GLASS

OSRAM – G.E.C. GLASS WORKS

L. G. Timmins

GLASS

BLOWN, DRAWN
PRESSED . . . .

SOFT, HARD
NEUTRAL
COLOURED
OPAL . . . . . .

BULBS, TUBING
ROD . . . . . .

OSRAM-G.E.C. GLASS WORKS PRODUCTS

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CONTENTS

OSRAM - G.E.C. GLASS WORKS
OF THE GENERAL ELECTRIC CO. LTD.
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INTRODUCTION

by

GEORGE CHELIOTI

Director of The General Electric Co. Ltd. and General Manager of the Osram G.E.C. Group

The presence of an Electrical Manufacturing Company in the Glass industry may seem surprising, and indeed it must have been remote from the intentions of the founders of the General Electric Co. Ltd., but as a logical outcome of industrial history it certainly needs no apology. There is no record of this Company being seriously interested in glassware, except as a component of lighting fittings, until its entry, about 1893, into the manufacture of electric lamps. After that the need for regular supplies of lamp bulbs and tubing made the G.E.C. a growing buyer of glass products not only from Britain, but from many continental countries, and as all the available ware was then 'mouthblown', it is easily imagined that these fitful supplies from different sources of what should ideally have been strictly standardized and uniform articles were not very satisfying.

Accordingly, in 1906, Christopher Wilson, who is still very well remembered in both Glass and Electrical industries as the moving spirit of what was then the Robertson Electric Lamp Company, and later as a director of the G.E.C., eagerly grasped an opportunity of buying a small glassworks at Lemington-on-Tyne, so founding the Lemington Glassworks Ltd. and giving the Company its first foothold in the field of glass manufacture.

The early history of this venture is nowadays a little dim, but it is on record that during the 1914-18 war there was still an insufficiency of glass to meet the needs of the British lamp industry. Under this stimulus the 'Westlake Syndicate' was formed to import machinery from America and the first 'Iron Men', as they were dubbed, went into production at Lemington about 1917. The mirage of a prolonged trade boom after the 1918 Armistice induced many industrial plans that came to nothing, or worse, but the G.E.C., moved by the vision of Lord (then Mr. Hugo) Hirst, held tenaciously to its belief that prospects in home and foreign markets justified a big increase in British production of electric lamps. In the face of all discouragement a large Glassworks was built on what has since become a great G.E.C. industrial estate at North Wembley, and between 1921 and 1926, first Danner and later Westlake machines began to turn out tubing and bulbs respectively on a scale that gave us a real claim to membership of the Glass industry. This union of modern engineering and ancient craftsmanship was strengthened by the support of the G.E.C. Research Laboratories (founded in 1919) and by the adoption with enthusiasm of the budding resources of a then new branch of applied Science, Glass Technology.

Since then the Osram-G.E.C. Glass Works have steadily grown in scale of production, in range of glass compositions and in ambition to be among the leaders of a great and complex modern industry. The management organization has been built in careful detail with the aim that its several branches—production, commercial, technical and engineering—may support and interact with each other at every level. It is a management which appreciates the human importance of every person employed in the total effort, and also that every industrial unit, in the long run, has to justify its existence and survival by the quality of the service which it provides to the buyers of its products.

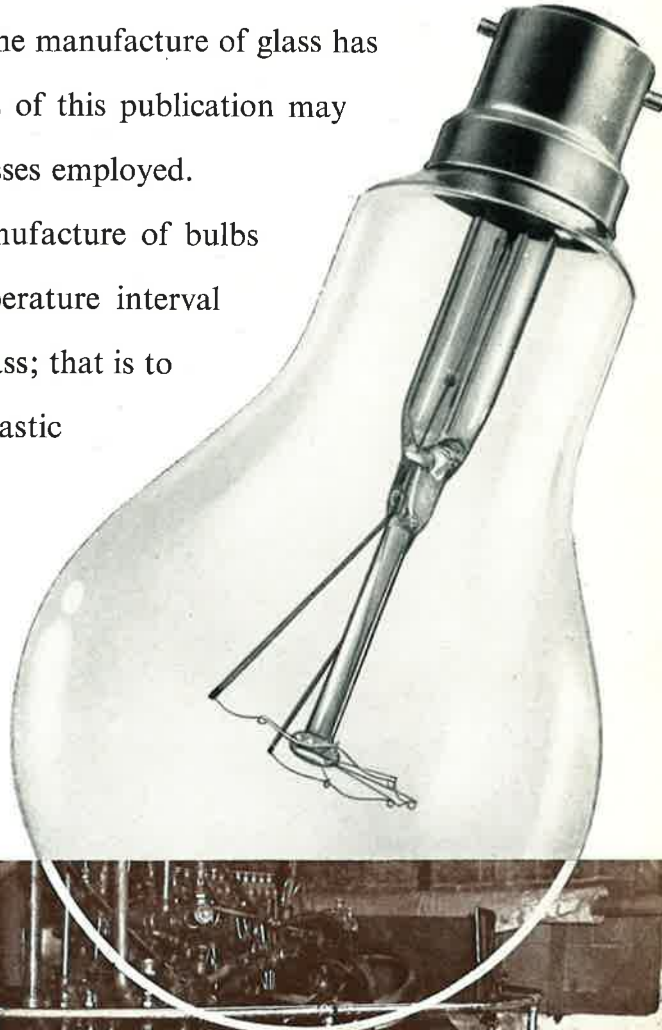
In 1949, the Osram-G.E.C. glass group comprises the original Lemington and the newer Wembley Glass Works together with the Charlton Tubeworks, founded in 1943 as a relatively small, but vigorous newcomer. Within this group Wembley produces some 65% and 90% of the machine-made bulbs and tubing respectively, with Lemington and Charlton making up the totals. The most varied programme, however, is Lemington's, for this factory, continuously at work since 1780 and still making by hand a wide range of blownware and tubing of kinds too specialized for mechanical production, maintains the craft skills on which the whole adventure has been founded. Moreover Lemington, having during the late war tentatively undertaken the pressing of small hard glass components for ultimately destructive ends, set out in 1945 to prove its ability in more peaceful directions, and the Tyneside factory is now making a great variety of pressware, in several different glasses, for uses ranging from Television tubes to Transmitting valves and from Aerodrome beacons to Streetlighting 'diffractors'.

The Company entered Glass manufacture solely to satisfy its special needs for a uniform and controlled product, but many other outlets have been found for its ware, often in industries whose end-products have no relation to Lamp and Valve manufacture. Our recurring experience has been that a development in Glass technology which solves a problem of our own solves many others of which we were quite unaware, and we believe that the Osram-G.E.C. glass group has been able in this way to render a unique service far outside the circle of the industries from which it sprang. It has, besides, been for many years past, and especially during the late war, a main support of all manufacturers of electric lamps and radio valves, irrespective of their particular affiliations. It is a striking fact that in 1948 more than 70% of all our glass products were sold outside the Osram-G.E.C. factories.

The pages which follow in this publication seek to tell our friends, in some detail but in handy form, about the products and potentialities of these factories.

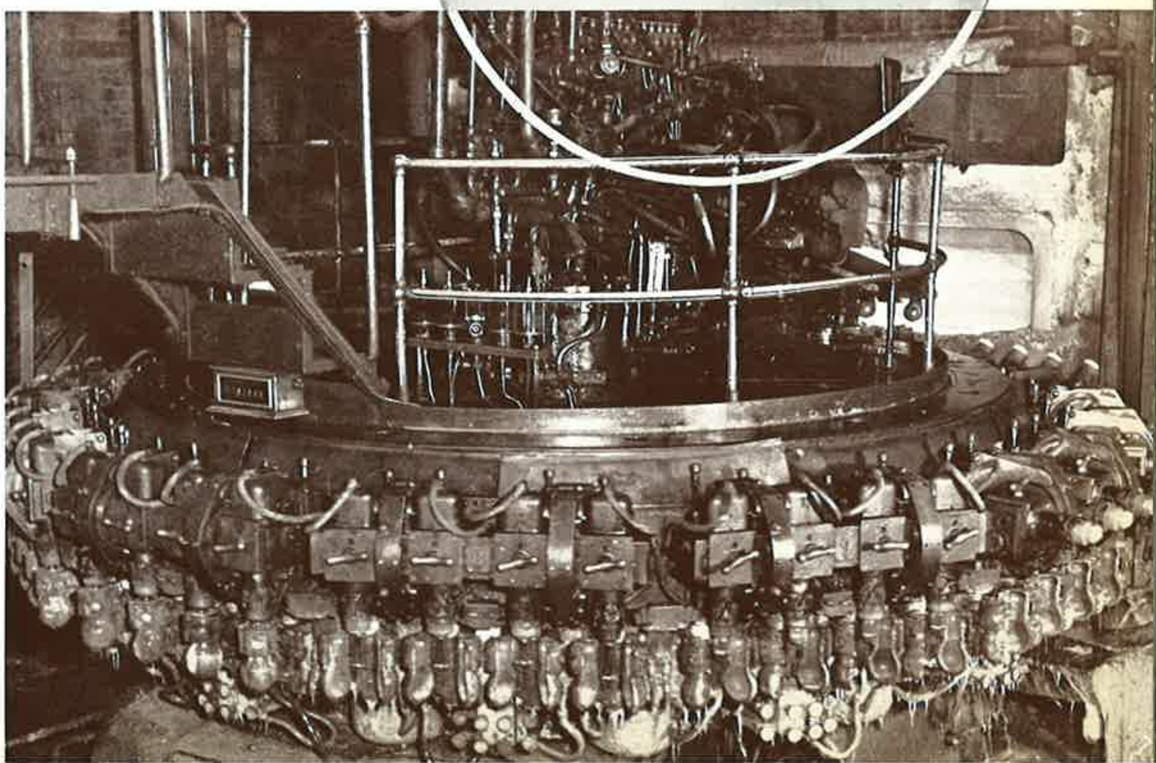
CHAPTER 1

OSRAM-G.E.C. GLASS WORKS PRODUCTS



The reason why the Company embarked upon the manufacture of glass has been explained in the Introduction, but readers of this publication may value a short technical description of the processes employed.

Glass being a thermo-plastic material, the manufacture of bulbs and of tubing must take place within a temperature interval which is known as the 'working range' of the glass; that is to say, that range in which the glass is sufficiently plastic to be blown or pressed or drawn, as the case may be. This means that all operations in the manufacture of glass products must take place between temperatures of, say, 500°C. and 1100°C.



Ohio bulb blowing machine

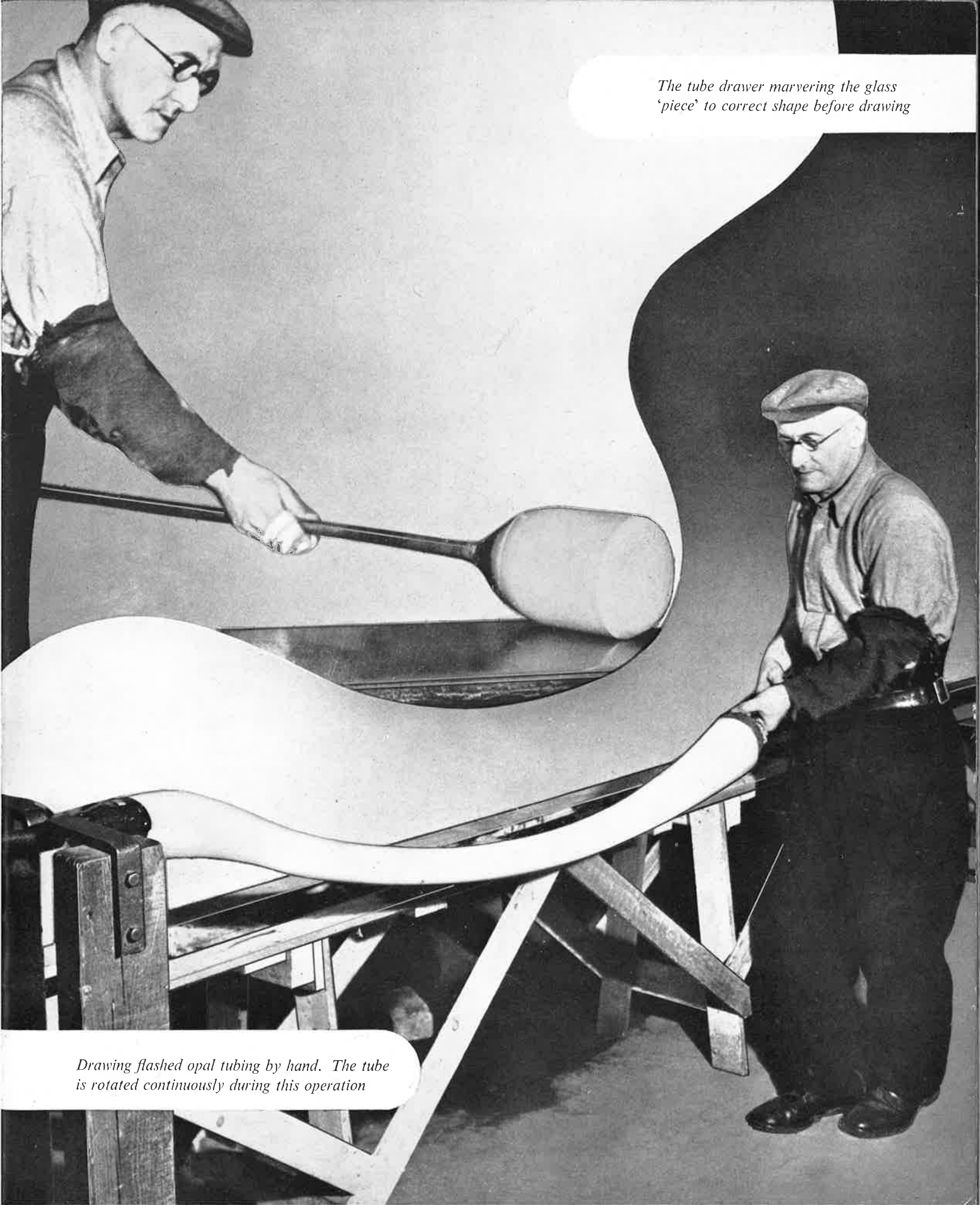
Blowing a cathode-ray tube

BULBS AND HAND DRAWN TUBES

The Hand Blower, in the manufacture of bulbs and of tubing, gathers molten glass from the pot on an iron, allows it to cool, and blows a bubble of air into it through the iron to form a hollow cylinder, or what may be described as a 'blank' of plastic glass. Subsequent manipulation of this 'blank' and the blowing of it up to shape in a mould, produces the finished bulb.

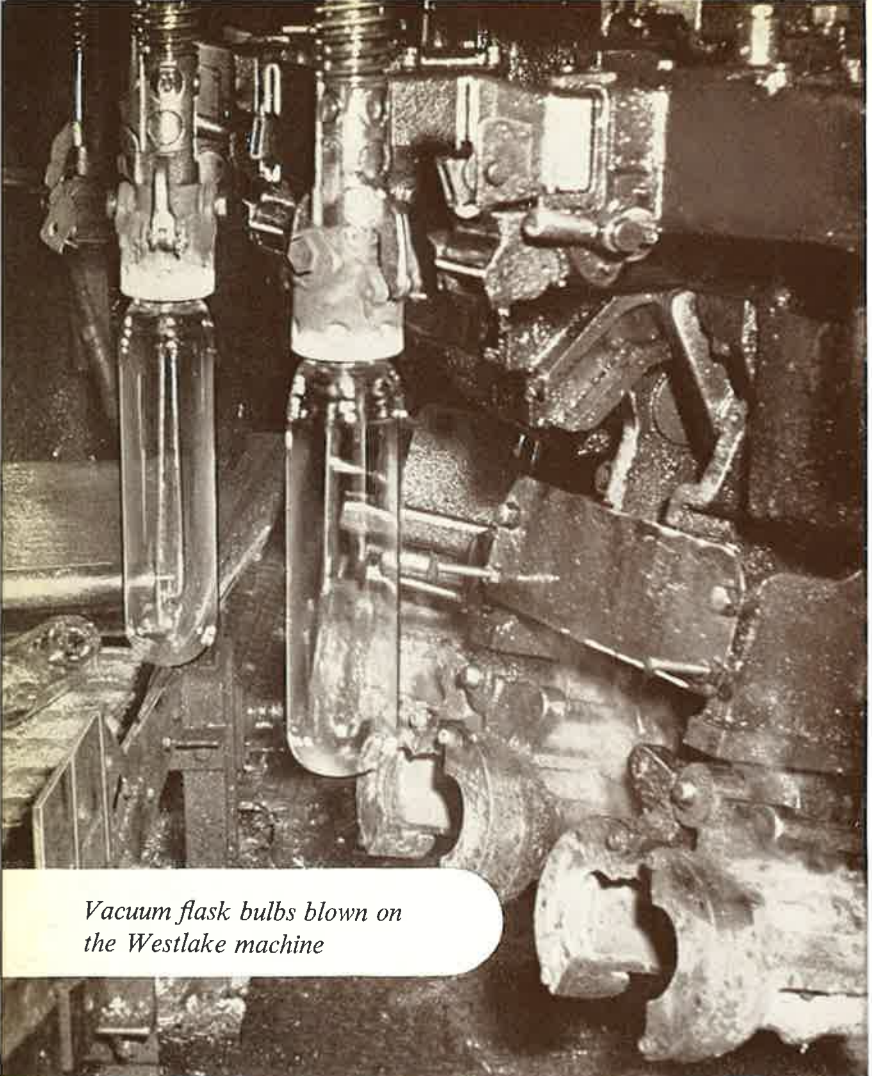
If he is making tubing he forms his 'gather' of glass into a heavier walled hollow cylinder or 'core', rolling it on a cast iron plate. Subsequently an assistant attaches an iron to the other end of the 'core' and the two men walk away, drawing out the plastic glass between them. In this way tubing can be produced of varying wall thickness and diameter, depending upon the amount of glass gathered and the extent to which it is subsequently drawn down.

Burning-off mouth-blown bulbs at Lemington



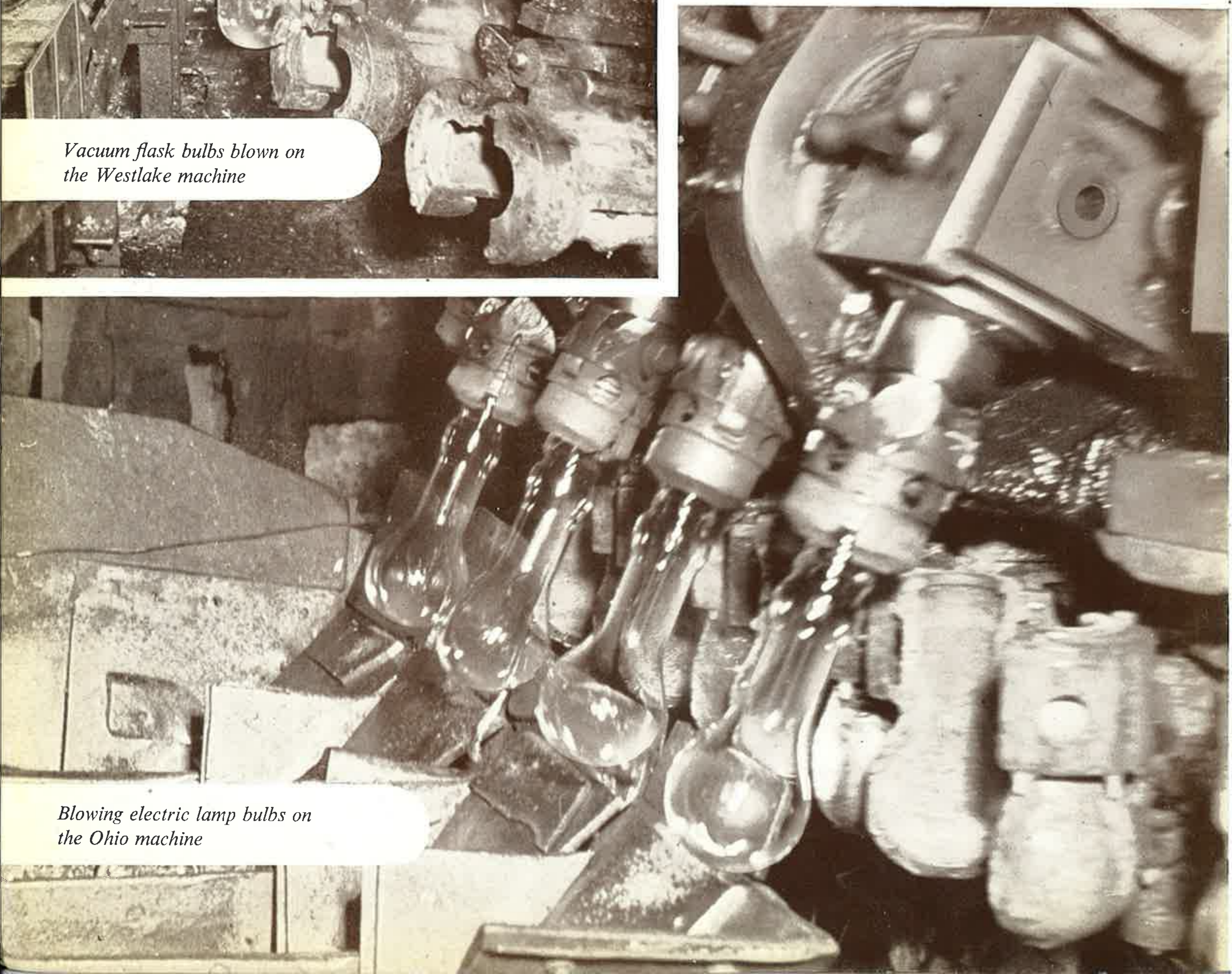
The tube drawer marvering the glass 'piece' to correct shape before drawing

Drawing flashed opal tubing by hand. The tube is rotated continuously during this operation



Vacuum flask bulbs blown on the Westlake machine

Inspecting machine-blown lamp bulbs



Blowing electric lamp bulbs on the Ohio machine

OPERATION OF WESTLAKE MACHINE

Stage 1 Ram enters furnace and gathers 'gobs' of glass.

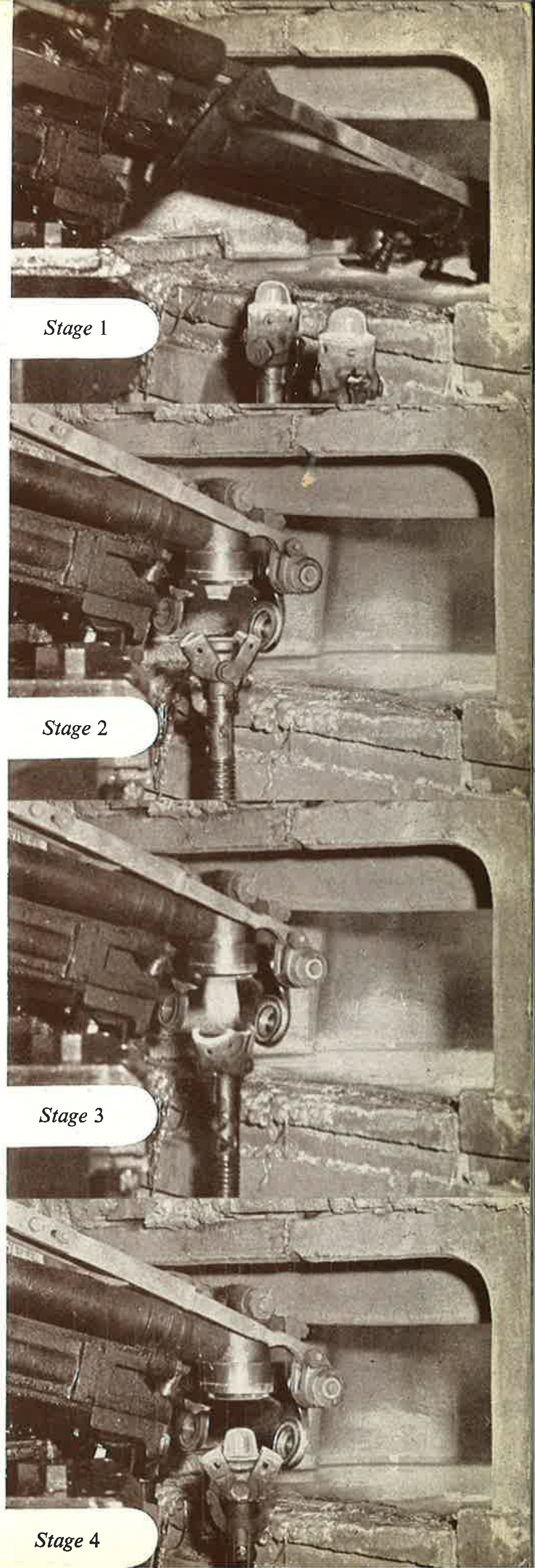
Stage 2 Ram returns, neck moulds drop, ready to release blanks.

Stage 3 Blanks drop into upturned spindles.

Stage 4 Blanks resting on spindles, jaws prepare to close.

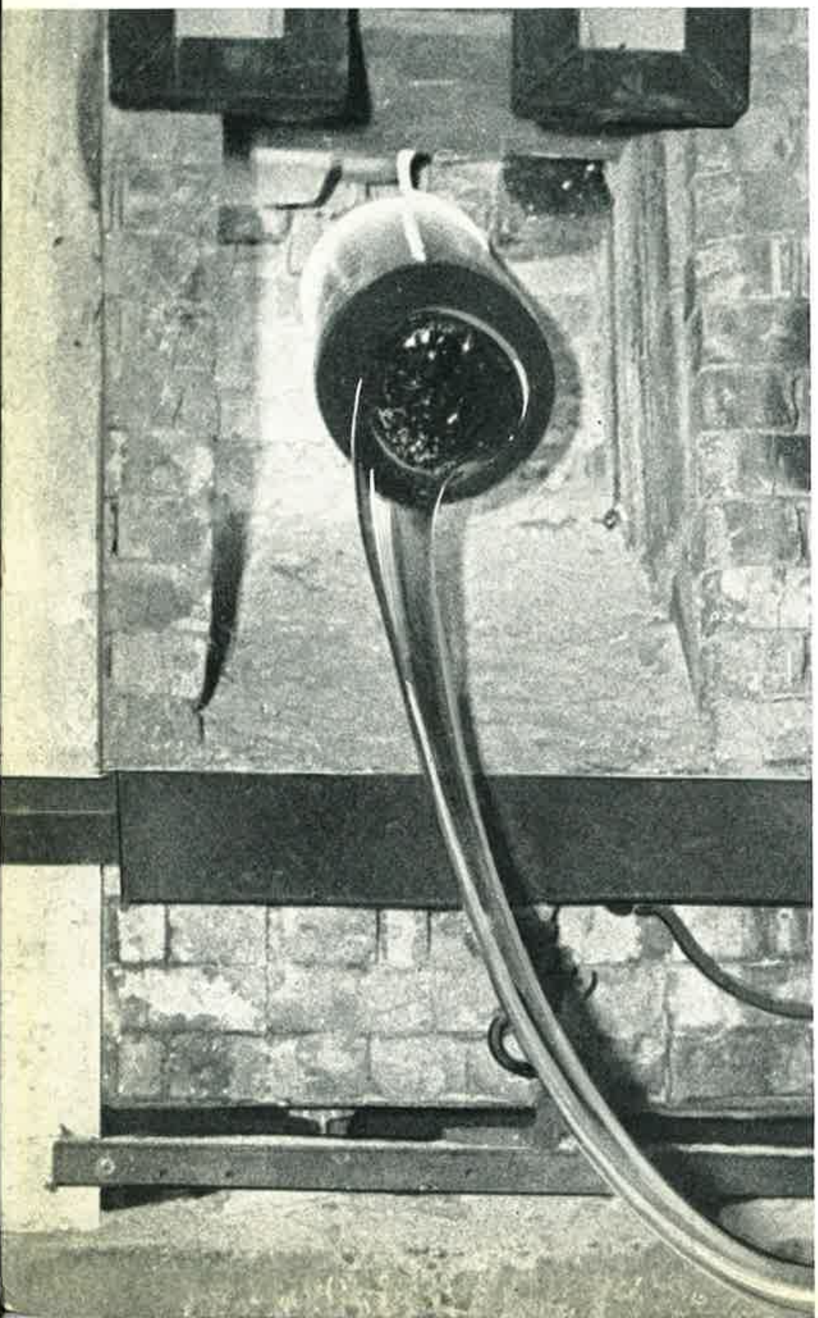
MACHINE-BLOWN BULBS

In the manufacture of bulbs and tubing by machinery, roughly the same temperature interval has to be coped with, and, generally speaking, the first attempts at blowing bulbs by machine copied the hand blower as precisely as possible by mechanical means. The glass is gathered by suction from a pot or tank furnace, and each separate gather is dropped from a 'chuck' on the end of a blowpipe, where it is blown and formed into the finished product by rotating the blowpipe in a finishing mould while applying air pressure to the glass.



MACHINE DRAWN TUBING

In the manufacture of tubing, a ribbon of fluid glass is wrapped around a slowly rotating, hollow refractory cylinder. As the even coating of glass flows off the nose of this cylinder, air blown through forms it into a tube, and a tractor mechanism placed 100 ft. or so away from the nose of the blowpipe draws the tube off continuously along a roller track at speeds varying from 15 to 1,000 feet a minute. The wall thickness and diameter of the tube are controlled by regulating the air pressure, the quantity of glass and the speed of draw. By this method it is possible to draw tubing much more precise dimensionally than when making it by hand, and today nearly all tubing is made by machine. It is probably true to say that the highly-developed automatic machinery now in use for the manufacture of lamps and valves owes its success to the fact that precision limits in respect of the components (tubing and bulbs) have been made possible by the use of bulb blowing and tube drawing machines.



Fluorescent lamp tubing from the Danner machine

The Wembley Tubing Department now produces a range of glass tube compositions covering a very wide field of utility.

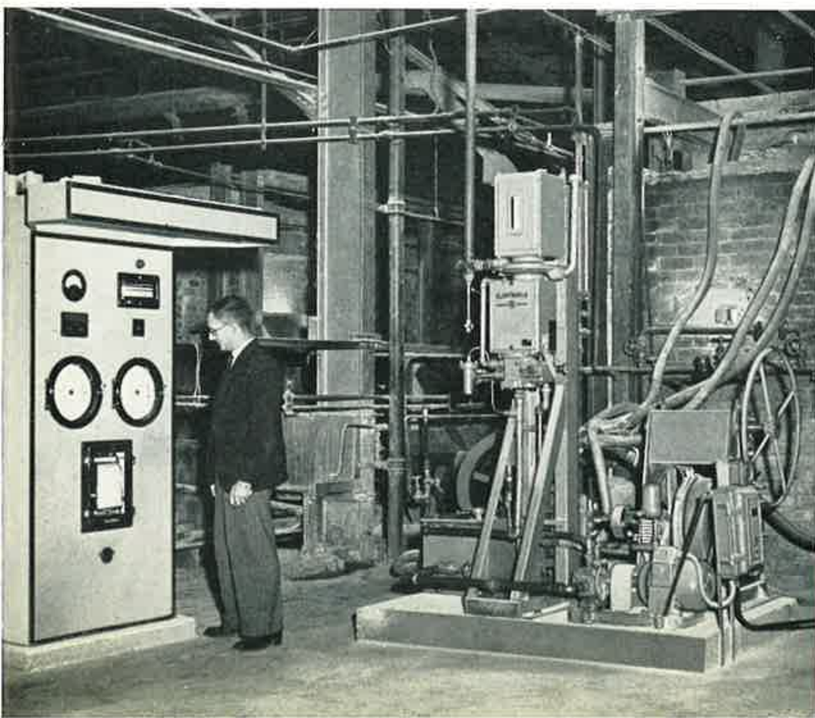
L.1., which contains approximately 30% of lead oxide, is used in the manufacture of lamps, valves and cathode-ray tubes.

X.8. is a soft soda glass used to make chemical apparatus, pill-tubes and vials, hypodermic syringes and a thousand-and-one other requirements.

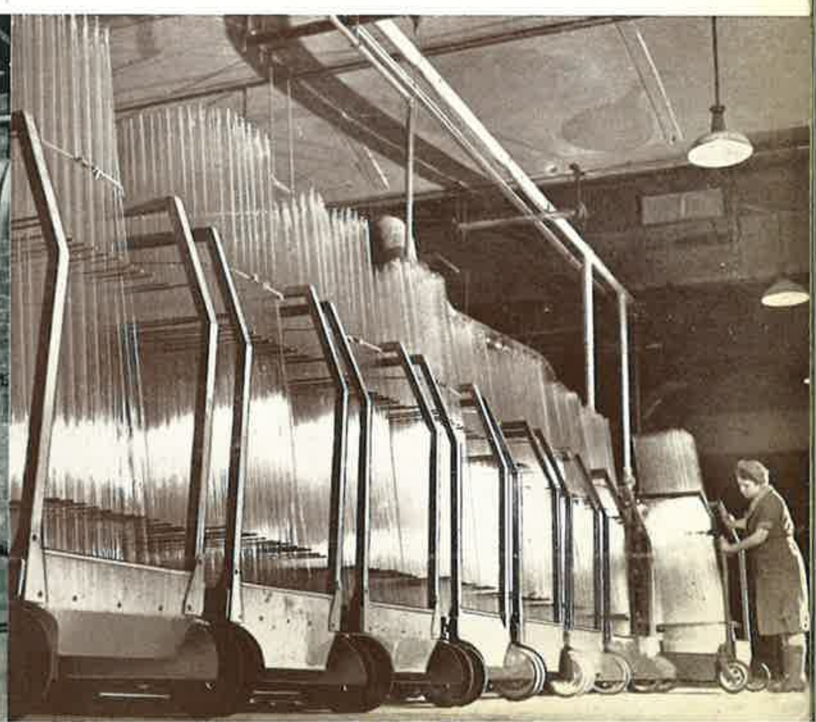
During the past 15 years Wembley 'neutral' tubing has been produced for making ampoules and other containers for biological fluids, such as serums, vaccines, etc., where the glass has to be chemically-resistant to attack. A very large quantity of this tubing is now made and the demand is continually increasing.

An idea of the quantity of tubing of these three kinds may be given by the statement that the present annual output of Wembley, calculated as 10 mm. diameter tubing, amounts to about 32,000 miles, or enough to go one and one-third times round the Globe at the Equator.

Control gear on glass melting furnace



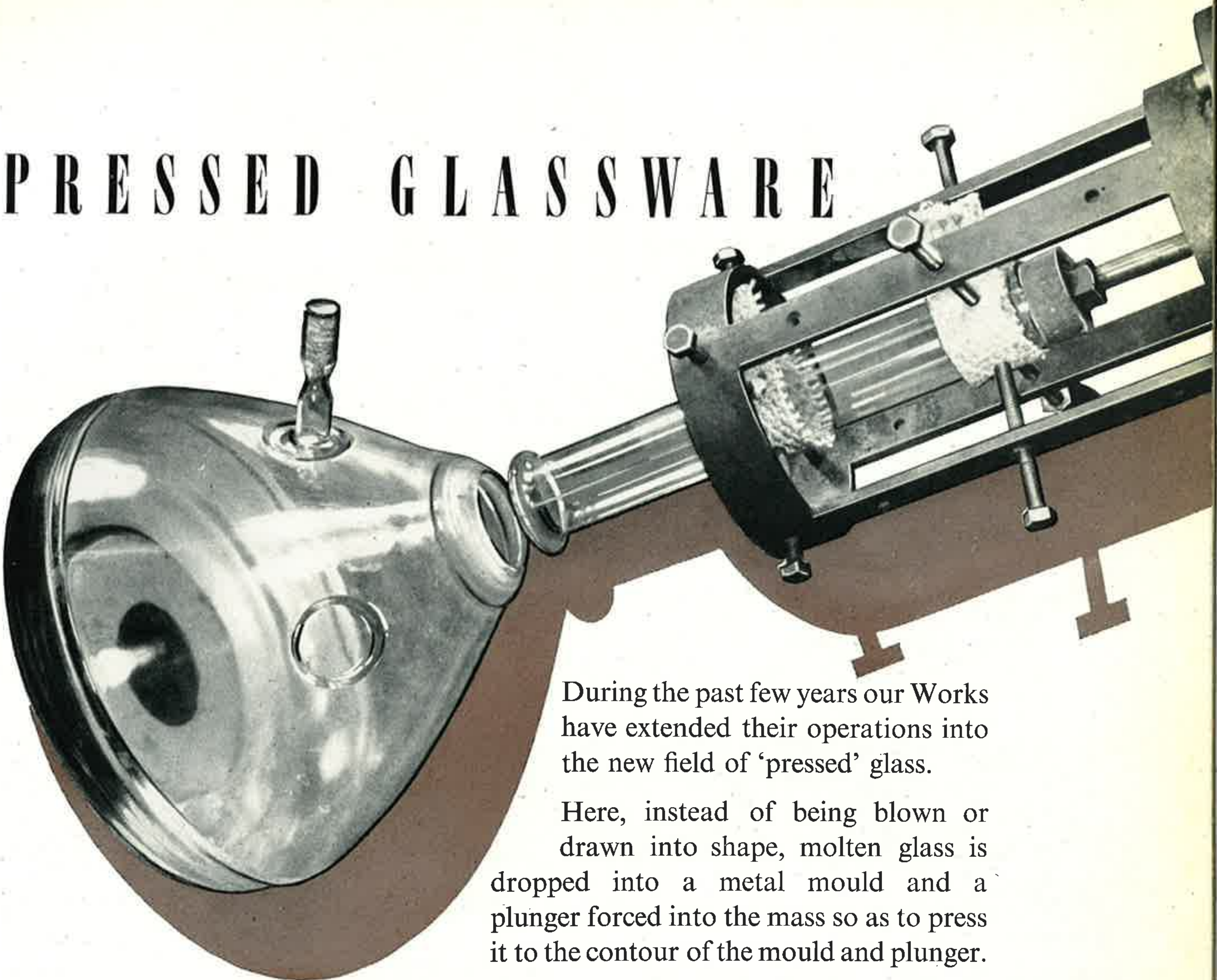
Fluorescent lamp tubing in lamp store



Delivering hard glass to a mould ready for pressing

Removing the pressed glass illuminating refractor from the mould

PRESSED GLASSWARE



During the past few years our Works have extended their operations into the new field of 'pressed' glass.

Here, instead of being blown or drawn into shape, molten glass is dropped into a metal mould and a plunger forced into the mass so as to press it to the contour of the mould and plunger.

By this means many useful and complicated shapes may be made which are impossible by the methods of blowing or drawing. For example, directional lighting fittings, which may have prismatic ridges both on the inside and the outside, are made in this way.

Other pressings of special form are used in the manufacture of valves and certain types of lamps in which the normal forms of seal construction are undesirable.

It is desirable in the large 'Cathode-Ray Tube' now used for television to have very flat fronts or 'screens'. Using pressed components to build up the 'tubes' we are able to meet this need.

Over the whole field, pressings of innumerable shapes and sizes are produced, which may vary in weight from 4 or 5 grams each to as much as 12 or 13 lb. in the case of some of the large lighting refractors.

File cutting of glass tubing for lamp and valve manufacture

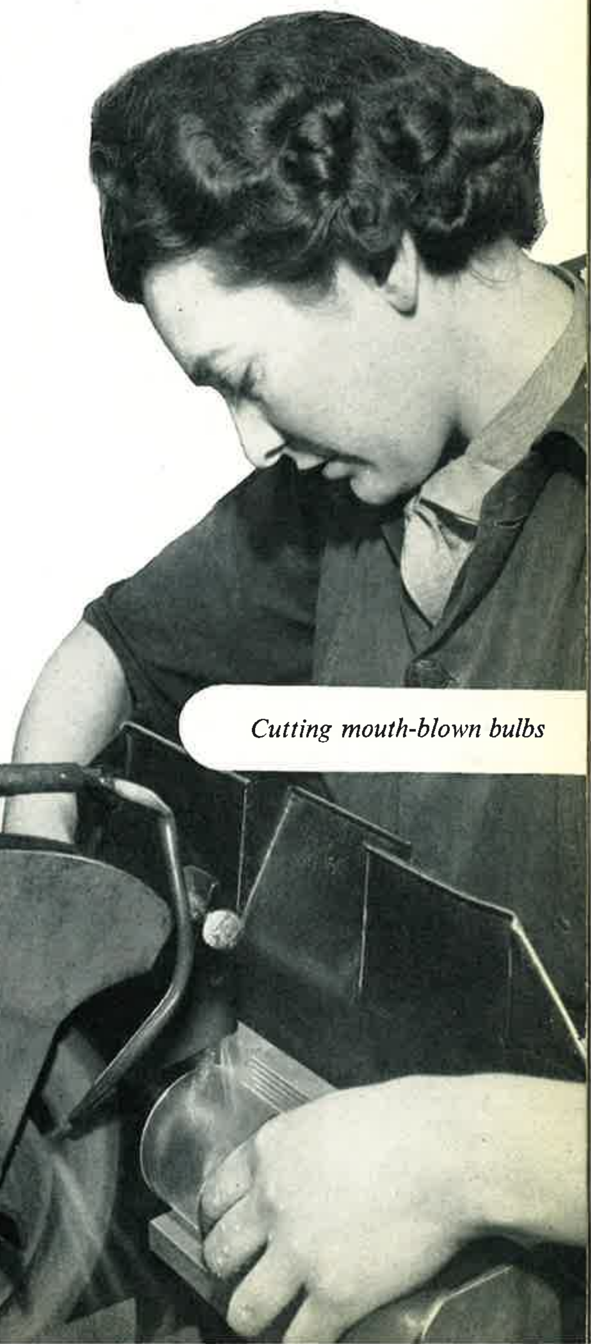
Steel or carborundum wheels are also employed in cutting short lengths of tubing

CUTTING AND FINISHING PROCESSES

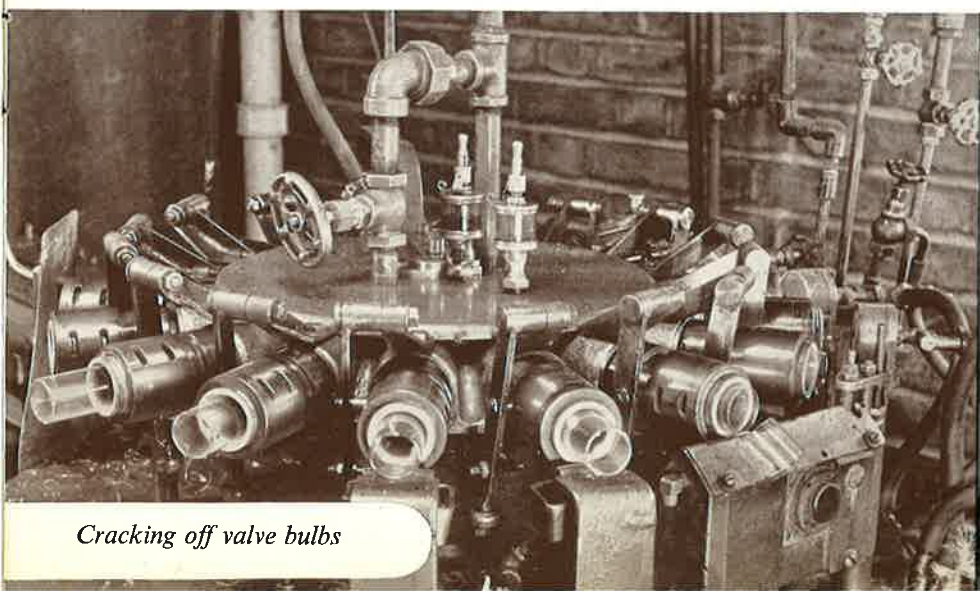
A further service rendered by the Works to its customers is in the supply of partly-finished components to be used in the manufacture of lamps, valves and other articles.

For example, millions of pieces of tubing are cut into precise lengths for the manufacture of fuse tubes and for use as exhaust stems in the manufacture of lamps and valves.

Special finishes are also provided on bulbs in order to assist factories making special types of equipment.



Cutting mouth-blown bulbs



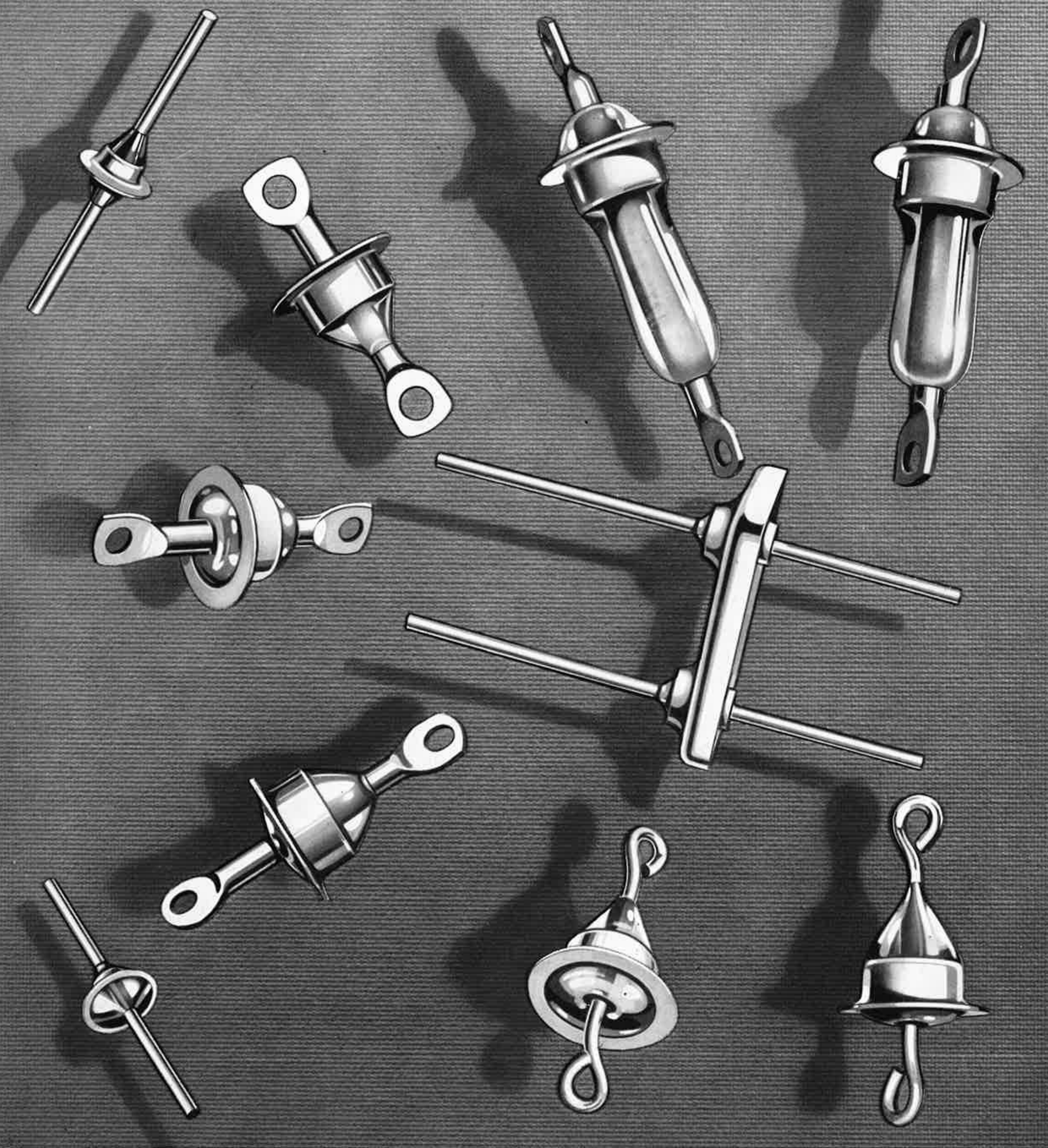
Cracking off valve bulbs

Modern radio valve manufacture involves the use of small tubular glass bulbs. In making these miniature types, tubing is first cut into short lengths, which are then fed through a machine similar to those used for making test-tubes. Each length of tubing is divided to make two bulbs, which are cracked off to the correct length and glazed on an automatic machine. All these operations are carried out in the Tube Finishing Department.

GLASS-TO-METAL SEALS

An increasing demand for vacuum-tight and insulated leads for small electrical assemblies has been met by the production of glass/metal terminal components, now supplied in many patterns to meet customers' requirements. Special glasses are needed to match the metal parts which have to be sealed together, and it is probable that there will be considerable expansion in the use of these components as the requirements of industry develop.

OSRAM - G.E.C.
GLASS-TO-METAL SEALS



CHAPTER 2

GLASSES MANUFACTURED BY THE OSRAM-G.E.C. GLASS WORKS

In the following pages, technical data are given for a number of glasses manufactured by the Osram-G.E.C. Glass Works. In every case they are special-purpose glasses, carefully specified as to composition and physical properties. Control is exercised during manufacture on those physical properties which are most important for the purpose for which the individual glass is to be employed.

Of the glasses listed, some are manufactured at the Company's Wembley Works and others at Lemington-on-Tyne or the Company's Charlton Works. In general, all pot-melted and special glasses are melted at Lemington, manufacture at Wembley being confined to the automatic production of bulbs and tubing from X.8, L.1 and M.6.

Glasses described in the following pages are tabulated below.

OSRAM-G.E.C. GLASSES

WEMBLEY X.8. SODA GLASS

X.8. is a development of former WEMBLEY glasses X.7. and X.4., combining the properties essential to the automatic production of lamp and valve bulbs on Westlake and Ohio Machines and for the automatic production of tubing by the Danner process. It is a soda-lime-silica glass containing magnesia and boric oxide. A typical chemical composition is given below.

Chemical Composition

Silica (SiO_2)	70·12%
Alumina, etc. (Al_2O_3)	2·58%
Lime (CaO)	5·40%
Magnesia (MgO)	3·60%
Sodium Oxide (Na_2O)	16·82%
Potassium Oxide (K_2O)	0·35%
Boric Oxide (B_2O_3)	0·78%
Sulphur Trioxide (SO_3)	0·20%

Linear Coefficient of Thermal Expansion

Thermal expansion of X.8. is controlled between the limits $9{\cdot}65 \pm 0{\cdot}10 \times 10^{-6}$ measured between 20°C. and 350°C. A typical thermal expansion curve is shown in Fig. 1.

Softening Temperature

There are two methods for defining softening temperature. The simplest and the one in widest use is to define it as the highest point reached on the thermal expansion curve.

Softening Temperature (Mg point) = 550° ± 10°C.

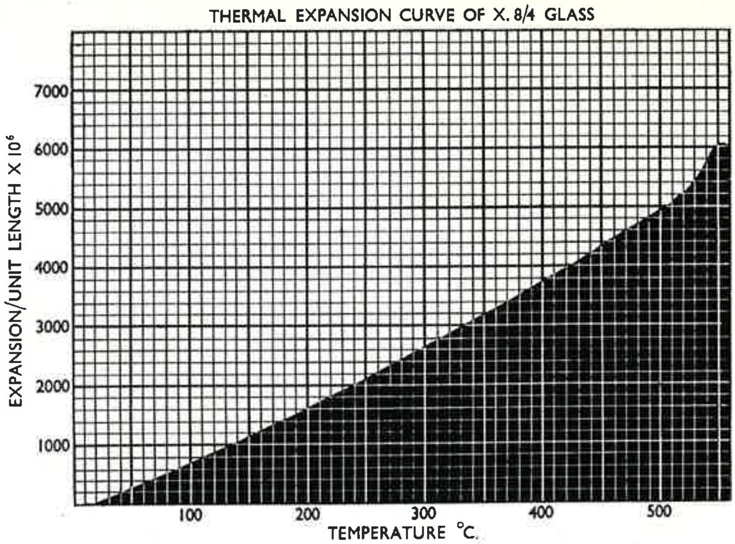
Another method of defining softening temperature depends upon the rate of extension of the fibre under its own weight and corresponds to a viscosity of $10^{7\cdot6}$ poises. On this basis,

Softening Temperature = 690° ± 15°C.

Density

This is not an important property and for all soda glasses in this range will not depart by more than ± 0·005 from the value 2·50.

FIG. 1



Refractive Index

The refractive index is again not important in the production of bulbs and tubing, but for reference purposes will be found to be within the range 1·515 ± 0·005.

Specific Electrical Resistance

For the purpose of comparison with other glasses the following data are quoted:

Log_{10} Sp. Electrical Resistance		
(ohms/cm.^{3}) at	200°C.	6·7
	300°C.	5·3
	500°C.	3·3

Devitrification Temperature

Wembley soda glasses are very stable on 'lamp' working, but devitrification temperature is used as a control in manufacture and is maintained within the limits of 815° to 840°C.

The devitrification temperature so quoted is that at which on prolonged heating the first traces of devitrification products could appear.

Annealing Range

The chapter on annealing should be consulted. In the annealing of articles manufactured from tubing the annealing schedule specified in the appendix should be followed. The annealing range of X.8. glass is from 520° to 400°C.

WEMBLEY L.1. LEAD GLASS

L.1. is a mixed alkali lead oxide-containing glass of excellent electrical insulation and working properties developed primarily for the manufacture of machine-drawn tubing for making pinches and exhaust tubes in lamp and valve manufacture. It is employed also in the form of mouth-blown bulbs as the envelope of many large transmitting valves and for pressings in the production of pressed screens and covers for television tubes. In these latter uses a very high standard of glass quality is required with freedom from all flaws such as stones, blisters and cord. This glass seals directly to platinum and 'copper-clad' wire, giving substantially stress-free seals, and may also be sealed to 50/50 nickel-iron alloy.

Chemical Composition

Silica (SiO_2)	56·0%
Lead Oxide (PbO)	30·0%
Alumina (Al_2O_3)	1·0%
Sodium Oxide (Na_2O)	5·2%
Potassium Oxide (K_2O)	7·5%
Lime (CaO)	0·5%
Magnesia (MgO)	0·3%

Linear Coefficient of Thermal Expansion

The thermal expansion of L.1. is controlled between the limits $9{\cdot}05 \pm 0{\cdot}15 \times 10^{-6}$ measured between 20°C. and 320°C. Fig. 2 shows a specimen thermal expansion curve.

Softening Temperature

As shown on Page 24 the highest point reached on the thermal expansion curve is 470°C. and in general

Softening Temperature (Mg point) = 470° ± 10°C.

When measured by the rate of extension of a fibre under its own weight, corresponding to a viscosity of $10^{7{\cdot}6}$ poises,

Softening Temperature = 610° ± 15°C.

Density

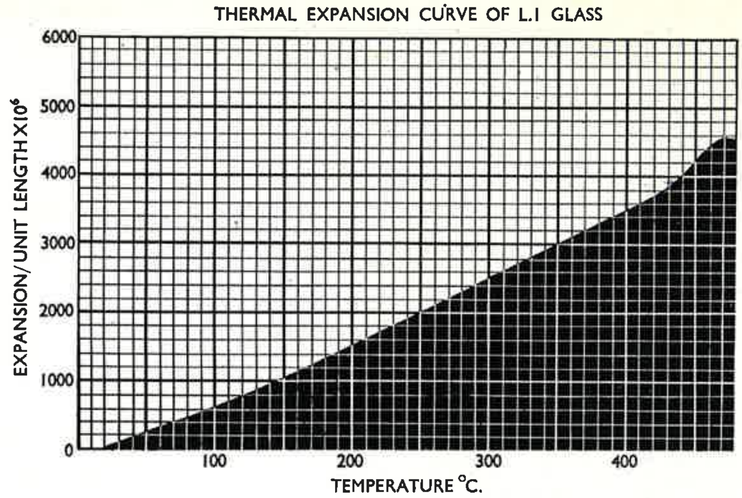
Due to its high lead oxide content L.1. glass is much denser than soda glass and in calculating tonnages from dimensions allowance must be made for this.

Average density of L.1. glass = 3·08.

Refractive Index

This property is closely related to density and is therefore highest for lead glasses. The refractive index of L.1. glass lies within the range 1·565 ± 0.005.

FIG. 2



Specific Electrical Resistance

At room temperatures, and at normal lamp operating temperatures, the electrical resistance of L.1. glass is approximately one million times greater than that of soda glass so that its value as a medium for sealing electrical conductors, as in a lamp or valve pinch, is at once apparent. Typical values are given below.

Log$_{10}$ Sp. Electrical Resistance (ohms/cm.^{3}) at		
	150°C.	12·0
	200°C.	10·8
	300°C.	8·6
	500°C.	5·1

Devitrification Temperature

It is extremely difficult to cause L.1. glass to devitrify and therefore no reliable figure can be quoted. Tests carried out in the devitrification range for more than 100 hours fail to show any signs of crystallization. It is inherently a very stable glass, although prolonged heating at high temperatures above 1,000°C. may cause sufficient volatilization of alkali from the surface for silica to crystallize out but this is not true devitrification.

Annealing Range

The chapter on annealing should be consulted. The annealing range of L.1. glass is from 430°C. to 340°C. In annealing articles made from tubing the annealing schedule specified in the appendix should be followed. The lower thermal expansion of L.1. glass compared with soda will normally balance its greater density so that no significant difference occurs in the maximum permissible heating and cooling rates to avoid fracture.

WEMBLEY M.6. 'WHITE NEUTRAL' GLASS

M.6. is a chemically neutral glass made as machine-drawn tubing. It is largely employed in the manufacture of medical ampoules and fulfils all the requirements of British Standard Specification No. 795 for neutrality. It is intermediate in thermal expansion between the 'soft' glasses, soda and lead (X.8. and L.1.), and the 'hard' glasses (W.1., H.H. and H.26X.), and is in fact sometimes employed in the making of 'graded seals'.

The demand for M.6., formerly a pot-melted glass, is now such that it is made in a continuous melting tank, the first such tank for the manufacture of tubing by the Danner process to be put into operation in this country.

Chemical Composition

A typical composition is:

Silica (SiO_2)	67·0%
Boric Oxide (B_2O_3)	7·5%
Alumina (Al_2O_3)	8·5%
Lime (CaO)	4·0%
Magnesia (MgO)	0·3%
Potash (K_2O)	4·0%
Soda (Na_2O)	8·7%

Neutrality

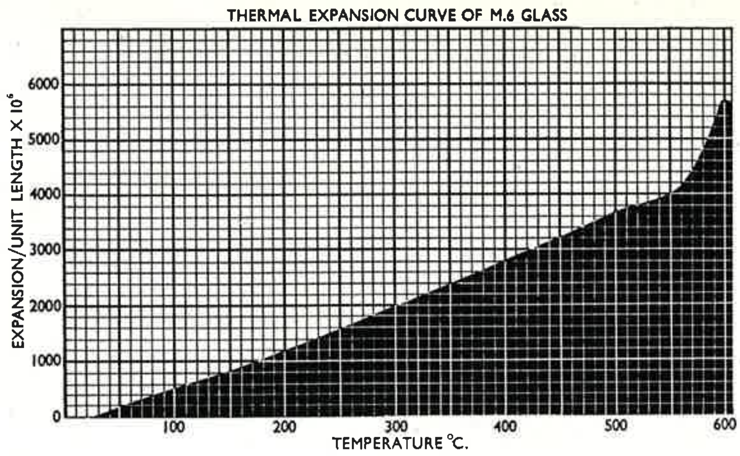
M.6. is carefully controlled to preserve its chemical neutrality and daily checks are carried out to ensure compliance with the specification. The requirements of the test are:

Fill the ampoules to their prescribed capacity with *acid solution of methyl red, seal by means of a blowpipe, and heat in steam at a pressure of 15 lb. per square inch for half an hour. Cool and examine the colour of the solution. The Glass passes the test if the colour of the test solution has not changed from pink to the full yellow colour of methyl red.

Users sometimes report ampoules failing to pass the neutrality test, and this usually occurs after storage in unsuitable conditions. Attention is drawn to the extract from the specification quoted overleaf.

*Acid solution of Methyl Red: Mix 20 millilitres of strong solution of methyl red (·04% methyl red in 75% alcohol; pH = 5·2) with 8·3 millilitres of N/50 hydrochloric acid and a sufficient quanitity of distilled water to produce 1,000 millilitres

FIG. 3



(*Extract from the B.S. No. 795*)

'Ampoules which have once passed the test on whole ampoules may fail to do so after being stored. Whenever possible, the test is carried out not more than fourteen days before the ampoules are to be used. If a batch of ampoules which has passed the test but has been stored does not subsequently pass the test, a sample of them *may* be re-submitted to the test after each ampoule has been washed internally with a 5% v/v aqueous solution of glacial acetic acid, followed by three washings with water. If the sample then passes the test, each ampoule of the batch is similarly washed before being used.'

Linear Coefficient of Thermal Expansion

Control of M.6. composition is effected on the basis of the neutrality test. Although not specifically controlled for other properties this results indirectly in controlling all other properties. The thermal expansion is within the range $7{\cdot}3 \pm 0{\cdot}2 \times 10^{-6}$ measured between 20°C. and 350°C.

Softening Temperature

As measured by the highest point reached on the expansion curve this is 600° ± 10°C.

Devitrification Temperature

A control exercised in the manufacture of M.6. tubing is the determination of devitrification temperature on account of the higher temperatures at which tube drawing takes place. In lamp working on the bench or in automatic ampoule making machines the glass is very stable and no devitrification should ever be encountered. Variation in devitrification temperature is employed simply as a sensitive control of composition, the control limits being 860° to 880°C.

Annealing Range

The chapter on annealing should be consulted. The annealing range of M.6. glass is between 580°C. and 450°C. Articles of white neutral glass are invariably manufactured from tubing and the annealing schedule shown in the appendix should be followed.

WEMBLEY 'AMBER NEUTRAL' GLASS

For all practical purposes amber neutral may be considered identical with white neutral in so far as working properties are concerned. It is made for the same purposes but more especially where the contents of ampoules require protection from decomposition by ultra-violet radiation. It is an iron-manganese amber with the following typical composition:

Chemical Composition

Silica (SiO_2)	64·1%
Alumina (Al_2O_3)	7·1%
Iron Oxide (Fe_2O_3)	4·1%
Manganese Oxide (MnO)	1·4%
Lime (CaO)	6·8%
Magnesia (MgO)	0·1%
Soda (Na_2O)	6·3%
Potash (K_2O)	3·0%
Boric Oxide (B_2O_3)	7·1%

Neutrality

See Wembley M6 'white neutral' glass.

Linear Coefficient of Thermal Expansion

Due to additions of iron and manganese this is slightly higher than that of white neutral glass and amounts to $7{\cdot}5 \pm 0{\cdot}2 \times 10^{-6}$ measured between 20°C. and 350°C.

Softening Temperature

Amber neutral is very slightly softer than white neutral and the highest point reached on the expansion curve is 580° ± 10°C.

Devitrification Temperature

See Wembley M6 'white neutral' glass.

Annealing Range

The upper annealing temperature remains as for white neutral but being slightly softer the complete annealing range lies between 580°C. and 400°C. See the appendix for annealing schedules.

Examples of mouth-blown soda glass lamp and valve bulbs

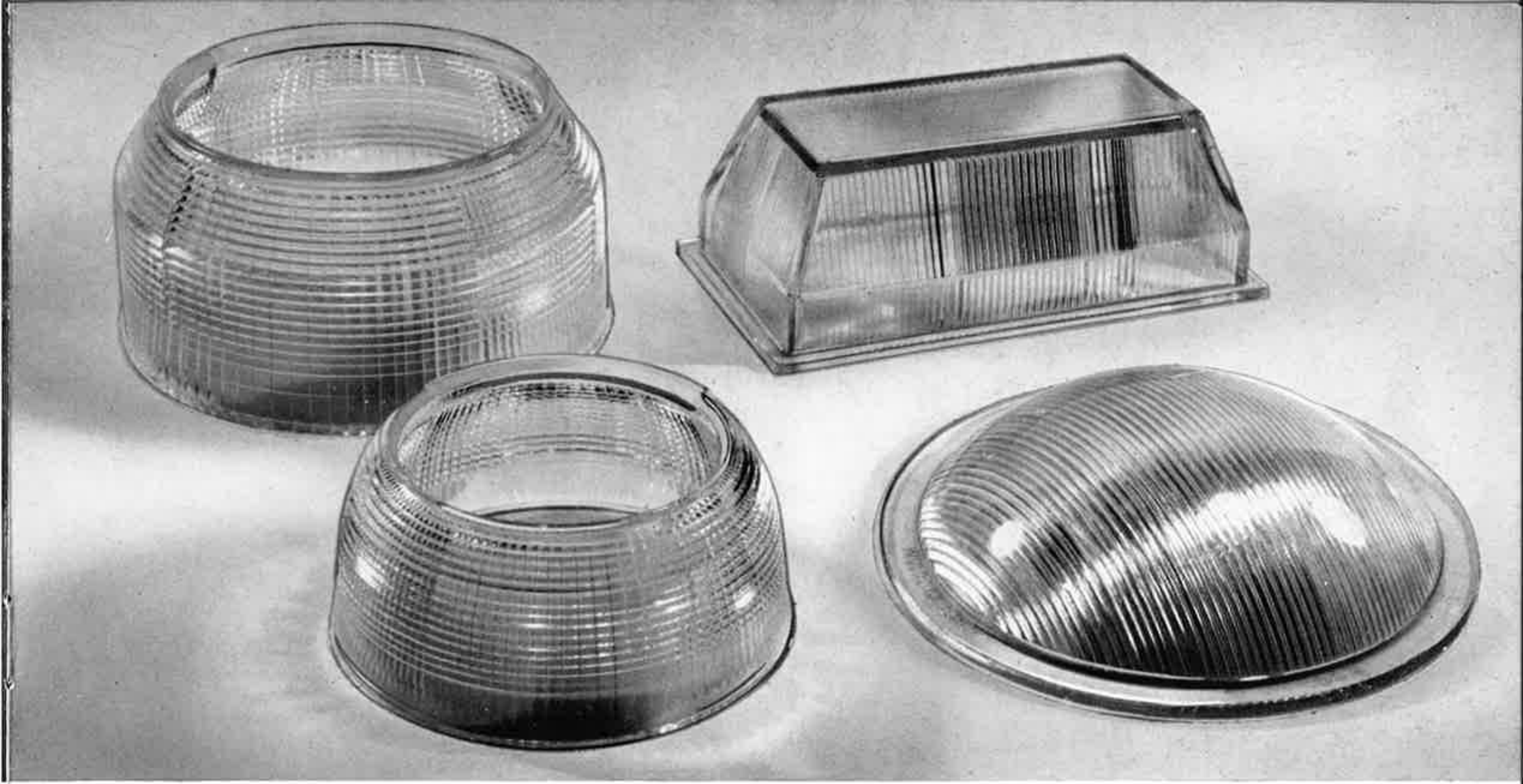
OSRAM - G.E.C. SODA GLASS LEMINGTON B.8.

B.8. glass is a pot-melted soda-lime-silica glass with similar properties to X.8. It is necessitated by a demand for small numbers of special shaped bulbs which, either on account of the small number required or because of their size, cannot be blown by automatic machines and are, therefore, still mouth-blown at the Company's Lemington factory.

Although the chemical composition differs slightly from that of X.8., due to the conditions imposed by pot-melting, for all practical purposes its physical properties may be taken as identical with those of X.8. set out in the previous pages.

Chemical Composition

Silica (SiO_2)	70·0%
Alumina (Al_2O_3)	2·0%
Lime (CaO)	4·75%
Magnesia (MgO)	3·5%
Barium Oxide (BaO)	1·0%
Sodium Oxide (Na_2O)	16·5%
Potassium Oxide (K_2O)	1·0%
Boric Oxide (B_2O_3)	0·50%
Antimony Oxide (Sb_2O_3)	0·75%



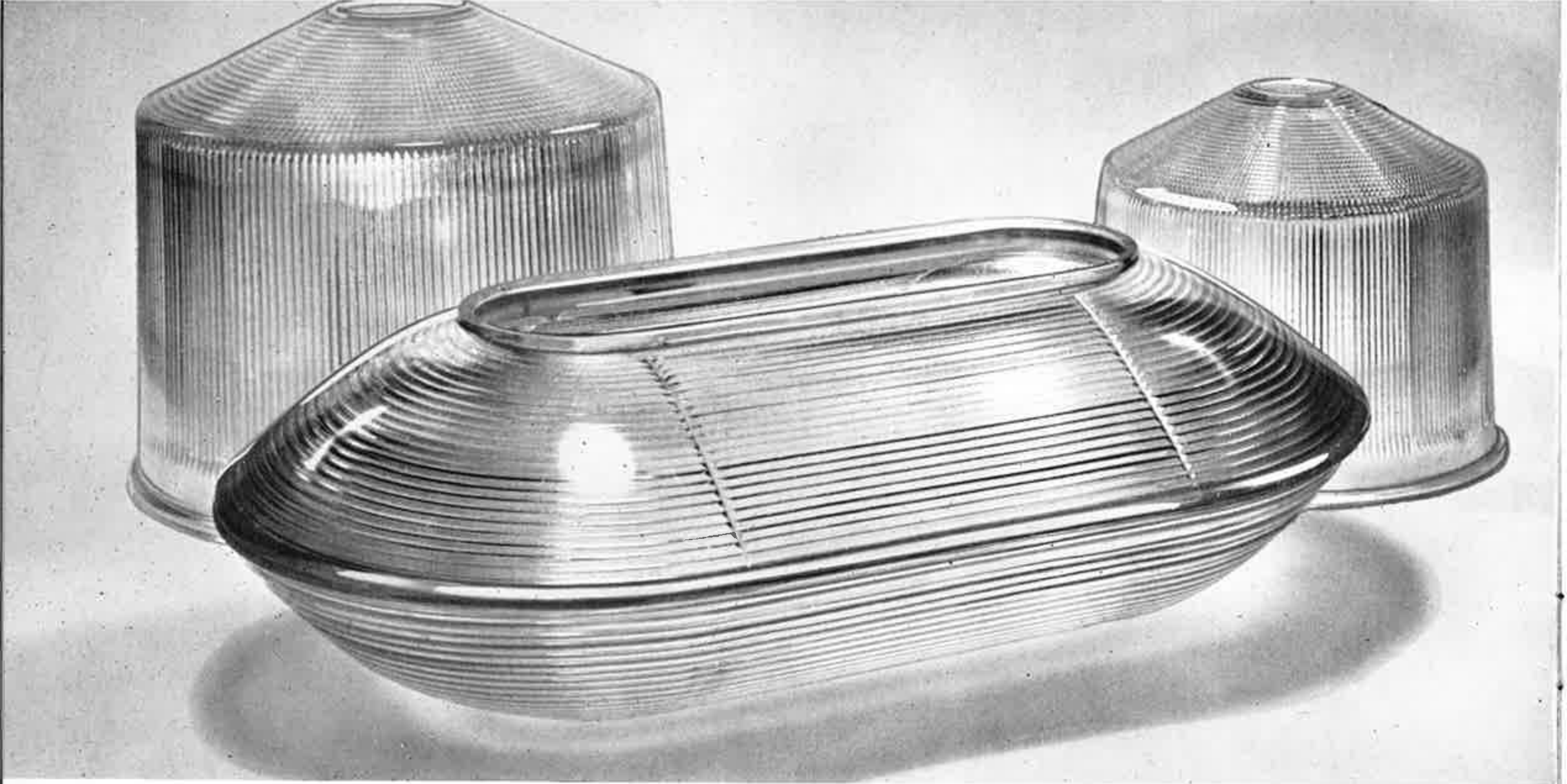
Illuminating refractors pressed from soda glass

LEMINGTON X.9M. GLASS

A range of street lighting refractors which do not have to withstand such difficult conditions as those described under HR.9. is required and also a range of domestic lighting ware and other products. These are made in X.9M. glass, which is a pot-melted soda-lime-silica glass of good colour. This latter property, namely, appearance, is its main requirement and no limiting conditions of physical properties are imposed. However, the same care is taken to maintain constancy of chemical composition in order to preserve the good colour. A range of ware made in this glass is shown in the photograph above.

Chemical Composition

Silica (SiO_2)	70·0%
Alumina (Al_2O_3)	0·5%
Lime (CaO)	8·75%
Magnesia (MgO)	0·5%
Sodium Oxide (Na_2O)	17·75%
Boric Oxide (B_2O_3)	2·0%



Examples of pressed hard glass street lighting refractors

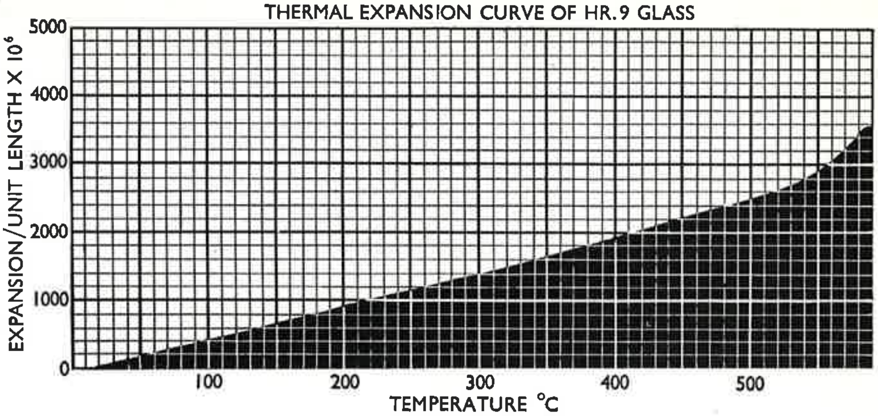
LEMINGTON H.R.9. GLASS

A glass of the heat-resisting type though not of such low thermal expansion as W.1. or H.H. is H.R.9. This is a pot-melted borosilicate glass not required to seal specifically to any particular metal, but made expressly for the manufacture of pressed street-lighting refractors of the type shown in the accompanying photographs. The essential requirement, therefore, is that pressings made from it must be able to withstand in service all climatic conditions likely to be encountered.

Chemical Composition

Silica (SiO_2)	68·5%
Lead Oxide (PbO)	6·0%
Alumina (Al_2O_3)	2·5%
Lime (CaO)	0·75%
Magnesia (MgO)	0·25%
Barium Oxide (BaO)	1·0%
Sodium Oxide (Na_2O)	7·5%
Boric Oxide (B_2O_3)	13·5%

FIG. 4



Thermal Expansion

To ensure adequate resistance to thermal shock this property is controlled between the limits $5{\cdot}15 \pm 0{\cdot}15 \times 10^{-6}$ measured between 20°C. and 350°C.

Resistance to Thermal Shock

Water spray testing of street lighting illumination units

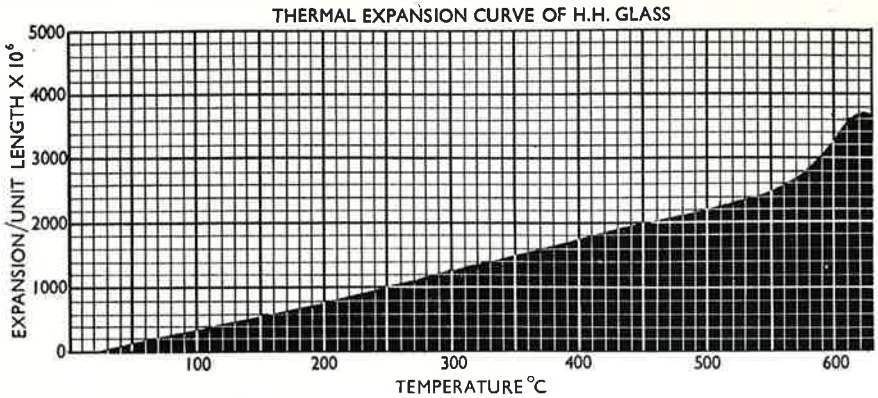
This property is tested practically in the following manner by an artificial rain splash test. The test consists of directing a spray of water in droplets equivalent to 8 in. of rainfall per hour on to the lantern heated by a light source at an overload corresponding to an increase of supply voltage of 6%. In carrying out the test the lighting unit is first allowed to burn for one hour under steady conditions, sprayed without switching off, allowed to burn for another hour, and finally sprayed again. The refractors must not crack under the conditions of this arduous test.

With large street lighting refractors a 100% testing schedule is undertaken which is equivalent to a tropical rain storm with the lighting unit operating in the overloaded condition.

In this way the satisfactory performance of the unit in service is guaranteed as far as it is humanly possible to do so.

FIG. 5

THERMAL EXPANSION CURVE OF H.H. GLASS



LEMINGTON H.H. GLASS

Chronologically H.H. was the first of the hard glasses made specifically for sealing to molybdenum. In recent years its applications have been largely transferred to W.1. and tungsten seals, but some cases still remain for which H.H. is technically desirable either on account of the molybdenum seals or on account of the slightly greater hardness (25°C. or so) which H.H. has over W.1. It is correctly described as a borosilicate heat resisting glass and apart from sealing to molybdenum finds its chief applications as lamp envelopes for high temperature service.

Chemical Composition

Silica (SiO_2)	72·0%
Alumina (Al_2O_3)	4·0%
Lime (CaO)	3·0%
Magnesia (MgO)	0·5%
Boric Oxide (B_2O_3)	13·0%
Sodium Oxide (Na_2O) . . .	3·5%
Potassium Oxide (K_2O) . . .	4·0%

Linear Coefficient of Thermal Expansion

Being intended for sealing to the metal molybdenum, this property is controlled within the limits $4{\cdot}7 \pm 0{\cdot}10 \times 10^{-6}$ measured between 20°C. and 450°C. It will be noted that this value is slightly higher than the thermal expansion of H.26X. glass ($4{\cdot}6 \pm 0{\cdot}10 \times 10^{-6}$) similarly intended for sealing to molybdenum. This difference arises due to the difference in softening points of the two glasses, namely, 780°C. for H.26X. and 625°C. for H.H.

Softening Temperature

For the highest point reached on the thermal expansion curve,

Softening Temperature (Mg point) = 625° ± 10°C.

Measured by the rate of extension of a fibre under its own weight,

Softening Temperature = 780° ± 15°C.

Density

As with other borosilicate glasses this is not an important property but will be found to lie within the range 2·33 ± 0·005.

Specific Electrical Resistance

In electrical resistance H.H. is intermediate between W.1. and H.26X., being slightly superior to W.1. although practically there is little significant difference above 200°C.

Log$_{10}$ Sp. Electrical Resistance		
(ohms/cm.^{3}) at	150°C.	11·7
	200°C.	10·3
	300°C.	8·3
	500°C.	5·9

Annealing Range

The chapter on annealing should be consulted. The annealing range is from 590°C. to 500°C., and for articles made from tubing the schedules in the appendix should be followed.

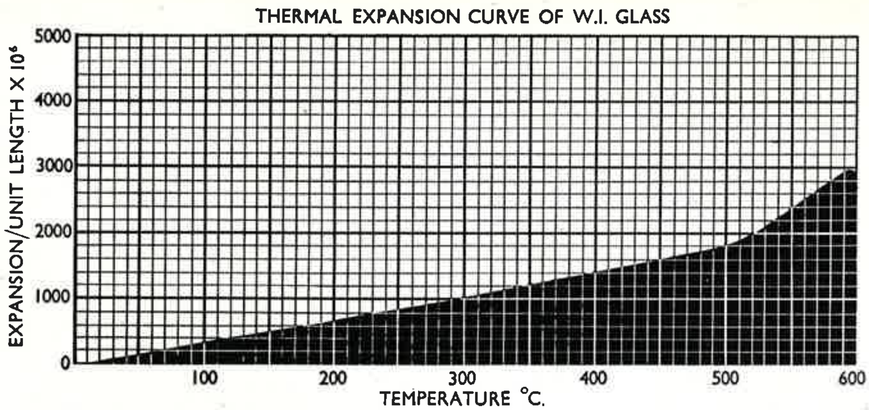
LEMINGTON W.1. GLASS

W.1. is a hard borosilicate glass developed in the first place to make strain-free seals with tungsten metal. Its mechanical and thermal properties are such, however, as to make it a very satisfactory medium for the envelopes of high-wattage lamps of the projector type which have to withstand high operating temperatures. At the present time all W.1. bulbs are mouth-blown and the tubing is hand-drawn. A variety of pressings are made which have to be resistant to thermal shock.

Chemical Composition

Silica (SiO_2)	75·5%
Alumina (Al_2O_3)	2·2%
Boric Oxide (B_2O_3)	16·3%
Sodium Oxide (Na_2O)	4·0%
Potassium Oxide (K_2O)	2·0%

FIG. 6



Linear Coefficient of Thermal Expansion

As with all special glasses for sealing to metals the thermal expansion is the important control exercised in manufacture to preserve the ability to give strain-free seals, and in this case also the resistance to thermal shock. The control limits are $3{\cdot}75 \pm 0{\cdot}1 \times 10^{-6}$, measured between 20°C. and 350°C.

Softening Temperature

As shown on the thermal expansion curve, the highest point reached on the curve is 600°C. and the softening temperature (Mg point) determined by this method lies in the range 600° ± 10°C.

By the extension of a fibre under its own weight, that is for a viscosity of $10^{7{\cdot}6}$ poises,

Softening Temperature = 760° ± 15°C.

Density

In common with most glasses containing high proportions of boric oxide, W.1. is appreciably lighter than soda glass, its density being 2·25 ± 0·005.

Refractive Index

In keeping with its lower density the refractive index is also reduced by comparison with soda glasses and has the value 1·478 ± 0·005.

Specific Electrical Resistance

W.1. is not quite so good electrically as L.1., but is a considerably better insulator than ordinary soda glass. At maximum operating temperatures of 400°C.—450°C. however, it approaches L.1. in electrical resistance with the advantage that it does not soften at these temperatures as would L.1. glass. Values are as follows:

Log_{10} Sp. Electrical Resistance		
($ohms/cm.^3$) at	200°C.	9·9
	300°C.	8·0
	500°C.	5·6

Annealing Range

The chapter on annealing should be consulted. The annealing range is from 570°C. to 450°C. Due to its lower thermal expansion, approximately one third that of soda glass, once the lower annealing temperature has been reached the glass may be cooled down to room temperature much more rapidly without risk of fracture.

LEMINGTON H.26X.

The hardest of the borosilicate glasses is H.26X., an alkali-free glass of high softening point made in the form of mouth-blown bulbs and hand-drawn tubing for the manufacture of High-pressure Mercury Vapour Lamps. For this purpose it is essential that the glass seals to molybdenum and should have high electrical and thermal shock resistance.

Chemical Composition

The nominal composition of this glass is as follows. It will be noted that the glass contains no alkali, and further the iron oxide content is maintained at a very low value so as not to impair the Ultra-violet transmission properties of the glass.

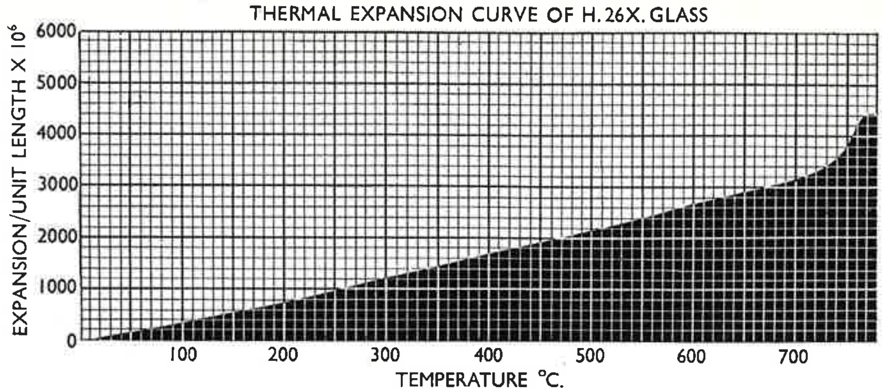
To do this with a glass melted at 1570°C. necessitates the use of the purest batch ingredients, and tank blocks highly resistant to the corrosive action of the glass.

Silica (SiO_2)	54·25%
Alumina (Al_2O_3)	22·0%
Boric Oxide (B_2O_3)	7·5%
Calcium Oxide (CaO)	13·25%
Barium Oxide (BaO)	3·0%
Sodium Oxide (Na_2O)	Nil
Potassium Oxide (K_2O)	Nil

Linear Coefficient of Thermal Expansion

In order to make a satisfactory seal to molybdenum this property is controlled between the limits $4{\cdot}6 \pm 0{\cdot}1 \times 10^{-6}$ measured between 20°C. and 580°C. A typical expansion curve is shown in Fig. 7.

FIG. 7



Softening Temperature

Measured by the highest point reached on the thermal expansion curve:

Softening Temperature (Mg point) = 780° ± 10°C.

Measured by the rate of extension of a fibre under its own weight equal to a viscosity of $10^{7\cdot6}$ poises,

Softening Temperature = 930° ± 15°C.

Density

As with other borosilicate glasses the density is low, being 2·30 ± 0·005.

Refractive Index

Due to the barium oxide content this property has a slightly higher value than for ordinary soda glass, being 1·535 ± 0·005.

Specific Resistance

H.26X. has the highest electrical resistance of all the glasses, so high in fact that it is not easily measured below 300°C. The following values may be quoted:

Log_{10} Sp. Electrical Resistance.		
(ohms/$cm.^3$) at	300°C.	11·4
	500°C.	8·8

Annealing Range

The chapter on annealing should be consulted. The annealing range of H.26X. is from 725°C. to 600°C. On account of the high temperatures involved in annealing this glass, which are in excess of any temperatures reached in available continuous lehrs, articles of H.26X. glass are customarily kiln or box annealed when the schedule in the appendix should be followed.

SODIUM RESISTANT GLASS NA.10.

Na.10. is a sodium resistant glass which is melted in platinum pots to give a glass resistant to sodium metal vapour and free from all impurities. These requirements can only be met by a composition consisting essentially of soda, alumina and boric oxide melted from the purest available material and free from any contamination of the containing vessel. Owing to the very high boric oxide content the melting temperature is comparatively low (1250°C.) and it is possible to melt the glass on a commercial scale in platinum pots each holding about 75 lb. of glass.

Na.10. is employed only in the form of an internal flashing in soda glass X.8. tubing, this tubing then being made up into sodium vapour discharge lamps.

A high degree of purity is essential to prevent blackening of the glass under operating conditions due to the action of the sodium metal vapour with which it is in contact.

Chemical Composition

Silica (SiO_2)	8·0%
Alumina (Al_2O_3)	24·0%
Lime (CaO)	6·0%
Sodium Oxide (Na_2O)	14·0%
Boric Oxide (B_2O_3)	48·0%
Iron Oxide (Fe_2O_3) . . . less than	0·01%

Thermal Expansion and Strain

With such a soft glass, thermal expansion measurements cease to be of value in determining the suitability of the glass for sealing to the base glass X.8. The glass is, therefore, normally controlled by measurement of the degree of strain in the inner layer of Na.10. in the composite tube. The inner layer of sodium resistant glass of the annealed tube should preferably be in slight compression and the maximum permissible stresses allowed are controlled within the following limits measured by the retardation of polarized light through a cross section of the tube:

Maximum permissible stress, from 10 mμ/mm. tension to 130 mμ/mm. compression.

Thickness of the Na.10. layer

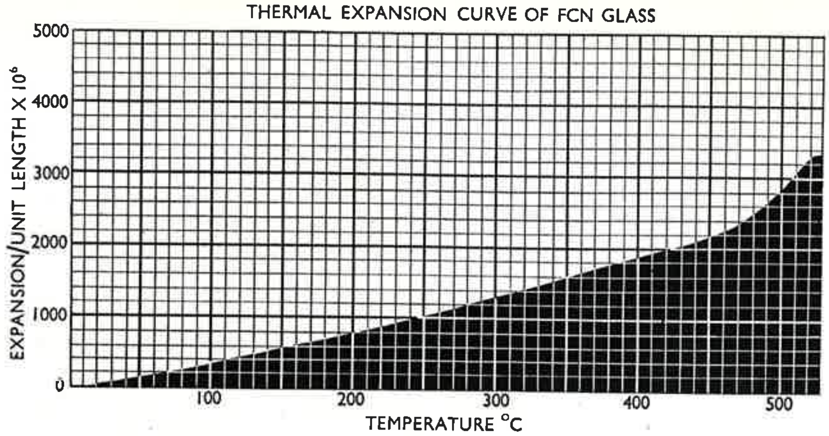
For satisfactory performance of the composite tube it is apparent that the sodium resistant layer must be sufficiently thick to give adequate protection from the sodium metal vapour to the base X.8. glass, but not so thick as to set up high stresses at the X.8./Na.10. boundary. The thickness of the flashed inner layer is therefore controlled between the limits 0·025 to 0·075 mm.

The above tests are carried out immediately after manufacture of every pot of Na.10. glass.

Electrical Resistance

High electrical resistance and high resistance to the action of sodium metal vapour cannot be obtained at the same time. The specific electrical resistance of Na.10. is low and therefore any electrical conductors requiring to be sealed into the X.8./Na.10. tube must first be sheathed with a glass of satisfactory electrical resistance.

FIG. 8



LEMINGTON FCN. GLASS

One of the range of special glasses is FCN, which is a high borosilicate glass made specifically to seal to iron-nickel-cobalt alloys such as those sold under the trade names of Fernico, Kovar and Nicosil. It is employed chiefly in the production of glass-to-metal terminals, the manufacture of which is undertaken at the Company's Lemington Works, in the production of valve parts and in the manufacture of high-wattage tungsten filament 'bipost' lamps. It is a pot-melted glass which requires carefully controlled melting conditions for its successful production and is manufactured in the form of mouth-blown bulbs, hand-drawn tubing and pressings.

Chemical Composition

Silica (SiO_2)	66·0%
Alumina (Al_2O_3)	2·0%
Lime (CaO)	0·5%
Sodium Oxide (Na_2O)	4·0%
Potassium Oxide (K_2O)	3·5%
Boric Oxide (B_2O_3)	24·0%

Linear Coefficient of Thermal Expansion

This property is controlled within the limits $4{\cdot}75 \pm 0{\cdot}15 \times 10^{-6}$ measured between the range 20°C. and 350°C. A typical thermal expansion curve is shown in Fig. 8.

Softening Temperature

Measured by the highest point reached on the thermal expansion curve,

Softening Temperature (Mg point) = 575° ± 10°C.

It will be noted that although of much higher boric oxide content than any of the other borosilicate glasses its softening point is much lower and comparable with ordinary soda glass. This is typical of all such glasses containing very high proportions of boric oxide.

GRADED SEAL GLASSES

In scientific apparatus and many technical applications it is often necessary to make a seal between soft and hard glass, or even between soft glass and fused silica. Such a seal cannot be made directly due to the great difference which exists in the thermal expansion coefficients. To surmount this difficulty what is known as a 'graded seal' is made.

Thus, starting with soft soda-glass, this is first sealed to a glass of slightly lower expansion using as little of the second glass as possible, the combination is then joined to a third glass of slightly lower expansion than the second, the procedure being repeated with glasses of successively lower thermal expansion, often as many as ten intermediate sealing glasses being required before the final seal is made to fused quartz.

In this way, for example, a soft soda tube is joined to a fused silica tube by a reasonably stress-free seal, the stresses in the seal being uniformly distributed from end to end so that nowhere do they reach such a magnitude as to cause mechanical failure of the seal.

The complete range of intermediate sealing glasses made by the OSRAM-G.E.C. Glass Works is given in the Table below, together with their thermal expansion coefficients and softening temperatures.

Sealing Glass Type	*Coefficient of Linear Thermal Expansion*	*Softening Temperature 'Mg' point*
	Sealing Glasses for joining silica to hard glass.	
WQ.31	$1{\cdot}0 \times 10^{-6}$	750°C.
WQ.34	2·1 ,,	700°C.
H.428	3·2 ,,	840°C.
	Sealing Glasses for joining hard to soft glass.	
G.S.1	$5{\cdot}2 \times 10^{-6}$	625°C.
G.S.2	5·8 ,,	625°C.
G.S.3	6·6 ,,	620°C.
G.S.4	7·2 ,,	625°C.
G.S.5	7·8 ,,	560°C.
G.S.6	8·4 ,,	515°C.

The above glasses are naturally expensive to produce since all have to be specially melted and the compositions carefully controlled, and comparatively small quantities are required. However, the small amount of each glass used in making a graded seal forms only a small proportion of the cost of making the seal.

OPAL AND COLOURED GLASS

In addition to the normal range of colourless glasses a wide range of opal and coloured glasses is manufactured for the production of illuminating ware and special applications such as coloured lamps for dark room illumination, signalling and indicator lamps. They may be produced in the form of blown bulbs, hand-drawn tubing and pressings.

Generally, coloured glassware is produced to a specification defining the light-transmitting properties and physical properties such as thermal expansion and softening points are of lesser importance. They are all special glasses in the sense that they are melted when required and it is only possible in this publication to indicate the range of colours manufactured.

Opal Glasses

Opal 27 and AS.5.

A 'solid' opal in the form of bulbs and pressings is known as Opal 27, and is simply a pot-melted fluoride opal glass and is the glass employed for the production of opal lamps, blown illunminating ware and pressings.

AS.5. is a very dense opal only employed in the form of a thin flashing in the manufacture of two- and three-ply opal tubing, the base glass being L.1. This tubing is used exclusively in the manufacture of the so-called architectural lamps.

Coloured Glasses

Blue and red glasses are the two main types manufactured, covering a wide range of light transmission and known by the following descriptions.

Blue	Daylight Blue Ordinary Blue Dark Blue—known as Admiralty Blue.
Red	Light Ruby Dark Ruby Admiralty Ruby Photo Ruby Aviation Red.

Green, amber, yellow and orange glasses are also manufactured.

With certain exceptions in the form of pressings, blown bulbs comprise the bulk of the output of the coloured glasses.

CHAPTER 3

TECHNICAL CONTROL

(a) In Glass Manufacture

All glasses manufactured by the OSRAM-G.E.C. Glass Works are made to a specification which defines the chemical composition and relevant physical properties of the individual glasses. The greatest care is exercised in the selection of raw materials, in the preparation of the batch and control of melting conditions to ensure that the glasses produced comply with the specifications.

An important clause in all the Glass Works' specifications is as follows:

> '*Glass Composition.* No variation of glass composition which will result in physical properties . . . . outside the specified limits is permitted without the customer's approval of samples submitted.'

In general, the important physical property is the coefficient of linear thermal expansion, and the Glass Works' Technical Department carries out daily checks of this property on all tank-melted glasses to keep it within the limits of the specification. Particular precautions are taken in the case of pot-melted lead glasses used for the manufacture of expensive radio valves and at the Company's Lemington Works the thermal expansion is measured of every pot of lead glass. Thus, the descriptions X.8., L.1., W.1., H.26X., and so on mean not only a type of glass, namely, soft soda, lead and borosilicate glasses, but glasses of certain defined chemical compositions and properties. So that as closely as is possible every piece of X.8. or L.1. will be similar in characteristics to any other piece of glass of the same name.

A sensitive indicator of small changes in chemical composition is the 'Devitrification Temperature', which is simply the temperature at which the glass would begin to crystallize out if cooled at a sufficiently slow rate. The lower the devitrification temperature the more stable the glass will be on reheating. In the case of tank-melted soda glass, daily checks are also made of this property, which in conjunction with the thermal expansion results enable very close control to be exercised on the glass composition.

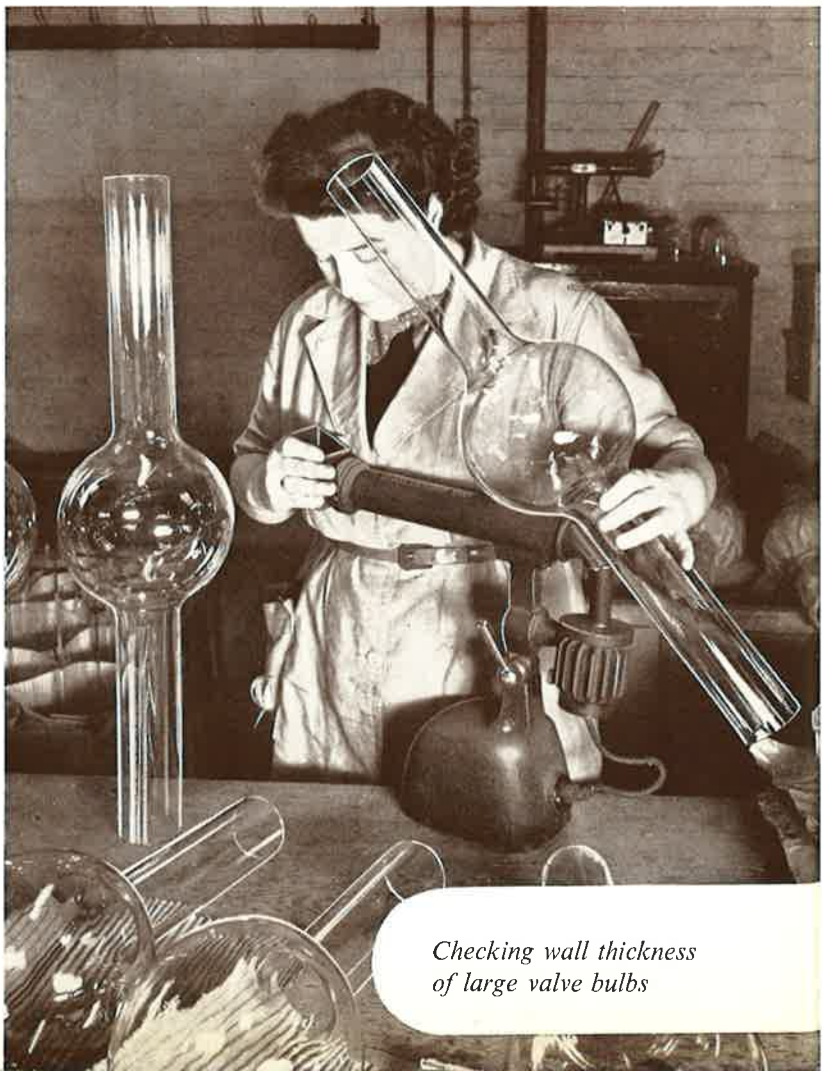
M.6. Neutral Glass is a well known product, in the manufacture of which not only are the usual properties determined to ensure constancy of chemical composition, but daily tests are made to ensure that the glass produced complies in every way with the requirements of British Standard No. 795 for neutral glass. The label M.6. therefore is a guarantee that the glass passes the British Standard Specification. In actual fact M.6. is superior to this specification and is deliberately so maintained.

Where glasses are required for special applications particular attention is paid to some detail of chemical composition or some special physical property. For example, H.26X. glass is required to be of very low iron content to obtain good ultra-violet transmission and the iron oxide content of every melt of

EXAMINATION AND SELECTION

Automatic machine for gauging small tubular valve bulbs

Inspection of pressed valve bases after manufacture



Checking wall thickness of large valve bulbs

H.26X. glass is determined to ensure that it is within the specified limits before the glass is released for lamp manufacture. In the case of Na.10., sodium-resistant glass, the strain developed between the layer of Na.10. glass and the base X.8. must be maintained within certain narrow limits and again the product from every melt of Na.10. is examined and the strain measured before released from the Glass Works.

(b) Examination and Selection of Finished Products

Every product of the Glass Works has a quality specification covering the dimensional tolerances permitted in bulbs and tubing and the extent to which certain defects may be tolerated. Quality Control Inspectors regularly sample and test all products ranging from 25 mm. lengths of 1·5/1·75 mm. diameter tubing weighing less than 0·001 oz. to the largest 14 in. diameter cathode ray tube weighing 20 lb. In this work, extensive use is made of statistical methods, and hour by hour, day and night, a regular sampling procedure is followed on all machine-blown bulbs and tubing to ensure that the product complies with the specifications.

From pot-melted glass, each shift's work is assessed as a separate unit. In many cases, particularly with large expensive bulbs, 100% checking of dimensions is undertaken. So far has this work advanced that Quality Control charts are kept on the factory floor and the blowers can see from the charts how they are progressing.

Examples of physical and chemical tests which the product may require to pass are:

Type of Test	Examples
Mechanical	Impact test of lamp bulbs. Pressure testing of cathode ray tubes.
Thermal	Thermal shock testing of hard glass illuminating ware.
Optical	Transmission tests of coloured glasses. Irradiation tests of bulbs for ultra-violet lamps.
Chemical	Durability Tests.

All the work of control in manufacture and subsequent testing, is part of the unremitting endeavour to provide products of constant chemical composition and physical properties.

CHAPTER 4

ANNEALING

That glassware must be annealed, except for special purposes, is commonly understood, but the reasons for annealing are not always clearly appreciated. Metals are annealed to remove the stresses remaining after cold working the metal, that is, the structure of the metal which has been broken up by mechanical working is restored. With glasses, annealing is necessary to remove the stresses which are present in the material due to unequal rates of cooling of different parts of the product resulting in temperature gradients being set up. The glass product as a whole cools too quickly for a uniform temperature to be reached before the glass becomes too rigid for any release of stress to take place, and results in stress gradients throughout the product where previously, at a higher temperature, the temperature gradients existed.

Annealing of glassware consists of nothing more than ensuring that all the glass is at a uniform temperature, at a temperature below which no permanent stresses as a result of subsequent temperature changes can be established. Subsequent cooling below this temperature may result in temporary stresses due to temperature gradients but on reaching a uniform temperature once more, say at room temperature, the glass will again be stress-free, i.e. it will have been annealed.

The important temperatures in this process define what is known as the annealing range. In Fig. 9 which may be considered a typical thermal expansion curve for any glass, the annealing range is defined by points 'A' and 'B'.

Point 'B', the highest point reached on the thermal expansion curve, is the *Upper Annealing Temperature*. Above this temperature the glass softens at a visible rate under its own weight, the more rapidly the higher the temperature. It will be appreciated, therefore, that this upper annealing temperature is not a fixed temperature similar to a boiling or melting point and the safe upper limit of annealing temperature will depend to a slight extent on the weight and thickness of the article to be annealed. For all normal products however it will not vary significantly from the information and graphs given in the foregoing pages.

Point 'A', is an intermediate temperature known as the *Lower Annealing Temperature* and normally coincides with a marked change in the shape of the thermal expansion curve. It is simply a temperature below which it will not be possible to anneal the glassware in any reasonable time. Again it is not truly a 'fixed' temperature, but it may in fact be regarded as such, much more so than the upper annealing temperature since it is far less affected by considerations of weight and shape.

When annealing it is essential to ensure that at the lower annealing temperature the whole of the glass article is at a uniform temperature. When this has been achieved, the subsequent rate of cooling below this temperature may be as rapid as desired and limited only by the requirement that the article should not be broken by thermal shock since once the article has reached a uniform temperature it will again be stress-free just as it was at the lower annealing temperature. All modern annealing lehrs are designed to carry out the annealing process along these lines in the minimum time consistent with the foregoing requirements.

The degree of annealing, that is to say, how closely the glassware approaches the ideal completely stress-free condition, is determined in some form of strain viewer which is an essential adjunct wherever annealing of glassware is carried out. Annealing is rarely so perfect that no stresses whatever remain in the article and so it is essential to have practical standards representing 'good commercial annealing' in which any residual stresses are less than 0·5% of the average breaking strength of the glass. For any article standards of annealing may be established rapidly by comparison with standards stressed to a known degree and in assessing the degree of annealing it is strongly recommended that comparison always be made to a precisely similar article kept as a reference standard. This procedure avoids all the complications dependent upon size, shape and wall thickness of the articles examined and is the most practical manner of using a strain viewer in the factory.

In this description of the annealing process it has been assumed that the article has been one single piece of glass or built up from components, bulbs, rod, tube, etc., of the same glass. When different glasses are joined together some residual stresses will always be present at the seal unless the thermal expansion coefficients of the two glasses are identical. Since it is rarely possible to achieve this ideal state some tolerance must be permitted and, for example, a safe tolerance for soda glasses is $\pm$ 0·15 $\times$ 10^{-6} on the thermal expansion coefficient. If this tolerance is not exceeded then satisfactory butt joints between two similar, though not necessarily identical, glasses will be possible, the extent of the residual stresses depending simply on the difference in the expansion coefficients of the two glasses. Here again it is more than ever essential to have reference standards by which the annealing may be judged.

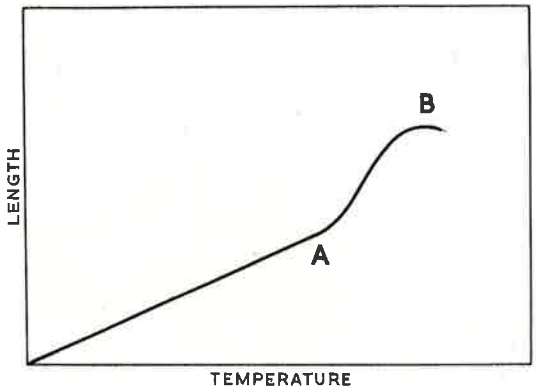


FIG. 9
Typical Expansion Curve.

WEMBLEY GLASS TUBING & ROD

(MACHINE-DRAWN AND HAND-DRAWN)

APPROXIMATE NUMBER OF FEET TO THE POUND IN VARIOUS SIZES AND WALLS
THESE TABLES ARE CORRECT FOR WEMBLEY X8 TUBING AND ROD.
IF USED FOR OTHER GLASSES, ADJUSTMENT SHOULD BE MADE ACCORDING TO THEIR SP.G.

	TUBING									ROD
Ext. Diam. mm.	Wall ·25mm.	Wall ·50mm.	Wall ·75mm.	Wall 1·0mm.	Wall 1·25mm.	Wall 1·50mm.	Wall 2·0mm.	Wall 2·5mm.	Wall 3·0mm.	
2	436	254	203	—	—	—	—	—	—	189
3	277	152	113	95·3	87·3	—	—	—	—	84
4	203	109	78·2	63·5	55·5	50·8	—	—	—	47
5	160	85	59·8	47·7	40·7	38·0	31·8	—	—	30
6	132	69	48·3	38·1	32·1	28·3	23·9	21·7	—	21
7	113	58·7	40·7	31·8	26·5	23·1	19·0	16·9	15·7	15·5
8	98	51	35·1	27·2	22·6	19·6	15·9	13·8	12·6	12
9	87	45	30·8	23·8	19·7	17·0	13·6	11·7	10·5	9·5
10	78·2	40	27·5	21·2	17·4	15·0	11·9	10·1	9·0	7·5
11	71·0	36·3	24·8	19·1	15·6	13·4	10·6	8·9	7·9	6·2
12	64·8	33·1	22·6	17·3	14·2	12·1	9·5	8·0	7·0	5·2
13	59·8	30·5	20·8	15·9	13·0	11·0	8·7	7·2	6·3	4·5
14	55·5	28·3	19·2	14·6	12·0	10·1	7·9	6·6	5·7	3·9
15	51·7	26·3	17·8	13·6	11·1	9·4	7·3	6·0	5·2	3·4
16	48·3	24·6	16·7	12·7	10·3	8·8	6·8	5·6	4·8	3·0
17	45·5	23·1	15·6	11·9	9·7	8·2	6·3	5·2	4·5	2·6
18	43·0	21·8	14·7	11·2	9·1	7·7	5·9	4·9	4·2	2·3
19	40·7	20·6	13·9	10·6	8·6	7·2	5·6	4·6	3·9	2·1
20	38·5	19·6	13·2	10·0	8·1	6·9	5·3	4·3	3·7	1·9
21	36·7	18·6	12·5	9·5	7·7	6·5	5·0	4·1	3·4	1·7
22	—	17·7	12·0	9·1	7·3	6·2	4·7	3·9	3·2	1·5
23	—	17·0	11·4	8·7	7·0	5·8	4·5	3·7	3·1	1·4
24	—	16·2	10·9	8·3	6·7	5·6	4·3	3·5	2·9	1·3
25	—	15·6	10·5	7·9	6·4	5·3	4·1	3·3	2·7	1·2
26	—	15·0	10·1	7·6	6·1	5·1	4·0	3·2	2·6	1·1
27	—	14·4	9·7	7·3	5·9	4·9	3·8	3·1	2·5	1·0
28	—	13·9	9·3	7·0	5·7	4·7	3·6	2·9	2·4	1·0
29	—	13·4	9·0	6·8	5·5	4·6	3·5	2·8	2·3	·9
30	—	12·9	8·7	6·6	5·3	4·5	3·4	2·7	2·3	·8

Tubing above the thick line in these columns is Capillary.

THE FORMULA FOR CALCULATING WEIGHT of Wembley Soda Tubing is

$$2{\cdot}98\,(D^2-d^2)=x$$

Where:—D = Mean outside diameter.
d = Mean bore.
x = Weight in grammes per 5-foot run.
(453 grammes = 1 pound).

(Lead Tubing and Rod is one-fifth heavier per unit length). (Borosilicate Tubing and Rod is approx. one-tenth lighter per unit length).

WEMBLEY GLASS TUBING & ROD

(MACHINE-DRAWN AND HAND-DRAWN)

APPROXIMATE NUMBER OF FEET TO THE POUND IN VARIOUS SIZES AND WALLS
THESE TABLES ARE CORRECT FOR WEMBLEY X8 TUBING AND ROD.
IF USED FOR OTHER GLASSES, ADJUSTMENT SHOULD BE MADE ACCORDING TO THEIR SP.G.

TUBING

Ext. Diam. mm.	Wall ·50mm.	Wall ·75mm.	Wall 1·0mm.	Wall 1·25mm.	Wall 1·50mm.	Wall 2·0mm.	Wall 2·5mm.	Wall 3·0mm.
31	12·5	8·4	6·3	5·1	4·3	3·3	2·6	2·2
32	12·1	8·1	6·1	4·9	4·1	3·2	2·5	2·1
33	—	7·9	5·9	4·8	4·0	3·1	2·5	2·1
34	—	7·6	5·7	4·7	3·9	3·0	2·4	2·0
35	—	7·4	5·6	4·5	3·8	2·9	2·3	2·0
36	—	7·2	5·4	4·4	3·6	2·8	2·2	1·9
37	—	7·0	5·3	4·3	3·5	2·7	2·2	1·9
38	—	6·8	5·1	4·1	3·4	2·6	2·1	1·8
39	—	6·6	5·0	4·0	3·3	2·5	2·1	1·7
40	—	6·5	4·9	3·9	3·3	2·5	2·0	1·7
41	—	6·3	4·7	3·8	3·2	2·4	2·0	1·6
42	—	6·1	4·6	3·7	3·1	2·4	1·9	1·6
43	—	5·9	4·5	3·6	3·0	2·3	1·9	1·6
44	—	5·8	4·4	3·5	3·0	2·3	1·8	1·5
45	—	5·7	4·3	3·4	2·9	2·2	1·8	1·5
46	—	5·6	4·2	3·3	2·8	2·2	1·7	1·4
47	—	5·5	4·1	3·2	2·8	2·1	1·7	1·4
48	—	5·4	4·0	3·2	2·7	2·1	1·7	1·3
49	—	5·3	3·9	3·1	2·6	2·0	1·6	1·3
50	—	5·2	3·9	3·1	2·6	2·0	1·6	1·3
51	—	—	3·8	3·0	2·5	1·9	1·5	1·2
52	—	—	3·7	3·0	2·5	1·9	1·5	1·2
53	—	—	3·6	2·9	2·4	1·9	1·5	1·2
54	—	—	3·5	2·9	2·4	1·8	1·5	1·2
55	—	—	3·4	2·8	2·3	1·8	1·4	1·2
56	—	—	3·3	2·8	2·3	1·8	1·4	1·1
57	—	—	3·2	2·7	2·2	1·7	1·4	1·1
58	—	—	3·2	2·7	2·2	1·7	1·4	1·1
59	—	—	3·1	2·6	2·1	1·6	1·3	1·1
60	—	—	3·1	2·6	2·1	1·6	1·3	1·1

GAUGING TOLERANCES ON DIAMETER are normally: 1mm. overall up to 25mm.; 2mm. from 25mm. to 30mm.; and 3mm. over 30mm. Special selection can, however, be undertaken if required.

STANDARD BUNDLES of machine-drawn tubing and rod are: Up to 25mm., 14 lb.; over 25mm., 10 lb. Hand-drawn tubing and rod can be supplied in any quantities.

FRACTIONS OF AN INCH AND THEIR MM. EQUIVALENTS

inches ...	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8
mm. ...	1·6	3·2	4·8	6·3	7·9	9·5	11·1	12·7	14·3	15·9	17·5	19·0	20·6	22·2	23·8	25·4	27·0	28·6	30·2	31·7	33·3	34·9

inches ...	1 7/16	1 1/2	1 9/16	1 5/8	1 11/16	1 3/4	1 13/16	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8	3	3 1/4	3 1/2	3 3/4	4
mm. ...	36·5	38·1	39·7	41·3	42·9	44·4	46·0	47·6	50·8	54·0	57·0	60·0	63·5	67·0	70·0	73·0	76·0	82·5	89·0	95·0	101·5

ANNEALING SCHEDULES

For articles made from tubing and rod the following annealing procedure is recommended:

	Important Temperatures		
	High	*Intermediate*	*Low*
Wembley X.8. Soda Glass	520°C.	460°C.	400°C.
Wembley M.6. Neutral Glass	650°C.	600°C.	500°C.
Wembley L.1. Lead Glass	430°C.	390°C.	340°C.

Operating Instructions

(1) Hold the glassware at the 'high' temperature for a period of 5 to 10 minutes.

(2) Cool the ware down from the 'high' to the 'Intermediate' temperature at the following rates:
   (*a*) 3°C. per minute for tubing up to ½ mm. wall thickness.
   (*b*) 2°C. ,, ,, ,, ,, ,, ,, 1 mm. ,, ,,
   (*c*) 1°C. ,, ,, ,, ,, ,, ,, 3 mm. ,, ,,

(3) Cool down from the 'intermediate' to the 'low' temperature at double the above rates.

(4) Cool down from the 'low' temperature to room temperature at any reasonable rate which can be accomplished without cracking the ware by excessive thermal shock.

(5) Examine samples of the articles when cold and at a *uniform room temperature* in a strain viewer.

The habitual use by glass blowers of a reliable strain viewer is strongly recommended.