 1920 and 1931 the list prices of the more widely used types of electric lamps, ranging in size from 10 to 60 watts, were reduced about 43 percent, and the prices of larger sizes were reduced even more.¹ The increasing efficiency and adaptability and the decreasing cost of the electric lamp have increased the demand for lamps. This in turn has helped to counteract a decline in volume of labor accompanying the introduction of remarkable labor-saving methods.

The Electric Lamp of Today

There are two main types of electric lamps—large and miniature. The definition is not absolute. "Although the miniature-lamp class designates broadly those lamps fitted with other than medium and mogul bases, the final determination as to whether a lamp is listed as a large or miniature lamp depends upon the service rather than the

¹ National Electric Light Association. Report of the Lamp Committee, June 1932. New York, pp. 2-4.

construction; for example, railway signal lamps and lamps for decorative service are classified as large lamps, even though fitted with bayonet candelabra or candelabra screw bases." Another distinction, which again is not absolute, is in the making of the bulbs. Bulbs for large lamps of standard types are blown from glass direct from the furnace by continuous automatic process. Bulbs for miniature lamps are for the most part made from tubing.

The structure and parts and also the materials of ordinary large lamps are shown in figures 1, 2, and 3. The materials are drawn from practically world-wide sources.

The filament is the central part of the lamp—the light-giving element. The way in which the filament is mounted and connected efficiently with the source of current becomes apparent from the diagrams presented in figures 1 and 2. The filament wire, usually coiled, is mounted on support wires and lead-in wires. The support wires are anchored in a glass rod or stem, which is usually merely an exten-

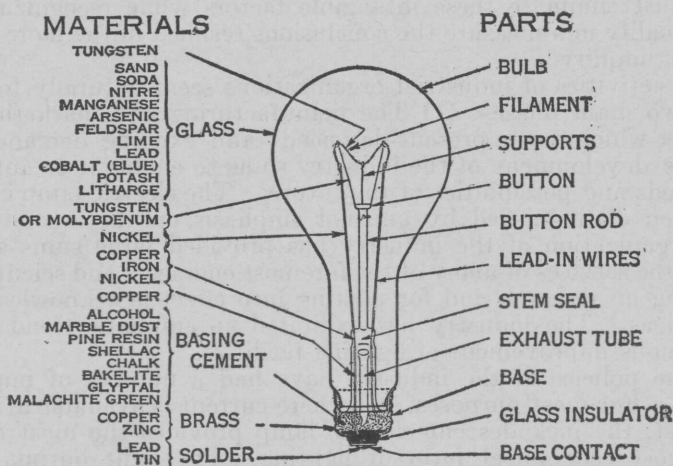


FIGURE 1.—Diagram of an electric lamp.

sion of a glass tube used for exhausting air from the bulb. The lead-in wires are for the purpose of connecting the filament with the wires extending from the central station (or source of current) to the socket. A lead-in wire consists of three parts—an outer lead, an inner lead, and a seal wire (a weld). It is at this central point, the seal wire, that the lead-in wires are fused with the glass of the stem. At the same point the exhaust tube is fused with the flare. These portions combined (the exhaust tube and the flare, the lead-in wires, the support wires, and the filament) form the mount, the mount minus the filament being called the stem. The mount is sealed to the neck of the bulb at the flange or enlarged portion of the flare. When the mount and the bulb have been sealed together by fusion of the glass the air is exhausted from the lamp, and if it is a gas-filled lamp, gas is inserted and the exhaust tube is sealed off by fusion of the glass. The base is then cemented on the neck of the bulb with one lead-in wire extending through the eyelet of the base, the other lead-in wire being soldered on the outside of the base.

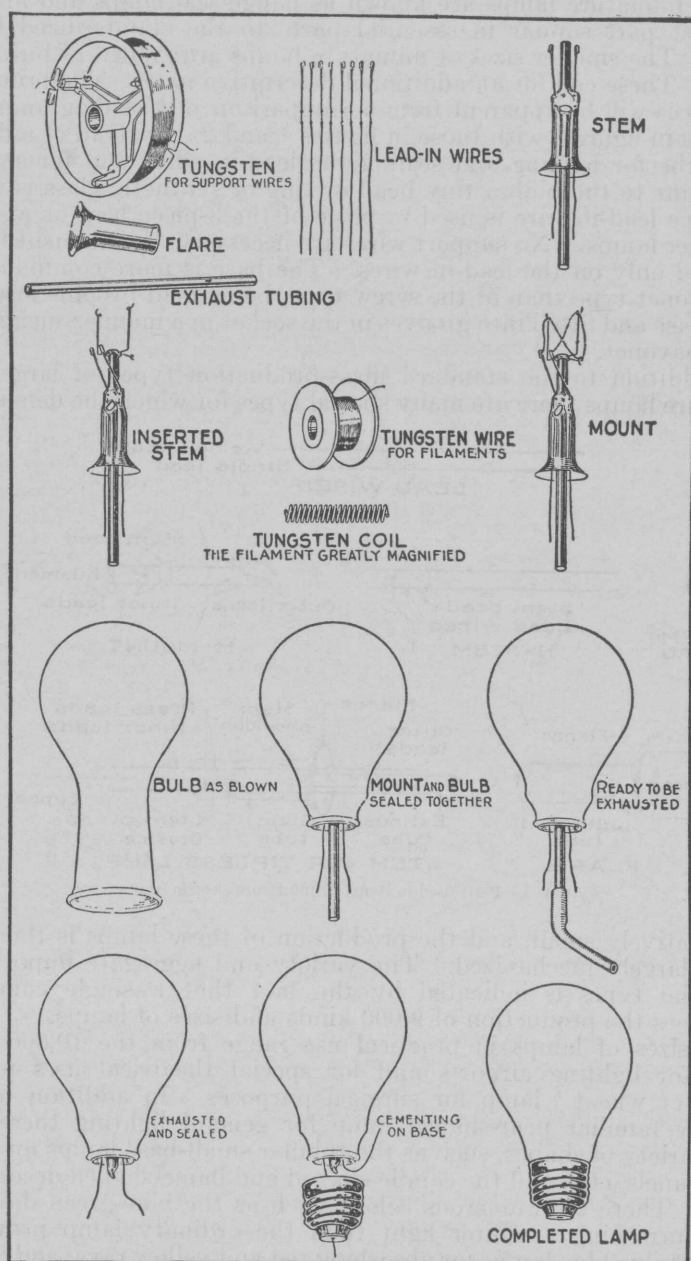


FIGURE 2.—Electric-lamp parts.

There are two standard types of miniature lamps. The larger sizes of miniature lamps are known as flange-seal lamps and are for the most part similar in essential parts to the standardized large lamps. The smaller sizes of miniature lamps are known as butt-seal lamps. These call for an additional descriptive note. The principal differences will be apparent from a comparison of the diagrammatic sketches in figure 3 with those in figures 1 and 2. Instead of a flared glass tube for holding and sealing the lead-in wires and for sealing the mount to the bulb a tiny bead or ring of synthetic glass is used. A 1-piece lead-in wire is used in place of the 3-piece lead or weld of the larger lamps. No support wires are necessary, the filament being mounted only on the lead-in wires. The base is more commonly of the bayonet type than of the screw type, being held by pins inserted in the base and fitted into grooves in the socket in a manner suggestive of the bayonet.

In addition to the standard mass-production types of large and miniature lamps there are many special types for which the demand is

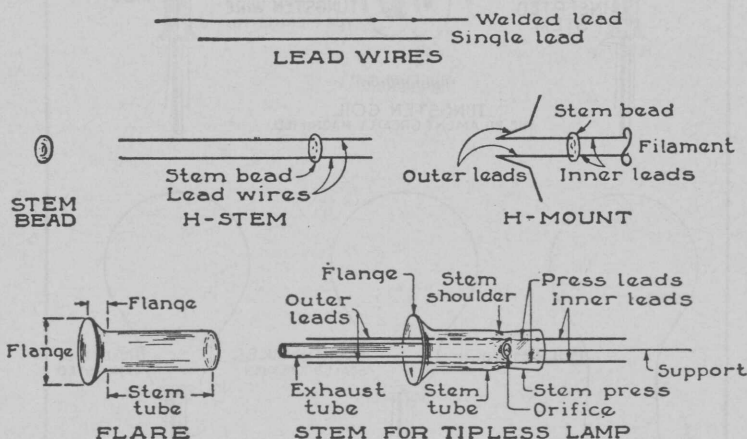


FIGURE 3.—Parts used in stems for miniature electric lamps.

comparatively small, and the production of these lamps is therefore not so largely mechanized. The variety and aggregate importance of special types is indicated by the fact that a single company announces the production of 9,000 kinds and sizes of lamps.

The sizes of lamps in practical use range from the 10,000 watt lamps for lighting airports and for special theatrical uses to the "grain of wheat" lamp for surgical purposes. In addition to the ordinary familiar pear-shaped lamp for general lighting there is a great variety of shapes, such as the tubular small-base lamps for show cases, panels, etc., and the candle-shaped and flame-shaped decorative lamps. There are numerous colors, such as the blue-green daylight lamp, furnishing a whiter light than the ordinary lamp provides; photographic blue lamps for absorbing red and yellow rays; and lamps with decorative colors, usually applied to the bulb in the form of a spray coating.

Special types of lamps include lamps for ordinary lighting use but applied under exceptional conditions. For mechanics, repair men,

and others, there are rough-usage lamps with sturdy structure and operated usually from a drop cord. For resisting vibrations there is a lamp with ring-shaped coiled filament mounted on a sturdy stem. For country homes, trains, etc., low-voltage and variable voltage lamps are provided. The exacting conditions of service and length of life necessary in the case of lamps for miners are met by special handling in the making and testing of such lamps. Where a light with a minimum of heat is important, water-cooled lamps are available. There is also a variety of under-water lamps for such purposes as marine rescue work; under-water work around docks, piers, etc.; study of under-water formations, flora, and fauna (as in the Beebe expeditions); under-water decorative uses, as in streams and fountains; illumination of swimming pools; and inspection of liquids.

Special lamps include those with special functions beyond ordinary lighting. Among these are projection lamps for such purposes as picture projection, beacons, floodlights, headlights, and spotlights. Among their special features are highly concentrated filaments, often "coiled-coil filaments"; and special handling in the manufacturing processes for the exact alining of the parts, testing, etc. Other special-purpose lamps are used in photography. There is, for instance, a ribbon-filament lamp used in taking microphotographs and for other purposes. Another lamp used in photography is the photo-flash lamp. In the bulb of this lamp is a very thin aluminum foil in an atmosphere of pure oxygen. A very small specially treated filament for a 1.5 voltage is used in starting the flash.

Among the most interesting of the special lamps are the so-called gaseous-conductor lamps for various purposes. Their main features include electrodes either alone or in connection with a filament; and a gas or vapor conductor of current between the electrodes. These lamps are in a sense a reversion to the carbon-arc lamp which was successfully used in series for street lighting before the development of the Edison incandescent lamp.

One of the most widely used of the gaseous-conductor lamps is the tube lamp ("luminous tube") for electric signs. This tube contains neon gas and frequently other gases which are made luminous by electrical discharge between electrodes. High voltages and transformers are used. These tubes are not lamps in the ordinary sense, and neither the output nor the labor of the neon-electric sign industry is included in the present study.

Other gaseous-conductor lamps include neon-glow lamps used, not for ordinary illumination, but as indicators and for testing purposes, etc. They are orange-red in color. There is a neon atmosphere in a bulb with metal electrodes. These lamps are used with ordinary bases and on ordinary voltages, and have the advantages of long life and low wattage.

There are also special lamps of the gaseous-conductor type for the purpose of ultraviolet radiation with or without ordinary light-giving facilities. One lamp of this type has a special bulb, a pool of mercury in the bowl of the bulb, two tungsten electrodes, and a tungsten filament connecting the electrodes. An electric arc is created in the mercury vapor between the electrodes. Most of the light is from the filament and the tungsten electrodes, and most of the ultraviolet radiation is from the arc. Transformers make possible

the use of ordinary light-socket voltages. Such lamps are used for the maintenance of health in connection with ordinary illumination needs; for the treatment of certain diseases, such as rickets; and in poultry husbandry in brooders for winter hatching and under conditions of limited sunlight.

In connection with the special types of lamps mention must be made of the photoelectric cell. This is often called a lamp, and it is made in connection with lamp manufacturing; but it is really a light-concentration tube or bulb for converting light into electricity—not electricity into light. Perhaps most intimately associated with the development of the photoelectric cell is Dr. Harvey C. Rentschler. Although the device is in a sense still in the experimental stage, its possibilities have already been demonstrated in a remarkable manner. One of its uses is in connection with the photometer for testing the light output of lamps. It has doubled the speed and also doubled the accuracy of this testing process. It records ultraviolet rays in the sunlight. It can be made to count passing objects, as for example the number of vehicles passing a given point, by registering the number of interceptions of a light beam. It may be made to actuate relay switches for various purposes, such as the setting off of a burglar alarm. Although it is one of the most remarkable and significant of recent scientific developments, it is merely an incidental phase of the electric-lamp industry.

How Lamps Are Made

General Description

The various parts of an electric lamp are produced in separate plants or at least in separate departments. In the wire plant tungsten ore is reduced and made into filament wire, and wire for use in supporting the filament and for other auxiliary purposes is also manufactured. Welds are made in the plant or department commonly called "the welds department." Welds consist of outer and inner lead wires and the seal wire, only the latter being manufactured ordinarily in the welds plant. Other wire, such as that used for mandrels on which filaments are coiled, is either made or adapted to appropriate uses in the same department. Glass tubing and cane for the glass parts of the mount and for smaller bulbs are made in tubing plants. Miniature bulbs are usually made from tubing in separate plants or departments. Large bulbs and some miniature bulbs are made in separate plants and are blown from molten glass drawn directly from a tank. There are also separate plants for the making of bases. Various other elements, such as cement, acids, gases, tools, and machines, are in part produced in separate departments by the lamp companies and in part purchased by them from other manufacturers.

Most of the labor required in the manufacturing divisions of the lamp industry is employed in what are known as "lamp-assembly plants." In these plants, however, the processes are more than those of merely assembling the parts. Various essential changes are made in the nature of the parts in the process of combining them into a completed lamp. From the point of view of manufacturing processes, lamps are of three main varieties: Large lamps of standard types, miniature lamps of standard types—both made in such large

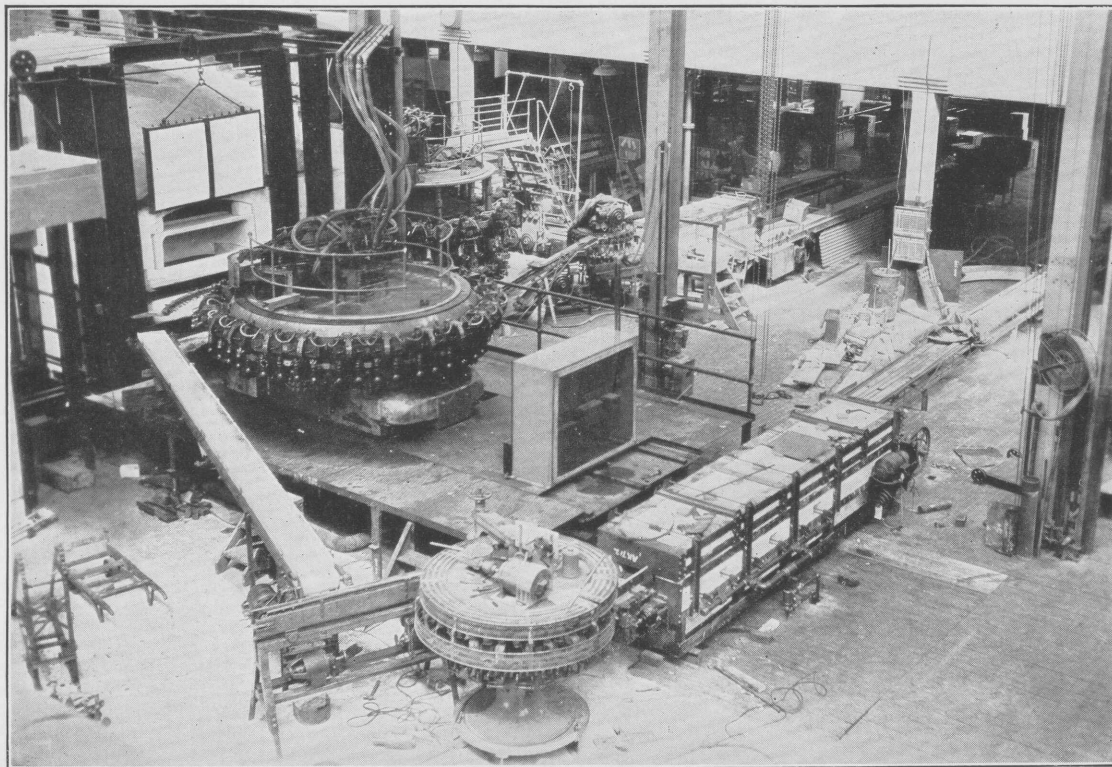


FIGURE 4.—GENERAL VIEW OF BULB-MAKING MACHINERY.

Glass furnace (cold) with arched mouth; Ohio machine (in front of furnace); hot-belt conveyor (left); tractor (a round segmented feeder plate not shown); burn-off machine (center foreground); conveyor (between burn-off machine and rectangular leir to the right); rectangular annealing leir; cooling conveyor.

quantities as to be adapted to mass-production methods—and special lamps not adapted to mass-production methods, mainly because of the limited demand. In the making of these special lamps the methods are more largely either manual or semiautomatic than in the case of lamps of standard types. Because of the great variety of types of special lamps and the relatively slight effects of technological changes on the volume of labor in their manufacture, the methods of making them will not be further discussed.

In the making of the various parts and also in the assembling of the parts, there have recently been hundreds of technological changes affecting employment. Two developments are of outstanding importance. One of these is the group or unit system of manufacture. A conception of what is meant by the group system may be gained from a photographic illustration of bulb-making machinery (fig. 4). In the left background is the arched mouth of the glass tank or furnace. In front of the furnace is the so-called Ohio machine for making bulbs. To the left is one form of hot-belt conveyor, which in turn connects with a tractor, the mechanism of which is not shown. By means of the hot-belt conveyor and the tractor the bulbs are transferred to the circular burn-off machine shown in the center foreground. From this the bulbs are conveyed to the rectangular annealing leir in the right foreground. From this they are in turn transferred to a cooling conveyor, which takes them to the inspection department. The same tank may supply other similar units. The underlying principle is the coordination and synchronized operation of the various related parts of a production unit, and it is extensively applied throughout the industry.

The second outstanding technological development is the perfecting of a widely used mechanism for performing a large proportion of the operations formerly requiring manual labor. This mechanism is extremely adaptable and assumes many forms. In general it may be described as a turret or spider rotating on a vertical axis operated by electrical motive power and usually indexing from one operating position to another. In some cases, however, there is a continuous tractor movement instead of an intermittent indexing arrangement, and in some cases the machine is oblong instead of circular.

The Ohio bulb-making machine and the burn-off machine shown in figure 4 are both of the general type described. The important features of this type of mechanism are shown in figures 5 to 7. Figure 5 illustrates the way in which such a mechanism rotates and indexes to successive operating positions. The machine illustrated is known as the finishing machine, and is used for attaching the base to the neck of the bulb containing the sealed-in mount.

Figure 6 illustrates the mechanical principles by which a rotating turret machine is operated (in this case a large-lamp stem-making and support-inserting machine). The diagram includes the main cam shaft and the indexing and operating mechanism. The main cam shaft, with the driving cams mounted thereon, actuates all the mechanisms on the machine.

Figure 7 shows in detail the manner in which one of the driving cams on a main cam shaft automatically operates a number of mechanisms (in this case the flare feeding fingers, the stem jaws for the flare feed, the stem jaws for the exhaust tube feed, and the exhaust tube nonfeed mechanism).

In general, such a machine is operated by a revolving main cam shaft. On this shaft is a series of driving cams varying in number, size, and shape, and adjusted by means of a master cam dial for maintaining exact time and space relations between the different operating mechanisms at the different indexing or working positions. The main cam shaft with its series of cams operates the indexing device for rotating the turret or spider; various levers, fulcrums, elbows, conveyors, fingers, pincers, and other operating devices; secondary cam shafts;

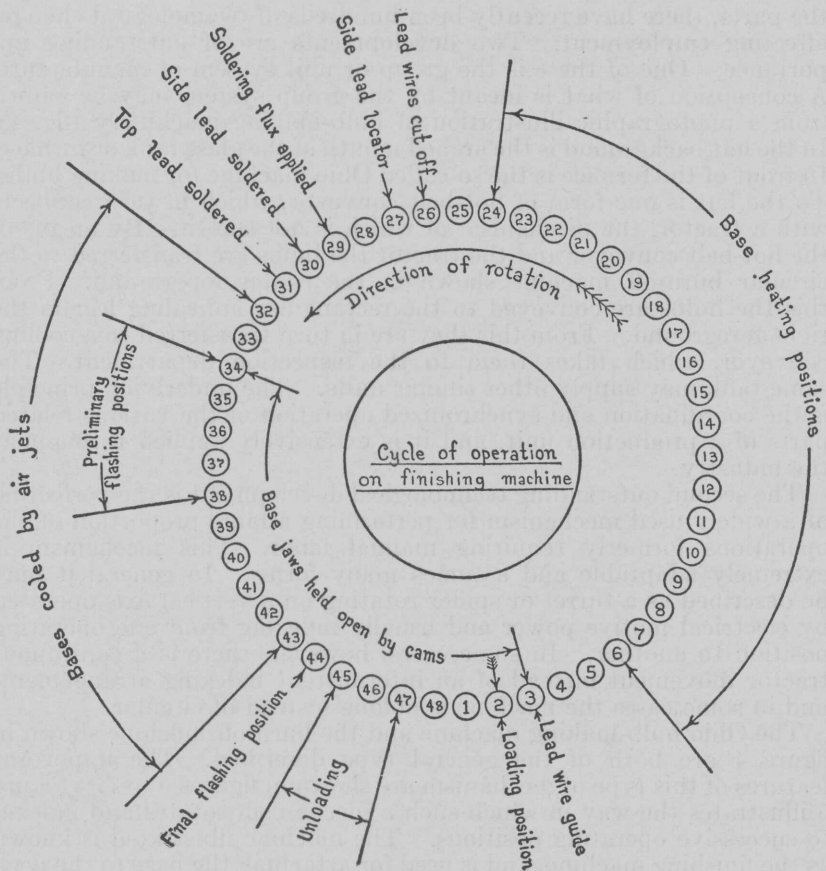


FIGURE 5.—Operation of a rotating turret type machine.

and in some cases a chain device for operating a second cam shaft containing a similar series of driving cams, which in turn control another series of operating devices of various kinds.

The cam-operated turret machines vary widely in size, and their adaptability ranges from the heavier to the most delicate operations. Thus there is the 48-head Ohio bulb-making machine (fig. 4) which indexes at 48 positions and turns out finished bulbs (except for frosting). In contrast there is the small filament-mounting machine perfected after about 10 years of study and experiment. The mechanical

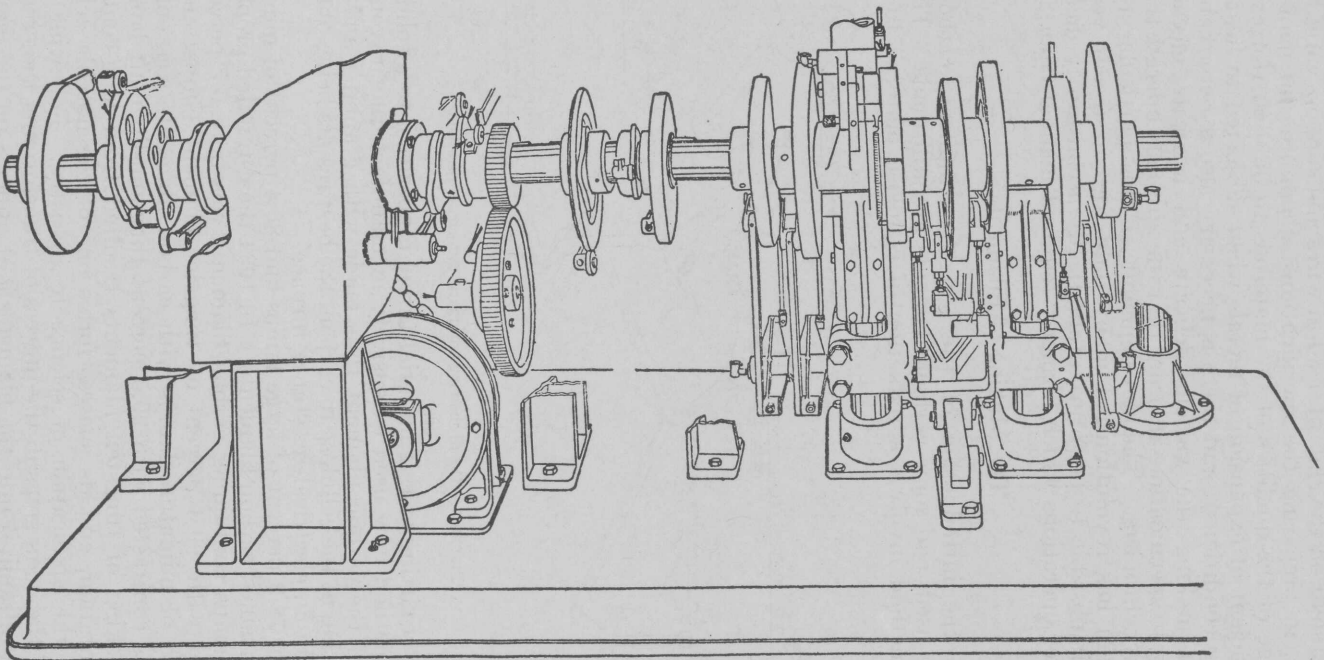


FIGURE 6.—Main cam shaft and indexing and operating mechanism.

principles are similar, but in such delicate operations as mounting a coiled filament on the ends of lead-in wires and support wires there is required, in preparing the specifications, a minute and painstaking knowledge of the qualities of the materials to be used (for example, the coefficient of expansion of metals when subjected to heat under operating conditions); and there is necessary also a remarkable precision in making the various delicate and intricate mechanisms according to specifications in order that the unit may operate throughout in synchronism. The development of this particular type of mechanism has revolutionized many industries in recent years by making it possible to perform automatically a constantly increasing number of operations which formerly required manual labor.

The Making of Filaments

Before the introduction of the tungsten filament, carbon was generally used, and some carbon filaments are still made. The prevailing method involves a reduction of cellulose material to liquid

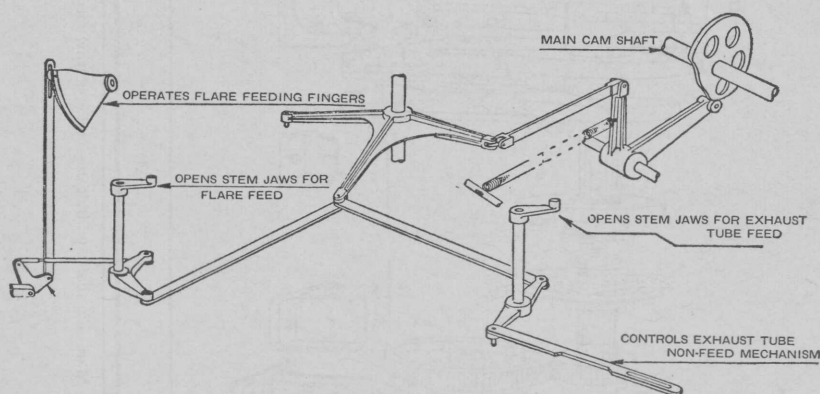


FIGURE 7.—Detail showing automatic cam-shaft operation.

form, the squirting of this material through nozzles into a solidifying fluid (a method now used extensively in manufacturing rayon), the coating of the carbon filament thus made with graphite, and firing for reduction of the cellulose to carbon, the best results being obtained by firing in an electrical-resistance furnace.

In 1910, 77.2 percent of large lamps and 86.4 percent of miniature lamps contained carbon filaments. In 1931 the estimated proportion of large lamps containing carbon filaments was only 0.7 percent as contrasted with 99.3 percent of tungsten-filament lamps; and the proportion of miniature lamps with carbon filaments was only 0.5 percent as contrasted with 99.5 percent tungsten-filament lamps.

The making of tungsten filaments resulted from long-continued experimentation, and its success forms one of the notable achievements in the application of science to industry. Following is an outline of the main steps in the process of transforming the crude ore (usually wolframite) into the filament as it appears on the mount of an electric lamp: (1) Chemical purification of the raw tungsten oxide to pure tungsten oxide; (2) "doping" with a chemical to in-

crease the nonsag quality of the metal; (3) hydrogen treatment for eliminating the oxide; (4) sifting of the purified powdered metal; (5) pressing into slugs; (6) a partial furnace sintering; (7) final sintering by electrical treatment for converting the pressed powder in the slug into a solid bar comparable to pig iron; (8) swaging (automatic hammering); (9) rough drawing through steel or carboloy dies; (10) final drawing through diamond dies; and (11) coil winding and cutting into filament form.

The ore is usually imported from China or Australia, because the finer grade of ores comes from these countries. It is first put through a chemical process for separating or precipitating the pure tungsten oxide from the ore. For this purpose it is placed in tanks, and later the dross elements are drained off through a screen which retains the tungsten oxide. In appearance and general consistency this resembles sulphur.

The tungsten oxide is reduced to a powder and mixed with a chemical "dope." This chemical, in the later processes to which the tungsten is subjected, changes the structure of the metal in a manner which helps to keep the filament wire in the lamp from sagging.

The next stage eliminates the oxide from the tungsten. The tungsten oxide, "doped" as already indicated, is placed in small elongated troughs. These troughs are conveyed slowly through tubes which are heated by gas. Pure dry hydrogen gas is passed through the same tubes from the opposite direction. The hydrogen combines with the oxide, and since the troughs of tungsten oxide are forced through the tubes against the hydrogen current, the latter drives off the oxide, leaving pure tungsten.

The pure tungsten after it comes from the hydrogen furnace is put through a fine-mesh silk screen. These screens are operated in units by a mechanical device. The result is a very fine and extremely pure tungsten powder.

The tungsten powder is carefully measured and weighed and a predetermined quantity (as 600 grams) is put into a metal compress and subjected to a pressure of 15 tons per square inch. The result is the compression of the powder into a slug, 600 grams being reduced to a slug 24 by $\frac{3}{8}$ inches. The slug is very brittle, and is held together merely by the compactness of the particles.

The slug is put on a molybdenum slab and the slab is then placed in a roasting or sintering furnace for a partial sintering. The particles are not melted but are only slightly fused together to impart additional strength to the slug.

The slug is then put into a copper bell jar and sintered by subjection to electrical treatment by the passing of 2,000 amperes through it at 40 volts pressure. The jar is filled with pure dry hydrogen to prevent oxidation of the tungsten while hot. The temperature approaches the melting point, and the use of an ordinary crucible is impossible because of the high melting point of tungsten. By means of this electrical treatment the slug is completely sintered and the particles are fused into a solid metal bar. It is in a state resembling that of pig iron and is not ductile.

For imparting ductility the bar is swaged or hammered. The sintered bar or rod, as it comes from the electrical treatment, is placed in an electrical furnace in which hydrogen is burning to avoid oxida-

tion. The mechanic who handles the operation places a heated end of the bar in a swaging machine having two hammers which together resemble a die. These hammers operate on an angular cam. The rod is forced through the center of the machine and then withdrawn, while the rotating hammers reduce the size and increase the length of the rod. The other end of the rod is then heated and put through the same process. (See fig. 8.) There are about 15 swaging machines in a unit and the rod is subjected to a large number of passes through these machines until it is reduced to ordinary wire (as size 14). As the rod is elongated into a wire in passing through the machines, the process becomes increasingly automatic.

The hammered wire is next subjected to a rough-drawing process through steel or carboboly dies. These dies are operated substantially according to standard wire-drawing practices. They not only reduce the size of the hammered wire, but impart to it the uniformity of size and the smoothness of surface necessary for further drawing through diamond dies (fig. 9).

These latter dies are necessary because of the extreme exactness and uniformity required of all filaments and the minute sizes necessary for small lamps. The dies are drilled mechanically in the wire-drawing department. For the finest filament wire (about one fourth the diameter of a human hair) the wire is drawn as many as 400 times. The dies are mounted on drawing machines and the machines are arranged in units. As a spool of wire is automatically fed through one die it is automatically wound on another spool. The manual parts of the drawing process consist of transferring the spools from one die to another, threading the dies and keeping the automatic mechanism properly adjusted and in running order.

In addition to the making of tungsten wire the wire department makes molybdenum wire. This is used for support hooks (the wires extending from the glass stem and used for mounting the filament) in lamps other than those burning at a very high temperature. Molybdenum has a melting point of about $2,500^{\circ}\text{C}$. For lamps burning at a higher temperature tungsten supports are used. Molybdenum is purified by a much simpler process than is necessary in the case of tungsten, which requires about a week for refining as compared with about 18 hours in the case of molybdenum. After the two metals are reduced to pure powder form, the processes already described for tungsten apply almost without modification to molybdenum.

The coiling and winding and final preparation of the filament wire for mounting on lamp stems are operations which are performed in lamp-assembly plants.

Lead-in Wires

The nature of lead-in wires is indicated in figures 2 and 3. Their purpose, in general, is to establish connection between the filament wire inside the lamp and the wires carrying the electric current from its source to the filament. The lead-in wires must pass through a nonconducting medium and for this reason, as well as for holding them in proper position, they pass through the glass portions of the mount. When glass is subjected to heat such as results from the burning of the lamp the result is an expansion. In order to maintain a perfect seal of the lamp against the entrance of air or the escape of



FIGURE 8.—SWAGING TUNGSTEN RODS TO STRENGTHEN METAL FOR MAKING FILAMENTS.

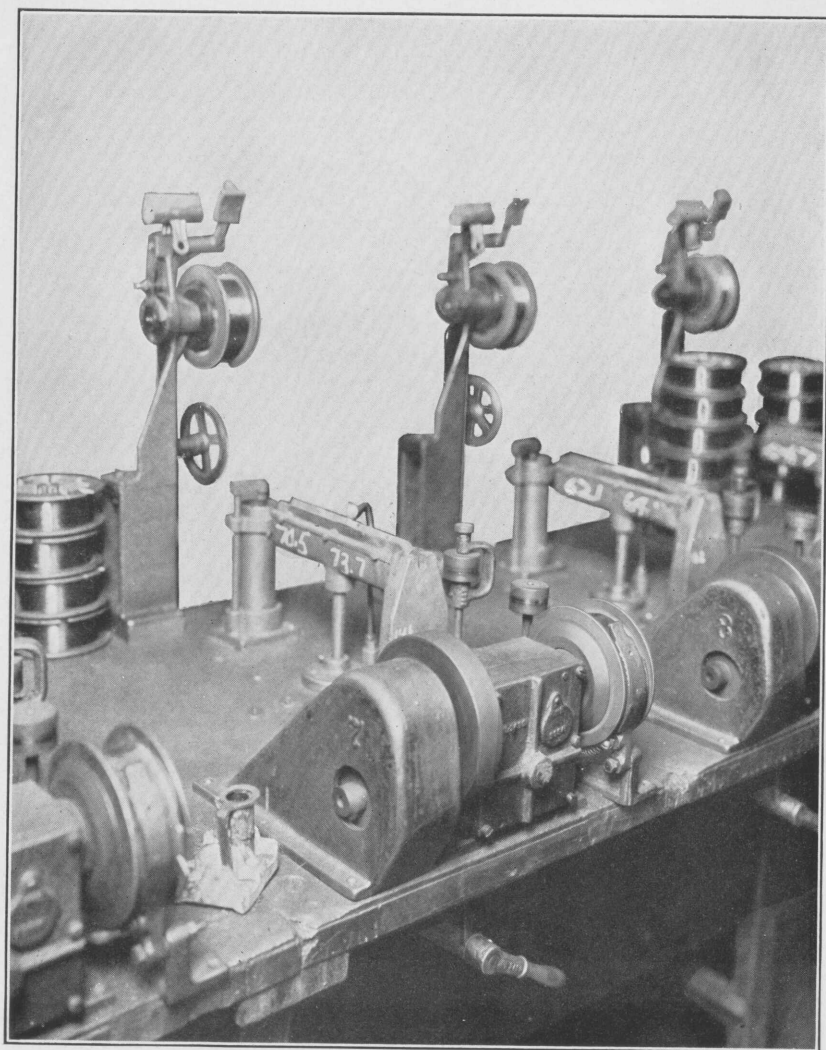


FIGURE 9.—DIAMOND DIES FOR DRAWING TUNGSTEN WIRE

gases from the lamp it is necessary, therefore, that the coefficient of expansion of those portions of the lead-in wires which are sealed in the glass should be the same as the coefficient of expansion of the glass itself.

An early solution of this problem of equalizing the expansion was the use of platinum for the sealed-in part of the lead-in wires. From 1911 to 1913 the use of nickel iron was introduced. Since 1913 dumet wire has come into general use for the sealed-in part of the lead-in wire. For the outer lead copper is generally used. In the case of filaments which are too small to warrant the welding of the sealed-in part to the inner and outer parts, the entire filament is made of dumet wire. In some lamps with very hard glass in the seal tungsten lead-in wires are used, but in general dumet wire is used for the seal and nickel and copper for the inner and outer leads. With the introduction of gas-filled lamps, nickel was used for the inner lead.

Dumet wire is composed of (1) a copper-plated nickel-iron core or rod, (2) a brass spelter in the form of a ribbon wrapped around the core rod, and (3) a copper tube which is slipped over the spelter and the core rod. The copper tube is shorter than the core rod. This composite rod is put on a large drawbench and drawn down until the copper tube completely covers the central core rod.

This process is merely mechanical. In order to solder the outer tube to the core rod the composite rod is placed in a hydrogen furnace at a predetermined temperature which melts the brass spelter, and thus a complete soldering is effected.

The composite soldered rod (about 5 feet long and 450 millimeters in diameter) is then put on a large drawbench and drawn down to 250 millimeters in diameter. Rods are then butt-welded together end to end so as to form one long piece. This piece, after being annealed, is put on a standard wire-drawing machine and drawn down to 120 millimeters. Then it is put on an upright wire-drawing machine and drawn down to 50 millimeters. The wire is then annealed and transferred to a diamond die wire-drawing machine. Here it is drawn from 50 millimeters in diameter to the finished sizes, as, for example, 10 millimeters. At this stage the wire is passed through a gas flame, through a borax solution, and then through a gas flame again. This produces a red coating on the wire which protects it from oxidation.

The wire is then inspected and the joints which were made by the butt-welding of the rods are cut out. The wire is then ready for use in the manufacture of leads or for other purposes.

The welding of the seal to the inner and outer leads was originally done by hand. The operator picked up a piece of copper wire, the outer lead, with the left hand and a piece of the seal wire (formerly platinum) by means of tweezers in the right hand. The copper wire was then held in a gas flame until the copper melted, when the seal wire was inserted into the melted ball on the end of the copper wire. This made what was called the first fused lead. These leads were then given to another operator who performed a similar operation. The first step toward mechanical operation was by means of the single electric welder, which welded only one copper wire to the dumet wire, the other copper wire being welded to the other end of the dumet wire by hand. By the addition of another mechanical unit at the

right end of the machine, the two units forming the double electric welder, all three parts of the lead-in wire were welded mechanically.

The next development was the miniature percussive machine. With the introduction of gas-filled lamps it was necessary to use some other metal than copper for the inner lead. Nickel wire was used for this purpose and the miniature percussive machine was developed for the purpose of welding the three parts—the nickel inner lead, the dumet seal, and the copper outer lead. For making welds for larger gas-filled lamps a large percussive machine was developed, which in addition to the operations performed by the miniature machine makes a hook on the end of the nickel inner lead, the hook being used for draping the filament wire.

Miniature lamps of the flashlight type do not use welds, but have 1-part dumet wire leads which extend from the base of the lamp to the filament. The end of the lead that connects with the filament is flattened by a machine, producing a knoblike enlargement. The wire is then drawn through a die and the knob is formed into a microscopic tube, into which the end of the filament is inserted, the two ends being clamped together. The inserting and clamping of the filament is, of course, done in the lamp-assembly plant.

The machines used in the welds department have not only become increasingly automatic but have been so perfected as to make it possible to increase the speed of operation by degrees until the output per operator has been multiplied many times.

In addition to the making of welds the welds department makes mandrel wire on which the filament is wound, the mandrel being later dissolved by acid. The department also makes nickel tubing for supports in larger lamps; nickel straights (pieces of straight nickel wire for specialized uses); and pieces of nickel ribbon used in large lamps for supports for the mica disks which are fitted above the neck to keep the heat from the base.

The materials used for these various parts are manufactured in other plants. The principal manufacturing processes in the welds department are connected with combining the nickel iron, the brass, and the copper parts of the dumet wire; wire drawing; welding the dumet wire to the other parts of the lead-in wire; and the making of the auxiliary parts such as mandrel wire.

Tubing and Cane

Glass tubing and cane are used principally for the glass parts of the mount (see fig. 2), for the making of miniature bulbs, and for luminous tubes. The processes are virtually the same without regard to the uses to which the tubing is to be put. The old method of making tubing was a method of hand drawing and blowing. A brief but unusually clear description of this earlier process may be quoted.²

Standing in front of the pot of molten glass, the gatherer inserts his long and heavy pipe into the molten mass, and by skillful manipulation accumulates at the end of the pipe the first bit of glass. He then withdraws the pipe and shapes the glass into a round ball by first marvering it on a flat and smooth surface and then blocking it in a wooden receptacle filled with water to cool the outer surface of the ball. He then returns it to the pot and makes a second gathering of glass over the formed ball, again marvers and blocks it, and then turns it over to the ball maker. The latter makes a third and final gathering of glass, at which

² U.S. Bureau of Labor Statistics Bul. No. 441: Productivity of Labor in the Glass Industry. Washington, 1927, p. 137.

time the ball on the end of the pipe weighs on the average from 30 to 40 pounds. After swinging the pipe several times forward and backward, at the same time blowing lightly into the pipe, the ball maker hands it over to the marverer, who, by repeated blowing, marvering, and blocking the glass, puts it into shape to be drawn.

In the meantime the punty boy has heated his punty, consisting of a large iron disk attached to an iron rod. The gaffer, to whom the carry-over boy has brought the pipe with the ball of glass ready to be drawn, lifts it over the punty, allowing the outer surface of the glass ball to become attached to the disk of the punty. The drawing boy then lifts the punty from the floor and begins to move away from the gaffer, pulling with him the glass, which has become firmly fastened to the punty. The gaffer, while continuously blowing into his pipe to keep the inside of the tube hollow, walks slowly in the opposite direction from the drawing boy, thus drawing out the glass to the required thinness. When the drawing is finished, the cutting boy, with the help of a file, cuts the useable part of the tubing into required sizes and throws the waste into a cullet receptacle. It is estimated that only 25 to 30 percent of the tubing thus drawn by hand is good tubing, the rest going back into the melting pot as cullet.

The present method of making tubing, except in the case of small quantities of special types, is by the so-called "Danner process." Patents covering it were issued in 1917. Since then many improvements have been made, which account for a progressive increase in productivity of labor. Variations in methods of applying the process naturally occur, but the following account is characteristic of the industry.

The raw materials come into the mixing house adjacent to the main plant on a private railway spur on the opposite side of the plant from the track for outgoing shipments in order to facilitate a constant flow. Bulk materials such as sand and cullet (broken glass) are lifted mechanically from cars to the second floor and placed in silos (storage and feed tanks). Cullet is ground by a crusher with a magnetized conveyor for removing metal. From the silos and the cullet crusher the bulk materials are dumped into the mixer by levers. The mixer is drawn by a tractor into position under each storage tank in turn, and as the material pours by gravity into the mixer it is weighed, the tank being closed by a lever when the right amount is emptied into the mixer, which is then moved to a new position under another tank.

Thus these materials, and various others such as lead oxide, niter, and potash, are handled by means of mechanical devices, and in a carefully coordinated manner so as to avoid waste motion and to reduce the amount of labor to a minimum. Similar mechanical methods and coordination of movements are utilized in the transfer of the materials to the furnace. A typical furnace installation consists of a feeder through which the "batches" of raw materials are emptied, the melting end of the furnace, the throat (an opening through which the molten glass flows), the working end, the reheater, and the mandrel or spool from which the fused glass is transformed into a line of tubing. As the materials are fused into molten glass of proper temperature and consistency the glass is allowed to flow to the rotating clay mandrel or spool. When ready to begin drawing a workman takes a long hooked piece of steel and drives the hook into the molten glass on the end of the rotating mandrel. He then withdraws the hook, to which a portion of the molten glass adheres, and as he moves away from the mandrel the drawing process begins. The "gob" of glass on the hook, with the crude tubing extending from it to the rotating mandrel, is drawn away from the mandrel and toward the drawing machine more than a hundred feet away (the distance

varying). Air is supplied through the mandrel to form a tube instead of a rod. At the proper moment the "gob", or rough end attached to the hook, is broken off. A man wearing asbestos mittens then seizes the tube and draws it out by hand along the runway over rollers covered with asbestos cloth until he reaches the drawing machine, when he feeds the tube into the machine. Thereafter the drawing process is automatic.

Various factors are involved in the regulation of the size of the tubing and the thickness of its walls, and exact ratios are worked out for such phases of the operation as the size of the mandrel, the amount of glass fed to it, the speed of its rotation, and the speed of the draw. The rate of drawing for smaller tubing runs as high as 7 miles an hour, with higher speeds attainable by means of recent improvements.

Remarkable as is the efficiency of the Danner machine in its operation in recent years, improvements now make possible a far greater productivity of labor. Among the more recent improvements are a die connected with the furnace for additional feeding control; a method of rotating the tubing for securing more perfect roundness instead of depending exclusively on the rotation of the mandrel; and an arrangement for taking advantage of the force of gravity by placing the drawing machine on a level below that of the furnace, thereby allowing the molten glass to flow by gravity from the mandrel so that the tubing is formed without being drawn or pulled, and therefore with a minimum of strain and with a much higher speed.

The tubing is passed on by the drawing mechanism to a cutting section, the two operating synchronously. A revolving disk saw nicks one side of the tubing and a slight mechanical pressure breaks it smoothly at the point of the nick. As the tubing passes through the drawing and cutting processes it is inspected, a check inspection being made of a certain percent of the output. The tubing thus inspected and cut to measure is passed through a gaging machine, which automatically sorts it by outside diameter. The sorted tubing is then put through packing machines which weigh, wrap, bind, and transfer it from one section to another in preparation for removal by elevators to the storage and shipping room below.

Bulbs

The making of miniature bulbs from tubing is a process radically different from the making of large bulbs from molten glass direct from the furnace.

In the making of miniature bulbs the tubing is transferred from the stockroom to the blowing department on hand trucks. The principal operations are by means of machines of the rotating vertical turret type. The ordinary blowing machine revolves around a vertical axis and assumes 12 indexed operating positions during the revolution. The same type of machine is used for all sizes of miniature bulbs, the sizes varying with the sizes of tubing. The tubes are placed upright in a circular row in chucks in the 12 operating positions. Six positions are required for making a bulb, so that there are two sets of six indexed positions and two bulbs are made by one complete rotation of the machine. The machine, which is automatic, indexes through a series of fires playing upon the lower end of the tubing in successive positions.

After being inspected, the bulbs are transferred to the cutting department and placed in hot-cut machines. As they come from the blowing machines, they are sealed by the fusion of the glass at the neck. It is necessary to open the bulb, and this is done by a process known as "cracking." There are two types of hot-cut machines. One of these, that for the larger miniature bulbs, is an indexing machine similar in operation to the blowing machine. After the bulb is "cracked" (opened by the removal of the lower fused end of the neck) it passes to another indexed position where the final cut is performed. On the outside a knife of the circular-saw type operates on the neck of the bulb, and a small inside knife, moving upward into the neck operates in synchronism with the outside knife. In the case of larger miniature bulbs a monogram is applied, and they are then subjected to final inspection and packing. In the case of smaller miniature bulbs a hot-cut machine has recently been developed which has a tractor or continuous operation instead of an indexing arrangement. The smaller miniature bulbs are not monogrammed. They are fed automatically into the hot-cut machine, and this automatic feed combined with the continuous tractor movement greatly speeds up the operation. Smaller bulbs are annealed, largely for the purpose of cleaning them.

Some miniature bulbs are blown from glass direct from the furnace, as in the case of large bulbs.

Large bulbs of standard sizes, shapes, and materials are made by automatic processes which illustrate in a remarkable manner the developments in the field of automatic machinery, although special types for which the demand is relatively small are made by semi-automatic or even manual methods.

In the handling of the raw materials mechanical methods have been developed resembling those used in the manufacture of tubing and cane. The principal ingredient, sand, is produced from sandstone rock. The sand is transported in tank cars and is handled in a manner similar to the method of handling liquids. The various processes of storing, assembling, weighing, and mixing the ingredients and of transferring the "batch" from the mixing house to the furnace have been developed in such manner as to eliminate most of the manual labor. The force of gravity is used extensively, as, for instance, in the unloading of sand from the tank cars.

Many improvements have been made in the melting furnaces. A typical furnace holds about 200 tons of molten glass and is large enough to contain a large reserve of glass beyond the amount needed for a single day's production of bulbs. A rectangular furnace containing 200 tons of molten glass feeds 4 bulb-making units, which may be operated independently.

A typical bulb-making unit (illustrated in fig. 4) fed by the melting furnace consists of: (1) A bulb-making machine; (2) a hot-belt conveyor; (3) a tractor conveyor for feeding bulbs from the hot-belt conveyor into (4) a round segmented feeder plate which feeds the bulbs into (5) a burn-off machine; (6) a conveyor for transferring the bulbs to (7) an annealing lehr; (8) a cooling conveyor; and (9) inspecting and loading tables.

In the typical unit illustrated by figure 4 a 48-spindle bulb-making machine of the Ohio type has a ram operated by compressed air. The ram, to which are attached four holders, is automatically extended

into the molten glass inside the furnace and each of the four holders, by suction, lifts out an exact quantity of molten glass, the quantity being determined by keeping the level of glass in the furnace constant within one thirty-second of an inch. The ram then withdraws the holders and they deposit their loads of soft glass on four spindles extending upward from the machine. The indexing mechanism of the machine then moves clockwise into position for allowing the next four spindles to be supplied by the ram holders. Thus in succession the 48 spindles on the rotating machine are fed. While the spindles rotate, for the purpose of securing a uniform distribution of glass, the entire indexing mechanism of the machine revolves on its vertical axis.

Following a set of four spindles around the machine from the furnace mouth one finds that at predetermined times they automatically change their position from upright or vertical to an outward or horizontal and finally to a downward position between the vertical and the horizontal. A cavity in the solid ball of glass is started by a plunger, and as the spindles rotate and change their position puffs of air are blown into the cavity through cam-operated valves. For each spindle there is a mold. At a certain position the two halves of the mold close about the glass. A final blow of air is then turned on and retained until the mold is ready to open and discharge the formed bulb from the machine. The jaws of the mold then open, releasing the bulb, and the spindle moves outward and drops the bulb onto an asbestos conveyor. The four spindles, having thus completed the circuit of the revolving mechanism, are then ready to take their turn once more at the furnace mouth. Eleven other units of 4 spindles each (48 in all) are simultaneously in operation in various stages of forming the bulb.

The process is almost entirely automatic, but one part of the operation is supervised. As the molten glass hangs on the spindle its weight elongates it, and its length before the mold closes about it is regulated by jets of air. It is necessary for an attendant to watch the process of elongation in order to regulate the amount of cooling air.

As the bulbs move automatically from the spindles to the inspecting and loading tables they pass through a burn-off machine. The purpose of this machine is to remove the surplus portion of the bulb that has been held by the spindle jaw. This is accomplished by feeding the bulb into horseshoe-shaped burners, where a sharp flame of artificial gas and air blows on the neck of the bulb. This flame softens the glass sufficiently to allow the weight of the undesired part to pull this portion away from the rest of the bulb.

When the bulbs reach the inspecting tables each bulb is inspected for various defects in glass or manufacture. Bulbs which do not require frosting are packed for shipment in hampers at the inspecting tables. Those which are to receive what is known as inside frosting are put up in trays, which are assembled in trucks and taken to the frosting department. The purpose of inside frosting is to diffuse the light and to reduce the glare from the filament. The process was introduced about 1925, and it required an additional labor force. Into each bulb is injected an acid solution which dissolves glass from the inner surface of the bulb, but the indentations thus formed weaken the bulb wall, and another acid solution is therefore injected for the purpose of reducing the sharpness of the angles etched by the first acid. The bulbs are finally washed with hot clean water for

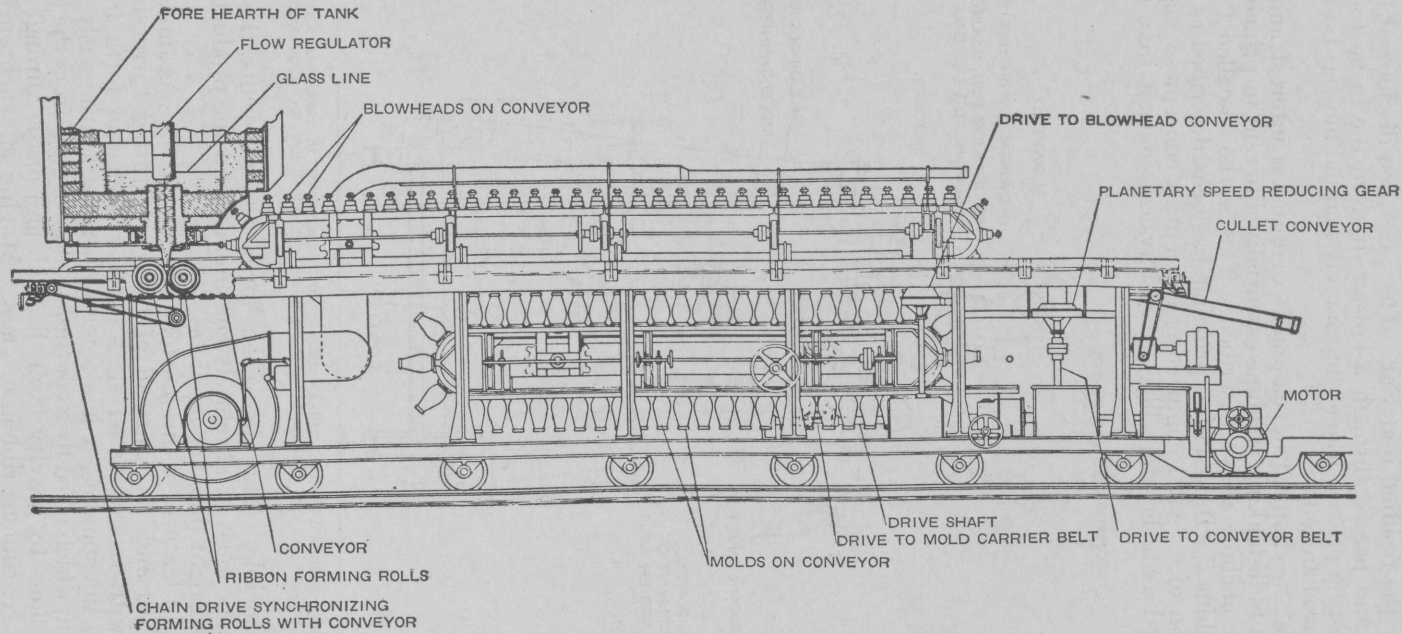


FIGURE 10.—Side elevation of Corning bulb machine (working side). (Reproduced from *The Glass Industry*, August 1931.)

removing the residual material. They are then discharged from the machine and passed through a hot-air drier to the inspectors. The inside frosting process was at first largely manual but has been almost entirely mechanized.

A recent mechanical development of unusual interest and importance is a bulb-making machine essentially different in principle from the Ohio machine above described. This is the so-called "Corning bulb machine." Its essential principle has been described as a major illustration of a "vital engineering concept, a concept so vague and generalized as to be more like a metaphysical concept than an engi-

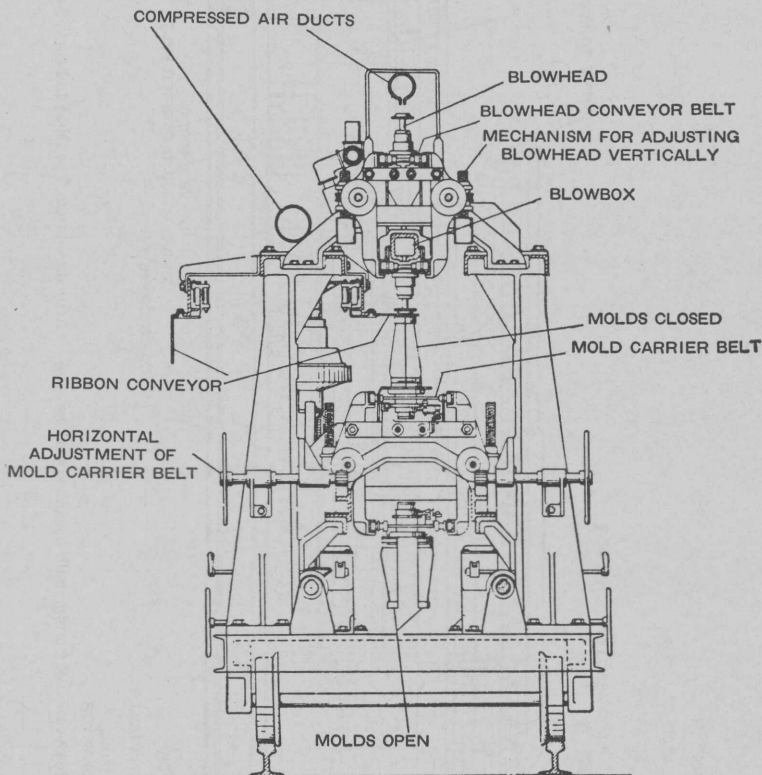


FIGURE 11.—Cross-section of Corning bulb machine taken through center of machine on a vertical plane and looking towards tail end of machine. (Reproduced from *The Glass Industry*, August 1931.)

neering principle. This idea is that for maximum results, the motion of machinery must be absolutely continuous, and the product should flow in a straight line, not in circles."³

Important features of this machine are illustrated diagrammatically in figures 10 and 11. Instead of being a rotating turret indexing machine with ram-operated arms moving back and forth from the furnace to the spindles, it is a tractor-operated continuously moving mechanism, which is fed by a continuous flow of glass from the furnace. The glass flows by gravity from the tank and passes through rollers, forming a continuous ribbon of glass. Moving in synchronism with

³ *The Glass Industry*, August 1931, p. 160: *New Lamps for Old*, by F. W. Preston.

the glass ribbon and the blow-head conveyor is a conveyor containing the molds for shaping the segments of the glass ribbon into bulbs. The completed bulbs are automatically conveyed through the various succeeding processes to the inspecting and packing section. This truly marvelous mechanism can produce as many as 440 bulbs per minute; and since the machine runs continuously day and night when production from the tank is begun, the daily capacity is far beyond the half million mark.

Bases

Before 1900 there were extensive variations in bases with regard to style, shape, and modes of contact with circuit wires. Standardization was undertaken about 1900, and as a result the number of sizes has been much reduced, and the modes of contact with circuit wires have been restricted to natural adaptations determined by the uses to which the lamps are put. There are three main types of bases: (1) The screw base with a screw thread formed in the shell of the base and a corresponding thread in the socket; (2) the bayonet base with pins or finlike projections in the shell of the base for fitting into corresponding slots in the socket; and (3) prong bases with metal prongs for fitting into corresponding openings in the socket. The principal sizes are miniature, candelabra, intermediate, medium, and mogul.

A base of the ordinary type consists of the shell (the cylindrical metal part which fits into the socket), with a thread formed in it or with inserted pins; the eyelet (the small metal tip of the base through which a lead-in wire extends for making contact with the socket wire); the glass portion connecting the shell and the eyelet; and cement which is inserted in the base at the lamp-assembly plant.

The brass shell of the bases was formerly made by five different machines, one for each of five main processes: (1) Cutting the blank or disk and cupping or indenting it; (2) drawing out the cup or indentation; (3) trimming and stamping; (4) threading; and (5) piercing and forming. These processes are now combined on two machines, the first making the unthreaded shell and the second adding the thread.

Both shells and eyelets are made on what is commonly called an eyelet machine. For ordinary shells this machine is a transfer slide machine with six or seven rams or plungers operated vertically. At the first position a plunger cuts the blank disk from roll strip brass. At the second position the disk is cupped, or compressed in the center into a cuplike shape, by pressure of the die and the plunger on the malleable blank. At the third position the cup is drawn or elongated. The fourth plunger pierces the cup at the base. The fifth plunger forms the dome by rounding out the cup about the pierced base. At the final position the upper edge of the cup is cut or trimmed.

The shells are discharged from the shell-making machine and dropped onto a conveyor belt, and by means of cross conveyors, air-conveyor posts, and an electrically controlled mechanical device are distributed to the threading-machine hoppers in such a manner as to keep a constant level in the hopper. Each shell is automatically placed between threaded cylinders and these revolving cylinders press the threads into the malleable brass shell. A typical machine threads

150 shells per minute, within a variation limit of six thousandths of an inch. When threaded the shells are dropped through an opening in the floor onto a belt conveyor and from this belt they are blown by air jets to the second floor above, and automatically weighed and barreled.

The bayonet type of base goes through a process known as "pinning" instead of threading. The shells are automatically fed into the pinning machine by means of a pin hopper, horizontal dials, turn-over chutes, and transfer fingers, for the purpose of placing them uniformly and synchronously in position for the automatic operations of the machine. A transfer finger places the shell on a piercing stud or anvil and two plungers, operating horizontally, pierce the shell on opposite sides. It is then raised from the piercing anvil by a stripper and two transfer fingers convey it to a riveting anvil. The wire for the pins is fed from two sides, and two steel fingers seize the ends of the two wires while shearing knives cut off short measured lengths for the pins. The fingers then place the pins in position and hold them until two riveting plungers drive them into the holes made by the piercing plungers and rivet them against the riveting anvil.

The eyelet of a base is essentially a brass disk embedded in the glass of the base and pierced in the center for threading one of the lead-in wires. The eyelet is made on a so-called "eyelet machine" similar to the machine used for the making of shells. The operations are similar. The first plunger cuts the blank, a tiny disk of brass, from a ribbon of brass; the second plunger makes an indentation in the center of the disk. At the third and fourth positions the disk is slightly cupped and formed preparatory to piercing. The next plunger pierces the center. Finally comes the crimping or shaping of the brass where pierced for the anchoring of the eyelet in the glass.

The shell and the eyelet are combined in the glass-base machine. A rotating indexing machine with 36 positions is the type of machine used for making medium screw bases. Its movement is clockwise. The eyelets and shells are fed automatically from hoppers, feed dials, and transfer fingers into operating position. There is a die or cavity for each of the 36 positions. In each die an eyelet and a shell are placed automatically and from the glass tank beyond and above the machine a glass string or stream of molten glass flows onto the dies of the machine. This glass stream is automatically controlled. The three parts (shell, eyelet, and glass connection) are joined together and formed by means of cam-operated plungers. At the end of the processes the die is raised and an air jet blows the shell into an annealer for giving the proper temper and hardness to the glass and for cooling the base.

From the glass department the bases are trucked by hand to the inspection department. Ingenious arrangements have been devised for subjecting them to inspection, and an even more remarkable system is projected. As the bases are moved along a conveyor each inspector examines a portion, putting the faulty bases into a small chute leading to a container and dropping the good ones through an opening onto the lower part of the endless belt. The supply of bases fed to the conveyor is gaged by the capacity of the 12 inspectors, but if for any reason there is a surplus of bases not inspected the surplus is automatically diverted from the main belt to an auxiliary

belt, which returns them to the head of the main belt where they are merged with the bases from the main supply hopper.

The inspected bases are taken to the finishing department. Here they are thoroughly cleaned and treated to give them a bright finish. They are poured into a feed hopper supplying a dipping machine. This machine is a hollow sectional revolving drum or cage, in which the bases are subjected to a succession of chemical solutions and rinses. They are finally passed through a gas-fired drum for heat drying; sawdust is mixed with the bases as the drum revolves, the sawdust absorbing the moisture in order to avoid spots.

In addition to the making of bases and the other parts already described, the manufacture of acids, gases, machines, and tools, and specialized lamps, and the carrying on of experimental work involve many distinctive processes. As there is no adequate means of correlating the amount of labor with the volume of output, and as these processes are relatively insignificant as affecting a statistical comparison of changes in volume of labor with changes in volume of output, they are omitted from further consideration.

Large Lamps of Standard Types

The description of lamp-making processes in assembly plants will be limited to standard types of lamps. It should be noted in this connection, however, that the term "standard lamp" has more than one meaning. From the technician's point of view a standard lamp is determined by photometric measurements and is "a lamp of known lumens or candlepower (spherical or horizontal) at a certain voltage used as a basis of comparison in the photometry of other lamps". As the term "standard type of lamp" is here used it applies to lamps that are most widely used and that are produced in quantities large enough to make possible large-scale or mass-production methods.

A lamp-assembly plant does more than merely put together the parts of a lamp. It makes essential changes in the parts and performs with marvelous exactness the operations required to combine the parts of the lamp. There is a considerable degree of specialization in these assembly plants. There are plants exclusively for standard types of large lamps, for standard types of miniature lamps (though now large and miniature lamps are usually made in the same factory), for special types of lamps, and for experimental work.

Among the principal steps in the making of large lamps are: (1) Making the filament coil; (2) making the mount; (3) sealing the mount in the bulb, exhausting the air, and (in the case of gas-filled lamps) filling with gas; (4) inserting cement in the base; and (5) basing and finishing.

The filament wire after it comes from the wire plant must be subjected to a large number of operations in a centralized coiling department. The wire is received in spools and is wound on bobbins previous to being put on coiling machines for coiling the filament on mandrels. The coiled filament must be cut to the lengths desired for different lamps, except in the case of certain types of filaments which are automatically cut in connection with coiling. With certain exceptions the mandrel around which the filament is coiled must be removed by a separate process. This includes a series of heated acid baths for dissolving the mandrel wire and also for cleaning the filament. After-

ward the filaments are put through hydrogen furnaces for annealing, in order to complete the cleaning process and to relieve any strain remaining from coil winding. Samples of the filaments are then spot-tested in an atmosphere of hydrogen to reveal any variations in diameter. The coils are projected through a series of mirrors and lights onto a screen and highly magnified for inspection. The final inspection is for length, uniformity, and color.

One of the most interesting processes connected with the preparation of the filament for mounting is called gettering. A large number of coils (perhaps 3,000) are put into a funnel-shaped cup over which a glass vessel is lowered. The coils are then whirled about in this vessel by means of high-pressure air. This creates a vacuum which sucks up the gettering fluid through a nozzle from a glass below the vessel and sprays it over the coils. This particular method is used for vacuum lamps but not for gas-filled lamps. A getter has been defined as a chemical substance introduced in the incandescent lamp bulb to improve the vacuum during the process of manufacture, in the case of certain types of lamps, and to maintain a more constant output of light during the life of the lamp.

In addition to the work on the filament in preparing it for the mount, the lamp-assembly plants do supplementary work on other parts as they come from the parts manufacturing plants. In the case of the bulb, for instance, some lamp-assembly plants have machines for inside frosting and outside spraying of bulbs. These machines are of the familiar rotating turret indexing type. In the case of the inside bowl frosting process the spray is, of course, applied to the bulb before the mount is sealed in. In case of the outside spraying process the spray is applied to the bulb after the mount has been sealed in and the base attached. In both cases the processes are almost entirely automatic.

Another operation performed in connection with the preparation of parts for final assembly is the inserting of cement in bases. This is done by a separate machine which is highly automatic, and the process is carried on in the lamp-assembly plant in order that the cement may retain its freshness until the base is cemented to the neck of the bulb.

After the filament has been made ready for draping on the stem, and after the various other parts have been assembled, the process of combining them into a lamp illustrates the working out of the unit system of manufacture. This is particularly true of the lamp-assembly plants for the making of standard types of lamps. Variations in procedure are, of course, numerous. The general principles of the procedure may be illustrated by the case of a high-speed unit lamp-making machine or group of machines in five sections.

The first section of this group is the stem-making section. It includes a 24-head turret indexing machine for joining together the lead wires, the flared glass tubing used for sealing the stem to the base, and the exhaust tubing which serves to exhaust the air and inject the gas in gas-filled lamps and anchor the support wires to the filament. One flare, two lead wires, and one exhaust tube are assembled and sent through a series of heating positions till the flare and the tube are fused with the lead wires, the fusion occurring at the exact portion of the lead wires which is made of dumet wire. All of these processes are synchronized and the operations are carried on by means of a series of cams as previously described.

The stem is then automatically conveyed to the second or inserting section of the machine, where a button is formed on the end of the exhaust tubing and where support wires are measured, cut off, inserted in the soft-glass button, and bent to proper pitch for receiving the filament.

In the third section the filament is mounted on the stem. This has usually been done by hand, the filament wire being draped around the support wires, each end being fastened to one of the lead-in wires. When the filament is thus mounted on the stem the mount is put in a tray, and the tray when filled is conveyed by a gravity slide to the next section.

The fourth section consists of a sealing-in and exhaust machine. This is a turret indexing machine with two tiers of heads. Each head on the upper tier has a mount pin for holding the mount. A bulb turret (a circular rotating bulb container) moves over in synchronism with the main machine to a position which places the bulb above and in line with the mount in the mount pin. As the bulb is moved into this position it is stamped on the top with a monogram in acid and etching ink which is later burned into the glass. An automatic bulb loader takes the bulb from the turret, and as the mount indexes in the proper position the bulb is dropped over it. As the machine rotates, the bulb with the mount thus inserted passes through a series of heating positions, the bulb itself revolving for uniform heating, until at the proper position the flared glass tubing of the mount is sealed to the neck of the bulb and the surplus glass (cullet) below the seal drops into a receptacle. When the bulb with the sealed-in mount has completed the circuit of the upper tier the exhaust tubing still extends through the neck of the lamp, and this tubing is put into a rubber stopper on one of the heads in the lower tier of the same machine. This lower tier is the exhaust deck. As the machine rotates the air is exhausted, and in the case of gas-filled lamps gas is injected. The final process on this machine is known as "tipping off" or sealing of the exhaust tube after exhausting and filling.

The lamp is then automatically ejected onto a conveyor, where it is momentarily retained by a finger device for testing, and then removed by the conveyor.

The fifth section of the unit is the basing and soldering section, to which the lamps are automatically conveyed. A typical basing machine is a 48-head turret indexing machine. The bases, which are made in another factory and which have been filled with cement on a separate machine, are placed on the neck of the lamp by hand with one lead wire through the eyelet of the base and the other lead wire on the outside of the base. The lamp with the base thus attached goes through the various operating positions where the base is cemented on, and the lead wires are trimmed and soldered into place.

A more highly developed instance of the unit system consists of three sections. In the first section of each unit there are two automatic mounting machines for making the stem, inserting the support wires in the stem, and mounting the filament. Each of these machines has a capacity of 1,500 per hour. The second section consists of three sealing-exhaust machines, each of which has a capacity of 1,000 per hour. The third section consists of three base-finishing machines each with a capacity of 1,020 per hour. The total output of a unit is 3,000 per hour. It is to be noted that the different sections

are coordinated on the basis of approximately equal capacity. The entire unit is synchronized and adapted to maximum capacity of the machines and to a minimum amount of labor. In addition to the automatic mounting of the filament by a recently developed machine various other hand operations that have survived earlier mechanization are being transferred to machines, as, for instance, a bucket conveyor for transferring the lamps from the sealing-exhaust machines to the base-finishing machines.

Miniature Lamps

From the point of view of methods of manufacture miniature lamps are of two main types—flange-seal and butt-seal lamps. The flange-seal type is similar to the large lamp insofar as the bulb is sealed around the flange of the mount. In the butt-seal lamp the lead wires are sealed in a glass bead to make the stem, and this bead is combined with an exhaust tube or top tube for sealing the mount in the bulb.

Flange-seal miniature lamps include headlight lamps, most of the miniature sign and decorative lamps, the larger Christmas tree lamps for outside use, and part of miner's lamps. Butt-seal lamps include lamps for flashlights, toy trains, radio panels, cowl and instrument lamps for automobiles, small low-voltage Christmas tree lamps, and a part of miner's lamps. There are various lamps for special uses of both types.

In the making of flange-seal miniature lamps the processes are not so radically different from those used in making large lamps as to call for detailed treatment. There are numerous variations, as, for instance, special handling of the filament in focusing lamps, and a modified stem-making process in connection with double-contact lamps using three lead-in wires. The main processes may be summarized as follows: (1) The glass parts, including the flange and the lead-in wires and support wires (where support wires are necessary), are assembled and combined into the stem. (2) In a large proportion of flange-seal miniature lamps there is a process known as "terminal spacing." The lead-in wires are trimmed to a predetermined length and the ends are bent. Terminal spacing is for the purpose of preparing the wires for mounting the filament and also for controlling the light source. (3) The filament is mounted on the stem either manually or automatically. (4) The mount is sealed in the bulb by fusing the flange with the neck of the bulb. (5) The bulb is exhausted, ordinarily filled with an inert gas, automatically tipped off, and unloaded. (6) Next come basing, soldering, and cleaning. (7) The final stages include marking, inspecting, and packing.

In the case of the butt-seal lamps the essential difference, as already stated, is in the use of a glass bead for making the stem, which is combined with the top tube for sealing the mount to the bulb. The bead for the mount is made in a glass factory. It consists of powdered glass mixed with a binder. This mixture is punched out under pressure into beads and not fused in the process of manufacture. In the lamp-assembly plant the bead is fused around the lead wires in making the stem, the stem consisting of the bead and the lead wires fused together.

In place of separate processes for stem making, terminal spacing, and mounting, as in flange-seal lamps, the mount for butt-seal lamps

is made by a single set of operations on an automatic beading and mounting machine. The lead-in wires are automatically fed from two spools of dumet wire, the entire lead-in wires being made of dumet instead of the dumet wire being limited to the sealed-in portion. The wire is automatically cut at a predetermined length. The bead is automatically dropped over the two lead-in wires and fused around them to make the stem. As the machine rotates to successive operating positions the lead-in wires are flattened in preparation for bending the ends into hooks, hooks are formed on the ends, the wires are properly spaced, and they are heat-cleaned in preparation for the mounting of the filament. The filament wire is coiled on the stem machine, being automatically wound around the mandrel, cut, stripped off the mandrel, and transferred to a position under the hooks of the lead-in wires, the wires already having been attached to the bead by the fusion of the bead around them to form the stem. Next the filament coil is clamped to the hooked ends of the lead-in wires. The position of the filament in relation to the lead-in wires, as the amount of bend or curvature in the filament, is automatically adjusted and is made to vary with different types and sizes of lamps. Finally the mount is automatically ejected from the machine.

If gettering is required the operator getters the mount and places it in the bulb. The bulbs with mounts inserted are placed on trays for transfer to the sealing machine.

One method of sealing the mount to the bulb is embodied in the operations of a 48-head automatic sealing machine. An operator loads a bulb containing the mount into the first position on the machine. Successive operations include the following: (1) The top tube—that is, the exhaust tube—is conveyed from the machine and sealed to the bulb. (2) A restriction is drawn in the tube (the tube is made smaller) at the place where the bulb is to be tipped off or sealed on the exhaust machine. (3) The mount is adjusted and centered in the bulb while the glass is still plastic, and the mount and bulb are fused together. (4) The sealed lamp is then removed from the machine, either automatically or manually, and is ready for the exhaust machine.

The process of exhausting the air is essentially the same as in the case of flange-seal lamps. For vacuum-type lamps a machine is now in use (a mercury condensation machine) for exhausting. Lamps are loaded manually, automatically tested under high pressure for leaks, exhausted, tipped off, and automatically ejected. The speed of operation has been greatly increased.

Basing is also similar to the corresponding process in the making of flange-seal lamps.

This account indicates a departmentalized arrangement in contrast with the unit system of manufacture. Much progress has been made toward the introduction of the unit system in the making of miniature lamps, but there are problems which limit the efficiency of the system. One of these problems lies in the fact that the machines used in the different stages do not have the same speed of operation. Unless the slower machines can be speeded up, or unless an appropriate combination of slow and fast machines can be made, as in the case of the large-lamp unit system described above, some of the machines will necessarily be idle a part of the time, and the advantages of synchronous continuous operation will not be realized.

Chronology of Principal Technological Changes

Technological changes which affect the amount of labor time required per unit of output have two main aspects. In the first place, there are changes in the physical facilities and materials of industry, and these are characteristically mechanical, though not exclusively so. Secondly, there are changes in the managerial technique of using the physical facilities and materials of industry. There is, of course, no absolute distinction between the two. Among the managerial changes may be classed the group or unit system of manufacture heretofore described,⁴ although this arrangement might, perhaps, be classed as a combination of managerial technique and changes in the physical facilities.

Many of the technological changes which have occurred in the electric-lamp industry are too intangible or too gradual to be placed in exact time sequence. This may be illustrated by the effects of the automatic weighing and gaging of glass tubing in speeding up the making of miniature bulbs from tubing. There has been a gradual increase of the speed of the machines due to the exact size of the tubing, and there has also been a reduction of the loss in process, so called—that is, a reduction of the percentage of imperfect bulbs—and this of course in turn increases the output of bulbs per man-hour or reciprocally reduces the amount of time required per bulb. Formerly a bulb-making machine requiring 1 operator and 1 inspector produced 5,000 bulbs a day, but with the making of more perfect tubing and with a more exact regulation of the gas and air, and blowing air, 1 operator supervises 3 machines producing 26,000 bulbs a day, the inspection of the output requiring the time of 1 inspector and half the time of another. Another bulb-blowing machine was designed to produce 5,000 per day with 1 operator and 1 inspector. With the development and perfecting of tubing, gaging, and weighing, and gas regulation, it is now possible for 1 operator to supervise 6 machines producing 66,000 bulbs per day, 2 inspectors taking care of the output.

Following is a list of technological changes in the electric-lamp industry since 1907. Only outstanding changes are included, and particularly those that have tended to reduce the amount of labor time per unit of output. The dates given are in some cases approximate.

1907

- (1) Mechanical mixing and control of "batch" for glass furnace.
- (2) Electric welding machine for making lead-in wires.

1910

- (3) Standardization of formulas for bulbs and tubing.
- (4) Tungsten made ductile.
- (5) Regenerative pot furnaces.

1912

- (6) Empire semiautomatic bulb-blowing machine.
- (7) Westlake bulb machine.

1913

- (8) Dumet wire for welds.
- (9) Double electric welding machine.
- (10) The gas-filled lamp.

⁴ See pp. 2, 19-20, 26-28.

1914

- (11) The first automatic indexing machine (for sealing).
- (12) Automatic miniature beading and mounting machine.
- (13) Automatic support-wire inserting machine.

1915

- (14) Lime glass for bulbs (facilitating automatic bulb making).
- (15) Automatic base-filling machine (for inserting cement).
- (16) Metal dies for drawing tungsten and molybdenum.
- (17) Automatic exhaust machine.

1916

- (18) Danner tube-drawing machine.

1917

- (19) Magnetic separator for automatically removing iron from glass.

1918

- (20) Development of standard machine parts for glass manufacture.
- (21) Continuous mandrel coiling machine.
- (22) Automatic miniature-bulb blowing machine.

1919

- (23) Tipless lamp.
- (24) Automatic glass-tube-sorting machine.
- (25) Tank furnace for automatic bulb production.
- (26) Tank cars for shipping sand.
- (27) Mixing of tungsten ores.

1920

- (28) Spray coating process.
- (29) Automatic safety stop, Westlake bulb machine.
- (30) Burn-off machine for automatically removing surplus glass from necks of bulbs.
- (31) Hot-cut flare machine.

1921

- (32) Miniature percussive welder.
- (33) Large percussive welder.
- (34) Development of group or unit system of manufacture.
- (35) Printing of monograms and labels on bulbs.
- (36) High-production tipless stem machine.

1922

- (37) High-production support-wire inserting machine.
- (38) Tungsten wire annealing.
- (39) Bulb annealing furnace (as high as 600,000 a day).

1923

- (40) Elimination of trays in bulb works.
- (41) Coiling machine for miniature-lamp filaments.

1924

- (42) Use of natural gas in cutting-off and burning-off processes.
- (43) Basing and soldering machine.
- (44) Photoelectric cell applied to photometry (measuring the light output of lamps).
- (45) Sealex machine (for sealing, exhausting, and gas filling).

1925

- (46) Automatic "batch" (glass) feeder.
- (47) Inside frosting machine.
- (48) Improved type of steel for cams.

- (49) Simplified and standardized line of bulbs, facilitating mass production.
- (50) Improved mandrels for use in making glass tubing.
- (51) Mercury pumps.
- (52) Combination miniature coiling and coil-mounting machine.
- (53) Standardization of lamps, facilitating mass production (6 standard lamps replacing 45 types and sizes for ordinary lighting).

1926

- (54) Improved packing of glass tubing.
- (55) The 48-spindle bulb machine.
- (56) Elimination of bulb washing.
- (57) Automatic miniature butt-sealing machine.

1927

- (58) The Corning ribbon bulb machine.
- (59) Improved method of mixing tungsten powders.
- (60) Mechanical temperature indicator for exhaust.
- (61) High-frequency testing device.
- (62) Cutting of glass tubing to predetermined length.
- (63) Elimination of tissue-paper bulb wrapping.
- (64) Improved dimension gages.

1928

- (65) Tubular bulb machine.
- (66) Tank furnace for tubing.

1929

- (67) Electric bulb annealing.
- (68) Automatic weighing of glass tubing.
- (69) Use of the photoelectric cell for sorting.
- (70) Machine for coiling filament wire without a mandrel.
- (71) Automatic mounting machine for mounting filaments in large lamps.
- (72) Centering of filament in focusing type miniature lamps by beam-of-light method.

1930

- (73) The Ohio bulb machine.
- (74) Improved methods of coil production and coil cleaning.
- (75) Extension of automatic mounting of filaments.
- (76) Improved lamp conveyor on sealex machine.
- (77) Multiple dip gettering machine.
- (78) Stem-making and sealing machine for 5,000- and 10,000-watt lamps.
- (79) Mechanical cullet (waste glass) pull-down device for sealex machine.
- (80) Development of butt-lamp sealing machine to seal automobile headlight lamps of the flange-seal type.
- (81) Development of conveyor and other units to allow continuous progressive operations in making automobile headlight lamps.
- (82) Improved soldering devices.

1931

- (83) Automatic cutting, sizing, and glazing of tubing for butt sealing.
- (84) Improved gas burners for glass cracking and burning operations.
- (85) Rivet soldering on basing machines.
- (86) Improved miniature-bulb hot-cut machine.

Production and Employment in Lamp-Assembly Plants

The lamp-assembly plant, as has already been indicated, is for the purpose of combining the filament, the glass tubing, the bulb, the base, and the various other parts into a finished product. The comparative importance of lamp-assembly plants in respect to the amount of labor employed is indicated by the fact that in 1920 they employed about 59 percent of the total labor (including nonmanufacturing labor) employed in the lamp industry. In 1931 the labor in the assembly plants was only about 42 percent of the total.

In the tables which follow, the figures of the volume of output and of labor are estimates derived from the best available sources. For relatively small portions of the industry, only the production figures are available, but manufacturing methods are known and the approximate amounts of labor can be apportioned. For other small portions of the industry, records of labor are not available for some of the years 1920 to 1931, but for these years reasonably close approximations can be made. In some of the minor details, the figures are not comparable for the entire period. For example, in the volume of labor employed in lamp-assembly plants there is included a small amount of labor used in making miniature bulbs before this work was completely transferred to separate plants. On the other hand, a counterbalancing illustration is the extension of dining-room facilities in lamp-assembly plants, which tended to increase the volume of labor in these plants during the later years of the period from 1920 to 1931.

While the basic figures given in the tables are not to be regarded as exact transcriptions of records, and while there is undoubtedly a margin of error, at the same time it is believed that the actual trends in lamp-assembly plants of the industry as a whole are shown with an unimportant margin of error.

The figures of unit time requirement and of the productivity of labor are meticulously extended, not with the idea of conveying an unwarranted impression of exactness, but for the purpose of narrowing the margin of error in using these as factors for computing the columns derived from the basic data of hours and output.

The changes in the volume of output in assembly plants from 1920 to 1931 are indicated in table 1. The number of so-called large lamps, including the ordinary sizes for household use, etc., varied between 1920 and 1931 from 161,665,000 in 1921 to 362,826,000 in 1929, the number declining, as might be expected, during the depression years 1921 and 1922 and 1930 and 1931. The number of miniature lamps, such as automobile lamps and flashlights, varied during the period 1920 to 1931 in a similar manner. The smallest number was 80,850,000 in 1921 and the largest number was 281,131,000 in 1929. The changes may readily be visualized by reference to the columns of index numbers for each of the two types and for their total in table 1.

TABLE 1.—*Estimated changes in volume of output in electric-lamp-assembly factories, 1920 to 1931*

[1920=100]

Year	Large lamps		Miniature lamps		Total	
	Number	Index	Number	Index	Number	Index
1920.....	234, 770, 000	100. 0	127, 370, 000	100. 0	362, 140, 000	100. 0
1921.....	161, 665, 000	68. 9	80, 850, 000	63. 5	242, 515, 000	67. 0
1922.....	206, 019 000	87. 8	105, 246, 000	82. 6	311, 265, 000	86. 0
1923.....	248, 347, 000	105. 8	155, 879, 000	122. 4	404, 226, 000	111. 6
1924.....	251, 752, 000	107. 2	183, 420, 000	144. 0	435, 172, 000	120. 2
1925.....	274, 087, 000	116. 7	185, 188, 000	145. 4	459, 275, 000	126. 8
1926.....	281, 588, 000	119. 9	200, 867, 000	157. 7	482, 455, 000	133. 2
1927.....	340, 545, 000	145. 1	203, 967, 000	160. 1	544, 512, 000	150. 4
1928.....	313, 475, 000	133. 5	243, 478, 000	191. 2	556, 953, 000	153. 8
1929.....	362, 826, 000	154. 5	281, 131, 000	220. 7	643, 957, 000	177. 8
1930.....	335, 001, 000	142. 7	218, 198, 000	171. 3	553, 199, 000	152. 8
1931.....	326, 613, 000	139. 1	176, 737, 000	138. 8	503, 350, 000	139. 0

Estimated changes involving labor employed in electric-lamp-assembly plants during the same period 1920 to 1931 are included in table 2. The average number of hours per employee per year varied from a maximum of 2,213 to a minimum of 1,968. The reduction in number of man-hours was somewhat greater than the reduction in average number of employees. In order to visualize the change in number of man-hours in terms of workers the average number of hours per worker per year for the entire period has been computed (2,105 hours). Dividing the total number of hours worked in each year by the average number of hours per employee per year gives the number of employees if the number of hours per worker had remained constant. On this equated basis, the number of workers would have ranged from 17,171 in 1920 to 5,438 in 1931. The index of change in the last column of table 2 (ranging from 100 in 1920 to 31.7 in 1931) is the same as the index of change in number of man-hours.

TABLE 2.—*Estimated changes in volume of labor in electric-lamp-assembly factories, 1920 to 1931*

[1920=100]

Year	Large lamps		Miniature lamps		Total				
	Man-hours	Average number of employees	Man-hours	Average number of employees	Man-hours	Average number of employees	Average number of hours per employee	Employees on basis of average number of hours, 1920-31, per employee (2,105)	
								Number	Index
1920.....	25, 194, 000	12, 196	10, 951, 000	5, 087	36, 145, 000	17, 283	2, 091	17, 171	100.0
1921.....	15, 764, 000	7, 826	5, 946, 000	3, 103	21, 710, 000	10, 929	1, 986	10, 314	60.1
1922.....	16, 484, 000	8, 387	8, 065, 000	3, 737	24, 549, 000	12, 124	2, 025	11, 662	67.9
1923.....	18, 459, 000	8, 844	8, 362, 000	3, 989	26, 821, 000	12, 833	2, 090	12, 742	74.2
1924.....	14, 240, 000	6, 574	7, 839, 000	3, 639	22, 079, 000	10, 213	2, 162	10, 489	61.1
1925.....	13, 055, 000	5, 915	6, 698, 000	3, 147	19, 753, 000	9, 062	2, 180	9, 384	54.7
1926.....	11, 498, 000	5, 383	6, 078, 000	2, 907	17, 576, 000	8, 290	2, 120	8, 350	48.6
1927.....	12, 064, 000	5, 442	5, 858, 000	2, 657	17, 922, 000	8, 099	2, 213	8, 514	49.6
1928.....	9, 902, 000	4, 564	6, 074, 000	2, 689	15, 976, 000	7, 253	2, 203	7, 590	44.2
1929.....	10, 097, 000	4, 425	5, 906, 000	2, 833	16, 003, 000	7, 258	2, 205	7, 602	44.3
1930.....	8, 521, 000	3, 987	4, 903, 000	2, 473	13, 424, 000	6, 460	2, 078	6, 377	37.1
1931.....	7, 520, 000	3, 753	3, 928, 000	2, 064	11, 448, 000	5, 817	1, 968	5, 438	31.7

Table 3 contains estimates of changes in the productivity of labor and in the amount of time required per lamp in electric-lamp-assembly plants, 1920 to 1931.

The productivity of labor is computed on the basis of the total number of man-hours and the total number of lamps. The average number of lamps produced per man-hour increased continuously even during years of declining production from 10.019 in 1920 to 43.968 in 1931. The index of productivity shows a corresponding increase from 100 in 1920 to 438.9 in 1931.

From the point of view of the employee the productivity of his labor naturally has primary interest, but for the statistical analysis of the effects of changes in productivity on employment, its reciprocal, namely, the amount of time required per lamp, is a more logical factor. Changes in time requirement per lamp are also shown in table 3, and these figures are used in most of the subsequent tables dealing with electric-lamp-assembly plants.

TABLE 3.—Estimated changes in productivity of labor and in time required per unit of output in electric-lamp-assembly plants, 1920 to 1931
[1920=100]

Year	Production of lamps		Employment		Lamps produced per man-hour		Time required per lamp	
	Number	Index	Man-hours	Index	Average number	Index	Man-hours	Index
1920	362,140,000	100.0	36,145,000	100.0	10.019	100.0	0.099809	100.0
1921	242,515,000	67.0	21,710,000	60.1	11.171	111.5	.089520	89.7
1922	311,265,000	86.0	24,549,000	67.9	12.679	126.6	.078868	79.0
1923	404,226,000	111.6	26,821,000	74.2	15.071	150.4	.066351	66.5
1924	435,172,000	120.2	22,079,000	61.1	19.710	196.7	.050736	50.8
1925	459,275,000	126.8	19,753,000	54.7	23.251	232.1	.043009	43.1
1926	482,455,000	133.2	17,576,000	48.6	27.450	274.0	.036430	36.5
1927	544,512,000	150.4	17,922,000	49.6	30.382	303.2	.032914	33.0
1928	556,953,000	153.8	15,976,000	44.2	34.862	348.0	.028685	28.7
1929	643,957,000	177.8	16,003,000	44.9	40.240	401.6	.024851	24.9
1930	553,199,000	152.8	13,424,000	37.1	41.210	411.3	.024266	24.3
1931	503,350,000	139.0	11,448,000	31.7	43.968	438.9	.022743	22.8

In order to visualize more readily the principal changes indicated by the previous tables, these changes are reduced to an index form, with 1926 as the base (table 4), and presented graphically in figure 12.

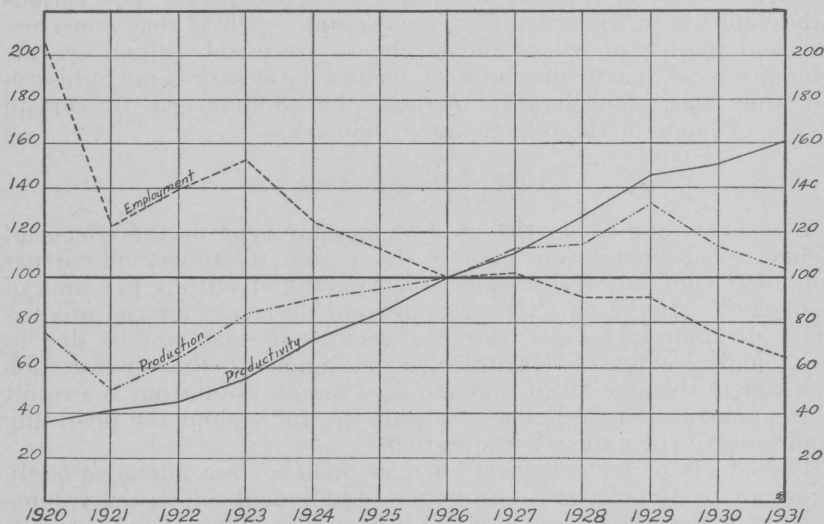


FIGURE 12.—Employment, production, and productivity in electric-lamp assembly plants, 1920 to 1931.

TABLE 4.—Estimated changes in volume of output and of labor and in productivity of labor in electric-lamp-assembly plants, 1920 to 1931
[1926=100]

Year	Production of lamps		Employment		Productivity	
	Number	Index	Man-hours	Index	Number of lamps per hour	Index
1920	362,140,000	75.1	36,145,000	205.6	10.0	36.5
1921	242,515,000	50.3	21,710,000	123.5	11.2	40.9
1922	311,265,000	64.5	24,549,000	139.7	12.7	46.4
1923	404,226,000	83.8	26,821,000	152.6	15.1	55.1
1924	435,172,000	90.2	22,079,000	125.6	19.7	71.9
1925	459,275,000	95.2	19,753,000	112.4	23.3	85.0
1926	482,455,000	100.0	17,576,000	100.0	27.4	100.0
1927	544,512,000	112.9	17,922,000	102.0	30.4	110.9
1928	556,953,000	115.4	15,976,000	90.9	34.9	127.4
1929	643,957,000	133.5	16,003,000	91.1	40.2	146.7
1930	553,199,000	114.7	13,424,000	76.4	41.2	150.4
1931	503,350,000	104.3	11,448,000	65.1	44.0	160.6

Problems in Estimating the Effects of Technological Changes on Employment

Nature of Technological Changes

Technological changes are perhaps most commonly associated with machines. Processes not primarily mechanical in nature should, however, also be included. Methods of economizing space, materials, and time are also essentially technological, even though there is no mechanical innovation. There are a few major technological changes, such as, for example, the introduction of the Ohio bulb-making machine, and the group or unit system of manufacturing in electric-lamp-assembly plants, but minor changes are occurring much more frequently, in fact almost continuously, and in the aggregate are probably more important than the relatively few major changes. "Scientific management" is often more effective than scientific mechanicism.

There are also technological changes which are indirect in their operation so far as a particular industry is concerned. The various improvements in transportation, for example, such as road construction and the use of trucks and airplanes, are made without specific reference to any particular industry such as the electric-lamp industry, but they may considerably increase the productivity of certain phases of labor in the electric-lamp industry.

Unit of Measurement

Whenever applicable, the unit of measurement of the effects of technological changes on labor is the amount of time required per unit of output, or, reciprocally, the amount of output per unit of labor time. If the unit time requirement decreases (or the productivity of labor increases), this change may or may not be due to technological changes. In order to determine whether or not such a change in the amount of time required per unit of output is a result of technological changes it is necessary to understand the operating conditions of the industry in question.

The effects of technological changes on labor are not adequately expressed by the change in unit time requirement unless the volume of labor is flexible in response to changes in volume of output. If, for example, production declines to a point where the minimum number of workers necessary for maintaining operations can produce more than the demand for output justifies, the productivity of labor will decline and the amount of labor time per unit of output will rise, due to declining production. Some industries, and some branches of most industries, are of such nature that the amount of labor does not readily fluctuate with changes in volume of output, and the unit time requirement will vary, therefore, in such instances not merely with technological changes but with changes in volume of output. The unit time requirement must be regarded as an adequate measure of the effects of technological changes on employment only when nontechnological factors are so unimportant in causing changes in unit time requirement that the margin of error due to their inclusion is not excessive. It is never a perfect unit of measurement, but ordinarily it is the best available method.

If an employer can increase the total number of man-hours of labor in proportion to increases in production and can reduce the total number of hours of labor in proportion to any falling off of business, the amount of time required per unit of output will remain constant unless there are changes in his methods which require an increase or decrease of labor. If there are such changes, their influence on employment will be measured approximately by any change in unit time requirement.

Technological Reduction of Labor Time

If there is a reduction in the amount of labor time per unit of output in a given year or period as compared with an earlier year or period, this reduction in labor time is likely to be viewed by the employer, who is interested in lowering the cost of production, as a "saving" of labor time. From the point of view of the employee, who is interested in keeping or finding a job, the reduction is a "loss" of labor time.

Ordinarily, in the major industries the employer estimates in advance the probable demand for his product, and the actual production of a given year is determined primarily by the actual or estimated demand of that year. The demand, in turn, is likely to be entirely unaffected by any changes in the productivity of labor during the year. In other words, if during a particular year an employer is able to make a reduction or saving in the average amount of time per unit of output, his total reduction or saving will be the unit saving multiplied by the number of units of output. Similarly, from the point of view of the employees the total loss of labor time or reduction of employment opportunities consists of the product of the reduction in the amount of time per unit of output times the total number of units produced. The only exception is an increase of production which is attributable to lower prices to consumers based on reduction of labor cost—in other words, an increase in production which would not have occurred had it not been for the reduction in unit time requirement.

Base Year or Period for Comparison

Any effort to ascertain the effects of technological changes on employment necessarily involves a comparison of one period with another. It is likely that employers and employees are primarily interested in the saving or loss of labor time of the current year, month, week, or cycle of production as compared with the similar period immediately preceding it. Ordinarily, therefore, a year-to-year comparison is perhaps of primary interest. But in order to discover long-time trends an earlier year or period must be compared with the present. Whatever the object in view, this point of departure should be made clear and the limitation of the result attained to the particular object in view should be kept in mind. Obviously, the amount of reduction of labor time in the current year as compared with the previous year will not be the same as the amount of reduction of labor time in the current year as compared with some earlier year. If the productivity of labor is an approximate measure of technological change in a given industry, then each result is valid for the particular object in view; but its limitation to this object must be made apparent.

Effects of Changes in Volume of Production

An increase in the productivity of labor tends to reduce the amount of employment. An increase in production tends to increase the amount of employment. The combined effect of these two factors on total volume of employment is readily ascertainable. The amount of saving of labor time (or from the employee's point of view, the amount of loss of employment opportunity) tends to increase not only with a rise in productivity of labor, but also with an expansion in the volume of production, up to a point where any additional volume of production is itself a result of declining labor cost. Up to that point the volume of production is a condition which determines the extent to which the rate of productivity of labor is effective in the saving (or loss) of labor time.

Technological Displacement in Lamp-Assembly Plants

Year to Year Changes

Changes in the total volume of employment are measured by (1) changes in total production and (2) changes in the production rate in terms of time required per lamp (or reciprocally, the number of lamps produced per unit of labor). Changes in the net volume of employment, and the significance of the change in the production rate in years of increasing production, are analyzed in tables 5 and 6. Table 5 contains the basic data of production, employment, and production rates. Table 6 analyzes the changes in employment as measured by changes in production and in production rates for each year as compared with the preceding year and for each year as compared with 1920. Since the volume of labor in electric-lamp-assembly plants fluctuates readily with changes in volume of production, the changes in production rates are approximate measures of technological change.⁵

If production should remain constant, the operation of the technological factor as measured by change in the production rate would be simple and obvious, but variations in production introduce complications.

If production declines, the technological reduction of labor time is a net reduction, to which is added the amount of labor displaced by the decrease in production. Thus, the technological reduction in 1921 amounted to 2,495,000 man-hours (table 6, col. 2), this sum being the product of the number of lamps manufactured and the average reduction, as compared with 1920, in the time required per lamp (table 5). But because of the fact that 119,625,000 fewer lamps were made in 1921 than in 1920, 11,940,000 fewer man-hours were needed (table 6, col. 1). The total change in employment is the sum of these reductions, or 14,435,000 man-hours (col. 6).

⁵ See p. 36-37.

TABLE 5.—*Production, employment, and production rates in electric-lamp-assembly plants, 1920 to 1931, estimated year-to-year changes, and changes as compared with 1920*

Year	Production			Employment			Production rates		
	Number of lamps	Year-to-year change (lamps)	Change as compared with 1920 (lamps)	Number of man-hours	Year-to-year change (man-hours)	Reduction as compared with 1920 (man-hours)	Man-hours required per lamp	Year-to-year reduction	Reduction as compared with 1920
	1	2	3	4	5	6	7	8	9
1920	362,140,000	-----	-----	36,145,000	-----	-----	0.099809	-----	-----
1921	242,515,000	-119,625,000	-119,625,000	21,710,000	-14,435,000	14,435,000	.089520	0.010289	0.010289
1922	311,265,000	+68,750,000	-50,875,000	24,549,000	+2,839,000	11,596,000	.078868	.010652	.020041
1923	404,226,000	+92,961,000	+42,086,000	26,821,000	+2,272,000	9,324,000	.066351	.012517	.033458
1924	435,172,000	+30,946,000	+73,032,000	22,079,000	-4,742,000	14,066,000	.050736	.015615	.049073
1925	459,275,000	+24,103,000	+97,135,000	19,753,000	-2,326,000	16,392,000	.043009	.007727	.056800
1926	482,455,000	+23,180,000	+120,315,000	17,576,000	-2,177,000	18,569,000	.036430	.006579	.063379
1927	544,512,000	+62,057,000	+182,372,000	17,922,000	+346,000	18,223,000	.032914	.003516	.066895
1928	556,953,000	+12,441,000	+194,813,000	15,976,000	-1,946,000	20,169,000	.028685	.004229	.071124
1929	643,957,000	+87,004,000	+281,817,000	16,003,000	+27,000	20,142,000	.024851	.003834	.074958
1930	553,199,000	-90,758,000	+191,059,000	13,424,000	-2,579,000	22,721,000	.024266	.000585	.075543
1931	503,350,000	-49,849,000	+141,210,000	11,448,000	-1,976,000	24,697,000	.022743	.001523	.077066

TABLE 6.—*Analysis of changes in employment in electric-lamp-assembly plants, 1920 to 1931*¹

Year	Reduction in employment (man-hours)—				Increased employment in making additional output (man-hours)	Net change in man-hours	Total reduction in man-hours as measured by change in production rate ²	
	In years of decreasing production as measured by—		In years of increasing production as measured by change in production rate ²				Man-hours	Equivalent number of workers ³
	Decrease in production	Change in production rate ²	On output equal to base year's production	On additional output				
	Each year as compared with preceding year							
1921	11, 940, 000	2, 495, 000				-14, 435, 000	2, 495, 000	1, 185
1922			2, 583, 000	732, 000	5, 422, 000	+2, 839, 000	3, 315, 000	1, 575
1923			3, 896, 000	1, 164, 000	6, 168, 000	+2, 272, 000	5, 060, 000	2, 404
1924			6, 312, 000	483, 000	1, 570, 000	-4, 742, 000	6, 795, 000	3, 228
1925			3, 363, 000	186, 000	1, 037, 000	-2, 326, 000	3, 549, 000	1, 686
1926			3, 022, 000	153, 000	844, 000	-2, 177, 000	3, 175, 000	1, 508
1927			1, 696, 000	218, 000	2, 042, 000	+346, 000	1, 914, 000	909
1928			2, 303, 000	53, 000	357, 000	-1, 946, 000	2, 356, 000	1, 119
1929			2, 135, 000	334, 000	2, 162, 000	+27, 000	2, 469, 000	1, 173
1930	2, 255, 000	324, 000				-2, 579, 000	324, 000	154
1931	1, 209, 000	767, 000				-1, 976, 000	767, 000	364
	Each year as compared with 1920							
1921	11, 940, 000	2, 495, 000				-14, 435, 000	2, 495, 000	1, 185
1922	5, 078, 000	6, 518, 000				-11, 596, 000	6, 518, 000	3, 096
1923			12, 116, 000	1, 408, 000	2, 792, 000	-9, 324, 000	13, 524, 000	6, 425
1924			17, 771, 000	3, 584, 000	3, 705, 000	-14, 066, 000	21, 355, 000	10, 145
1925			20, 570, 000	5, 517, 000	4, 178, 000	-16, 392, 000	26, 087, 000	12, 393
1926			22, 952, 000	7, 625, 000	4, 383, 000	-18, 569, 000	30, 577, 000	14, 526
1927			24, 225, 000	12, 200, 000	6, 002, 000	-18, 223, 000	36, 425, 000	17, 304
1928			25, 757, 000	13, 856, 000	5, 588, 000	-20, 169, 000	39, 613, 000	18, 819
1929			27, 145, 000	21, 124, 000	7, 003, 000	-20, 142, 000	48, 269, 000	22, 931
1930			27, 357, 000	14, 433, 000	4, 636, 000	-22, 721, 000	41, 790, 000	19, 853
1931			27, 909, 000	10, 882, 000	3, 212, 000	-24, 697, 000	38, 791, 000	18, 428

¹ For basic data see table 5.² Primarily technological. See pp. 36-37.³ Based on the average number of hours per employee per year (2,105). See table 2.

If production increases, as in 1922 as compared with 1921, the technological reduction of labor time, amounting to 3,315,000 man-hours (col. 7), is not a net reduction in employment, for employment increased as compared with 1921. This increase of 2,839,000 man-hours (col. 6) was because of the fact that the labor used in the production of 68,750,000 more lamps than in 1921 more than counterbalanced the technological reduction, in spite of the lower production rate. In this case the technological reduction of labor time did not mean, therefore, a net falling off in the amount of employment as compared with 1921, but it did mean that employers, because of the lower production rate, were able to produce the output of 1922 by employing 3,315,000 fewer man-hours than would have been required if the production rate had not fallen. Stated in another way, the net increase in employment in 1922 was only 2,839,000 man-hours, but if there had been no change in the production rate, the increase would have been 2,839,000 man-hours plus the technological reduction of 3,315,000 man-hours, or a total of 6,154,000 man-hours.

A similar situation existed in 1923 as compared with 1922. But in 1924, as compared with 1923, there was a net decline of employment as well as a technological reduction of labor time. In making 404,226,000 lamps, equaling the number made in 1923, lamp-assembly plants were able to reduce employment to the extent of 6,312,000 man-hours (col. 3). In making the 30,946,000 additional lamps produced in 1924, they were able to effect a further technological reduction of 483,000 man-hours (col. 4)—a total of 6,795,000 man-hours. But in making the added 30,946,000 lamps at the lower production rate of 1924 they required 1,570,000 man-hours (col. 5). Therefore, because of the increased output made at the lower production rate of 1924, the technological reduction was counterbalanced to the extent of 1,570,000 man-hours, so that the net decline in employment was 4,742,000 man-hours (col. 6).

In the larger industries, such as the electric-lamp industry, the volume of production in any given year is determined primarily, not by any decrease in labor cost during the year, but by the actual or estimated demand for the product. The 30,946,000 additional lamps manufactured in 1924 as compared with 1923, for example (table 5, col. 2), were produced, not because there was a decline in unit time requirement, but because expanding demand warranted the additional output. Improvements in methods of production, however, made possible the reduction in unit time requirement, and employers thereby effected a saving of labor time in manufacturing during 1924 not only a quantity of lamps equal to the production of 1923, but also the additional output of 1924. The total amount of labor saved, therefore, by virtue of technological changes as measured by changes in unit time requirement was the reduction in time requirement per unit (0.015615 man-hour) times the total number of lamps produced in 1924 (435,172,000), or 6,795,000 man-hours. Since the average number of hours per worker per year was 2,105, the equivalent number of workers was 3,228.

The total technological effect on labor time in each of the years 1920 to 1931 as compared with the preceding year ranged from 324,000 man-hours, equivalent to 154 employees, in 1930, to 6,795,000 man-hours, equivalent to 3,228 employees, in 1924 (table 6, cols. 7 and 8). These estimates represent, to lamp-assembly plants, a saving of labor,

and to workers, a shrinkage of employment opportunities in each year as compared with the preceding year resulting from technological changes as measured by changes in the production rate.

Changes in Successive Years as Compared with 1920

The first section of table 6 analyzes the year-to-year changes in employment in electric-lamp-assembly plants from 1920 to 1931 by comparing each year with the preceding year. Ordinarily the employer and the employee alike are primarily interested in comparing each year or cycle of production with the similar period immediately preceding it. But it is also desirable to analyze the long-term trends, and for this purpose a modification of the method used in the first section of table 6 is necessary. Such a modification is embodied in table 5 and the second section of table 6 (p. 39), in which the employment in lamp-assembly plants analyzed in each year from 1920 to 1931 is compared, not with the preceding year, but with 1920.

There was a decrease in total volume of employment in each of the years from 1921 to 1931 as compared with 1920. The decline ranged from 9,324,000 man-hours in 1923 to 24,697,000 man-hours in 1931. The only years in which there was a decrease in production as compared with 1920 were 1921 and 1922. In 1929 the additional production beyond that of 1920 was greatest and amounted to 281,817,000 lamps—an increase of 78 percent. In each year, as compared with 1920, there was a reduction in the production rate in terms of unit time requirement.

In years when production was less than in 1920 (the years 1921 and 1922), the declining production rate was reinforced by the reduced output in causing a decline in total employment. Thus, in 1922, 5,078,000 fewer man-hours were required than in 1920 because of the fact that 50,875,000 fewer lamps were made; and in the making of the 311,265,000 lamps of 1922 there was an additional reduction of 6,518,000 man-hours because of the lower production rate, bringing the total reduction of man-hours to 11,596,000 (table 6, second section, cols. 1, 2, 6).

In 1923 and later years the quantity of lamps made increased beyond that of 1920. The lower production rate of 1923 enabled employers to produce a quantity of lamps equal to that of 1920 with 12,116,000 fewer man-hours. But 42,086,000 additional lamps were made in 1923 beyond the quantity made in 1920, and the making of these additional lamps, at the lower production rate of 1923, required 2,792,000 additional man-hours. Therefore, the net reduction in man-hours was only 9,324,000 (cols. 3, 5, 6). Similarly, in succeeding years, the additional output beyond that of 1920 counteracted in part the effect of the declining production rate in its effect on the net reduction of employment.

But if there had been no reduction in the production rate, the additional output of 1923 could have been produced only by the employment of 1,408,000 additional man-hours (col. 4). In other words, lamp-assembly plants were able to produce the output of 1923 with 13,524,000 fewer man-hours (col. 7), equivalent to 6,425 workers (col. 8), because of the change in the production rate; and workers consequently experienced an equivalent shrinkage in employment

opportunities. A similar analysis for each of the succeeding years reveals a progressive increase in the amount of labor saved, as compared with 1920, and as measured by changes in the production rate, ranging from 21,355,000 man-hours in 1924 to 48,269,000 man-hours in 1929. Stated in another way, the output of 1929, the peak year, if produced on the basis of the 1920 production rate, would have given employment to 22,931 additional workers. Thereafter the amount declined to 38,791,000 man-hours, equivalent to 18,428 workers, in 1931.

These figures are overestimates of the effects of technological changes as measured by changes in unit time requirement, because they are based on the assumption that the number of lamps produced in each of the years would have been produced even if the amount of time required per lamp had remained the same as in 1920. There were extensive reductions in prices during the period since 1920,⁶ and these reductions, which were partly due to the declining cost of labor, undoubtedly had some effect in stimulating the demand for lamps and thereby in causing an increase in production. In the making of any portion of the increased output which would not have been made if there had been no reduction of labor time per lamp, there is no saving of labor by the employer or no loss of opportunity for employment from the worker's point of view. The increased production of 1929, for example, as compared with 1920 was probably due in part to the decrease in unit time requirement from 0.099809 man-hour in 1920 to 0.024851 man-hour in 1929. But the increased production of 1929 as compared with 1928 was essentially unaffected by the reduction in unit time requirement in 1929 as compared with 1928.

The purpose of table 7 is to correct the overestimate of the long-term effects of technological changes shown in the second section of table 6. This overestimate is due to the fact that the reduction in time required per lamp in each successive year is based on the unit time requirement of 1920, and thus fails to take into account the probability that increased production was in part dependent on declining labor cost. In table 7 the unit time requirement of each year is compared with that of the preceding year, with the exception of years of declining production. Since the purpose of using each preceding year as the base is to discount the effects of declining unit time requirement on volume of production when production is increasing, the unit time requirement of 1922 and of 1923 is compared with that of 1920, and similarly, the 1931 unit time requirement is compared with that of 1929.

The total reduction of labor time in 1921 as compared with 1920, as measured by the change in unit time requirement, was 2,495,000 man-hours, equivalent to about 1,185 workers. The total production in 1922 remained below that of 1920, and a direct comparison is therefore made with 1920, with an indicated total reduction in labor time, as measured by reduction in unit time requirement, of 6,518,000 man-hours, equivalent to about 3,096 employees. The first year to show an increase in production over 1920 was 1923, and it may be assumed that this increase was a result not of reduction in labor cost but of the general revival of business. Therefore there is still a direct comparison with 1920, indicating that the total reduction of labor time

⁶ See p. 3.

in 1923 as compared with 1920, and as measured by the reduction in unit time requirement, amounted to the equivalent of 6,425 workers.

TABLE 7.—*Reduction of labor time in electric-lamp-assembly plants, 1920 to 1931, estimated on basis of reductions in unit time requirement*

[Except in years of declining output, each preceding year is used as base]

Year	Number of lamps	Man-hours		Reduction of labor time, based on time required per lamp in each preceding year			
		Total number	Per lamp	Per lamp	In making total number of lamps		
					Man-hours	Equivalent number of workers ¹	Annual saving as compared with 1920
				Man-hours			Workers
1920.....	362,140,000	36,145,000	0.099809	0	0	0	0
1921.....	242,515,000	21,710,000	.089520	0.010289	2,495,000	1,185	1,185
1922.....	311,265,000	24,549,000	.078868	² 0.20941	² 6,518,000	3,096	3,096
1923.....	404,226,000	26,821,000	.066351	² 0.33458	² 13,525,000	6,425	6,425
1924.....	435,172,000	22,079,000	.050736	.015615	6,795,000	3,228	9,653
1925.....	459,275,000	19,753,000	.043009	.007727	3,549,000	1,686	11,339
1926.....	482,455,000	17,576,000	.036430	.006579	3,174,000	1,508	12,847
1927.....	544,512,000	17,922,000	.032914	.003516	1,915,000	910	13,757
1928.....	556,953,000	15,976,000	.028685	.004229	2,355,000	1,119	14,876
1929.....	643,957,000	16,003,000	.024851	.003834	2,469,000	1,173	16,049
1930.....	553,199,000	13,424,000	.024266	.005585	324,000	154	³ 13,941
1931.....	503,350,000	11,448,000	.022743	⁴ .002108	⁴ 1,061,000	504	⁵ 13,054

¹ Based on average number of hours per employee per year (2,105).

² Unit time requirement in 1920 used as base, because output of 1922 was smaller than that of 1920, and therefore the decrease in unit time requirement obviously resulted from technological changes and was independent of changes in output.

³ The reduction in labor for 1929 (16,049) applies to 1930 only in the ratio of 1930's output to that of 1929 (85.9 percent).

⁴ Unit time requirement of 1929 used as base, because of declining output. See note 2.

⁵ The reduction in labor for 1929 (16,049) applies to 1931 only in the ratio of 1931's output to that of 1929 (78.2 percent).

In 1924, production continued to increase, and unit time requirement continued to decline. It is possible that none of the increased production is attributable to the reduced amount of time required per lamp since 1920. But the long-term downward trend of unit time requirement probably had some effect on the rising production curve even as early as 1924. Therefore, the 1920 unit time requirement is no longer used as the base, and that of 1923 is substituted. The reduction in unit time requirement of 0.015615 man-hour in 1924 as compared with 1923 is multiplied by the number of lamps produced in 1924 (435,172,000), and the result indicates a total reduction of 6,795,000 man-hours, equivalent to 3,228 workers in 1924 as compared with 1923.

But it is desired to estimate the effects of technological changes in each year as compared not with the preceding year but with 1920. If it is assumed that in 1924 the output and the unit time requirement remained the same as in 1923, there would still be a saving of labor in 1924 equal to that of 1923, that is, 6,425 employees. But because of the change in the volume of output and in the unit time requirement there was a saving in 1924 as compared with 1923 of 3,228 employees. Therefore, by adding 3,228 to 6,425 there is obtained a conservative indication (9,653) of the saving in labor time in 1924 as compared with 1920, due mainly to technological changes, after discounting the effects

of technological changes in adding to the volume of output in 1924. In a similar manner it may be assumed that if in 1925 the output and the unit time requirement had remained the same as in 1924 the labor saved in 1925 as compared with 1920 would have amounted to 9,653 employees. By adding the saving in 1925 as compared with 1924 due to the changes in output and unit time requirements in 1925 the total saving in number of workers in 1925 as compared with 1920 becomes 11,339. The same method is used for each year in turn except for the years 1930 and 1931. Because of the decline in output during these years the reduction in amount of labor for 1929 as compared with 1920 (16,049 employees) applies to 1930 and 1931 only in the ratio of the output of each of these years to that of 1929. The amount of labor saved in 1931 as compared with 1920 is computed on this basis at 13,054 workers.

Production and Employment in Plants Making Parts

An account of the processes of manufacturing the more important parts used in lamp-assembly plants has already been presented.⁷ The main parts, as has already been seen, are the filament, the lead-in wires, glass tubing, bulbs, and bases. In compiling information regarding the volume of output and volume of labor in the manufacture of lamp parts during the years 1920 to 1931 a number of difficulties make exact and complete analysis impossible. Some of the parts are made in plants which are not a part of the lamp industry. Especially is this true of glass tubing and bulbs. In the case of the lamp companies, there have been changes in the extent to which they have made their own parts instead of purchasing them. There has also been a difficulty connected with the separate classification of labor devoted to the making of parts for electric lamps and parts for other uses, as, for instance, radio tubes.

Glass Bulbs for Large Lamps

The case of bulbs is particularly interesting because of popular confusion regarding changes in methods of manufacturing bulbs and the effects of these changes on volume of labor. In this connection the following is a widely quoted statement: "An electric-lamp machine, recently installed, has a production of 531,000 lamp globes a day, an increase per man of 9,000 times the method previously employed."⁸ This statement, as it has been popularly interpreted, involves a number of confusions. In the first place, the terms "globe", "bulb", and "lamp" have been confused, and the statement has been applied to the finished lamp, whereas in the process of manufacture the bulb is merely the outer glass part in which the lamp is sealed. In the second place, the figure 9,000 should be regarded as an index number with 100 as the base, and this 90-fold (not 9,000-fold) increase in productivity results not from the introduction of a single machine but from a large number of technological changes extending over more than a decade. In the third place, this indication of change in the productivity of labor applies not to the entire lamp industry, and not even to most of the labor required for the making of bulbs, but only to that portion of the labor which is required for the actual

⁷ See pp. 12-25.

⁸ Statement attributed to the group known as Technocracy, in the *New York Times*, Aug. 21, 1932.

operation of machines for making bulbs for large lamps as distinguished from miniature lamps.

The effects of improved machinery in multiplying the productivity of labor are illustrated in a remarkable manner by the data shown in table 8⁹ for the making of glass bulbs for large electric lamps. The table deals only with 25- and 40-watt bulbs, but these may be regarded as typical of the standardized types. The effects of the more important steps in the transition from hand production to automatic production are clearly shown by means of typical samples of output. The index of output per man-hour from 1916 to 1932 runs from 100 to 8645.5—more than an 86-fold increase—in the case of 25-watt bulbs, and from 100 to 7171.3—nearly a 72-fold increase—in the case of 40-watt bulbs. These indexes do not reveal the full extent of the transition, for the reason that comparable figures relating to the most recent improvement, the so-called ribbon bulb machine,¹⁰ are not available. The output of a single unit for 24 hours runs beyond half a million bulbs, but the exact number of man-hours is not known and therefore the index of man-hour output is omitted.

The figures for man-hour output presented in table 8 apply only to labor used in the actual operation of the machines named in the table. Labor required for preparing the materials, for feeding the furnace, for inspecting the bulbs, and for various other operations is not included.

TABLE 8.—*Estimated changes in the productivity of hand and machine labor in selected plants in making glass bulbs for 25- and 40-watt electric lamps*

Method of production	Year	Number of workers per unit	Number of unit-hours	Number of man-hours	Number of bulbs produced	Output per unit-hour	Output per man-hour	
							Bulbs	Index (output in plant A = 100)
<i>25-watt bulbs</i>								
Hand production: Plant A...	1916-19	2¼	63,946	143,879	7,556,500	118.2	52.5	100.0
Hand production: Plant B...	1923 ¹	2¼	1,573	3,539	198,941	126.5	56.2	107.0
Semiautomatic machine (Empire E).....	1925 ²	3	912	3,192	370,492	406.2	116.1	221.1
Automatic machine (Empire F).....	1925 ¹	2½	1,898	4,428	3,550,427	1,870.6	801.8	1527.2
Automatic (24-spindle Westlake, old type).....	1925	1¾	6,784	11,302	14,514,503	2,139.5	1,284.2	2446.1
Automatic (24-spindle Westlake, new type).....	1925 ³	1¾	2,596	3,570	6,066,484	2,336.9	1,699.3	3236.8
Do.....	1931-32 ⁴	1¾	558	767	1,974,031	3,537.7	2,573.7	4902.3
Automatic (48-spindle Ohio).....	1931-32 ⁵	1¾	1,908	2,624	11,910,157	6,242.2	4,538.9	8645.5
Ribbon bulb machine.....	1932 ⁶	-----	653	-----	13,557,900	20,762.0	-----	-----
<i>40-watt bulbs</i>								
Hand production: Plant A...	1916-18	2¼	205,686	462,794	24,361,352	118.4	52.6	100.0
Hand production: Plant B...	1923 ⁶	2¼	2,463	5,544	309,143	125.5	55.8	106.1
Semiautomatic machine (Empire E).....	1925 ⁶	3½	3,247	11,364	1,324,494	407.9	116.6	221.7
Automatic machine (Empire F).....	1925 ⁶	2½	3,010	7,022	5,530,679	1,837.4	787.6	1497.3
Automatic (24-spindle Westlake, old type).....	1925	1¾	9,058	15,091	19,915,140	2,198.6	1,319.7	2508.9
Automatic (24-spindle Westlake, new type).....	1925	1¾	5,244	7,211	12,283,960	2,342.5	1,703.5	3238.6
Do.....	1931-32 ⁷	1¾	1,157	1,591	3,866,497	3,341.8	2,430.2	4620.2
Automatic (48-spindle Ohio).....	1931-32 ⁸	1¾	939	1,291	4,869,767	5,186.1	3,772.1	7171.3
Ribbon bulb machine.....	1932 ⁶	-----	379	-----	7,440,800	19,633.0	-----	-----
¹ 7 months. ² 4 months. ³ 11 months. ⁴ 14 months. ⁵ 16 months. ⁶ 6 months. ⁷ 13 months. ⁸ 15 months.								

⁹ Table 8 has been compiled in part from material contained in U. S. Bureau of Labor Statistics Bul. No. 441: Productivity of Labor in the Glass Industry, Washington, 1927, pp. 127-131, and in part from later material furnished by manufacturers.

¹⁰ See pp. 21-23.

The productivity of labor as a whole used in the manufacturing of glass bulbs for large electric lamps during the years 1920 to 1931 is computed in table 9. For certain minor portions of the industry direct figures were not available, but on the basis of available information the estimates contained in the table are a close approximation for the entire industry. On the basis of changes in the number of bulbs and changes in the number of man-hours the index of productivity of labor (100 in 1920) ranges from 82.7 in 1921 to 487.6 in 1931. It will be noted that this change in the rate of productivity for the entire labor force used in the manufacturing of bulbs for large lamps is radically different from the indexes of the productivity of machine labor in table 8. The change in the productivity rate from 100 to 487.6, applying to all labor in the large bulb plants, corresponds closely to the changes in the productivity of all labor in the lamp-assembly plants as presented in table 3, where the index runs from 100 to 438.9. Table 9 also includes changes in the number of workers actually employed, estimated changes in number of workers equated on the basis of average hours worked, the number which would have been required if the productivity rate of 1920 had continued, and the number which would have been required if the output had remained constant from 1920 to 1931.

TABLE 9.—*Estimated changes in output and employment in plants for making glass bulbs for large¹ electric lamps, 1920 to 1931*

Year	Number of bulbs made	Number of man-hours	Index of productivity of labor (1920=100)	Employees			Number of employees required on basis of—	
				Average number	Equated on basis of number of hours per employee in 1920		Productivity rate of 1920	Output of 1920
					Number	Index (1920=100)		
1920.....	255,815,000	6,587,400	100.0	2,892	2,892	100.0	2,892	2,892
1921.....	199,989,000	6,226,700	82.7	2,878	2,733	94.5	2,260	3,497
1922.....	257,892,000	3,352,200	198.2	1,485	1,472	50.9	2,918	1,459
1923.....	308,707,000	2,886,400	275.8	1,288	1,267	43.8	3,494	1,049
1924.....	244,218,000	2,537,600	247.9	1,093	1,114	38.5	2,762	1,167
1925.....	299,517,000	1,942,800	397.4	863	853	29.5	3,390	728
1926.....	327,649,000	2,466,500	342.3	1,092	1,083	37.4	3,707	845
1927.....	377,910,000	2,346,400	415.2	1,042	1,030	35.6	4,277	697
1928.....	334,915,600	2,031,700	424.7	905	892	30.8	3,788	681
1929.....	388,159,000	2,005,000	499.0	836	880	30.4	4,391	580
1930.....	360,726,000	2,077,400	447.4	919	912	31.5	4,080	646
1931.....	348,203,000	1,840,000	487.6	968	808	27.9	3,940	593

¹ As distinguished from miniature lamps, the bulbs for which are usually made from tubing.

An incidental phase of the manufacture of glass bulbs is the development of the process known as inside frosting.¹¹ This recently developed process involves an additional amount of work in the making of bulbs. Effects of the changes in methods of carrying on the process in typical units are shown in table 10. The index of output per man-hour increased from 100 in 1927, when the process was largely manual, to 175.9 in 1929, when mechanical control had been introduced. The later use of electrical control was largely responsible for the increase of the index of productivity to 264.6 in 1932.

¹¹ See pp. 20-22.

TABLE 10.—*Changes in productivity of labor in inside-frosting department of a glass-bulb factory (24-hours' operation), 1927, 1929, and 1932*

Year	Number of employees (3 shifts)	Number of hours worked	Number of bulbs frosted	Output per man-hour	
				Bulbs	Index
1927 (hand method).....	51	408	245,351	601	100.0
1929 (mechanical method).....	42	336	355,104	1,057	175.9
1932 (electrical control).....	33	264	419,688	1,590	264.6

Glass Tubing and Miniature Bulbs

The making of glass tubing ¹² has been marked by radical innovations, but complete statistics covering indirect as well as direct labor are not available. Changes in the productivity of hand and machine labor in selected plants in making tubing are analyzed in table 11.¹³

TABLE 11.—*Estimated changes in the productivity of hand and machine labor in selected plants for making glass tubing*

Method of production	Year	Number of workers per unit	Number of unit-hours	Number of man-hours	Tubing produced	Output per unit-hour	Output per man-hour	
							Pounds	Index
Sizes 19-21 (1,100 to 890 inches per pound):					<i>Pounds</i>	<i>Pounds</i>		
Hand production.....	1917-18	8	10,309	82,472	821,176	79.7	10.0	100.0
Danner machine.....	1925 ¹	4	4,000	16,000	942,968	235.7	58.9	589.0
Improved Danner process.....	1929	3½	2,231	7,809	880,900	394.8	112.8	1128.0
Do.....	1931	3½	1,108	3,878	408,226	368.4	105.3	1053.0
Sizes 32-34 (270 to 216 inches per pound):								
Hand production.....	1917-19 ²	8	18,900	151,200	1,522,152	80.5	10.1	100.0
Danner machine.....	1925	4	6,579	26,316	1,978,281	300.7	75.2	744.6
Improved Danner process.....	1929	2½	6,766	16,915	2,378,797	351.6	140.6	1392.1
Do.....	1931	2½	2,073	5,183	661,359	319.0	127.6	1263.4

¹ 9 months.² January 1917 to June 1919.

On the basis of the operation of machines during selected periods, the output of specified sizes of tubing and the number of man-hours used in the actual operation of the machines are compared for the purpose of showing changes in the productivity of labor. These changes with respect to tubing of sizes 19 to 21 run from 100 in 1917 to 1053 in 1931—more than a tenfold increase in productivity. In the case of tubing of sizes 32 to 34 the productivity index runs from 100 in 1917 to 1263.4 in 1931—almost a thirteenfold increase, but in this case, as in the case in table 8, relating to direct labor in the making of large bulbs, the changes in the rate of productivity for all labor used in the making of tubing are very much smaller.

As has already been stated in connection with the description of the making of miniature bulbs,¹⁴ most of the bulbs of this description

¹² For description of the processes see pp. 16-18.¹³ Table 11 has been compiled in part from data contained in U. S. Bureau of Labor Statistics Bul. No. 441: Productivity of Labor in the Glass Industry, Washington, 1927, pp. 143, 144, and in part from data furnished by manufacturers.¹⁴ See pp. 18-19..

are made from glass tubing. The estimated changes from 1920 to 1931 in output and employment in all plants for making bulbs for miniature lamps are analyzed in table 12.

TABLE 12.—*Estimated changes in output and employment in plants for making glass bulbs for miniature electric lamps, 1920 to 1931*

Year	Number of bulbs made	Man-hours			Index of productivity of labor (1920=100)			Employees (total)			Number of employees required on basis of—	
		Direct labor	Indirect labor	Total labor	Direct labor	In-direct labor	Total labor	Average number	Equated on basis of number of hours per employee in 1920		Pro-ductivity rate of 1920	Out-put of 1920
									Num-ber	Index (1920=100)		
1920-----	117, 170, 000	232, 900	389, 800	622, 700	100. 0	100. 0	100. 0	259	259	100. 0	259	259
1921-----	71, 850, 000	75, 600	266, 500	342, 100	188. 9	89. 7	111. 7	330	142	54. 8	159	232
1922-----	95, 646, 000	92, 400	217, 100	309, 500	205. 8	146. 5	164. 4	226	129	49. 8	212	158
1923-----	145, 979, 000	51, 200	320, 200	371, 400	566. 6	151. 5	209. 0	214	154	59. 5	322	124
1924-----	173, 400, 000	58, 100	401, 800	459, 900	592. 8	143. 5	200. 5	193	191	73. 7	383	129
1925-----	175, 030, 000	49, 800	354, 800	404, 600	699. 4	163. 8	230. 3	161	168	64. 9	387	112
1926-----	188, 891, 000	52, 200	297, 500	349, 700	720. 1	211. 0	287. 2	142	145	56. 0	416	90
1927-----	194, 135, 000	50, 500	280, 100	330, 600	764. 0	230. 2	312. 2	155	138	53. 3	431	83
1928-----	232, 459, 000	53, 800	293, 200	347, 000	859. 2	263. 5	356. 4	202	144	55. 6	513	73
1929-----	269, 711, 000	59, 900	275, 500	335, 400	895. 4	325. 2	427. 7	204	140	54. 1	599	61
1930-----	205, 740, 000	45, 300	250, 800	296, 100	903. 4	272. 4	369. 7	196	123	47. 5	455	70
1931-----	168, 143, 000	36, 500	173, 300	209, 800	915. 3	322. 3	426. 1	140	87	33. 6	371	61

It has been found possible to divide the labor used in the making of miniature bulbs into direct labor and indirect labor. These terms are not always used consistently, and the number of man-hours assigned to each class of labor is approximate. One definition of direct labor, widely but not universally accepted, describes it as labor which modifies the physical conditions or appearances of products or which is concerned with the inspecting or handling of products. From this definition it is apparent that direct labor includes some labor in addition to what is required for the actual operation of machines.

In miniature-bulb plants the number of man-hours of direct labor is much more variable than the number of man-hours of indirect labor. In other words, direct labor is much more flexible, and can be made to conform in volume much more readily to changes in methods and to changes in volume of output. The productivity index of direct labor tends consistently upward from 100 in 1920 to 915.3 in 1931. (See table 12.) The index of productivity of indirect labor, on the other hand, fluctuates widely and in 1921, with the falling off of volume of production, the productivity rate declines to 89.7. A slight decline in the productivity rate appears also in 1930 and 1931, and is to be accounted for by the fact that the volume of indirect labor is not so readily adaptable to changing volume of output as is the volume of direct labor. In consequence the index of productivity of direct and indirect labor combined also shows a decline in 1930 and 1931. The index for the aggregate of both classes of labor runs from 100 in 1920 to 427.7 in 1929 and then tends downward to 369.7 in 1930, but rises again to 426.1 in 1931.

In connection with the making of miniature bulbs it should be noted that the transition to automatic methods had already been effected very largely by 1920. In a typical plant, for instance, in 1920, only 3,650,000 bulbs were produced by hand methods while 87,550,000 bulbs were produced by automatic methods. The principal technical changes accounting for the increased productivity of labor since 1920 were connected with the perfecting and speeding up of automatic machines.

Lead-in Wires

In the making of lead-in wires ¹⁵ only a small percent of total labor is used. The portion of the lead-in wire which is sealed in the glass is made of dumet wire. In the making of dumet wire there have been no essential technological changes since 1920. In table 13 are shown the production in meters, the number of employees, and the average output per employee from 1920 to 1931. The productivity of employees engaged in making dumet wire fluctuated widely, ranging as low as 63 in 1922 (from 100 in 1920) and as high as 305 in 1929. In so small a group of workers the variations in volume of output do not readily find proportionate effect on volume of employment.

TABLE 13.—Changes in productivity of labor in a plant for making dumet wire, 1920 to 1931

Year	Production of wire	Number of employees	Average output of wire per employee	
			Meters	Index (1920=100)
	<i>Meters</i>			
1920.....	5,474,773	10	547,477	100
1921.....	3,414,236	7	487,748	89
1922.....	2,779,375	8	347,422	63
1923.....	4,782,627	9	531,403	97
1924.....	7,204,775	9	800,531	146
1925.....	6,873,878	9	763,764	140
1926.....	6,879,484	13	529,191	97
1927 ¹	16,883,280	17	993,134	181
1928.....	23,258,129	19	1,224,112	224
1929.....	31,760,287	19	1,671,594	305
1930 ²	16,889,999	15	1,126,000	206
1931 ³	11,618,108	11	1,056,192	193

¹ Production of plating core rods was increased by dipping 140 instead of 10 at a time.

² Number of rods annealed in 1 operation was increased from 105 to 140.

³ Decreased productivity was partly due to retention of surplus labor beyond production requirements.

The sealed-in portion of the lead-in wire (the part made of dumet wire) is welded to the other portions by machines which have not undergone any fundamentally important change since 1920. One of the earlier automatic devices was the double electric machine for making welds, and changes in the productivity of labor in the operation of this machine are shown in table 14. From 1919 to 1931 the productivity of labor used in the direct operation of these machines increased from 100 to 255. This increase was due in part to the perfecting of the machine in such manner as to make higher speeds and

¹⁵ See pp. 14-16.

increased output practicable. This is indicated by figures for each year for average production per machine and for speed shown in table 14.

TABLE 14.—*Changes in productivity of labor in operation of double electric machine for making welds, in selected plants, 1919 to 1931*

[1919=100]

Year	Number of machines (including idle machines)	Average production per machine	Speed (revolutions per minute)	Number of workers		Index of productivity per worker		
				Machine labor	Inspection labor	Machine labor	Inspection labor	Total labor
1919.....	15	35,000	74	3	7	100	100	100
1920.....	16	40,000	92	3	8	122	107	111
1921.....	25	43,000	92	4	12	154	119	128
1922.....	25	44,500	92	4	12	159	124	132
1923.....	25	44,500	92	4	12	159	124	132
1924.....	25	44,500	92	4	12	159	124	132
1925.....	31	44,500	92	5	15	158	123	131
1926.....	30	47,700	106	5	15	164	127	136
1927.....	36	46,700	106	7	18	137	125	128
1928.....	36	47,500	106	7	18	140	127	130
1929.....	36	48,700	106	4	18	250	130	152
1930.....	36	50,600	106	4	18	260	135	158
1931.....	36	49,500	106	4	18	255	132	154

The increase in productivity of machine labor is also due in part to an increase in the number of machines without a proportionate increase in the number of employees to operate the machines, as is indicated by figures in table 14. The increase in the productivity of inspection labor was much smaller, ranging from 100 in 1919 to 132 in 1931.

Among the other machines used for the making of welds (welding the dumet wire to the other portions of the lead-in wire) are the miniature percussive machine and the large percussive machine. The changes in the productivity of machine labor and inspection labor used in the operation of these machines are estimated in tables 15 and 16. In these cases, as in the case of the double electric machine, the productivity of machine labor increased much more rapidly than the productivity of inspection labor. In the case of the miniature percussive machine, productivity of machine labor increased from 100 in 1921 to 277 in 1931, due in part to an increase in the number of machines and in part to more efficient operation of the machines, leading to increased output per machine (table 15). In the case of the large percussive machine the increase in the productivity of machine labor from 100 in 1922 to 305 in 1931 is attributable to the same causes and also to an increase in speed of the machine (table 16).

These statistics relating to the making of lead-in wires involve such small numbers of workers as to be of no special significance; but they illustrate the difference between the effects of technological changes on direct machine labor as compared with other labor such as is used in the inspection of the output. They illustrate also the comparative difficulty of maintaining flexibility in the volume of labor in proportion to changes in the volume of output when, as in this case, the volume of labor is already small and highly specialized.

TABLE 15.—*Changes in productivity of labor in operation of miniature percussive machine for making welds, in selected plants, 1921 to 1931*

[1921=100]

Year	Number of machines	Average production per machine	Speed (r.p.m.)	Number of workers		Index of productivity per worker		
				Machine labor	Inspection labor	Machine labor	Inspection labor	Total labor
		<i>Welds</i>						
1921.....	8	41,500	138	3	8	100	100	100
1922.....	8	41,500	138	3	8	100	100	100
1923.....	8	41,500	120	3	8	100	100	100
1924.....	9	49,500	120	3	9	134	119	123
1925.....	8	49,500	120	3	8	119	119	119
1926.....	12	49,500	120	3	12	179	119	131
1927.....	17	47,400	120	3	17	243	114	133
1928.....	17	55,400	120	3	17	284	133	156
1929.....	17	55,600	120	3	17	285	134	157
1930.....	17	55,200	120	3	17	283	133	155
1931.....	17	54,100	120	3	17	277	130	152

TABLE 16.—*Changes in productivity of labor in operation of large percussive machine for making welds, in selected plants, 1922 to 1931*

[1922=100]

Year	Number of machines	Average production per machine	Speed (r.p.m.)	Number of workers		Index of productivity per worker		
				Machine labor	Inspection labor	Machine labor	Inspection labor	Total labor
		<i>Welds</i>						
1922.....	5	31,000	74	2	5	100	100	100
1923.....	6	30,000	74	2	6	116	97	102
1924.....	9	32,600	74	3	9	126	105	110
1925.....	9	33,600	74	3	9	130	108	114
1926.....	33	35,900	83	8	33	191	116	130
1927.....	54	35,900	83	11	54	227	116	135
1928.....	39	38,300	86	8	39	241	124	144
1929.....	28	38,700	86	5	28	280	125	148
1930.....	35	39,700	86	6	35	299	128	153
1931.....	35	40,500	86	6	35	305	131	156

Bases

Table 17 contains estimates of the changes from 1920 to 1931 in the number of bases produced, in the average number of employees, in the number of man-hours, and in the average output per man-hour. The figures are in part derived from actual records and in part computed on the basis of ratios which are believed to be conservative. With the exception of the year 1921, when an abnormal decline in output occurred, the index of the average output per man-hour has been higher than in 1920 and has increased materially even during the years 1930 and 1931 when the output was declining. The estimated number of man-hours declined from 1,023,900 in 1920 to 619,300 in 1921 and then increased by 1929 to 1,006,300, after which occurred a decline to 641,700. The index of productivity declines from 100 in 1920 to 72 in 1921 and then rises for the most part consistently to 189 in 1931.

Some of the most important of the machines used in the making of bases were developed before 1920. The changes in the productivity of labor in the making of bases are attributable in large degree to more efficient operation of machines and to improvements of a secondary nature in the handling of materials and of the bases in the various stages of manufacture, as for instance the development of more efficient conveyor systems.

TABLE 17.—*Estimated changes in productivity of labor in making of bases for electric lamps, 1920 to 1931*

Year	Estimated number of bases produced	Estimated average number of employees	Estimated number of man-hours	Average output per man-hour	
				Number	Index (1920=100)
1920.....	432, 068, 000	455	1, 023, 900	422	100
1921.....	187, 648, 000	275	619, 300	303	72
1922.....	348, 932, 000	314	706, 300	494	117
1923.....	442, 751, 000	375	843, 000	525	124
1924.....	435, 901, 000	389	875, 300	498	118
1925.....	463, 571, 000	352	788, 700	588	139
1926.....	488, 024, 000	330	786, 200	621	147
1927.....	565, 616, 000	350	803, 400	704	167
1928.....	573, 129, 000	361	806, 000	711	168
1929.....	713, 849, 000	405	1, 006, 300	709	168
1930.....	559, 017, 000	348	797, 500	701	166
1931.....	513, 001, 000	317	641, 700	799	189

Changes in Employment in All Branches of the Industry

In the entire electric-lamp industry it is possible to classify the labor used under the following four heads:

- (1) Labor used in lamp-assembly plants;
- (2) Labor devoted to the manufacturing of parts;
- (3) Workers in the equipment divisions, which are concerned with the development and testing of machinery and other equipment used in the manufacturing of lamps and parts; and
- (4) Nonmanufacturing labor connected with sales, home offices, and warehouses.

Information is less adequate regarding the number of workers outside of lamp-assembly plants than in them, especially for the earlier years of the period from 1920 to 1931. For a large portion of the industry available information makes possible accurate estimates, but for the industry as a whole these estimates must be regarded as indicating only the trends.

The most radical change in number of workers between 1920 and 1931 occurred in lamp-assembly plants. In 1920 the proportion of total labor employed in these plants was about 59 percent; by 1931 it had declined to about 42 percent. The proportion of labor used in the manufacturing of parts, 23 percent in 1920, declined somewhat thereafter, but by 1931 it had risen to approximately the same percent of the total. Labor devoted to the development and testing of equipment rose from about 3 percent in 1920 to about 6 percent in 1931. Nonmanufacturing labor increased from about 15 percent in 1920 to about 29 percent in 1931.

The rate of productivity of labor in each of the four main classifications and in all classifications combined may be estimated by dividing the total number of lamps produced by the number of workers in each classification, and by the total number of workers. The basic figures are approximations with regard to certain portions of the industry, and the results must therefore be viewed, when applied to the entire industry, as indicating merely the trends. On the basis of available data the changes in rates of productivity of labor, as compared with 1920, are estimated as follows:

TABLE 18.—*Rate of productivity of labor in the main classifications of the electric-lamp industry, 1920, 1929, and 1931*

Classification	1920	1929	1931
Lamp-assembly plants.....	100	1 448	1 457
Manufacturing of parts.....	100	349	324
Equipment divisions.....	100	166	167
Nonmanufacturing divisions.....	100	192	175
Total.....	100	340	329

¹ These estimates of productivity differ from those given in table 6 because they apply only to portion of the industry for which full information is available regarding employment outside of lamp-assembly plants and because they are based on average number of employees instead of man-hours.

In the nonmanufacturing divisions important technological changes occurred alike in office equipment and in managerial technique. But supervisory work, sales, and general overhead activities are naturally less affected by labor-saving innovations. This is due in part to the nature of the work and in part to the more stable tenure of positions in these phases of the industry. Employees are more commonly engaged on a monthly or annual basis, and separations from employment follow less readily any downward trend of output than in those divisions where hourly or daily rates of pay prevail. Similarly, when the volume of production is increasing, employees in the nonmanufacturing divisions are able to handle any additional work with a minimum increase in numbers. Because of these conditions, the volume of nonmanufacturing labor fluctuated with changes in output less readily than in the case of manufacturing labor, especially in lamp-assembly plants. This is indicated by a comparison of the rates of productivity for 1929 and 1931 in table 18, the rate falling in the nonmanufacturing divisions and continuing to rise in assembly plants.

In the divisions devoted to the making of parts, many vital technological changes were made, as in the manufacturing of bulbs, but many phases of parts manufacturing were slightly affected by labor-saving innovations, especially after 1920. Furthermore, in these plants and in the equipment divisions the number of employees was too small, and the proportion of supervisory labor was too large, to make possible a facile adjustment of the volume of labor in response to changes in the volume of output.

In lamp-assembly plants, on the other hand, conditions facilitated a flexible adaptation of employment to changes in production. The number of workers in these plants was comparatively large, the stability of tenure of the supervisory force was a relatively insignificant factor, and the use of automatic machinery and of new managerial technique was more extensively feasible. The outstanding effects of technological changes on volume of labor were therefore experienced in lamp-assembly plants.

Appendix A.—Outline of the History of Lighting

Earlier Methods of Lighting

Early methods of lighting consisted mainly of open fires and primitive sources of illumination involving lighting as an incidental function or involving a minimum of fabrication or adaptation of materials found in nature. Camp fires gave light as well as heat. Signal fires were mainly for communicating intelligence. "Brands from the burning" in the form of unfabricated torches and rush lights were no doubt widely used. Among the earliest arts and crafts appeared the manufacturing of torches in the form of rosin splinters, rushes, stalks of flax soaked with grease, etc.; and primitive peoples early learned to fabricate torch holders as well as torches. Another primitive method of lighting consisted of the use of fire baskets containing glowing coals or inflammable material.

Among the more civilized groups of early times, as well as among present-day peoples, the principal lighting device aside from the electric lamp is the basin lamp in its various forms. Materials for basins included natural stone, shells, pottery, metals, and glass.

Materials used for burning in basin lamps have ranged so widely as to include animal oils derived from game and domestic animals, seal oil, whale oil, lard, tallow, vegetable oils derived from various sources such as nuts, rape seed, olives, and resinous woods (as camphene, a purified oil of turpentine freed by distillation from rosin), and mineral oils, particularly "coal oil" or kerosene derived from petroleum.

Basin lamps have also included various auxiliary devices for controlling the flame or for increasing its lighting power, such as wicks, wick holders and chimneys. Wicks have been made of porous natural fibers, such as moss, reeds, etc., but mainly from spun or woven textiles. In connection with the control of the wick, of the flow of oil, and of the burning process, the most primitive method is simply the floating of the wick. A somewhat more ingenious device consisted of a wick trough or channel or basin mouth (in some cases a series of them) through which the wick protruded. The final development in this connection consisted of separate wick holders or burners. These were introduced in the latter part of the eighteenth century. There are movable devices for adjusting the wick as it burns, snuffers for removing the carbonized portion, and arrangements for controlling the air currents to aid combustion. For the latter purpose tubular air chambers were introduced below the flame and chimneys or globes were added for enclosing the flame. The most highly developed basin lamp consists of the modern kerosene lamp with a glass basin or bowl, a textile wick, an adjustable metal wick holder or burner with air passages, and a glass chimney or globe. An obvious modification of the ordinary basin lamp is the portable lamp or lantern.

Rivaling the basin lamp in antiquity and in extent of use is the candle. Candles have been made of solidified oil or wax (ranging from the ancient beeswax candles to the modernistic bayberry or wax myrtle candles), of spermaceti (a fatty substance from sperm oil), of tallow, and most recently and extensively of paraffin derived from petroleum. The manufacture of candles with string wicks and of candlesticks was long one of the leading industries. The primitive method of making the candle was by dipping the string in the oil or wax, but the use of molds operated first by hand and later by machinery supplanted the primitive method.

Before the development of the electric lamp, gas lighting made rapid headway against the more primitive lamps and candles. The pioneer in gas lighting was William Murdock, who was connected with the firm of Boulton & Watt, at Birmingham, England, in the latter part of the eighteenth century. He developed a process for deriving gas from coal, and a method of using it in the Soho factories near Birmingham. Murdock's first successful experiment was in 1792. Its use in the Soho plants passed beyond the experimental stage in the early nineteenth century. It was used for lighting some of the streets of London as early as 1807. Other materials besides coal gas include natural gas, vaporized gasoline, and acetylene derived from calcium carbide and water.

There have been two main types of gas burners. One type consists of luminous or flame burners, the light coming directly from the combustion as in basin lamps and candles. Burners of the second type are incandescent and are commonly called gas mantles. Platinum gauze was used, but was short-lived and uneconomical. The Welsbach mantle was patented in 1885, and in its various modifications came into wide use.

In addition to the ordinary gas lamps there are what are known as gaseous-conductor electric lamps, in contrast with electric-arc lamps and electric-filament lamps. Recent developments in this field of lighting have been particularly significant.¹⁶

The development of gas lighting, which before the ascendancy of electric lighting was a most promising phase of the lighting industry, has been severely restricted by the rise of the electric-lighting industry. The most important remaining field in which gas lighting predominates is found in isolated places where electricity is not available and where a better mode than the kerosene lamp can be afforded.

Early Control of Electric Phenomena

Among the most important incidents in the scientific and technical background of electric lighting was the development of the battery for generating electricity. This was derived primarily from the voltaic pile of Volta in 1799. Somewhat later came Faraday's experiments, from which is traceable the dynamo for converting electrical energy into mechanical energy or into light. Generations of experiment and invention and scientific study in all of the leading countries contributed innumerable important elements. Particularly significant was the discovery of the laws of electrical currents flowing through wires. These are indicated by the terms in everyday use in the industry. One of these is the term "volt", the unit for meas-

¹⁶ See pp. 7-8.

uring electromotive force. Another is the ampere, for measuring the current. A third is the ohm, the unit of measurement of resistance. Ohm's law, which was propounded in 1825, is to the effect that a current measured in amperes equals the electromotive force in volts divided by the resistance in ohms. A fourth term in everyday use is the watt, the unit of measurement of work done over a circuit. It is not without significance to note that these four terms are from the names of four outstanding scientists and inventors—one an Italian, one a Frenchman, the third a German, and the last an Englishman.

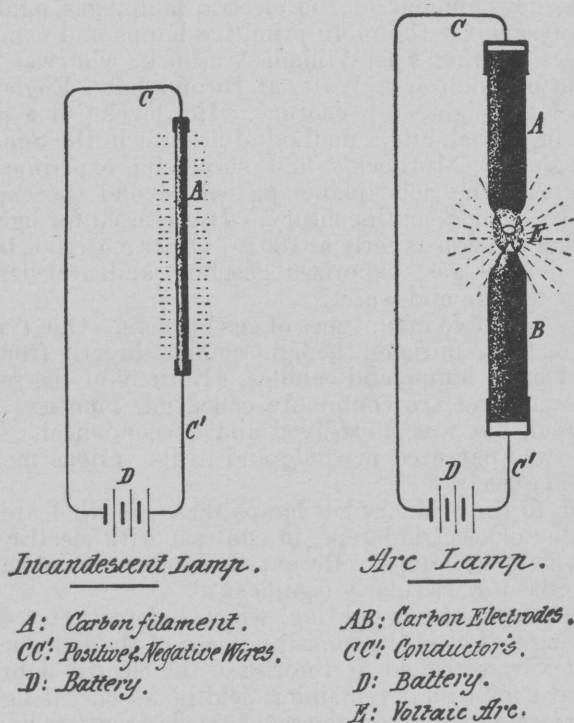


FIGURE 13.—Diagrams of incandescent and arc lamps.

The Electric-Arc Lamp

In a recent history of the electric lamp¹⁷ there are illustrations of 19 electric lamps invented before Edison's lamp of 1879. The first successful electric lamps were arc lamps. The electric-arc lamp includes an open circuit between two electrodes, usually of carbon, the electric discharge being accompanied by the ionizing of gas or vapor between the electrodes. The light comes either from the heated electrodes or from the gas or vapor between them or from both. The incandescent lamp, on the other hand, has a closed circuit with a filament which evaporates very slowly and which is heated so intensively as to give light.

¹⁷ Howell, J. W., and Schroeder, H. *History of the Incandescent Lamp*. Schenectady, 1927, pp. 25-44.

The discovery of the electric arc is attributed to Sir Humphry Davy in the first decade of the nineteenth century. Carbon sticks or electrodes were attached to the two terminals of a battery. The carbon or charcoal became white-hot. Upon the withdrawal of the electrodes there was "a constant discharge" between the points of carbon, "producing a most brilliant ascending arch of light"—an electric arc.

The successful use of the electric arc in arc lamps in series, especially for street lighting, dates from the late seventies. At first the arc was an open arc, but during the last decade of the century the enclosed arc came into use. This furnished less light per watt, but the carbons lasted much longer, the light was much steadier, and the lamps gave less trouble. There was developed a self-adjusting double-carbon arc lamp which automatically placed a second pair of electrodes in operation when the first pair burned out.

In the early electric-arc lamps the source of light was mainly the electrodes. The positive electrode or carbon furnished about 85 per cent of the light. Toward the end of the century there was developed the enclosed flame arc, the arc itself having light-giving power due to the impregnation of the carbons with such metallic salts as calcium fluoride. By such means there was about a threefold increase in the amount of light per watt. There was also developed the luminous arc produced by noncarbon electrodes, as, for example, the magnetite arc lamp with one copper electrode and one hollow iron electrode containing magnetite and titanium oxide. In still later developments the source of light has included the gases used in the gaseous-conductor electric lamps already mentioned.

Among the limitations of the electric-arc lamp were its relatively large size and its use in series only. The development of an electric lamp, small, compact, and adaptable to individual use as well as use in series, awaited the genius of Thomas A. Edison.

The Carbon-Filament Lamp

A preliminary to the development of the individual electric lamp in the form of the carbon-filament lamp was Edison's multiple distribution system devised in 1878. The problem which he undertook to solve was the problem of tapping the current for a single lamp as distinguished from a series, as was necessary in the case of the arc lamps then widely used, especially for street lighting. His solution of the problem had three essential features. He developed a dynamo with drum-wound armature having large wires for low resistance in the armature. He made possible a constant voltage of about 110 between the brushes of the armature, the voltage remaining constant in spite of variations in the consumption of current. He devised a wiring arrangement for tapping current for any lamp desired. This arrangement consisted at first of a 2-wire system, but in 1882 he substituted a 3-wire system which effected a saving of 60 per cent in the amount of copper used.

Edison's new dynamo theoretically made possible the supply of current to any individual lamp desired; but in practice it was necessary for him to develop a lamp with a much higher resistance in the filament than that of any lamps then in existence. This necessity he deduced from his application of Ohm's law to the problem—the

rate of flow of current in amperes equals the force of the current in volts divided by the resistance of the conductor in ohms. By transposing the terms, the resistance in ohms equals the force in volts divided by the rate in amperes. In a wire conductor resistance is low in a large wire and high in a small wire, somewhat as is true of the resistance to the flow of water in a pipe. That is to say, for a given wattage (consisting of volts times amperes), low voltage means high amperage requiring large wire, and high voltage means low amperage with small wire. Edison's conclusion was that he should use high voltage and low amperage in order to attain the economy of the use of small wire. The necessary conditions included a dynamo of high voltage with suitable small high-resistance wire, and a corresponding high-resistance-filament lamp to be burned singly, as compared with the carbon arc series lamps. The first condition was met by his 110-volt dynamo and multiple distribution system for burning lamps singly; but the second condition he had yet to meet for existing lamps had a low resistance. The best available lamp was a 110-watt lamp of 10 amperes and 11 volts. Its resistance, therefore, was 1.1 ohms, or 11 volts divided by 10 amperes. The remaining problem, therefore, was the development of a high-resistance lamp.

Edison's aim was the development of a 110-watt lamp which would compete with prevailing gas lamps to be used on a 110-volt circuit. What must be the resistance of such a lamp? Its wattage is 110; its voltage 110. Its amperage, therefore, would be 110 divided by 110, or 1. Its resistance would be the quotient of the voltage divided by the amperage, or 110 divided by 1, that is 110. It was necessary, therefore, for Edison to make a change from the existing lamp of 1 ohm resistance to a lamp of 110 ohms resistance.

In order to achieve this end he undertook a quest for materials which would enable him to develop a high-resistance filament. He experimented with platinum, then generally used, but abandoned it because it was too costly and too short-lived. He then undertook a prolonged study of carbon filaments. After absorbing available existing knowledge he carried out a series of experiments. The material used would need resistance not only to the high voltage of the lamp which he had in mind but to combustion, vaporization, and fusion. It must also have suitable light-giving qualities. As the outcome of his experiments he developed a cellulose thread which he carbonized by extreme refinements of the methods used for carbonizing wood into charcoal and coal into coke.

The lamp which he completed in 1879, and for which a patent was granted in 1880, has been described as having four main features: "(1) A high resistance filament of carbon, in (2) a chamber made entirely of glass and closed at all points by fusion of the glass, which contained (3) a high vacuum and through which (4) platinum wires passed to carry current to the filament."¹⁸

In addition to these primary features of the lamp itself there were several secondary developments, mainly Edison's work, which were essential to the extensive use of the new lamp. Among these were sockets, switches, lead fuses to protect the dynamo and the transmission system, meters, and underground cables. An outstanding development was the central power station. A temporary station

¹⁸ Howell, J. W., and Schroeder, H. History of the Incandescent Lamp. Schenectady, 1927, p. 61.

was built in lower New York in 1880. The first permanent station was completed in 1882. It contained six large direct-current dynamos and it served 58 customers using 1,284 sockets. The establishment of this central power station is of utmost importance in the history of other electrical industries as well as lighting. Although a considerable development of commercial electric lighting was possible by means of direct current, the successful use of an alternating-current system by George Westinghouse at the Chicago World's Fair in 1893 had a revolutionary effect on the electric-lighting industry.

The Tungsten-Filament Lamp

Many improvements were made in the carbon-filament lamp. From the mechanical point of view, perhaps the most notable improvement was the squirted cellulose-carbon filament of 1888. From the point of view of the light-giving efficiency of the filament a most important improvement was the gem or metallized-carbon filament, which came into use, however, only a short time before the development of the tungsten filament.

In connection with the tungsten filament, which came into extensive use as early as 1907, there have been three principal developments. The first was the pressed-tungsten filament which was devised after prolonged experiments in the reduction of the extremely difficult tungsten ores. The pressed-tungsten filament, although extremely efficient with respect to light-giving qualities, was fragile and could not be used except in limited fields. With the development of the drawn-tungsten-wire filament, however, the fragility was remedied, and the light-giving efficiency also was increased. A third important development in connection with the tungsten-filament lamp was the substitution of the gas-filled lamp for the vacuum lamp. The gas-filled lamp came gradually into use after 1913.

Increase in Efficiency (Large Lamps)

The efficiency of the electric lamp is measured in terms of lumens per watt. This expression "represents the quantity of light (in a practical sense) obtained from an incandescent lamp (or other source) per unit of electrical power supplied to the source." The watt, of course, is the unit of current used, and consists of volts times amperes.

Available statistics of efficiency apply for the most part only to large lamps. The efficiency of miniature lamps under actual operating conditions—on automobiles, and under various other conditions—cannot readily be ascertained. The following figures apply, therefore, only to large lamps. The carbon-filament lamps of 1881 are estimated to have had an efficiency of 1.68 lumens per watt, and those of 1906 an efficiency of 3.4 lumens per watt.¹⁹ The tungsten-filament lamps of 1920 are estimated to have risen in efficiency to 10.6 lumens per watt, and in 1931 to 13.4 lumens per watt.²⁰

¹⁹ Howell, J. W., and Schroeder, H. *History of the Incandescent Lamp*. Schenectady, 1927, pp. 83-84.

²⁰ National Electric Light Association. *Report of the Lamp Committee*, June 1932. New York, p. 2.

Appendix B.—Length of Life and Efficiency of Electric Lamps

With most consumed products the length of time the product will last in use is generally the most important element of its value. A better tire, for example, is usually one which will last for a greater number of miles, and progress in the art of making tires has been largely a matter of making them last longer and cost less.

Because length of life is so commonly the correct criterion of value in other products, it is a frequent error to consider the value of a lamp as being based solely upon its length of life. In so doing the consumer fails to give consideration to other fundamental elements of lamp value and may frequently arrive at a conclusion which works to his disadvantage.

The electric incandescent lamp is a device whose function is to transform electric energy into light. The passage of the current through the fine wire which forms the filament of the lamp heats this filament so that it glows brightly. The high temperature, however, causes a gradual evaporation of the metal, so that the filament becomes thinner and thinner, and after some hundreds of hours, it usually burns through at some point and the lamp fails.

The life of the lamp—that is, the number of hours it will burn before failure—depends upon two factors. The first is the temperature at which the filament is operated. A lower temperature lengthens the life but reduces disproportionately the light output. A higher temperature shortens the life but increases the light output. The second factor is the inherent quality of the lamp; that is, the value which the manufacturer has built into it. This factor is influenced by the relative excellence of all the materials and the precision of all the processes used in the fabrication of the lamp. If a lamp of superior quality and a lamp of inferior quality are operated so as to give the same amount of light and consume the same amount of power, the lamp of superior quality will have the longer life. By taking advantage of the longer life to be obtained through low filament temperature, a comparatively poor lamp can be made to last for a comparatively long life, but long life obtained in this way is not due to, nor evidence of, good value. On the contrary, that additional life is obtained only by accepting low efficiency of light output which is inevitably the penalty of low filament temperature.

A manufacturer of lamps could, if it seemed desirable, design lamps for a very long life, actually 100 years or more, or for a very short life, one day or less. The long-life lamp would produce a very small amount of light for the electricity consumed; the other would produce a large amount of light for the electricity used, but the expense for lamp replacements would be high. Neither extreme would produce light at the lowest cost.

It is not possible to tell what the designed life of a lamp should be for the lowest unit cost of light until the price to be paid for electric energy is known. Obviously, where the rate for energy is very low, one can afford to use longer-lived lamps which consume relatively more power for the amount of light they give. Where the rate for electric energy is higher, it pays to use lamps that give as much light as practicable for the power they use, even though the lamps themselves must be replaced more frequently. For any rate paid for electric energy there is a corresponding expenditure for lamps which will result in a minimum over-all cost for lighting. It was first established by Thomas Edison and confirmed by many later investigators that to secure the minimum cost for lighting the amount paid out for lamps must be approximately one sixth of the amount paid out for electricity to operate lamps. A few examples will illustrate this relationship.

(1) Assuming we have paid 20 cents for a 60-watt lamp and are burning this on energy costing 2 cents per kilowatt-hour, then, at the end of 1,000 hours we will find that we have used \$1.20 worth of electricity. If the lamp we purchased has been designed for a 1,000-hour life, then we are very close to the point of getting the most economical lighting, because 20 cents (the price paid for the lamp) is exactly one sixth of \$1.20 (the amount spent for energy). This is not quite a typical illustration because nearly everyone who is able to purchase energy at the very low rate of 2 cents is a large wholesale consumer who can also purchase his lamps at a substantial discount; such a consumer should use a lamp designed for a higher filament temperature and a shorter life than the foregoing illustration indicates.

(2) If energy costs 5 cents (which is nearer the usual household rate), then \$1.20 worth of energy will be used up by a 60-watt lamp in 400 hours of burning rather than in 1,000 hours. To obtain the most for his money, the consumer, paying 5 cents for electricity, must get more light out of his 60-watt lamp than where energy costs 2 cents. A lamp designed for a 400-hour life will give materially more light than a 1,000-hour lamp and in 400 hours will cost for lamp renewals 20 cents, or just one sixth of the cost of the energy consumed. A 400-hour lamp is, therefore, the economical 60-watt lamp to use on 5-cent current.

(3) If a 60-watt lamp were purchased for 10 cents, then its most economical life on 5-cent electricity would be 200 hours.

In general, it may be said that the manufacturer in designing lamps, and the consumer in buying them, should be guided by the cost of electric energy and by the prices to be charged or paid for the lamps. High rates for electric energy call for lamps designed for comparatively short life with high light output, because they are more economical than lamps of equal or higher prices designed for longer life with lower light output.

There is another factor which influences the length of time a lamp should burn to obtain maximum economy. This factor is the cost involved in the effort required to replace lamps which have burned out. Obviously, a lamp which burns 500 hours will have to be renewed twice as often as a lamp which burns 1,000 hours; therefore, the labor cost of changing 500-hour lamps will be twice as great as the cost of changing 1,000-hour lamps. However, this cost is usually

low, and for the lamps regularly used in the home it is practically negligible, as, on the average, such lamps are burned less than 500 hours annually. The cost of lamp replacement may become an important factor, however, in some industrial and commercial uses where lamps are located in places not easily accessible, and this is frequently of sufficient moment to justify a longer life, and therefore a higher rate for lighting than would otherwise be economical.

It is evident that different lamp wattages, different kilowatt-hour rates, and different lamp prices all require different lamp lives to obtain the minimum cost for a unit of light. If the lamp manufacturer attempted to make all of these varieties, the cost of lamps would be prohibitive and the confusion intolerable. The only practical solution of this problem is to design each type of lamp for maximum economy at average kilowatt-hour rates, with a reasonable allowance for the effort expended in replacing burned-out lamps. At the prices which now prevail for lamps and energy, the life of lamps of a given quality and price may vary a hundred or two hundred hours from the optimum value without greatly increasing or decreasing the cost of light, because the shorter-lived lamp, giving more light, will in this way usually fully balance the additional cost of lamp renewals. If, however, the shorter-lived lamp is materially lower in price than the longer-lived lamp, and is of the same high quality, there will usually be a substantial economy in using the shorter-lived lamp.

Since the most economical lamp is necessarily one designed for a length of life based on the relative cost of energy, it is obvious that no specifications requiring a particular length of life, as 1,000 hours, can be valid except for the limited conditions in which the ratio of cost of energy to cost of lamps calls for the specified length of life.

LIST OF BULLETINS OF THE BUREAU OF LABOR STATISTICS

The following is a list of all bulletins of the Bureau of Labor Statistics published since July, 1912, except that in the case of bulletins giving the results of periodic surveys of the bureau only the latest bulletin on any one subject is here listed.

A complete list of the reports and bulletins issued prior to July, 1912, as well as the bulletins published since that date, will be furnished on application. Bulletins marked thus () are out of print.*

Conciliation and arbitration (including strikes and lockouts).

- *No. 124. Conciliation and arbitration in the building trades of Greater New York. [1913.]
- *No. 133. Report of the industrial council of the British Board of Trade on its inquiry into industrial agreements. [1913.]
- *No. 139. Michigan copper district strike. [1914.]
- *No. 144. Industrial court of the cloak, suit, and skirt industry of New York City. [1914.]
- *No. 145. Conciliation, arbitration, and sanitation in the dress and waist industry of New York City. [1914.]
- *No. 191. Collective bargaining in the anthracite-coal industry. [1916.]
- *No. 198. Collective agreements in the men's clothing industry. [1916.]
- No. 233. Operation of the industrial disputes investigation act of Canada. [1918.]
- No. 255. Joint industrial councils in Great Britain. [1919.]
- No. 283. History of the Shipbuilding Labor Adjustment Board, 1917 to 1919.
- No. 287. National War Labor Board: History of its formation, activities, etc. [1921.]
- *No. 303. Use of Federal power in settlement of railway labor disputes. [1922.]
- No. 341. Trade agreement in the silk-ribbon industry of New York City. [1923.]
- No. 402. Collective bargaining by actors. [1926.]
- No. 468. Trade agreements, 1927.
- No. 481. Joint industrial control in the book and job printing industry. [1928.]

Cooperation.

- No. 313. Consumers' cooperative societies in the United States in 1920.
- *No. 314. Cooperative credit societies (credit unions) in America and in foreign countries. [1922.]
- No. 437. Cooperative movement in the United States in 1925 (other than agricultural).
- No. 531. Consumers', credit, and productive cooperative societies, 1929.

Employment and unemployment.

- *No. 109. Statistics of unemployment and the work of employment offices [in the United States]. [1913.]
- *No. 172. Unemployment in New York City, N. Y. [1915.]
- *No. 183. Regularity of employment in the women's ready-to-wear garment industries. [1915.]
- *No. 195. Unemployment in the United States. [1916.]
- *No. 196. Proceedings of Employment Managers' Conference, held in Minneapolis, Minn., January 19 and 20, 1916.
- *No. 202. Proceedings of the conference of Employment Managers' Association of Boston, Mass., held May 10, 1916.
- No. 206. The British system of labor exchanges. [1916.]
- *No. 227. Proceedings of Employment Managers' Conference, Philadelphia, Pa., April 2 and 3, 1917.
- *No. 235. Employment system of the Lake Carriers' Association. [1918.]
- *No. 241. Public employment offices in the United States. [1918.]
- *No. 247. Proceedings of Employment Managers' Conference, Rochester, N. Y., May 9-11, 1918.
- *No. 310. Industrial unemployment: A statistical study of its extent and causes. [1922.]
- No. 409. Unemployment in Columbus, Ohio, 1921 to 1925.
- No. 542. Report of the Advisory Committee on Employment Statistics. [1931.]
- No. 544. Unemployment benefit plans in the United States and unemployment insurance in foreign countries. [1931.]
- *No. 553. Fluctuation in employment in Ohio, 1914 to 1929.
- No. 555. Social and economic character of unemployment in Philadelphia, April, 1930.

Foreign labor laws.

- *No. 142. Administration of labor laws and factory inspection in certain European countries. [1914.]
- No. 494. Labor legislation of Uruguay. [1929.]
- No. 510. Labor legislation of Argentina. [1930.]
- No. 529. Workmen's compensation legislation of the Latin American countries. [1930.]
- No. 549. Labor legislation of Venezuela. [1931.]
- No. 554. Labor legislation of Paraguay. [1931.]
- No. 559. Labor legislation of Ecuador. [1931.]
- No. 569. Labor legislation of Mexico. [1932.]

Housing.

- *No. 158. Government aid to home owning and housing of working people in foreign countries. [1914.]
- No. 263. Housing by employers in the United States. [1920.]
- No. 295. Building operations in representative cities, 1920.
- No. 545. Building permits in principal cities of the United States in [1921 to] 1930.

Industrial accidents and hygiene.

- *No. 104. Lead poisoning in potteries, tile works, and porcelain-enameled sanitary ware factories. [1912.]
- No. 120. Hygiene of the painters' trade. [1913.]
- *No. 127. Dangers to workers from dusts and fumes, and methods of protection. [1913.]
- *No. 141. Lead poisoning in the smelting and refining of lead. [1914.]
- *No. 157. Industrial accident statistics. [1915.]
- *No. 165. Lead poisoning in the manufacture of storage batteries. [1914.]
- *No. 179. Industrial poisons used in the rubber industry. [1915.]
- No. 188. Report of British departmental committee on the danger in the use of lead in the painting of buildings. [1916.]
- *No. 201. Report of the committee on statistics and compensation insurance costs of the International Association of Industrial Accident Boards and Commissions. [1916.]
- No. 209. Hygiene of the printing trades. [1917.]
- *No. 219. Industrial poisons used or produced in the manufacture of explosives. [1917.]
- No. 221. Hours, fatigue, and health in British munition factories. [1917.]
- No. 230. Industrial efficiency and fatigue in British munition factories. [1917.]
- *No. 231. Mortality from respiratory diseases in dusty trades (inorganic dusts). [1918.]
- *No. 234. The safety movement in the iron and steel industry, 1907 to 1917.
- No. 236. Effects of the air hammer on the hands of stonecutters. [1918.]
- *No. 249. Industrial health and efficiency. Final report of British Health of Munition Workers' Committee. [1919.]
- *No. 251. Preventable death in the cotton-manufacturing industry. [1919.]
- No. 256. Accidents and accident prevention in machine building. [1919.]
- No. 267. Anthrax as an occupational disease. [1920.]
- No. 276. Standardization of industrial accident statistics. [1920.]
- *No. 280. Industrial poisoning in making coal-tar dyes and dye intermediates. [1921.]
- *No. 291. Carbon monoxide poisoning. [1921.]
- No. 293. The problem of dust phthisis in the granite-stone industry. [1922.]
- No. 298. Causes and prevention of accidents in the iron and steel industry, 1910-1919.
- No. 392. Survey of hygienic conditions in the printing trades. [1925.]
- No. 405. Phosphorus necrosis in the manufacture of fireworks and in the preparation of phosphorus. [1926.]
- No. 427. Health survey of the printing trades, 1922 to 1925.
- No. 428. Proceedings of the Industrial Accident Prevention Conference, held at Washington, D. C., July 14-16, 1926.
- No. 460. A new test for industrial lead poisoning. [1928.]
- No. 466. Settlement for accidents to American seamen. [1928.]
- No. 488. Deaths from lead poisoning, 1925-1927.
- No. 490. Statistics of industrial accidents in the United States to the end of 1927.
- No. 507. Causes of death, by occupation. [1930.]
- No. 582. Occupation hazards and diagnostic signs: A guide to impairments to be looked for in hazardous occupations. (Revision of Bul. No. 306.) [1933.]

Industrial relations and labor conditions

- No. 237. Industrial unrest in Great Britain. [1917.]
- *No. 340. Chinese migrations, with special reference to labor conditions. [1923.]
- *No. 349. Industrial relations in the West Coast lumber industry. [1923.]
- *No. 361. Labor relations in the Fairmont (W. Va.) bituminous-coal field. [1924.]
- No. 380. Postwar labor conditions in Germany. [1925.]
- No. 383. Works council movement in Germany. [1925.]
- No. 384. Labor conditions in the shoe industry in Massachusetts, 1920-1924.
- No. 399. Labor relations in the lace and lace-curtain industries in the United States. [1925.]
- No. 483. Conditions in the shoe industry in Haverhill, Mass., 1928.
- No. 534. Labor conditions in the Territory of Hawaii, 1929-1930.

Labor laws of the United States (including decisions of courts relating to labor)

- *No. 211. Labor laws and their administration in the Pacific States. [1917.]
- *No. 229. Wage-payment legislation in the United States. [1917.]
- No. 285. Minimum-wage laws of the United States: Construction and operation. [1921.]
- No. 321. Labor laws that have been declared unconstitutional. [1922.]
- No. 322. Kansas Court of Industrial Relations. [1923.]
- No. 343. Laws providing for bureaus of labor statistics, etc. [1923.]
- No. 370. Labor laws of the United States, with decisions of courts relating thereto. [1925.]
- No. 408. Laws relating to payment of wages. [1926.]
- No. 581. Laws relating to employment agencies in the United States, as of January 1, 1933.
- No. 590. Labor legislation, 1931 and 1932. (In press.)
- No. 592. Decisions of courts and opinions affecting labor, 1931 and 1932. (In press.)

Prison labor

- No. 372. Convict labor in 1923.

Proceedings of annual conventions of the Association of Governmental Officials in Industry of the United States and Canada. (Name changed in 1928 from Association of Governmental Labor Officials of the United States and Canada.)

- *No. 266. Seventh, Seattle, Wash., July 12-15, 1920.
- No. 307. Eighth, New Orleans, La., May 2-6, 1921.
- *No. 323. Ninth, Harrisburg, Pa., May 22-26, 1922.
- *No. 352. Tenth, Richmond, Va., May 1-4, 1923.
- *No. 389. Eleventh, Chicago, Ill., May 19-23, 1924.
- *No. 411. Twelfth, Salt Lake City, Utah, August 13-15, 1925.
- *No. 429. Thirteenth, Columbus, Ohio, June 7-10, 1926.
- *No. 455. Fourteenth, Paterson, N. J., May 31 to June 3, 1927.

- *No. 480. Fifteenth, New Orleans, La., May 21-24, 1928.
- No. 508. Sixteenth, Toronto, Canada, June 4-7, 1929.
- No. 530. Seventeenth, Louisville, Ky., May 20-23, 1930.
- *No. 563. Eighteenth, Boston, Mass., May 18-22, 1931.

Proceedings of annual meetings of the International Association of Industrial Accident Boards and Commissions.

- No. 210. Third, Columbus, Ohio, April 25-28, 1916.
- No. 248. Fourth, Boston, Mass., August 21-25, 1917.
- No. 264. Fifth, Madison, Wis., September 24-27, 1918.
- *No. 273. Sixth, Toronto, Canada, September 23-26, 1919.
- No. 281. Seventh, San Francisco, Calif., September 20-24, 1920.
- No. 304. Eighth, Chicago, Ill., September 19-23, 1921.
- No. 333. Ninth, Baltimore, Md., October 9-13, 1922.
- *No. 359. Tenth, St. Paul, Minn., September 24-26, 1923.
- No. 385. Eleventh, Halifax, Nova Scotia, August 26-28, 1924.
- No. 395. Index to proceedings, 1914-1924.
- No. 406. Twelfth, Salt Lake City, Utah, August 17-20, 1925.
- No. 432. Thirteenth, Hartford, Conn., September 14-17, 1926.
- *No. 456. Fourteenth, Atlanta, Ga., September 27-29, 1927.
- No. 485. Fifteenth, Paterson, N.J., September 11-14, 1928.
- No. 511. Sixteenth, Buffalo, N.Y., October 8-11, 1929.
- No. 536. Seventeenth, Wilmington, Del., September 22-26, 1930.
- No. 564. Eighteenth, Richmond, Va., October 5-8, 1931.
- No. 577. Nineteenth, Columbus, Ohio, September 26-29, 1932.

Proceedings of annual meetings of the International Association of Public Employment Services.

- No. 192. First, Chicago, December 19 and 20, 1913; second, Indianapolis, September 24 and 25, 1914; third, Detroit, July 1 and 2, 1915.
- *No. 220. Fourth, Buffalo, N.Y., July 20 and 21, 1916.
- No. 311. Ninth, Buffalo, N.Y., September 7-9, 1921.
- No. 337. Tenth, Washington, D.C., September 11-13, 1922.
- No. 355. Eleventh, Toronto, Canada, September 4-7, 1923.
- No. 400. Twelfth, Chicago, Ill., May 19-23, 1924.
- No. 414. Thirteenth, Rochester, N.Y., September 15-17, 1925.
- No. 478. Fifteenth, Detroit, Mich., October 25-28, 1927.
- *No. 501. Sixteenth, Cleveland, Ohio, September 18-21, 1928.
- No. 538. Seventeenth, Philadelphia, Pa., September 24-27, 1929; eighteenth, Toronto, Canada, September 9-12, 1930.

Productivity of labor and technological unemployment

- No. 356. Productivity costs in the common-brick industry. [1924.]
- No. 360. Time and labor costs in manufacturing 100 pairs of shoes. 1923
- No. 407. Labor cost of production and wages and hours of labor in the paper box-board industry. [1926.]
- *No. 412. Wages, hours, and productivity in the pottery industry. 1925.
- No. 441. Productivity of labor in the glass industry. [1927.]
- No. 474. Productivity of labor in merchant blast furnaces. [1928.]
- No. 475. Productivity of labor in newspaper printing. [1929.]
- No. 550. Cargo handling and longshore labor conditions. [1932.]
- No. 574. Technological changes and employment in the United States Postal Service. [1932.]
- No. 585. Labor productivity in the tire industry. [1933.]

Retail prices and cost of living.

- *No. 121. Sugar prices, from refiner to consumer. [1913.]
- *No. 130. Wheat and flour prices, from farmer to consumer. [1913.]
- *No. 164. Butter prices, from producer to consumer. [1914.]
- *No. 170. Foreign food prices as affected by the war. [1915.]
- No. 357. Cost of living in the United States. [1924.]
- No. 369. The use of cost-of-living figures in wage adjustments. [1925.]
- No. 405. Retail prices, 1890 to 1928.

Safety codes.

- *No. 336. Safety code for the protection of industrial workers in foundries.
- No. 350. Rules governing the approval of headlighting devices for motor vehicles.
- *No. 351. Safety code for the construction, care, and use of ladders.
- No. 375. Safety code for laundry machinery and operations.
- *No. 382. Code of lighting school buildings.
- No. 410. Safety code for paper and pulp mills.
- *No. 430. Safety code for power presses and foot and hand presses.
- No. 447. Safety code for rubber mills and calenders.
- No. 451. Safety code for forging and hot-metal stamping.
- No. 463. Safety code for mechanical power-transmission apparatus—first revision.
- No. 509. Textile safety code.
- No. 512. Code for identification of gas-mask canisters.
- No. 519. Safety code for woodworking plants, as revised 1930.
- No. 527. Safety code for the use, care, and protection of abrasive wheels, as revised 1930.
- No. 556. Code of lighting: Factories, mills, and other work places. (Revision of 1930.)
- No. 562. Safety codes for the prevention of dust explosions.

Vocational and workers' education

- *No. 159. Short-unit courses for wage earners, and a factory school experiment. [1915.]
- *No. 162. Vocational education survey of Richmond, Va. [1915.]
- *No. 199. Vocational education survey of Minneapolis, Minn. [1917.]
- *No. 271. Adult working-class education in Great Britain and the United States. [1920.]
- No. 459. Apprenticeship in building construction. [1928.]

Wages and hours of labor

- *No. 146. Wages and regularity of employment and standardization of piece rates in the dress and waist industry of New York City. [1914.]
- *No. 147. Wages and regularity of employment in the cloak, suit, and skirt industry. [1914.]
- No. 161. Wages and hours of labor in the clothing and cigar industries, 1911 to 1913.
- *No. 163. Wages and hours of labor in the building and repairing of steam railroad cars, 1907 to 1913.
- *No. 190. Wages and hours of labor in the cotton, woolen, and silk industries, 1907 to 1914.
- *No. 204. Street-railway employment in the United States. [1917.]
- *No. 225. Wages and hours of labor in the lumber, millwork, and furniture industries, 1915.
- No. 265. Industrial survey in selected industries in the United States, 1919.
- No. 297. Wages and hours of labor in the petroleum industry, 1920.
- No. 356. Productivity costs in the common-brick industry. [1924.]
- No. 358. Wages and hours of labor in the automobile-tire industry, 1923.
- No. 360. Time and labor costs in manufacturing 100 pairs of shoes, 1923.
- No. 365. Wages and hours of labor in the paper and pulp industry, 1923.
- No. 407. Labor cost of production and wages and hours of labor in the paper box-board industry. [1926.]
- *No. 412. Wages, hours, and productivity in the pottery industry, 1925.
- No. 416. Hours and earnings in anthracite and bituminous-coal mining, 1922 and 1924.
- No. 484. Wages and hours of labor of common street laborers, 1928.
- No. 499. History of wages in the United States from colonial times to 1928.
- No. 502. Wages and hours of labor in the motor-vehicle industry, 1928.
- No. 514. Pennsylvania Railroad wage data. From Report of Joint Fact Finding Committee in wage negotiations in 1927.
- No. 516. Hours and earnings in bituminous-coal mining, 1929.
- No. 523. Wages and hours in the manufacture of airplanes and aircraft engines, 1929.
- No. 525. Wages and hours of labor in the Portland cement industry, 1929.
- No. 532. Wages and hours of labor in the cigarette-manufacturing industry, 1930.
- No. 534. Labor conditions in the Territory of Hawaii, 1929-1930.
- No. 539. Wages and hours of labor in cotton-goods manufacturing, 1910 to 1930.
- No. 547. Wages and hours of labor in the cane-sugar refining industry, 1930.
- No. 557. Wages and hours of labor in the men's clothing industry, 1911 to 1930.
- No. 566. Union scales of wages and hours of labor, May 15, 1931.
- No. 567. Wages and hours of labor in the iron and steel industry, 1931.
- No. 568. Wages and hours of labor in the manufacture of silk and rayon goods, 1931.
- No. 570. Wages and hours of labor in foundries and machine shops, 1931.
- No. 571. Wages and hours of labor in the furniture industry, 1910 to 1931.
- No. 573. Wages and hours of labor in metalliferous mining, 1924 to 1931.
- No. 575. Wages and hours of labor in air transportation, 1931.
- No. 576. Wages and hours of labor in the slaughtering and meat-packing industry, 1931.
- No. 578. Wages and hours of labor in gasoline-filling stations and motor-vehicle repair garages, 1931.
- No. 579. Wages and hours of labor in the boot and shoe industry, 1910 to 1932.
- No. 580. Wages and hours of labor in the baking industry—bread and cake departments, 1931.
- No. 584. Wages and hours of labor in woolen and worsted goods manufacturing, 1932.
- No. 586. Wages and hours of labor in the lumber industry, 1932.
- No. 587. Wages and hours of labor in the rayon and other synthetic yarn manufacturing, 1932.
- No. 588. Wages and hours of labor in the dyeing and finishing of textiles, 1932.
- No. 589. Wages and hours of labor in the leather industry, 1932. (In press.)
- No. 591. Wages and hours of labor in the hosiery and underwear industry, 1932. (In press.)

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- *No. 123. Employers' welfare work. [1913.]
- *No. 222. Welfare work in British munition factories. [1917.]
- *No. 250. Welfare work for employees in industrial establishments in the United States. [1919.]
- No. 458. Health and recreation activities in industrial establishments, 1926.

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- *No. 284. Index numbers of wholesale prices in the United States and foreign countries. [1921.]
- *No. 453. Revised index numbers of wholesale prices, 1923 to July, 1927.
- No. 572. Wholesale prices, 1931.

Women and children in industry

- *No. 116. Hours, earnings, and duration of employment of wage-earning women in selected industries in the District of Columbia. [1913.]
- *No. 117. Prohibition of night work of young persons. [1913.]
- *No. 118. Ten-hour maximum working-day for women and young persons. [1913.]
- *No. 119. Working hours of women in the pea canneries of Wisconsin. [1913.]
- *No. 122. Employment of women in power laundries in Milwaukee. [1913.]
- *No. 160. Hours, earnings, and conditions of labor of women in Indiana mercantile establishments and garment factories. [1914.]
- *No. 175. Summary of the report on condition of woman and child wage earners in the United States. [1915.]
- *No. 176. Effect of minimum-wage determinations in Oregon. [1915.]
- *No. 180. The boot and shoe industry in Massachusetts as a vocation for women. [1915.]
- *No. 182. Unemployment among women in department and other retail stores of Boston, Mass. [1916.]
- No. 193. Dressmaking as a trade for women in Massachusetts. [1916.]
- *No. 215. Industrial experience of trade-school girls in Massachusetts. [1917.]
- *No. 217. Effect of workmen's compensation laws in diminishing the necessity of industrial employment of women and children. [1917.]
- *No. 223. Employment of women and juveniles in Great Britain during the war. [1917.]
- No. 253. Women in the lead industries. [1919.]
- No. 467. Minimum-wage legislation in various countries. [1928.]
- No. 588. Labor conditions of women and children in Japan. [1931.]

Workmen's insurance and compensation (including laws relating thereto).

- *No. 101. Care of tuberculous wage earners in Germany. [1912.]
- *No. 102. British national insurance act, 1911.
- No. 103. Sickness and accident insurance law in Switzerland. [1912.]
- No. 107. Law relating to insurance of salaried employees in Germany. [1913.]
- *No. 155. Compensation for accidents to employees of the United States. [1914.]
- *No. 212. Proceedings of the conference on social insurance called by the International Association of Industrial Accident Boards and Commissions, Washington, D.C., December 5-9, 1916.
- *No. 243. Workmen's compensation legislation in the United States and foreign countries, 1917 and 1918.
- No. 301. Comparison of workmen's compensation insurance and administration. [1922.]
- No. 312. National health insurance in Great Britain, 1911 to 1921.
- *No. 379. Comparison of workmen's compensation laws of the United States as of January 1, 1925.
- No. 477. Public-service retirement systems, United States and Europe. [1929.]
- No. 496. Workmen's compensation legislation of the United States and Canada as of January 1, 1929. (With text of legislation enacted in 1927 and 1928.)
- No. 529. Workmen's compensation legislation of the Latin American countries. [1930.]

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- *No. 174. Subject index of the publications of the United States Bureau of Labor Statistics up to May 1, 1915.
- No. 208. Profit sharing in the United States. [1916.]
- No. 242. Food situation in central Europe, 1917.
- No. 254. International labor legislation and the society of nations. [1919.]
- *No. 268. Historical survey of international action affecting labor. [1920.]
- No. 282. Mutual relief associations among Government employees in Washington, D.C. [1921.]
- No. 319. The Bureau of Labor Statistics: Its history, activities, and organization. [1922.]
- No. 326. Methods of procuring and computing statistical information of the Bureau of Labor Statistics. [1923.]
- No. 342. International Seamen's Union of America: A study of its history and problems. [1923.]
- No. 346. Humanity in government. [1923.]
- No. 386. Cost of American almshouses. [1925.]
- No. 398. Growth of legal-aid work in the United States. [1926.]
- No. 401. Family allowances in foreign countries. [1926.]
- No. 461. Labor organizations in Chile. [1928.]
- *No. 465. Beneficial activities of American trade-unions. [1928.]
- No. 479. Activities and functions of a State department of labor. [1928.]
- *No. 489. Care of aged persons in United States. [1929.]
- No. 505. Directory of homes for the aged in the United States. [1929.]
- No. 506. Handbook of American trade-unions. 1929 edition.
- No. 518. Personnel research agencies. 1930 edition.
- No. 541. Handbook of labor statistics. 1931 edition.
- No. 561. Public old-age pensions and insurance in the United States and in foreign countries. [1932.]
- No. 565. Park recreation areas in the United States, 1930.

