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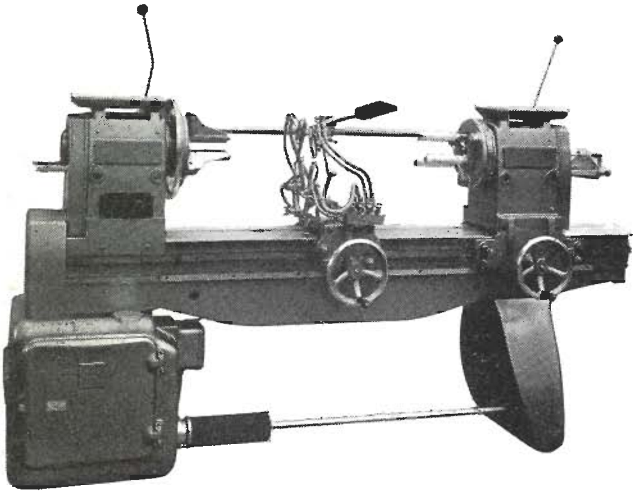

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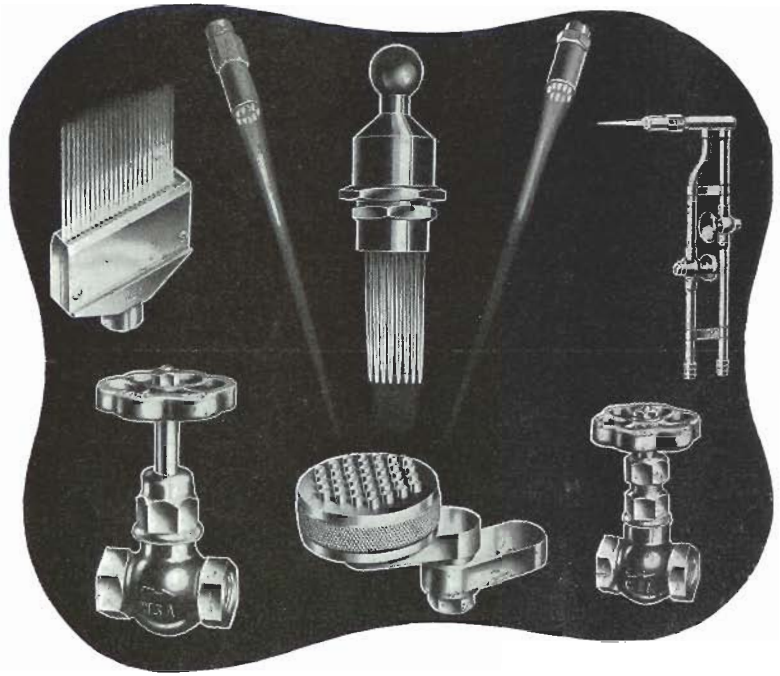

British Society of Scientific Glassblowers

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EDITORIAL

We are now able to publish a further stage in the establishment by the Board of Examiners of the conditions for the awarding of a Fellowship, and on Page 12 a list of subjects is given, a majority of which the intending Fellow should know and presumably be able to carry out. It will be noticed that some of these, such as welding, high frequency heating and metal deposition on glass are fields of their own with comparatively minor applications in glass-working, though in the case of vacuum technique the fundamental advances were made in glass. No doubt the definition of a scientific glassblower again came under scrutiny but there is no doubt that in many modern research laboratories the glassblower has extended his activities beyond the simple manipulation of hot glass and the Board of Examiners list is a realisation of this progress.

One of the greatest needs of our profession is some standardisation of what can be expected of the scientific glassworker at stages of his career for there is in fact a very wide variation in methods of working glass which are the result of environment and the original source from which they were acquired.

The early training years have a great influence on a glassworkers style and approach and their effect will in genral persist throughout his working life. There are few schools for practical instruction; research laboratories and production centres training according to their own particular needs and developing new techniques to meet the demands of advanced projects.

The great change in glassworking methods in recent years is reflected in the equipment which now appears in the modern glass workshop, maybe accumulated through lack of a more suitable site in the laboratory; but it is a fair statement that the possession of this equipment will have a great influence on a glassblower's methods and by leading him on to more advanced techniques will also be some indication of his standard of working.

Certainly without a basic minimum of equipment he will be forced to use methods now considered primitive.

But it can now happen that a large proportion of the activity of a glass workshop will centre around this ancillary equipment; it is doubtful however, whether its operation requires the same high standard of skill as normal hot glassworking, and many processes such as optical grinding, glass machining and metal welding, could be equally well carried out by other specialists with the appropriate engineering background.

Nevertheless the present trend is for the glass workshop to become a technique centre – possibly because it is found that experienced glassworkers are also very versatile and as yet few pure techniques laboratories have been established.

But it must be remembered that it was on his skill in manipulating hot glass that the glassblower's reputation was founded (and which led to the formation of the Society), and while that same skill has led to the acquiring of other techniques the sequence is not reversible; techniques cannot make glassblowers or be a substitute for straight down to earth glassworking.

Thus the Board are wise to jealously protect the craft by insisting that the ability to work glass to at least Certificate of Competence level shall be a necessary consideration to the awarding of a Fellowship, and at the same time encouraging members to extend their knowledge to other fields.

We hope there will be a big response to this latest move to further one of the objects of the Society.

J. H. Burrow

The Journal is published quarterly by the B.S.S.G. and is available free to members and at 10s 0d per copy (or 35s 0d per annum) to non-members. A limited number of back copies are available. Editorial communications should be addressed to the Editor, c/o H. H. Wills Physics Laboratory, Royal Fort, Clifton, Bristol 8, and enquire for advertising space to C. H. Glover. 'Saraphil', Highfield Lane, Cox Green, Maidenhead, Berks. Printed in Gt. Britain by Sawtells of Sherborne Ltd., Sherborne, Dorset.

GLASS ENGINEERING*

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Introduction

In this paper Glass Engineering means the extension of scientific glassblowing to meet the needs of the thermionic valve (electron tube), lamp and associated industries.

These industries require large numbers of low cost glass and glass to metal seal components, and it was obvious from the earliest days that the bench glassblower, however skilled, could not meet this demand. Machines have therefore, been developed to mass produce these components and the progression press, pinch, and sealing machines have replaced the skill of the glassblower by the skill of the machine designer and builder. It is not proposed to discuss this type of machine here.

A second class of machine or machine technique, however, supplements rather than replaces the glass craftsman particularly where specialist valves and lamps are required or when numbers do not warrant the tooling needed for large scale production.

A few of these methods will be discussed because they may be of use or interest to the general scientific glassblower. It is realised that some will already be familiar to many readers, for they have been used for many years, but others are perhaps newer and less well known. In any case it is hoped that this review will be of general interest and indicate the extent to which the techniques for making glass to metal seals and precision bore tubes have been developed. Before describing individual tehniques, however, the general requirements and range of materials used will be briefly discussed.

General requirements

Filament and electrode systems, as used in lamps and valves, have to operate either in a vacuum or in a controlled atmosphere. The basic purpose of the glass is to provide a suitable gas-tight envelope, transparent in the case of lamps, which is also an electrical insulator.

If the glass is merely to act as an envelope it can have a simple shape readily made, by the glass works. Sometimes, however, the glass envelope must either be accurate enough to position the electrode system, or have a shape which differs significantly from glassware as normally supplied. The glass engineer must then be able to produce these required envelopes from commercial tubing.

In addition to providing an envelope of the right shape, provision must be made for electrical contacts to the filament and electrode systems. This is done by making the necessary glass to metal seals either through the main envelope or more usually through a separate glass component, known according to its shape as a foot tube, base or pinch. In this case the system is mounted on this component which is sealed to the main envelope as a final valve or lamp making operation.

The glass engineer must therefore be able to form precision tube, unusual glass shapes and, most important, be capable of manufacturing a great variety of glass to metal seals.

In fact most of the methods described will involve glass to metal seals so it would seem reasonable to re-state briefly the principle of glass to metal sealing and list the main glass to metal combinations.

Requirements

The choice of glass for all-glass apparatus is governed by such obvious considerations as ease of working, cost, availability and resistance to chemical attack. For this purpose heat resistant borosilicate glass (Commercial Pyrex – Corning 7740) is generally used.

When glass to metal seals are involved, however, the position is more complex and usually if a particular type of metal or metal alloy is specified the glass to go with it is set, and similarly if a particular type of glass is required the choice of metal is very limited.

The reason for this is that a glass to metal seal made by allowing hot glass to adhere to metal must cool down from glass softening temperature without the glass cracking, and also survive subsequent heat cycling. This will, in general, only be the case if the thermal contractions of the metal and glass over the cooling and cycling ranges are matched, that is the change in dimensions of the metal will be followed more or less exactly by the glass during any heating or cooling that takes place.

There are, however, two important exceptions to this rule. The first is the 'Houskeeper' seal in which the metal component is thinned to deform sufficiently to prevent breakage when the two thermal expansions deviate. (Houskeeper was the name of the man who formulated the technique and it was originally spelt without the 'e').

***Paper given to the B.S.S.G. at Reading 1967.**

TABLE OF GLASSES*

GLASS TYPE	Coefficient of linear thermal expansion (50°–300°C)	SEALING METAL	APPLICATIONS	COMMENTS
Vitreous silica	0.5×10^{-6}/°C	(1) Tungsten rod, (via one grade) (2) Molybdenum foil	Laser flash tubes, Lamps and valves with high temperature envelopes	Unmatched oxide free seals
Borosilicate heat resisting ('Pyrex' Corning 7740)	3.2×10^{-6}/°C	(1) Tungsten rod via tungsten sealing glass (2) Thin wall platinum tube	General glassware	Not normally used for lamps and valves, or glass/metal seals
Tungsten sealing *(G.T. and C. Ltd. B37)	3.7×10^{-6}/°C	Tungsten	Lamps and valves with high current filaments	Oxide or oxide free seals
Alumino silicate (G.T. and C. Ltd. A43)	4.3×10^{-6}/°C	Molybdenum	Lamp and valves with high temperature envelopes	Not widely used. It is harder than all common glasses except vitreous silica
Borosilicate 'Kovar' sealing (G.T. and C. Ltd. B53 Plowden and Thompson Ltd. Kodial)	$4.8\text{–}5.0 \times 10^{-}/^{6}$°C	Nilo K alloy (Ni 28%, Fe 54%, Co 18%) (Kovar. Telcoseal 1 Vacon 10)	Seals of all types	Very widely used for special valves and vacuum devices
Lead Glass (G.T. and C. Ltd. L92)	9.1×10^{-6}/°C	(1) Copper clad 42% Nickel Iron (Dumet) (Red plat) (2) Nilo 475 (Ni 42%, Fe 52%) (Cr 6%) (No. 4 alloy) (3) 50/50 Nickel Iron variants (Nilo 50, 51 etc.)	Small glass pinches, pressed bases etc.	Used for most lamps and entertainment valves
Lime soda	9.6×10^{-6}/°C	(Cr 26%, Fe 74% alloy)	Envelopes for small lamps and valves	Not normally used for glass to metal seals but joins to lead glass pinches, bases etc.
Copper, nickel, iron sealing	$11\text{–}16 \times 10^{-6}$/°C	High expansion metals	Miscellaneous seals	Special applications

*Glass Tubes and Components Ltd., Sheffield Road, Chesterfield.

The second depends on the fact that tension stress at the surface is needed to break glass, and if the seal geometry can be arranged to eliminate this, considerable compression stress can be tolerated. In the so called 'compression' seal, a cylinder of high expansion metal surrounds and compresses a rod of lower expansion glass without danger of breakage.

Having decided on a glass and a metal that are compatible for thermal expansion, the correct conditions for achieving firm leak tight adhesion between the two must be satisfied.

The general condition is that an adherent oxide must be formed on the metal before sealing. This oxide dissolves partially into the glass, and forms a strong chemical bond with it. If the remaining oxide is sound and its adhesion to the base metal good, a satisfactory seal will result.

The art of making a seal is to leave the right amount of oxide when the seal is completed. If the seal is held at a high temperature for too long, the oxide will all be dissolved into the glass and the adhesion will depend on proximity (Van de Waals) forces. The seal will probably be vacuum tight but mechanically weak. If too much oxide remains, usually because the metal is over-oxidised in preparation, the oxide itself may fracture. Cleaning acids or reducing gases may also be able to penetrate and destroy the seal.

The methods of cleaning metals and oxidising them before glassing are too numerous to discuss here, but they may be found in the literature(1)(2). A typical pretreatment is, however, the one used for ferrous alloys (such as Nilo K) which are furnaced in an atmosphere of wet hydrogen at about 1100°C to remove surface carbon. If this carbon is not removed it will combine with oxygen in the glass to give unacceptable bubbles of carbon dioxide in the final seal.

Although oxide is generally present in a glass to metal seal there is the very important oxide free seal made to refractory metals, usually tungsten, where oxide is prevented from forming. This seal was developed because the normal brown tungsten oxide was found to be liable to water vapour attack(1).

Specific combinations of Glass and Metal

In the Table the more important types of glass are listed, together with the metals commonly joined to them, and the applications for which they are used. They are given in order of increasing coefficient of linear thermal expansion which in general is inversely related to the hardness (resistance to deformation by heating) of the glass. A difficulty with this sort of classification is the variety of different trade names and numbers which apply to basically similar materials. Throughout this paper the names and numbers most familiar to the author are used. In the Table some equivalents are given, but the omission of any particular equivalent does not, of course, imply that it is unsuitable. Designations and trade names used in the U.S.A. can be found in reference (2).

Glassworking methods

(1) ***Precision Bore Tube***

It is often necessary to provide glass tube with a more accurate bore diameter than is normally obtainable.

There are two general methods for making this type of tube from existing tube of normal commercial quality.

The first method illustrated in Figure 1 is capable of giving the highest accuracy. The tube to be sized is closed at one end and holds an accurately made stainless steel mandrel. The open end of the tube is connected to a vacuum pump

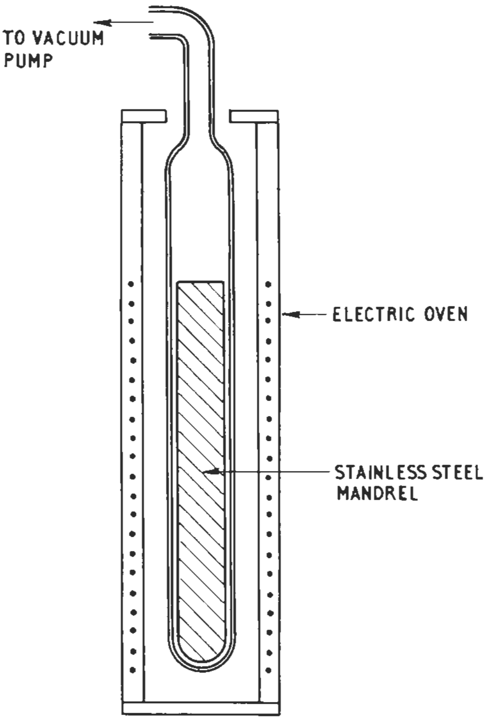

Figure 1 **Vacuum shrinking of glass tube**

and evacuated in an oven heated to glass softening temperature. The glass shrinks, due to the external pressure, on to the mandrel and takes its form and dimensions.

On cooling, the high expansion stainless steel contracts more than the glass and can easily be withdrawn when cold.

The precise size of the final glass tube depends on the mandrel size at the setting point of the glass and the extent to which the glass contracts after it has set. In general with borosilicate glass and a stainless mandrel the cold mandrel diameter is about .995 of the finished glass tube size. It is important to select the original tube so that it is only slightly bigger than the mandrel, otherwise creases may form if there is any uneven oven heating. The mandrel is generally coated with graphite to ease removal.

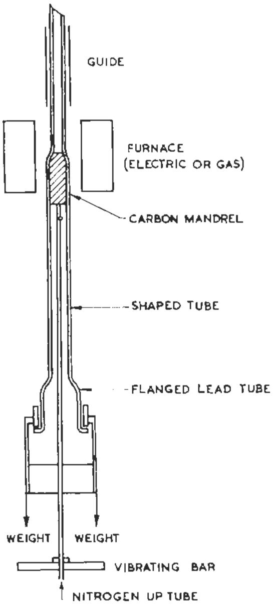

Figure 2 **Shaping glass tube by drawing it vertically downwards over a mandrel**

By this method tolerances of within .001″ can be achieved on a 1″ bore but unfortunately the glass picks up any scratches or other imperfections on the mandrel surface.

The second method illustrated in Figure 2 can give a better internal surface but at some cost in absolute accuracy.

As illustrated, the glass tubing is pulled by gravity over a fixed graphite mandrel held in a small gas or electrically heated oven. The mandrel is held vertically on a tube through which nitrogen is introduced to help preserve the graphite. A constant gravitational pull on the glass is achieved by hanging chains. These rest on the floor and as the glass tube slides over the mandrel the amount of chain actually hanging is automatically reduced to compensate for the increasing weight of glass. To prepare the tube for pulling, an auxiliary length of larger bore tube sufficient to clear the mandrel and flanged to carry the chain collar has to be joined to it. Care must be taken to prevent the tube bending as it leaves the mandrel and if the mandrel support tube is attached to a high frequency vibrator a smoother pull is generally obtained. It is, of course, possible in this general method to reverse the procedure by holding the glass stationary and moving the mandrel.

The final accuracy depends on the diameter of the graphite mandrel which can wear and the actual temperature at which the moving glass leaves the mandrel.

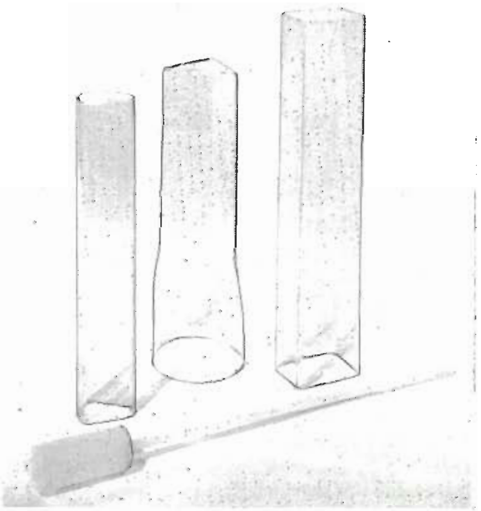

Figure 3 **Precision glass tubing**

Both methods can be used to make tubing of unusual cross-section although the graphite mandrel method is the more flexible. All conventional glasses can be sized although vitreous silica requires a molybdenum mandrel for vacuum shrinking and a very hot oven when using the graphite mandrel method.

In Figure 3 various examples of 'pulled' tube are shown, also an envelope made from shrunk tubing of two sizes. The external diameters of the tubes are 1″ and about $\frac{1}{4}$″, and they form the electron gun case and helix support of a "Travelling Wave Tube" a type of microwave amplifier valve.

(2) ***The manufacture of large tubular glass seals***

Large seals with a diameter of 12″ or more are sometimes required for specialised valves. Figure 4 shows a seal assembly held in a glass lathe. It consists essentially of two 12″ diameter "Nilo K" end tubes separated by an 18″ length of 12″ diameter B53 glass. Round the body of the glass are sealed 15 small Nilo K side tubes of about $1\frac{1}{2}$″ diameter which are accurately positioned with respect to each other and the end tubes.

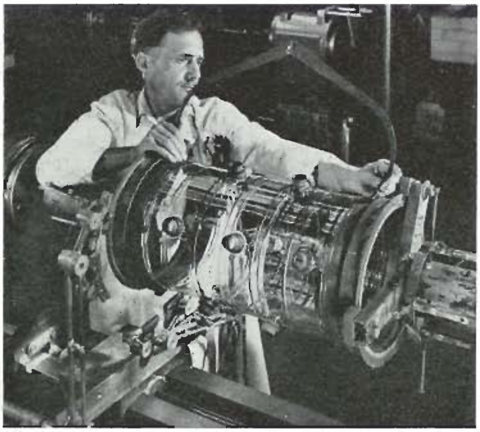

Figure 4 **12″ seal assembly held in glass lathe**

The manufacture of this type of seal assembly is obviously a challenge, not least because of its finished weight about 30lbs. which makes manual handling when hot rather difficult. After experiencing breakage while attempting to transfer the hot assembly from the lathe to a separate annealing oven, it was decided to perform all the working operations either actually in an electric oven or with an electric oven ready to be placed over the work as soon as each stage of the glass working was complete. This oven technique proved completely successful allowing plenty of time for the completion of each operation without the continual possibility of loss due to uneven flame heating.

The stages of manufacture are illustrated in simplified form in Figures 5 to 8. The lathe used was a Heathway Model IV-6 with a 36″ swing and 72″ maximum between heads. The oven was a box made of double wall 1″ thick "Marinite". The ends and top were removable and it was heated by a series of Nichrome V elements held in vitreous silica tubes.

The components were held in the lathe by 'bell' chucks specially made for this work and the large bulb, which was supplied with one domed end, had a thick walled 4″ diameter tube joined to it to make handling easier. All the necessary glass cutting was done using a hot wire. Before starting the main work all the metal tubes were prepared by wet hydrogen furnacing and prebeading with glass. This allowed glass to glass sealing to the main bulb a technique which was found to be more satisfactory than attempting direct glass to metal sealing.

In Figure 5 the first stage is shown. Because clearances between the bulb and the internal electrodes were critical at certain points, the bulb had to be rolled to give a series of bands, each with the same precision internal diameter. This was achieved by means of an internal carbon roller of the required band width spaced accurately from a central fixed spindle. It could be moved along the inside of the bulb on an auxiliary spindle.

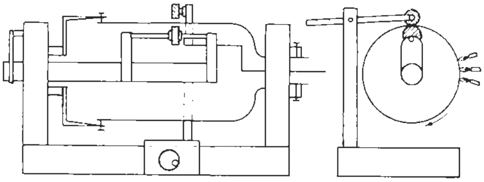

Figure 5 **Rolling bands on 12″ diameter bulb**

The rotating bulb was heated locally and rolled against this small roller by an external carbon roller attached to the burner carriage. The band position was set by moving the external roller and the burners the required distance along the lathe bed. The internal roller was pulled into its matching position by means of a wire passing through the small diameter tube by which one end of the bulb was supported.

Annealing was carried out in the oven which was lowered on to the lathe bed after the last precision band had been rolled.

Figure 6 shows the essentials of the second stage, the vacuum forming of glass projections to take side seals. To do this a carbon vacuum tool mounted on the lathe bed was held against the glass in each of the fifteen positions in turn. The contacting glass was heated strongly, vacuum was applied and the projection formed. Between each forming operation the tool was lowered and the inevitable local strain in the glass was flame annealed out with the lathe rotating. For each projection the lathe was stopped and the rotational position of the bulb accurately set, also the position of the vacuum tool on the burner carriage lengthwise along the bulb. After final oven annealing the blank ends of the projections were cut off using the hot wire technique leaving a short tubular section suitable for accepting the beaded side tubes.

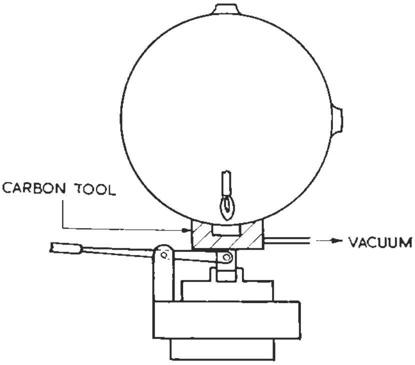

Figure 6 **Forming projections on 12″ diameter bulb (end view)**

Figure 7 shows the arrangement for the joining of the side seals. This was a long operation carried out in the oven, with the bulb at 500°C throughout.

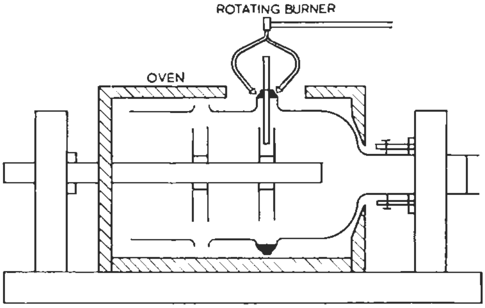

Figure 7 **Sealing side G/M seals**

To position the small tubular seals accurately against the side projections, a spider mandrel was placed inside the bulb so as to rotate with it. Each arm of the spider was a tube which could accept a jig temporarily fastened to a tubular metal seal. The lathe was stopped with a projection uppermost, some of the oven roof was removed and the jig with its side seal attached was passed through the projection. The jig then fitted into a spider arm positioned so that the glass bead of the small seal located against the glass projection tube. The seal was made with a motor driven rotating gas/oxygen twin burner. A certain amount of collapse was allowed and this was set by the bottoming of the support jig in the spider tube. When this seal was complete the jig was pulled out, leaving the side tubular seal in place. The oven lid was then replaced and the bulb rotated to anneal out any glass strain. This operation was repeated for each of the fifteen seals.

In Figure 8 the final joining of the 12″ end tubular seals is shown. This operation was carried out twice, once for each seal. The first prebeaded tube is shown in position in the movable lathe head and the bulb with all its side seals is shown in the other fixed head. The oven was arranged to slide along the lathe bed and was first set to bring the bulb up to working temperature while the tubular seal was flame pre-heated outside.

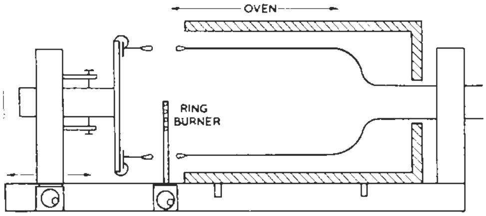

Figure 8 **Joining 12″ end seals**

The oven was then withdrawn from the sealing end of the bulb and the tubular seal advanced to meet this open end. The glass to glass seal was then made using a partial ring of burners. When the join was complete the 12″ metal tube was released from its lathe head which was withdrawn with the burner carriage out of the way. This allowed the oven to be pushed along the lathe bed over the whole assembly for annealing.

The second end seal was made in the same way except that different jigging was obviously required.

The seal formed the main envelope component of an experimental Mercury pool rectifier valve designed in collaboration with the C.E.G.B. for a rating of 180 kV, 1000 A peak, one of a series designed and made at The General Electric Company Limited, Hirst Research Centre (Fig. 9).

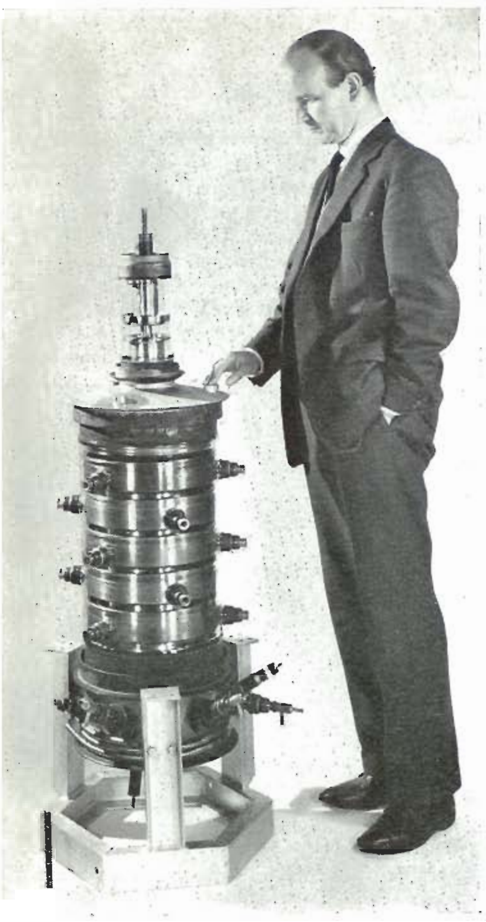

Figure 9 **Complete 'five grid' mercury pool rectifier**

(3) *The forming of glass and glass to metal seals in carbon moulds using a Centrifuge Machine*

A convenient method of making large numbers of small glass to metal seals is the carbon (graphite) mould technique. Generally the metal and glass to be joined are loaded into a carbon mould which is passed through a belt furnace (lehr) where the glass flows and makes the seal. The shape of the mould sets the shape of the final seal which can be withdrawn from the mould when cold because carbon and glass do not stick together. To preserve the carbon at glass flowing temperature the belt furnace is fed with a suitable inert gas. It is convenient to use glass as sintered preforms, or powder.

A variation of this technique (3) is illustrated in Figure 10. In the apparatus shown, the loaded carbon moulds instead of being fed through a furnace are placed, open end inwards, round the interior of an annular trough made from heat resistant steel (Cronite made by the Cronite Foundry Co. Ltd., Lawrence Road, London, N.15). This closed trough, fed with nitrogen to preserve the carbon, is rotated about its axis at high speed, and at glass flowing temperature. The speed of rotation which can be varied from about 250 r.p.m. to 500 r.p.m. produces a centrifugal outwards force of from 20–30 g. and the fluid glass is therefore forced outwards into the moulds. The outward thrust is capable of forcing the glass into intricate shapes and allows tubular sections of solid glass to be used instead of preforms as the starting material. Rapid heating is achieved by

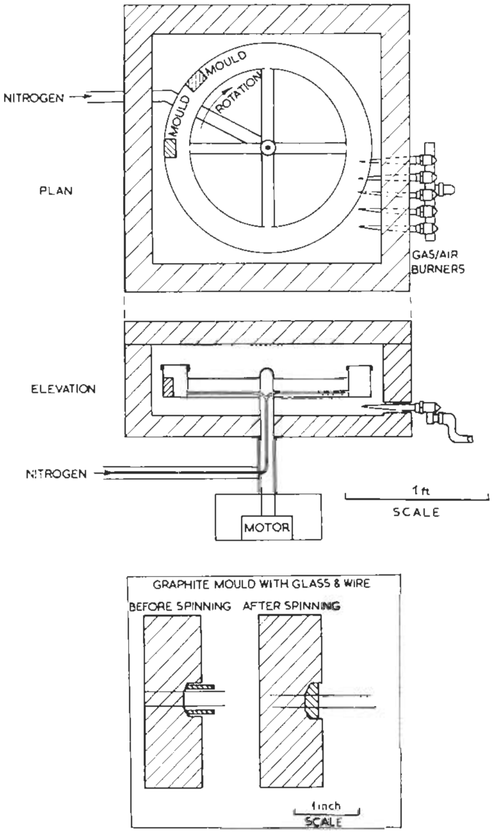

Figure 10 **Glass centrifuge machine**

using gas burners directed so that the rotation of the trough helps to distribute the hot gases throughout the fire brick furnace. Figure 11 illustrates some carbon moulds and a selection of seals and glass shapes made in this machine. The seals include a 19 pin C.R.T. base made from lead (L.92) glass, and an ionisation gauge base with a stem formed integrally in the centrifuge. This is made from 'Nilo K' and B.53 glass. The various other components illustrate the range of items which can be formed.

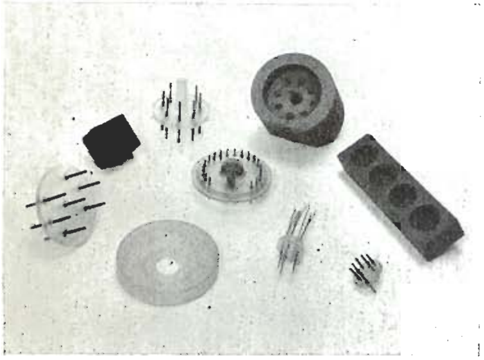

Figure 11 **Centrifuge formed components with graphite moulds**

When comparing the centrifuge with the belt furnace technique it is obvious that for simple seals the belt furnace is the more efficient because it is a continuous process whereas the centrifuge is a batch processing machine. On the other hand shapes can be formed in the centrifuge which would otherwise need expensive press tools. It is, in fact, quite economical to make experimental moulds for only a few items off, because of the ease with which the graphite can be machined.

The use of Moulded Graphite

In Figure 12 a pressed graphite mould is shown together with a reproduction of a coat of arms formed in it from plain sheet glass in the centrifuge. Also shown is a $1\frac{1}{2}''$ diameter glass medallion made in the same way. The detail in both mould and glass is very fine and is made possible by a graphite moulding technique developed at the Royal Aircraft Establishment, Farnborough, Hants.

This process is basically to press a graphite powder loaded with thermosetting resin round a required pattern. When the mixture has set and pattern has been withdrawn, the resulting mould is further heat treated(4). This gives a carbon shape, at least as good for glass forming as commercial solid graphite from the wear point of view and having the advantage of providing much finer detail.

The process for making this graphite is now being exploited commercially by Fordath Engineering Co. Ltd., Brandon Way, West Bromwich, under a license from the N.R.D.C.

Figure 12 **Pressed graphite mould with glass plaque and medallion**

(4) *Glass to metal sealing by high frequency (HF) induction heating*

When a piece of metal is placed in a high frequency electric field it is heated by the eddy currents induced in it. This effect can be used to make glass to metal seals.

The glass components to be joined are held within the coil of a suitable HF generator while power is applied. As the metal temperature increases, the glass in contact with it is heated by conduction until it softens, flows over the metal and forms a seal. The metal and glass are often tubes of similar diameters jigged vertically so as to butt against each other with the glass uppermost. The seal is made by allowing the hot glass to flow under gravity on to the end of the heated metal.

This method, particularly, if the work is surrounded by an inert atmosphere has the advantage of being cleaner and more controlled than flame heating.

A useful application of this technique is illustrated in Figure 13. In this case the metal is in the form of a shim or washer which is used to join two glass components in a double 'back to back' glass to metal seal.

The two glass parts to be joined are the envelope and the two pin box of a quartz crystal holder. The plan shape of these is not cylindrical but an oval with straight sides, and this makes flame sealing extremely difficult, if not impossible.

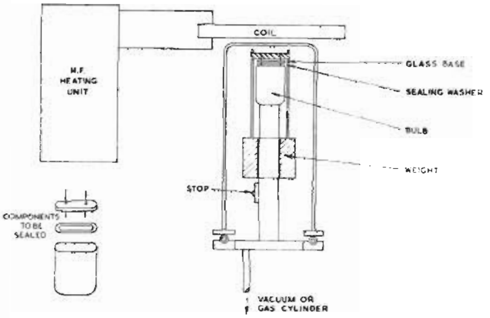

Figure 13 **Sealing of glass crystal holders**

The base and envelope are held in a jig with the washer between them. The jig is placed in a bell jar either evacuated or filled with an inert gas, and HF power is applied as shown. The washer which matches the bulb and base heats up, and the glass in contact with it flows to form the double seal. To ensure a satisfactory 'run in' a certain amount of collapse is allowed. The holder is then complete with the washer permanently embedded between the two glass components. Immediate annealing is required because of the strain set up by the very local melting.

In Fig. 14 a complete lead glass crystal holder is shown together with its separate components. The shim is .005″ thick and made from Nilo 475 (No. 4 alloy).

It is more usual, however, to use a hard glass with a Nilo K (Kovar) washer; this washer is often supplied embedded in the base itself and covered with a glaze. The final seal is then effectively glass to glass rather than glass to metal.

The same general method has been used to join small optical windows on to tubular glass bulbs where the distortion of the window had to be minimised.

High frequency heating is also used to make glass to metal seals in carbon moulds. In this method the carbon itself is heated by HF currents and acts as an oven to heat the glass and metal inside it. To preserve the hot carbon an inert atmosphere is, of course, essential.

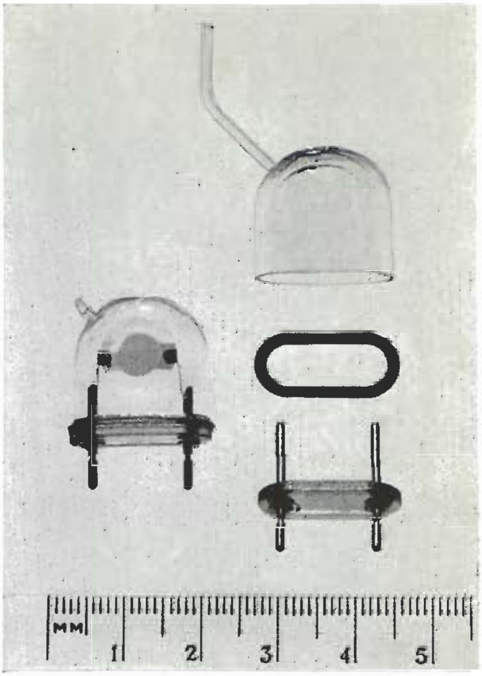

Figure 14 **Quartz crystal holder components**

This HF induction method where a metal component is heated should not be confused with the HF (or indeed low frequency) method of heating glass itself. This depends on the fact that if glass is preheated, for example by a flame, its electrical resistance will be lowered enough to pass a heating electrical current. This current can dissipate enough power in the glass to melt it. Glass tubes can be joined using this effect, but metal must not be present as this would effectively short circuit the hot glass.

Tubular Houskeeper Seals

Copper to glass tubular feather edged seals have been available for many years, and are still widely used although 'Nilo K' (Kovar) matched seals have tended to replace them. Diameters can range up to about 4″ but usually they are made in sizes up to 1″.

To accommodate expansion mismatch the metal at the edge of the copper tube is rolled to a 3 degree taper with a maximum edge thickness of .001″. The seal is made so that the metal is effectively embedded in the glass with a greater length of seal on the inside bore than on the outside. Most glass types can be sealed, the limit being set not by thermal expansion mismatch, but by the hardness of the glass. In practice any glass harder than tungsten sealing glass is difficult to use directly because the heat required to work it tends to damage the thin copper edge.

The copper tube is usually flared outwards near the seal. This increase in diameter prevents the glass sealed on the inside of the copper from restricting the bore diameter of the main tube.

More recently this technique has been extended from copper to stainless steel. Instructions for preparing suitable feather edge in stainless steel can be found in Reference 2. Seals made using tube prepared in this way are satisfactory, but as the steel has to be turned to the correct taper they are rather expensive.

Rolled feather edges in stainless steel (EN58B) have been developed to make a cheaper seal, and these are used in a 'sight tube' assembly (Figure 15) made only of stainless steel and glass. The assembly which is 13″ long overall incorporates a bellows to allow for installation misalignment, and can withstand 100 lbs/sq. inch internal pressure. Also shown in the photograph is a selection of small copper feather edged seals.

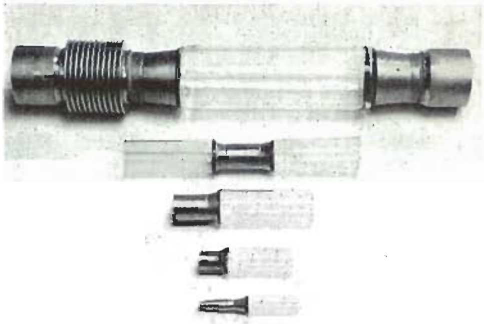

Figure 15 **Houskeeper, feather edge tubular seals**

References

(1) Glass to metal seals. J. H. Partridge, Society of Glass Technology, 'Elmfield', Northumberland Road, Sheffield, 10.

pp. 34–38	Preparing of metals for sealing
pp. 105, 113, 114	Oxide free seals

(2) Handbook of electron tube and vacuum techniques, Fred Rosebury, Addison, Wesley

pp. 54–64	Preparing of metals for sealing
pp. 64, 65, 66	Stainless steel Houskeeper seals

(3) British Patent Nos. 851068, 870297

(4) 'Moulded carbon components' Foundry Trade Journal, No. 2638, June 29th, 1967, pp. 3–7

PREPARATION, PROPERTIES AND APPLICATIONS OF GLASS-CERAMICS

Abstract of paper given at 1967 *Reading Symposium*

by B. P. Hodgson *Nelson Research Laboratories The English Electric Company Limited, Stafford*

Glass - ceramics which are polycrystalline materials made by the catalysed crystallisation of special glasses have outstanding physical properties and they have attracted considerable attention since their discovery.

The paper described the basic features of the method of preparation including nucleation and crystal growth processes in glasses, the selection of suitable glass types and nucleating agents and the crystallisation heat treatment process. The outstanding features of the process such as the ability to produce very fine grained ceramics of high strength, the relatively small dimensional changes which occur during crystallisation and the versatility of the materials, were discussed.

A general description was given of the mechanical, electrical and thermal properties of phosphate-catalysed glass-ceramics and comparisons were made with the properties of conventional ceramics and glasses. Wherever possible the properties of the glass-ceramics were related to their microcrystalline structure and to the crystal phases which are produced during heat treatment. The types of crystal phases present have a marked influence on the physical properties of the materials, particularly on their linear thermal expansion coefficients, and materials covering a wide range of thermal expansion coefficients (-4×10^{-6} per degree C to $+18\times10^{-6}$ per degree C) have been prepared.

Selected applications of glass-ceramics were discussed. These included their use for the production of improved insulator/metal vacuum seal assemblies by processes which exploit the versatility of the general method of preparation of glass-ceramics. The development of photochemically machinable glass-ceramics and their use in the production of micro-miniature devices for electronics and fluid logic applications was discussed. Other applications of glass-ceramics which were described included missile radomes, heat exchangers, telescope mirror blanks, cooking and table-ware.

BOARD OF EXAMINERS

FELLOWSHIP

The Board of Examiners have finalised the requirements for application for Fellowship of the B.S.S.G. from full and overseas members. As stated in the December issue of the Journal the scheme is based on a dissertation to be submitted by the applicant to the Secretary of the Board.

The thesis is to comprise two parts:—

Part One (one typewritten copy) giving details of the applicant's professional glassblowing career.

Part Two (three typewritten copies) giving details of knowledge and experience of the following subjects, including any original work.

Glassworking ability,
  a) Bench b) Lathe, c) *In-situ.*
Silica working.
Coil winding, glass and silica.
Bourdon gauge making.
Stopcocks, joints and valves.
Glass moulding and drawing.
Glass machining, grinding and polishing.
Metal to glass seals.
Graded glass seals.
Sintering and powder glass techniques.
Principles of glass cutting.
Properties of glasses.
Annealing, temperature measurement and control.
Glass cleaning methods.
Mercury cleaning methods and distillation.
Vacuum techniques including evaporation, sputtering, dewar pumping, gas handling and pressure measurements.
Metal deposition on glass including electro plating.
Metal joining, welding, brazing and soldering.
H.F. methods of heating.
Engineering and technical drawing including elements and furnaces.
Workshop design including safety requirements.
Adhesives.

The thesis must be under-written by two responsible persons, one on behalf of the applicant's employer.

All recommendation by the Board will be subject to confirmation by Council.

A. D. Wood and Jobling Cups

To save time at the Annual Symposium and to assist competitors for these cups, the Board have notified student members of a change in entry procedure. The entry pieces should be in the hands of the local section examiner by the end of July and in some cases section meetings will afford a suitable opportunity. All entries will, as usual, be displayed at the Annual Symposium. The list of examiners on this page should be of assistance to student members.

Certificate of Competence

Mr. Y. Williams, University of Ife, Nigeria, has joined the Society by taking the examination for the Certificate of Competence. This he passed at Isleworth Polytechnic on February 9th, 1968.

Isleworth Polytechnic

In June 1967, Isleworth Polytechnic ran a summer school in which the B.S.S.G. Syllabus was used and the Society provided an examiner.

All eight students who entered for the examination passed and have recieved certificates from the Society.

Brian Ferris, Raymond Gannon (winner of the A. D. Wood Cup, 1967), Keith Yates and Philip Meade were successful in passing the Part One examination of the City and Guilds Institute, Glass Manufacturing and Processing 362.

N. H. Collins

EXAMINERS

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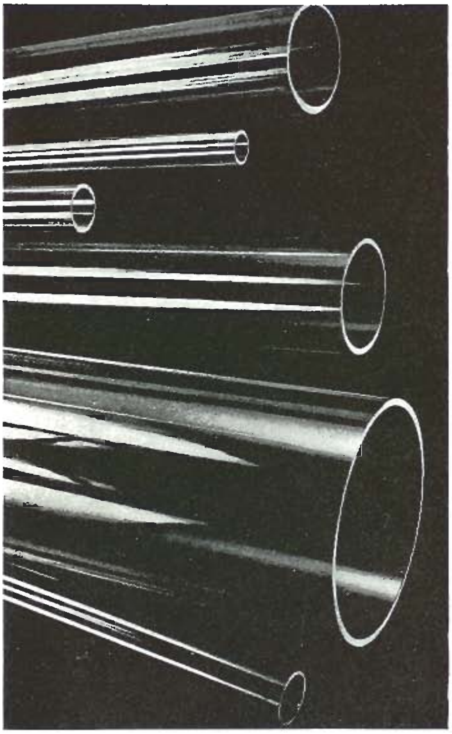

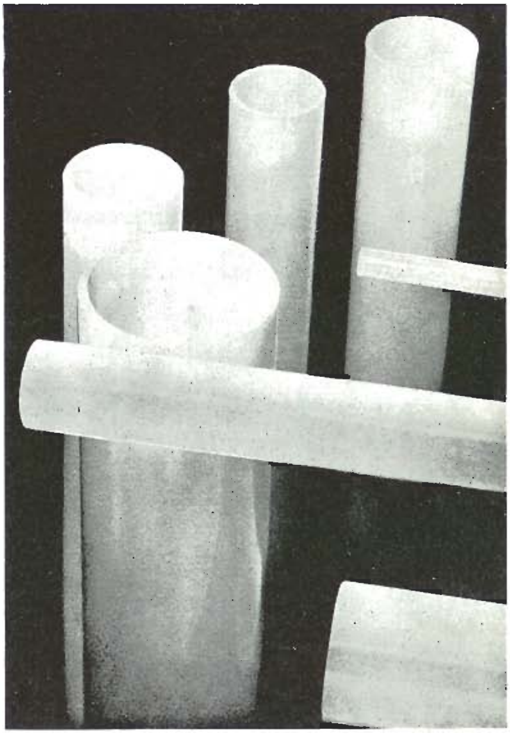

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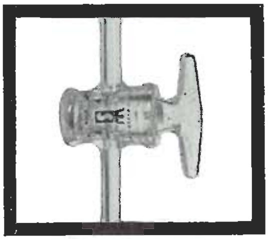

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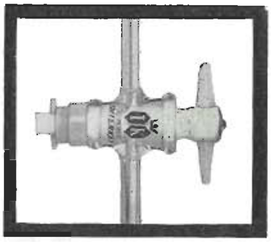

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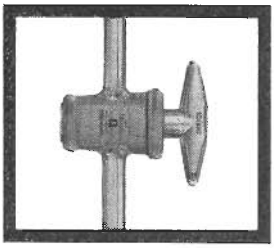

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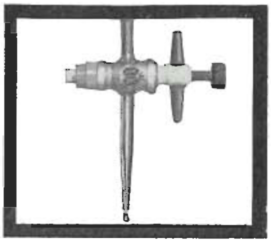

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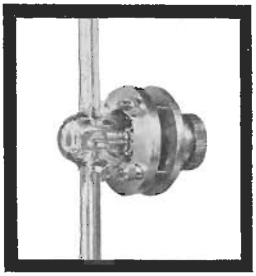

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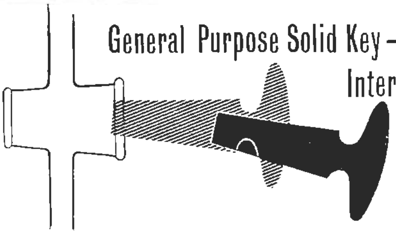

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ABSTRACTS

Compiled by S. D. Fussey

DISTILLATION

(464) Simple Float-and-Bell Device for Filling Bottles.

V. Vesely, *Chem. Anal.*, 56, 3, p.69, July 1967.

Distilled water is frequently collected in 5 or 10 gallon bottles. Full constructional details and drawings of a ball-valve operated device to signal when bottle is full. D.A.H.

(465) Technique for Internal Distillation–Condensation.

B. L. Johnson, *Jour. Chem. Educ.*, 44, 8, p.465, Aug. 1967.

Details of a semi-micro and large scale internal distillation apparatus. Essentially a refinement of the Soxhlet principle. F.G.P.

FIBRES, – GLASS

(466) A Simple Glass-Fibre Drawing Apparatus.

R. C. Devekey and A. J. Majundar, *Jour. Sci. Instru.*, 44, 10, p. 864, Oct. 1967.

Detailed account of the construction and operation of a vertical platinum resistance tube furnace which has been operated up to 1600°C. Tensile strength results of Pyrex and other glass fibres are given. Drawing and graph. D.A.H

(467) A Strong Carbon-Coated Silica Fibre.

G. A. Cooper, *Jour. Mat. Sci.*, 2, 3, pp. 206-210, May 1967.

A cheap and simple method of coating freshly drawn silica fibre by passing the hot filament through heated acetylene. The tensile strength of the fibre is dependent on the carbon coating thickness, the temperature of the fibre and the temperature of the acetylene. Optimum conditions gave fibres with a mean strength of 500,000 lbs./in^2. S.D.F.

FLOW-CONTROL

(468) A simple Flood Protection Device for Cooling Systems.

J. R. Forrest, *Jour. Sci. Instruc.*, 44, 4, p. 305, April 1967.

The system centres around a small 230V D.C. solenoid operated flow valve connected to the permanent water supply. A water-sensing element is placed either in the floor or at a point where water will run should a leak occur. Other relay contacts can be fitted to switch-off heaters or operate alarm systems. Details of electronic control circuit. D.A.H.

GAS-CONTROL

(469) A Simple Mercury Cut-off for Use in Gas Admission to Evacuated System.

D. H. T. Spencer, *Jour. Sci. Instru.*, 44, 4, p. 295, April 1967.

To prevent mercury being ejected into the evacuated part of the system when a U-tube type cut-off is used, a constriction 0.2 mm. bore, 5 mm. long is made in the pressure (gas) limb, giving 1 atm. pressure differential. Drawing. D.A.H.

(470) An Automatic Toepler Pump.

Marijon, Bufalini and J. E. Todd, *Jour. Chem. Educ.*, 44, 7, p. 425, July 1967.

A standard glass Töepler pump is operated by a photocell instead of internal contacts. Circuit F.G.P.

GAUGE-PRESSURE

A Simple Maximum Pressure Differential Gauge.

N. R. Way and M. Block, *Jour. Sci. Instru.*, 44, 4, p. 307, April 1967.

A gauge designed to determine the bursting pressure of relatively weak air filter papers in the pressure range 0–60 in/water gauge. Drawing. D.A.H.

Sensitive Differential Pressure Gauge for Corrosive Gases.

H. Blens, *Rev. Sci. Instru.*, 38, 10, p. 1527 October 1967.

A hollow glass spiral, sealed at the lower end is suspended inside a tubular glass enclosure. The reactive gas enters the spiral at the top and the non-reactive gas surrounds the spiral. A damping vane is attached to the lower end of the spiral. Sketch. S.D.F.

GLASS, – WINDOWS

Thin Glass Windows for Use in Fast Electron Irradiation Vessels.

R. Cooper and H. A. Kemphausen, *Jour. Sci. Instru.*, 44, 4, p. 306, April 1967.

Description of method for producing glass windows of thickness down to 0.0004 in. with excellent mechanical protection, high stability to pressure differentials and good thermal stability. When used with 1.0 MeV electron beams, only about 1% is lost. Diagrams. D.A.H.

GLASSBLOWING – BURNERS

A Dual Purpose Glass Blowing Torch.

D. Johnston, *Jour. Sci. Instru.*, 44, 4, p. 302, April 1967.

Pre-mix and surface-mix flames are produced with the same torch by means of an interchangeable nozzle assembly. Both borosilicate and alumino-silicate glasses can be worked with this torch. D.A.H.

LASERS

Fabrication of Wide Bore, Hollow Cathode Hg.+ Lasers.

H. Wieder, R. A. Myers, and C. L. Fisher, *Rev. Sci. Instru.*, 38, 10, p. 1538, October 1967.

A pyrex envelope containing a hollow tantalum cathode and two anodes has heaters to keep the mercury in the cathode region. Full constructional details together with sketch. S.D.F.

MATERIALS

Scientific American, 217, 3.

Sept. 1967.

The Solid State
The Nature of Metals
The Nature of Ceramics
The Nature of Glasses
The Nature of Polymeric Materials
The Nature of Composite Materials
The Thermal Properties of Materials
The Electric Properties of Materials
The Chemical Properties of Materials
The Magnetic Properties of Materials
The Optical Properties of Materials
The Competition of Materials.

Twelve very readable papers by different authors giving an insight to the nature and properties of materials. S.D.F.

MERCURY – CLEANING

A Convenient "Clean-up" of Mercury.

H. G. Gadd, *Chem. Anal.*, 56, 3, p. 70, July 1967.

A circle of soft polyurethane foam of suitable diameter and ⅛" thickness, inserted in an appropriate vessel, has been

found to be satisfactory as a filter for dirty mercury. The disc can be cleaned by washing and therefore used repeatedly.
D.A.H.

PUMPS – CIRCULATING

A Double-Acting All-Glass Circulating Pump.

F. Dawson, and S. Duncan, *Jour. Sci. Instru.*, 44, 5, p. 388, May 1967.

A glass-covered metal piston is driven by a ring magnet sliding on two-parallel rods, over a range of 5 to 100 strokes per minute. The flow rate, which is governed by the speed of the magnet, can be varied from 0.25 to 6 litres per minute. The pump has been designed for use where chemical or radioactive contamination is a problem. Photo and sketch.
D.A.H.

A Demountable Glass Circulation Pump with Variable, High Pumping, Speed.

J. E. Gustavsson, *Jour. Sci. Instru.*, 44, 10, p. 860, Oct. 1967.

A piston type pump with a double non-return valve system, allows the apparatus to pump for each half-cycle stroke. The valves are made from ball joints, while the soft iron piston is enclosed in Teflon. By changing the length of the piston stroke, the flow rate can be varied from 0.8 to 8 litres/min^{-1}. Drawing.
D.A.H.

SEALS – LIQUID

Gas-tight Thermobalance-load Seal.

V. Vasantasree, D. A. Pantony and M. G. Hocking, *Jour. Sci. Instru.*, 44, 9, p. 791, Sept. 1967

The point of entry of the wire to a corrosive atmosphere is sealed by a drop of liquid which, in this case, is concentrated sulphuric acid, being held by capillarity in a constriction in the glass. Sketch.
D.A.H.

THIN FILMS

Low Power, Self Heated Glass Substrate.

J. F. O'Hanlon and R. R. Haering, *Rev. Sci. Instru.*, 38, 10, p. 1542, Oct. 1967.

Description and sketch of a substrate heater for use in the vacuum deposition of thin films. Important features are its short time constant and extremely low power requirements; e.g. thermal equilibrium achieved in 10 mins., 4 watts dissipation gave a temperature of 200°C.
S.D.F.

TRAP, – COLD

An electrically Insulating Cold Trap.

S. K. Handel, *Jour. Sci. Instru.*, 44, 4, p. 312, April 1967.

To electrically insulate a discharge from the pumping system, a length of pyrex tube 150-200 mm. long and 74 or 80 mm. diameter, is inserted via "O" rings. A container 38 or 40 mm. diameter is sealed into the side of the tube to form a trap for liquid nitrogen.
Pressures of 10^{-6} and 10^{-7} Torr maintained. Drawing.
D.A.H.

VACUUM – PUMPS

Gas Contamination in a Field-ion Microscope Pumped by Sputter-ion Pumps.

D. S. Whitmel, *Jour. Sci. Instru.*, 44, 9, p. 802, Sept. 1967.

Investigation shows that unless amounts of helium and hydrogen admitted to the pump are restricted, the life of that pump is reduced owing to re-emission of gas when heated. Estimated life, approximately 5,000 hours at 1 u Toor. Sketch.
D.A.H.

WINDOWS

Gas-Tight Metal Foil Windows.

D. C. Robinson, *Jour. Sci. Instru.*, 44, 5, p. 392, May 1967.

Microscopic holes in nickel foils 1 u m. thick and 0.79 cm. diameter were sealed with three separate layers of formvar with a total thickness of approximately 0.03 mg. $cm.^{-2}$. The films were formed by allowing a drop of formvar solution to spread on the surface of distilled water.
The films are then removed on a wire loop and applied to the nickel foil. Excellent adhesion of film to metal was achieved.
D.A.H.

MISCELLANEOUS APPARATUS.

(464) Hand Operated Micro Applicator to Deliver Drops of Five Sizes.

A. J. Arnold, *Lab. Prac.* 16, 1, 56, Jan. 1967.

Ready selection of drop size, rapid changing of syringes and ability to mount the apparatus in any position is claimed. Photograph and sketch.
B.R.W.

(465) Clamp for Low Temperature Experiments.

Lab. Prac., 16, 3, 346, March 1967.

Short article and photograph of a dewar clamp with features not ordinarily available in low temperature apparatus B.R.W.

(466) The Technician as an Apparatus Designer.

A. Mitchell, *Lab. Equip. Dig.*, 5, 4, 84 and 86, April 1967.

Description of an evaporator using a stream of hot nitrogen passing through Pasteur pipettes. Also a description of a simple jig for cutting glass cover slips.
B.R.W.

Photochemical Oxidation of Aqueous Iodide Solutions.

Ayscough, Burchill, Twin and Logan, *Jour. Chem. Educ.*, 44, 6, p. 349, June 1967.

Article describing a teaching laboratory experiment in which hydrated electrons are formed by a photochemical method. Full description of reaction vessel and bubbler.
F.G.P.

Low Temperature Fused Salt Experiment

C. T. Moynihan, *Jour. Chem. Educ.*, 44, 8, p. 531, Sept. 1967.

Details of electrodes and bridged glass tube used for measuring conductivity, viscosity and density of molten calcium nitrate tetrahydrate.
F.G.P.

A Technique for De-gassing Liquid Samples.

R. E. Rondeau, *Jour. Chem. Educ.* 44, 8, p. 531, Sept. 1967.

Simple degassing method for removing all traces of air from NMR and ESR samples using a liquid-air trap.
F.G.P.

Micro Boiling Point Apparatus at Atmospheric Pressure.

M. C. Chaco, 44, 8, p. 475, Aug. 1967.

A small capillary tube within a large capillary tube is used to determine melting points of micro quantities of liquids.
F.G.P.

A Thermostatic Bath for temperatures between 90° and 300° K.

T. Aylmer-Wood, *Jour. Chem. Educ.*, 44, 7, p.423, July 1967.

Gives details and method of operation of variable temperature bath using liquid nitrogen as a refrigerant of a cooled bath liquid.
F.G.P.

Simple Dropping Apparatus, for the Victor Meyer Apparatus.

M. D. Murphy, *Jour. Chem. Educ.* 44, 7, p. 395, July 1967.

Shows a simple method of introducing a sample in Victor Meyer apparatus. Tube is supported on a thread which is severed by rubbing action on unpolished tube end.
F.G.P.

Laboratory Experiments in Low Temperature X-ray Diffraction.

Rueben Rudman, *Jour. Chem. Educ.*, 44, 6, p. 331, June 1967.

Cooling apparatus of basically a double walled dewar with thermocouple enabling cold and warm gas to be passed. F.G.P

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UNITS

COEFFICIENTS OF EXPANSION AND WAVELENGTHS OF LIGHT

For practically all solids the coefficient of linear expansion has been given, using a multiplication factor of 10^{-6}, but for glass alone some workers, particularly on the foundry side, have used the factor 10^{-7}, and this can lead to confusion: however at a meeting of ISO/TC48 in Frankfurt in October 1966, the decision was made, at least for laboratory glassware and glass engineering purposes, to use the factor 10^{-6} bringing glass into line with other solids, frequently used in conjunction with it. It will therefore be the policy of this Journal to use only the factor 10^{-6} and to convert as far as possible any writings or reports given to this scale.

When the above was under discussion at Frankfurt, it was pointed out by a representative of the Bureau International des Poids et Mesures, that it was present policy to use factors in multiples of three. Examples are given below.

The last unit is now preferred for wave-lengths of light, the visible band being between 300 and 800 millemicron, $m\mu$. Infra red carries on at 1μ upwards. The Angstrom is 10^{-10} metre and was originally devised as being close to the diameter of an atom, and had been picked up for wave-lengths of light.

An advantage of the 10^{-6} factor for coefficients of expansion is that the figure given alternatively represents microns per metre per degree Centigrade, and can simplify calculations. A metre length of steel or of glass for instance of expansion 10, raised 100°C, will expand 10×100 microns or 1 millimetre. Likewise for volumetric expansions, the figure represents microlitres per litre per degree C.

In the case of light wave-lengths one simplification is in the use of interference wave-bands when checking surfaces. One wave band per centimetre is equivalent to a wedge or slope of half a wave-length per centimetre. Using light of say $500 m\mu$ (5000 Å) the wedge is $250\ m\mu$ high, or $\frac{1}{4}$ micron per 1 centimetre slope.

factor	*prefix*	*symbol*	*example*
1 000 000 = 10^6	mega	M	megawatt MW megaton Mtn
1 000 = 10^3	kilo	k	kilowatt kW kilometre km
0.001 = 10^{-3}	mille	m	millimetre, mm
0.000 001 = 10^{-6}	micro	μ	micron or micrometre, μ or μm
0.000 000 001 = 10^{-9}	nano or millemicro	n $m\mu$	millemicron $m\mu$

I. C. P. S.

HIGH POWER GAS LASERS

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1. Introduction

Since the first demonstration of laser action seven years ago a large research effort has been put into the development of various types of lasers and their applications. The reasons for this are the unique properties of laser beams and the great potential of such light sources in scientific research and civil and military applications.

These properties may be summarised as follows:—

1. Monochromatic	(narrow spectral line width – about seven orders of magnitude smaller than the sharpest line produced by conventional means).
2. Coherent	(the light wave is continuous in space and time, like a radio wave).
3. High power	(continuous powers greater than 1 kW and pulse powers greater than 10,000 MW have been produced).
4. Parallel beam	(a spot of less than 1 mile in diameter can be produced on the moon. Because of the above properties the beam can be focussed to a spot only microns in diameter producing power densities $\sim 10^{16}$W/cm^2 – many orders of magnitude greater than has ever been produced before).

Laser action has now been produced in solids, liquids and gases. Apart from the ability of the solid lasers (mostly ruby and neodymium doped glass) to produce very high power pulses for very short times (less than 1/1000 microsecond) the gas laser has been shown to be superior in most other respects.

By suitable choice of gas or mixture of gases the output wavelength can be chosen anywhere from the quartz ultraviolet near 200 $\sim$ to the far infrared at 0.4 mm.

Because of the good optical homogeneity of low pressure gases, systems may, from the optical point of view, be scaled up to produce higher powers. There is a number of fundamental limitations, however, on the size of systems and limitations on the ultimate power obtainable from gas systems. These limitations will be discussed together with possible means of overcoming them.

2. Laser principle

An atom can absorb energy and increase its own internal energy. This internal energy increase cannot have any random value, the atom can only be raised to a certain number of levels. For an atom to be raised to one of these levels by absorbing light energy (which it does in discrete quantities – called photones) the photon energy must be exactly equal to the energy jump required. The energy of a photon is inversely proportional to the wavelength of the light. Thus only light of a particular wavelength can cause a given energy jump. This process, producing the loss of a photon (absorption), is shown in figure 1a.

When an atom is in an excited state it can fall back to its normal state (ground state). Energy is released from the atom as light – the wavelength of the light being the same as that required to excite the atom in the first place. This spontaneous emission process occurs a time after the absorption depending on the atom and the level. The time can be from fractions of a microsecond to seconds. This process is shown in figure 1b.

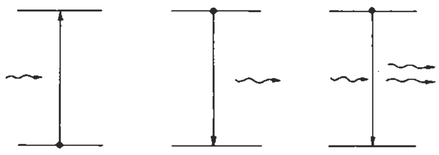

FIG. I. a) ABSORPTION b) SPONTANEOUS EMISSION c) STIMULATED EMISSION

A further phenomenon, discovered from theoretical consideration by Einstein in 1917 is known as "stimulated emission". When an atom is in an excited state the atom can be made to fall back to its normal state in a time much shorter than the spontaneous life-time. This is by the "impact" of a photon whose energy is equal to the energy level difference. The photon that is emitted by the atom travels in the same direction and has the same wavelength as the colliding photon. In addition the waves of the two photons (electromagnetic) are exactly in phase. This process producing a gain of light energy is shown in figure 1c.

The above three processes can occur between two levels neither of which is the ground state. The processes of absorption and stimulated emission are equally probable such that a beam of light of correct wavelength, travelling through a medium where there were more atoms in an upper excited state than in a lower excited state, would be amplified.

The invention of the LASER (standing for Light Amplification by the Stimulated Emission of Radiation) required the solving of two problems.

1. How can more atoms be raised to an upper useful level than a lower level?
2. How can the resulting gain be used to produce light output?

The first problem could be solved by finding a material whose atoms had three energy levels with the following properties:— (see figure 2)

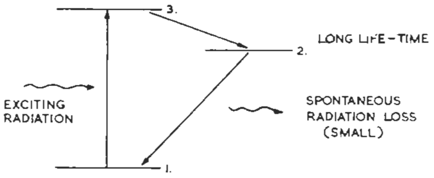

FIG. 2. SCHEME FOR PRODUCING MORE ATOMS IN AN UPPER STATE (2) THAN IN A LOWER STATE (1)

(a) Atoms can be raised from the normal (ground) level (1) to the highest level (3) by absorption of photons.

(b) Instead of the atom spontaneously jumping back to the ground level it jumps to a lower level (2). (The excess energy must be given off as light or heat).

(c) Level 2 must have a long life-time so that atoms can be excited to the level faster than they fall back to the ground level. Eventually there would be more atoms in level 2 than level 1.

The first material discovered with these properties was ruby. Since then it was found that if in some material the lifetime of level 2 was very short and that of level 3 long then more atoms could be produced in level 3 than in level 2. This latter situation was one which was found to be a property of many gases.

The second problem was solved by placing the amplifying medium (in the form of a rod) between two parallel plane mirrors (see figure 3). The light to be amplified is, at the start of the process, the spontaneous emission produced by atoms falling back to the ground level (1) from level 2. This radiation is emitted in all directions. Photons which are emitted at an angle to the axis of the rod either pass quickly out of the rod through the curved surface or do so after a few reflections at the mirrors. Only photons emitted along the axis of the rod stay in the system. These will pass up and down the rod continually being augmented by the photons they produce by stimulated emission. Because of the property of stimulated emission all the photons will be in phase. (An additional property of the parallel mirror system is that light with a wavelength that is an exact sub-multiple of twice the length of the "cavity" is preferentially amplified. This leads to very narrow line widths within the normal spontaneous emission linewidth and plays a major part in establishing a coherent wave throughout the rod). Light is obtained from the system by making one of the mirrors partially transmitting.

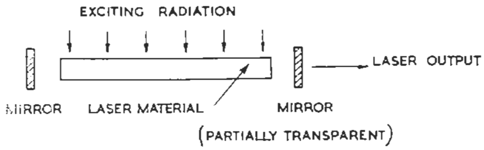

FIG. 3 SCHEMATIC DIAGRAM OF A LASER

In the ruby laser, discovered by Maiman in 1960, the excitation from level 1 to 2 was produced by the light from a xenon flash lamp. Only the radiation in the green part of the spectrum could produce this excitation. In gas lasers, as will be seen, the most common means of excitation is by electron collision.

For a coherent wave to build up within the reflecting cavity the overall double pass gain must be greater than 1. Because losses occur on reflection (especially at the output end) and scattering and absorption losses can occur in the laser materials, sufficient gain must be provided to overcome the losses. This condition when obtained is known as "threshold" and is the time when laser action commences.

It was found that by using concave mirrors instead of flat mirrors losses due to light being diffracted outside the mirrors could be reduced. This is particularly important in gas systems where the gain per pass is not very large.

3 Brief history

Shortly after the discovery. in 1960 of the ruby laser (emitting radiation at 694.3μ) the first gas laser was discovered by Javan, Bennet and Herriot. This was the helium-neon laser giving an output at 1.15 microns. During the following two years improvements were made on this laser and a number of other infrared gas lasers were discovered, including those employing other noble gases and oxygen.

In 1962 the gas laser began to show even greater promise when the helium-neon laser was made to emit red light at 632.8μ. Since that time this laser has undergone a great amount of development leading to higher power (over 100 mW) and a more compact system.

Meanwhile it was becoming evident that far from being a property of only a few gases, laser action could (under the correct conditions) be obtained from almost any gas. Of particular significance were the discoveries of laser action in pulsed discharges in nitrogen and carbon-monoxide by Mathias at S.E.R.L., Baldock.

All the gas systems up to nearly the end of 1963 were based on transitions in neutral gas atoms, that is, atoms with their full complement of electrons. It was soon found, however, that transitions in ionized atoms (atoms with one or more electrons removed) could also lead to laser action. Following the discovery of the mercury-ion laser came the discovery in 1964 of a new powerful visible laser – the argon-ion laser. This laser was made to emit simultaneously several wavelengths extending over a large part of the visible spectrum. Unlike many of the other systems which could only be made to emit pulses of light, the argon-ion laser could be run continuously. Total output powers of greater than 10 watts have been obtained.

In the attainment of higher powers a constant worry was the low efficiency of conversion of electrical power (used to excite the gases) into laser output power. Typical figures for the He-Ne and Argon-ion lasers are 0.1 % and 0.02 % respectively. (The cause of this low efficiency will be discussed later). In 1965, however, Patel discovered a laser with an efficiency greater than 10 %. This was the carbon dioxide laser with an output wavelength of 10.6 microns (or about $\frac{1}{2}$ thou). This is a molecular laser, the transitions occurring between energy levels of the whole CO_2 molecule. Continuous outputs of over 1 kW have now been obtained with the development of this laser.

The quest for higher power continues, particularly for high power at visible wavelengths. A number of possible future developments will be discussed together with some applications for high power gas lasers.

4. Types of gas lasers

As seen, laser action has been obtained using (a) neutral atoms, (b) ionized atoms and (c) molecules.

Excitation of the laser to produce the "threshold" condition can be achieved by

(a) optical absorption
(b) electron collision
(c) collision with an excited atom.
 (This excited atom is usually produced by electron collision).

With optical excitation only a narrow spectral range of the output of most high power lamps can be used for the excitation of gases. Most gas lasers, in fact, use electron collisions because all electrons above the excitation energy can be used to "pump" the laser. High velocity electrons can be produced by passing a current between electrodes in the gas or by producing an R.F. discharge using external electrodes. Both methods are used.

The practical details of gas lasers and the limitations on the highest powers obtainable vary significantly depending on the gas, the method of excitation and the wavelength of emission. These will be exemplified by considering three lasers: He-Ne (neutral atom), Argon (ion) and CO_2 (molecular).

4. 1 Helium-Neon Laser

The energy level diagrams for He and Ne are shown in figure 4. Atoms are excited to either of two levels in He by an electrical discharge. It happens that both of these levels coincide very closely with two levels in Ne. When an excited He atom collides with an unexcited Ne atom the He atom can give up its energy to the Ne atom. This excitation of neon leading to more atoms in upper levels than lower levels can produce laser emission at 3391.2μ, 632.8μ or 1152.3μ depending

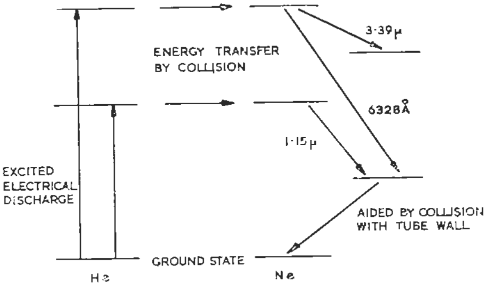

FIG. 4. ENERGY LEVEL SCHEMES OF HELIUM AND NEON SHOWING LASER TRANSITIONS

on the reflectivity of the mirrors at these wavelengths. The emission at 632.8μ being in the visible is the one of greatest interest.

Notice particularly that the lower laser level is still an excited level. In order that the laser cycle can be continuous the atom must return again to the ground level. In this laser the process is achieved by collision with the walls. If the diameter of the laser tube is increased, to obtain more power, the ratio of surface area to volume is decreased. This reduces the efficiency of the de-excitation and eventually places an upper limit to the tube diameter.

Similarly, if the excitation power is increased, eventually the atoms in the lower laser level will not be able to be de-excited fast enough. The number of atoms in this level will increase until there is insufficient gain to produce lasing. (In addition at high currents the upper laser level tends to be depopulated by electron collisions).

Figure 5 shows a diagram of an R.F. excited He-Ne laser. The tube is typically 4 feet long, 5 mm in diameter and made of silica. The windows at the ends of the tube are tilted at the "Brewster" angle to minimise reflection losses. They are made of high optical quality silica and are usually sealed onto the tube using quasi-optical seals. The high optical quality is required to reduce losses due to scattering and absorption and to maintain the good optical properties of the laser beam. Light may have to pass more than 100 times through each window before being transmitted out of the system.

The mirrors are multi-layer, dielectric coated to give high reflectivity in a narrow spectral range with small absoprtion losses. One of the mirrors is made as near to 100% reflecting as possible and the other about 98% reflecting at the wavelength at which laser action is required. The radii of the mirrors are usually made equal to the mirror separation, the focus of each mirror then being at the centre. This gives small diffraction losses and a good quality laser beam. The optimum gas filling is about 1 torr helium and 0.1 torr neon.

The two most significant developments of this laser in the attainment of higher power have been the conversion to D.C. excitation and the production of pulsed discharges.

(1) A D.C. discharge between heated electrodes in side arms has led to a more efficient system and reduced the overall size. Typically a power of 1 mW is obtained from a ½ metre long tube with an efficiency of about 0.1% (The reason for this low efficiency is that part of the energy is required solely to maintain the gas discharge. In addition, many of the excitations produced have nothing to do with the laser process and may even hinder it). Over 1 W has now been produced continuously from a 5 metre long tube.

(2) By pulsing the discharge the relative number of atoms in the upper and lower laser levels compared with the D.C. case can be increased for a short while. The laser pulse stops when the lower level population has built up such that net gain is no longer possible. Because de-excitation of the lower level is not required there is no limitation on the tube diameter from this cause.

Peak powers of over 200 watts have been produced for about 0.25 microseconds. A pulse repetition rate of over 500 p.p.s is possible.

Probably because other gas lasers have given higher power with the same volume little work appears to have been done to increase tube length. The limitations on length will be discussed in connection with the CO_2 laser.

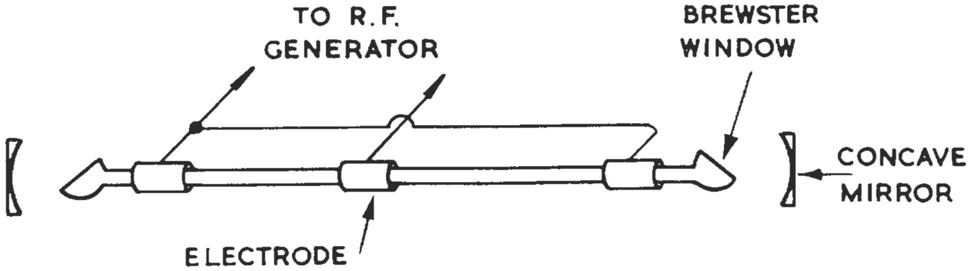

FIG. 5 DIAGRAM OF THE HELIUM-NEON LASER

4.2 Argon-ion laser

Figure 6 shows the relevant energy levels of singly ionized argon. This laser can either be excited continuously or in pulses, both by an electric discharge. In the continuous laser (where the voltage gradient is small) excitation is thought to occur in several steps by electron collision. In the pulsed laser (where the voltage gradient is high) single step excitation is possible.

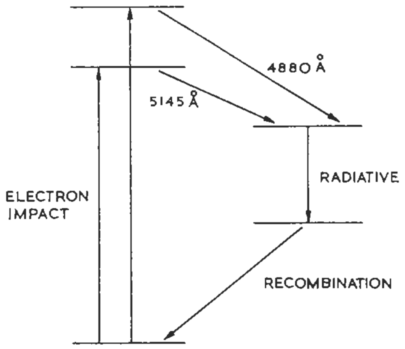

FIG. 6 ENERGY LEVELS OF SINGLY IONIZED ARGON SHOWING PRINCIPLE LASER TRANSITIONS

By using wide-band reflecting mirrors it is possible for the argon-ion laser to emit several wavelengths simultaneously. The most powerful emission occurs at 488μ and 514.5μ although about 10 other lines have been observed.

De-excitation of the lower laser levels appears to be a much more efficient process than in neutral atom lasers. The mechanism is probably by radiation of light and the capture of an electron (recombination) forming a neutral atom again.

In order to maintain a high population of excited ionized argon atoms a considerable current density is required (greater than 100A/cm^2). This has two consequences on the practical design of a laser tube.

(1) To supply enough electrons at reasonable tube voltages a heated cathode must be used. This is usually a tri-carbonate cathode similar to that used in large thyratrons.

(2) Because of the practical difficulty of obtaining high currents at high voltages the bore of the tube has to be kept small (about 2 mm).

The power input for 1 W of laser output is typically about 5 kW. The remaining power is eventually dissipated as heat in the laser tube. Without cooling, the silica tube would melt and so water is circulated around the capillary.

Figure 7 shows a typical D.C. excited ion laser tube. A gas return path must be provided since the ion pump action which occurs in the capillary would produce a pressure gradient leading to a decrease of efficiency. A typical gas pressure for the argon is 10 milli-torr.

The above structure, however, suffers from serious deficiencies that make it a not particularly long-lived or reliable device. The interface between silica capillary and cooling medium has a small area and since silica is a notoriously poor conductor of heat, this places a limitation on the power dissipation per unit length of capillary that can be tolerated. An even more serious problem is that the high plasma (highly ionized gas) temperature and ion bombardment in a D.C. discharge cause physical changes in the silica itself. This results in erosion, strains and eventual

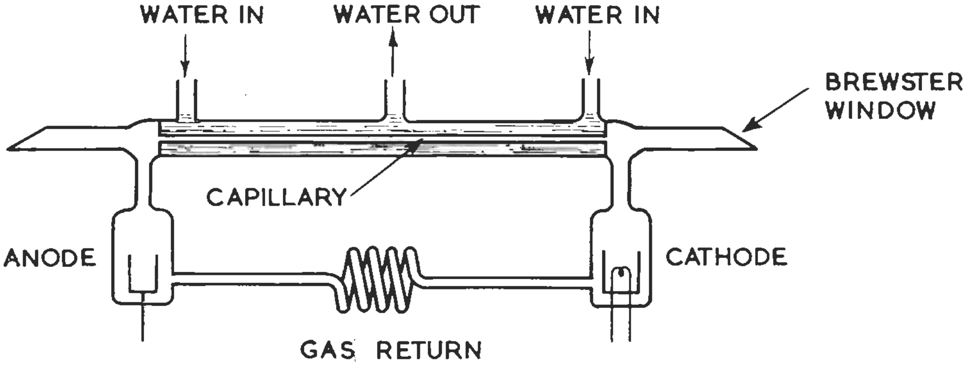

FIG. 7 TYPICAL D.C. EXCITED ARGON-ION LASER TUBE

destruction of the capillary walls.

Improvements have been made using high temperature ceramic materials for the bore or alternatively using short sections of low sputtering metals (the lengths being chosen so that the discharge is not short circuited). Magnetic confinement of the current has also been tried with success. At very high current densities, however, these improvements still do not produce the desired long life.

A different approach which virtually eliminates capillary erosion is to use R.F. excitation. The novel technique being used is to excite the discharge in a ring, generally a square or rectangle, one side of which is the water-cooled laser capillary, the ring constituting a single turn of an R.F. transformer (figure 8). The R.F. excitation does away with the electrodes and since work does not have to be done to accelerate electrons from rest each time to produce an ionizing collision, the power dissipation is reduced.

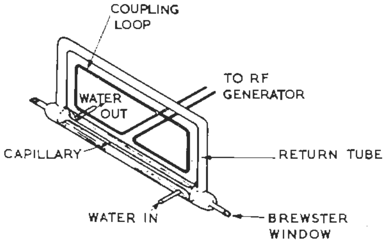

FIG.8. C.W. RF-EXCITED ARGON-ION LASER TUBE GIVING LONGER LIFE

4.3 Carbon-dioxide laser

In carbon dioxide the energy levels result from the vibration of the carbon atom and oxygen atoms relative to one another. The relevant energy levels of the molecule are shown on the right of figure 9. The laser output occurs at 10.6 microns.

The upper laser level can be populated by a variety of means. Initially direct excitation by electron collision (R.F. discharge) was demonstrated. It was later discovered that adding nitrogen produced higher laser power. The nitrogen helps populate the upper laser level by virtue of a close coincidence between this level and an excited level of nitrogen. A collision between an excited nitrogen molecule (previously excited by electron collision) and an unexcited CO_2 molecule results in energy transfer (see figure 9).

Since that discovery it was found that helium added to the mixture increased the power output still further. It has been speculated that helium, besides helping to populate the upper level, also assists in some way in emptying the lower level (which is normally emptied by radiative decay).

Other additives such as water vapour are also thought to assist in emptying the lower level, a very desirable contribution to the attainment of very high output powers.

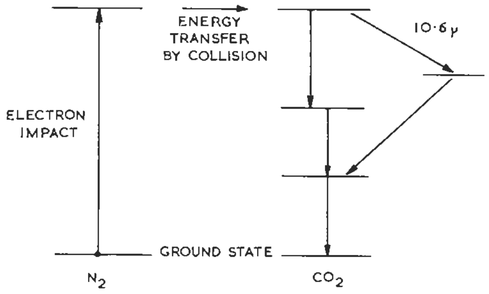

FIG.9 ENERGY LEVELS OF NITROGEN AND CARBON DIOXIDE MOLECULES SHOWING RELEVANT LASER TRANSITIONS

The lower laser lever can get repopulated by collisions from below due to the thermal motion of molecules and electrons. It is therefore necessary in high power systems to cool the gas to prevent this occurrence.

Figure 10 shows a typical laser system. Because glass is opaque to radiation at 10.6 microns either Brewster angled windows of special materials (e.g. NaCl) or internal mirrors must be used. The latter are more commonly employed.

The mirrors are usually made of stainless steel and coated with gold. This gives a high reflectivity in the infrared and allows conduction of heat away from the film thus preventing damage. The mirror radii are made several times the length of the tube. This allows more of the gas volume to be efficiently used. The mirrors are sealed onto the tube using a glass-to-metal seal, phosphor bronze bellows (to allow for adjustment) and O rings. The output from the laser is obtained through a hole in one of the mirrors. A window of NaCl or IRTRAN 2 (polycrystaline ZnS) is cemented over the hole.

Excitation is by R.F. discharge between two wires running the length of the tube or by D.C. discharge between internal electrodes.

A typical tube 6 feet long and 3 inches in diameter is capable of continuous laser output power of about 50 watts. The output hole would be about $\frac{1}{2}''$ in diameter. The overall efficiency of such a system is about 10% (i.e. 500 watts electrical input power required).

The optimum gas filling in the above system is 0.7 torr carbon-dioxide, 1.5 torr nitrogen and 10 torr helium.

There are two main reasons why this system is capable of such high powers.

(1) The upper laser level has a long lifetime (about 1 m. sec.).

(2) The walls of the laser tube are not required to produce de-excitation of the lower laser level as in the He-Ne laser case. This means that the diameter of the tube is not limited from this cause.

The limitation on diameter is set by how uniform the gas can be excited and how well the laser beam between the reflectors (a complicated distribution) can gain energy from the molecules in all parts of the tube. By experience there has been little more power obtained in going to tube diameters greater than 3 inches.

The only limitation on length, apart from practical considerations, is diffraction loss. A beam of light with a finite diameter cannot be made perfectly parallel, but has an intrinsic divergence. The divergence angle ($\sim$ milliradians for visible radiation, 1 cm in diameter) is inversely proportioned to the beam diameter and proportional to wavelength. This means that for a very long laser tube (and particularly in the infrared) a significant part of a "parallel" beam leaving one mirror will go beyond the edge of the mirror at the other end. When this loss becomes comparable with other losses in the system (mainly reflector losses) there is no point in further increasing the length of the tube.

One possible solution is to let the beam diffracted round the sides of one of the mirrors become the (annular) output beam thus avoiding the necessity of having a hole in one of the mirrors. This idea is currently being investigated in this country.

The diffraction limit has not been reached however. Recently, in America, a tube 20 metres long has produced a continuous power output of over 1000 watts. This is capable of burning a slot through a $\frac{3}{4}$″ thick block of wood at 18 inches/second or burning through an 18 mm silica tube in 2 seconds !

Because the upper laser level has a long lifetime (under non-lasing conditions) a large number of molecules can be "stored" in this level if lasing is prevented. Lasing can be prevented simply by misaligning one of the mirrors. If after excitation this mirror is suddenly made parallel with the other mirror (by rotating it using a high speed motor) then the laser process can start. Since there are many more molecules in the upper level than usual a very large gain can be produced down the tube. A much more rapid build up of power results and a very high peak power produced. The pulse terminates when there are not enough molecules in the upper level in excess of those in the lower level to produce sufficient gain to overcome losses. Peak powers of over 100 kW for

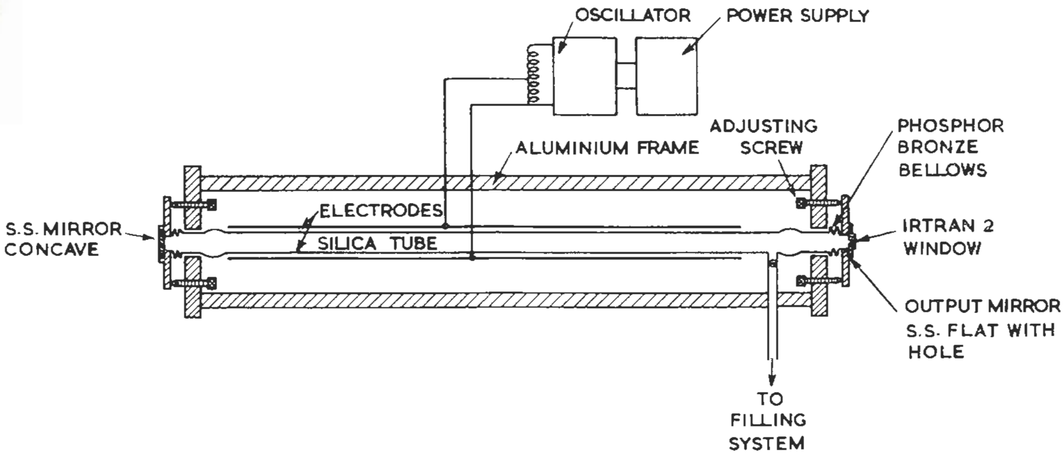

FIG. 10 CARBON DIOXIDE LASER SYSTEM

about 20 nanoseconds (20×10^{-9} seconds) have been produced.

5. Future systems

The higher the power of lasers the greater the number of applications that become possible. The quest for still higher power will continue and as technology improves so systems previously thought impracticable will be tried. (There is much research directed towards improving the quality of the laser beam and in obtaining more control of its characteristics – this will not be dealt with here).

I would like to give a few indications of how I think future systems will develop and how the present problems on power limitation may be solved.

5.1 Collisional de-excitation

It was seen that in the high power systems discussed, one of the major limitations on continuous high power was the rate at which atoms (or molecules) could be removed from the lower laser level. By the addition of a gas which has an energy level jump equal to the de-excitation energy required to be dissipated, it should be possible to transfer this energy by collision. With this limitation removed much higher pumping rates will be possible. In addition, higher gas densities will be able to be used producing greater volume efficiency.

5.2 Optical pumping

With electron excitation a time comes when increasing the current removes as many atoms from the upper laser level as are put there. The reasons for this can be complex since many processes are involved in a gas discharge. Basically the cause is the unselective nature of electron collisions. Besides producing unwanted excitations electrons dissipate much energy in increasing the kinetic energy of atoms, that is increasing the temperature of the gas.

Optical radiation on the other hand is very selective, only the correct wavelength will produce a given transition. If sufficient power can be produced at the correct wavelength, laser powers higher than produced by electron excitation may be possible. The efficiency of conversion is expected to be lower however, since it is difficult to produce high power in a single narrow line. This may not matter if the ultimate laser power obtained is higher.

A system combining optical pumping with collisional de-excitation is at present being investigated at A.W.R.E. A continuous power in the visible of several hundred watts is theoretically predicted. Special care has to be taken to avoid "self-reversal" of spectral lines. This is a phenomenon in discharge lamps where the emission at the centre of a spectral line is absorbed in the cooler layers of gas near the walls of the lamp. This removes the most useful part of the emission.

5.3 Large systems

Already lasers of over 20 metres (65 feet) in length have been constructed. Until a fundamental limitation (like diffraction) on length is reached there is no practical reason why systems hundreds of yards in length should not be constructed.

For obvious reasons it may be more convenient to contain a large system within a room or to make the system transportable. There is much effort at present aimed at developing a "folding" system where the laser beam is bent through two right angles at the end of one tube and passed down another tube next to the first.

It may be feasible to construct very large systems in space using orbiting mirrors. Since both nitrogen and oxygen have exhibited laser action a gas enclosure would not be required. This pre-supposes that at the orbit height the gas pressures were suitable. The excitation source to be used (the sun?) and the possible applications such a monster would have are matters for speculation.

5.4 New excitation sources

The two basic methods of exciting lasers have been described – optical radiation from a discharge lamp and a direct electrical discharge in the laser gas. If pulsed or remote operation is required energy is usually stored in batteries or capacitors. There are, however, sources of energy which are far more compact. Examples are – nuclear fuel, explosives and superconducting coils. Solid lasers have already been pumped using light from conventional explosives. Even the sun has been used to pump these lasers. Undoubtedly these and other energy sources will be investigated in connection with the excitation of gas lasers.

5.5 New gases

Recently a new family of neutral atom gas lasers has been discovered. These use metal vapours – lead, manganese and copper. Laser action is obtained for a short duration by electrically pulsing the laser tube. Very high gains have been produced and high efficiencies (30%) claimed. The laser outputs are in the visible. It may be possible to keep the lifetime of the lower state sufficiently short for a pulse rate to be maintained high enough to give a mean power higher than any continuous system.

5.6 Frequency doubling

When high power radiation is incident on some crystals (e.g. KDP) some of this radiation is converted into radiation at twice the incident frequency (half the wavelength). For example 530μ radiation has been obtained by frequency doubling the 1.06 micron radiation from a neodymium doped glass laser. The possibility therefore exists of producing from existing sources many more laser wavelengths, even extending well into the ultra-violet.

6. Applications

It is beyond the scope of this article to describe all the applications (over 100) that high power gas lasers are being used for and are being considered for.

In many cases, the laser is not yet competitive with currently used methods. For example, the large bandwidth available with an electromagnetic wave of such high frequency is ideal for communications. As yet, however, no modulator or detector are fully able to use this bandwidth.

There are a number of applications which only the advent of the laser has made possible and also some applications which are now performed better using a laser.

6.1 Holography

A normal photograph is produced by imaging light scattered from a scene onto a photographic film using a lens. The film records the intensity of the light falling on it. No information is stored on the relative depth of objects in the scene. Only a two dimensional reconstruction can be seen by looking at a photographic transparency.

In holography (discovered by Cabor in 1948 using weak, semi-coherent light) not only the intensity but the phase of the light scattered from objects is stored. This is achieved by recording the interference pattern produced when coherent light scattered from an object is combined with part of the coherent illumination (reference beam). Coherent light is required in order to maintain the phase differences between light scattered from different parts of the object.

A transparency of the recorded interference pattern is known as a hologram. When the original reference beam illuminates the hologram the original object is seen (even though not physically present) by looking through the hologram. It is as if the light waves scattered from the object are frozen in time and then allowed to pass on into the eye. All the three dimensional properties of the original object are seen, including parallax.

The argon-ion laser with its multiple wavelength output has made it possible to produce multi-colour reconstructions. This may be the beginning of three dimensional colour television! The possibilities in information presentation, information processing and a number of research applications are immense.

6.2 Micro-machining

The laser beam can be focussed down to a spot only a few microns in diameter. The power density produced with a high power gas laser is sufficient to melt or vapourize most metals and even some ceramics. It is therefore possible to cut very narrow tracks in metal films, drill very small holes and weld very thin materials. These processes can often be performed in an evacuated enclosure by passing the laser beam through a glass window. All these processes are needed in the production of micro-electronic circuits.

6.3 Micro-surgery

Not only metals may be welded and evaporated but also human bone and tissue. The solid laser (mostly ruby) has been predominantly used in laser surgery (particularly the detached retina operation). This is because of its high energy content in a pulse short compared with thermal diffusion times. A number of gas lasers are now becoming competitive. Operations on teeth, arteries, cancer growths and brain tumours as well as individual human cells are among many possibilities being investigated.

6.4 Metrology

Using interference techniques and a highly stabilised laser very small displacements ($\sim 10^{-11}$ cm) can be measured. Distances can be measured to an accuracy of 1 part in 10^6 over many kilometres.

6.5 Alignment

The laser beam provides effectively a very straight reference line which is unaffected by gravity. This not only enables laboratory optical systems to be easily aligned but also large structures. The 2-mile-long electron accelerator at Stamford was aligned using a He-Ne gas laser.

6.6 Fundamental research

Because of the unique properties of laser beams a large number of research investigations into the properties of materials and behaviour of plasma have been made possible. Many of these involve scattering experiments, where a powerful, highly collimated beam is necessary.

6.7 Breath-a-laser

A rather unusual application was discovered by the author in connection with research on the CO_2 laser. Since nitrogen, carbon dioxide and water vapour are all present a successful attempt was made to obtain laser action in breath at reduced pressure.

SECTION ACTIVITIES

Western Section

The November meeting was held in the Chemistry Department of the University of Cardiff, when Mr. L. T. Paget gave a talk on the grinding of stopcocks, a field in which he has worked for many years.

He described the equipment used and stages in the grinding of both barrel and key, finishing by smoothing with 500 to 700 grit size. The key is made to fit the barrel within 1 mm of its final position and is finished by machine using optical smoothing powder. Mr. Paget mentioned that during this part of the process the smoothing slurry must be evenly distributed and never allowed to become dry. The results obtained are more reliable than the normal hand lapping procedure.

Numerous grinding laps, tools and holders were on display and the talk was followed by a long discussion on problems associated with the drilling and grinding of stopcocks.

The Section Annual Dinner took place in December 1967, at Ashton Court Country Club where Mr. and Mrs. Handford acted as hosts and after a good meal members were free to use the facilities of the Club which included a first class cabaret and indoor swimming pool.

The Annual General Meeting was held at the H. H. Wills Physics Laboratory with a poor attendance of only ten members.

Reports were read by Mr. Garrard, Chairman of the Section, Mr. F. Porter, Council Representative, and Mr. D. A. Jones, Section Treasurer.

In addition, Mr. Garrard as member of the Board of Examiners read the conditions accepted by Council which apply to the awarding of Fellowship of the Society. There was considerable interest and discussion with one or two suggestions and it was agreed to circulate a copy of the conditions to each Section member.

At the February meeting Mr. I. C. P. Smith, now a member of the section, at short notice replaced the advertised meeting with a talk on "Flanges". He began by deducing a formula to give the thickness a flange should be made in order to be safe under vacuum use. This in its simple form is $0.5 \times \sqrt{\text{Tube diameter in mm.}}$ Then followed a description of methods used in making flanges including specially shaped forming tools to give the correct contour.

While giving the procedure for grinding flanges a list of grit sizes was included and the texture of the surface each produced measured in microns. Finally methods of testing were described including gauges and flow meter with the use of thin sheet melinex to calibrate the latter. A long series of questions followed which were answered from Mr. Smith's long experience and the interest shown was a demonstration of how much is involved in the technique. J.H.B.

East Anglian Section

A "Jobling Evening" was held at the Golden Hind Hotel, Cambridge, on the 9th February and was attended by 36 members and their wives. Three 'Jobling' speakers gave a run-down on Production Methods, Market Research and the New Factory. Slides were shown indicating its size the modern methods used at the factory, and its extensive rail linkage with industry. A very long discussion time gave the speakers some awkward questions to answer which they did admirably. The Chairman suggested that the only way to get a true picture of Market Research was through Glassblowers and not Companies, which statement was accepted by Joblings who said they would follow this line in the future.

During the interval between talks and questions, refreshments were supplied with drinks.

The Chairman gave a vote of thanks to Messrs. Joblings for such an interesting meeting and hoped that co-operation with the Society would continue. Further thanks were given for their hospitality and bearing the cost of a very enjoyable evening.

The Section A.G.M. was held on the 19th January when officers, committee and Council Representatives were elected for this year.

Chairman	E. G. Evans
Secretary	D. Willis
Treasurer	A. Stripe

A general discussion on the 1968 programme was held after the meeting and it was decided to arrange four talks, two discussions and one visit.

Southern Section

The activities of the Section are reported in a regular news bulletin and at the December meeting the topic was Sheet Glass. Those who attended were surprised how little they knew about this very interesting subject and it was felt that the lecture should have received better support.

The Section Annual General meeting was also only moderately attended but was encouraging in the appearance of new members who asked questions and made one or two complaints.

As no nominations were made for changes the 1967 committee was re-elected.

It was also noted that Mr. E. G. Evans has taken up the position of Sales Director of Quadrant Glass, Harlow.

On the 14th February the very popular Mr. John Patrick of G.E.C. Hirst Research Centre gave his talk on 'Glass in the Valve Industry'; having been introduced to the meeting by Mr. T. Parsell.

Mr. Patrick began his talk by explaining how and why a simple valve works illustrating his remarks with drawings on the blackboard. We were told that Edison noted the effects of anode and cathode around 1880, and A. Fleming made the first valve around 1901–1902. Mr. Patrick said there were three types of valve and went on to talk about the first, the entertainment valve. The type of wire used, why lead glass is used, how the heat generated is lost, grids and their manufacture, the oxides for the cathode, how metals are treated before use, pumping, getters, the oxide on the glass and its use; all these things Mr. Patrick explained and illustrated at great length.

He then passed on to the second type, the transmitting valve and said that these were really large entertainment valves. On the bench was an example of an old type, still made and a truly massive piece of work. We were told that the life of this valve was around half-a-million hours.

The third type of valve is the microwave valve: here again a full explanation was given of how it works and there was a sample to be seen and handled.

Judging from the number of questions that were asked, the assembled members found the subject most interesting and during question time Mr. Patrick explained how a centrifuge is used for making valve bases, illustrating his remarks by blackboard drawings.

The Stag Dinner

This annual event was held at the Horseshoe, Tottenham Court Road, on 16th Febraury. There was an attendance of 56 with quite a few people attending for the first time. From the remarks after the dinner it appears everyone enjoyed themselves, meeting old friends and making new ones.

T. J. MAPLE

North Western Section

A large part of the December meeting was occupied with discussion of arrangements for the 1968 Symposium, the remaining time being spent considering the methods used for small scale manufacture of ground joints which cannot readily be purchased.

J. W. STOCKTON

Thames Valley Section

The January meeting was held at the University of Reading, Mr. Collier of Johnson Matthey giving a talk on the "Decoration of Glass". The information he gave on liquid bright metals and lustres should be very useful to those who attended.

In February Mr. M. Baumback and his brother, Mr. H. P. K. Baumback gave a talk on the working of silica followed by a film on the subject made by the lecturer.

Two very good evenings.

The Section A.G.M. was held in March and the following officers were elected for 1968–69:

Chairman – J. S. MacDonald
Secretary – M. H. Noad
Treasurer – D. A. Henson
Council Representatives M. H. Noad, R. Mason

NEW MEMBERS

Southern Section	
J. T. Ayres (S)	46 Southcote Rise, Ruislip, Middx.
J. Bridge (F)	16 Cromwell Court, Alperton, Wembley, Middx.
B. D. Curd (F)	26 Victor Road, Harrow, Middx.
W. R. English (S)	13 Colebrook Avenue, Ealing, London, W.13
P. D. Kirk (F)	9 St. Margaret's Avenue, South Harrow, Middx.
D. W. Ledger (F)	25 Kenmore Road, Kenton, Middx.
C. F. Palmer (F)	3 Chapter Close, Hillingdon, Middx.
J. C. Pierce (F)	121 Bridgwater Road, Alperton, Wembley, Middx.
A. W. Soundy (F)	17 Ruislip Close, Greenford, Middx.
J. Wichelow (F)	55 Addison Way, Hayes, Middx.
Thames Valley	
J. W. Garnett (S)	72 York Road, Farnborough, Hants.
Western Section	
L. T. Paget (*Associate*)	23 Standard View, Ynyshir, Porth, Rhondda.

ANNUAL SUBSCRIPTIONS

The latest information is that in spite of the notices in the December Journal, a large number of annual subscriptions are still outstanding. The hesitation may have some connection with the increase to £3 3. 0, in which case those concerned should bear in mind; first, that the whole amount can be entered for Income Tax relief in the member's returns, which could cancel the increase; and secondly, even at three guineas our subscription is far less than other corresponding professional bodies; e.g., The American Society is now £6 7s. 0d. It must be remembered that the costs of all services to members have risen considerably since the original £2. 2. 0 subscription was instituted, and it is important that Council should know the year's income as soon as possible in order to plan expenditure.

It is hoped, therefore, that the remaining renewals will be speedily paid.

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As natural gas becomes available to more and more countries we are proud to announce our new and revolutionary development of Bench Burners and Hand Torches for **Natural and Propane Gas** incorporating two very important features:—

- **a smooth flame that never breaks**
- **perfect flame adjustment from pinpoint to large blast**

Hand Torch:—

for propane gas/natural gas, popular design, separate gas, air and oxygen feed, with cone burner head; also this model incorporates the new stabilising feature.

Fully suitable for operation on traditional town gas, if required or necessary.

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Jet Bore:—	4 mm	7 mm

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