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REVIEW AND BIBLIOGRAPHY ON: DESIGN AND USE OF WINDOWS FOR OPTICAL MEASUREMENTS AT ELEVATED TEMPERATURES AND PRESSURES (1881-1959)

R. E. Biggers
J. M. Chilton

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ORNL-2738
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ANALYTICAL CHEMISTRY DIVISION
CHEMICAL TECHNOLOGY DIVISION

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DATE ISSUED

MAY 27 1959

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ABSTRACT

The references in this bibliography cover the period from 1881 to 1959 (4/20), and were obtained from many sources. A brief abstract is given along with almost all of the 117 references that are listed. A review of the present and past status of the research effort in this field is given over the entire time period. The general design considerations for the past and present window designs are thoroughly discussed, and each paper is evaluated from the point of view of window design, temperature limits and pressure limits. The "Poulter" Window designed by T. C. Poulter in 1929 is extensively discussed. About eighty per cent of the window designs and research projects since 1930 have used this design. The Poulter type window has been very satisfactorily used at simultaneous temperatures and pressures up to 1200°C and 1500 atmospheres.

The literature is also reviewed from the standpoint of work carried out with the simultaneous use of elevated temperatures and pressures. Future developments are discussed for four different types of window designs that may permit the study of liquids at temperatures higher than 250°C up to at least 330°C and 200 atmospheres pressure, and probably up to the critical temperature of water. Sections are included on the arrangement of the bibliography, an author index, and a brief review of the source material.

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INTRODUCTION

During the last ten years there has been a large increase in the amount of research work carried out on materials at elevated temperatures and pressures. This has been true at ORNL, especially in the last few years. There are indications that both fundamental and applied research work in this area will become of increasing importance and usefulness in future years. Among other techniques, optical methods for observing and making measurements on systems while they are at elevated temperatures and pressures are of very great value, since it is not necessary to disturb the system chemically or otherwise to obtain the analytical and other physical data.

During the past few years work has been carried out at ORNL (cf. ref. No. 4) on the development of a spectrophotometric system for operation at temperatures from -50°C to 250°C and at pressures up to 3000 psi. The system has been used from 0°C to 250°C, and up to 1000 psi. Of particular interest, is the complete containment of liquids (and highly radioactive liquids) under these conditions with adequate safety. Since solutions containing large amounts of highly radioactive alpha emitting transuranics are among those to be studied, the apparatus must remain absolutely leak free over repeated pressure and temperature cycling.

For optical studies of solutions (or gases) under conditions of elevated temperature and pressure, the optical window system through which the radiant energy must be transmitted is, without doubt, one of the most important parts of a spectrophotometric system, and one of the most difficult to design and construct.

STATUS

There is interest in extending the limits of temperature and pressure for optical spectrometer cells which are designed to contain liquids. As a result of these limit extensions, there is a need for additional design work and study of other types of window arrangements which may well prove satisfactory. The tentative specifications of interest at ORNL for a system to contain aqueous liquids, is 330°C and 200 atmospheres pressure. However, a system that is designed to meet these specifications will probably suffice or enable one to readily design a similar system for experimentation up to near the critical point of water (374.4°C, ~3226 psi).

The system that has been built and designed at ORNL (cf. ref. No. 4) employs a somewhat new type of cell window design involving a spring-loaded Teflon ring-seal in an annulus between the polished cylindrical wall surface of a sapphire window disk and the concentric wall surface of the cylindrical recess in the end of a titanium cell core. The leak tight seal is made independently of the mount which holds the window disk against the end of the absorption cell core. This particular cell design has proven very satisfactory for the containment of aqueous solutions up to 250°C, and at 68 atmospheres pressure (tested). The design is probably satisfactory for a pressure up to 200 atmospheres. The temperature limit can probably be extended to -50°C, however the upper limit is fixed by the physical properties of Teflon and of the Inconel-X Springs. A slow outgassing of Teflon occurs at temperatures between 206°C and 316°C and the Teflon gives off small amounts of unidentified solids and gases. It is therefore necessary to use special additional shutters to prevent the deposition of organic material on the colder

windows adjacent to the cell windows. This organic material absorbs very strongly in the ultraviolet and causes variable reflection losses of a few per cent in the visible and near infrared.

It is the purpose of this bibliography to make available a complete up-to-date review of all of the pertinent literature on this subject. It is felt that this bibliography should not only be of considerable use in designing window arrangements for higher temperatures and pressures for ORNL interests, but also be of potential use to other physical, chemical, or engineering research workers interested in this subject.

CHRONOLOGICAL BREAKDOWN OF THE RESEARCH EFFORT IN THIS FIELD TO THE PRESENT DATE

This bibliography has been arranged chronologically from the present date back to earlier years. The quantitative breakdown of the literature by ten year periods is given in Table I.

TABLE I

Chronological Breakdown of the Number of Papers Published, by Ten Year Periods

Time Span, Years	Literature Found, Number of Papers
(1881)—1899 (incl.)	4
1900—1909 (incl.)	4
1910—1919 (incl.)	8
1920—1929 (incl.)	4
1930—1939 (incl.)	31
1940—1949 (incl.)	16
1950—1959 (4/20)	50
Total	117

As can be readily seen from this breakdown by 10 year periods, there was a rather low level of activity up through 1929. The large increase in activity in 1930 is without doubt due to the development of the first packingless window by T. C. Poulter, then at the Department of Physics of Iowa Wesleyan College. This now somewhat famous window design has come to be known as the "Poulter" window, and shall be so designated herein. Of the 31 papers published during this period,

9 were published by T. C. Poulter and his students. Of the 22 additional papers, 11 employed the type of window design set forth by Poulter.

The number of papers published between 1940 and 1949 (inclusive) was almost as great as all of the literature published between 1881 and 1930. The tremendous increase in the number of publications since 1950 (50, 1950-1959) can probably be attributed to the rapidly expanding world technology, and to the increasing importance of the behavior of materials, etc. at higher temperatures (which is frequently accompanyed by a necessary high pressure).

The publication distribution since 1950 shows a curious trend, and is given in Table II.

TABLE II

Chronological Breakdown of the Number of Papers Published: 1950—1959

Time Span, Year	Literature Found, Number of Papers
1959	1 (4/20/59)
1958	3
1957	7
1956	18
1955	2
1954	4
1953	2
1952	6
1951	6
1950	1

This large increase during 1956 is not confined to any particular group of workers, and is reasonably well divided among the various countries.

A most important fact is that 80 per cent of all of the published material in this field since Poulter introduced his packingless design in 1930, use the Poulter design. Of the 18 papers published during 1956, approximately 85 per cent are concerned with the Poulter type of window.

GEOGRAPHICAL DISTRIBUTION OF THE RESEARCH

In view of the large increase in the number of publications on this subject since 1950, a listing of the institutions which appear to be the primary ones from which such work is published are given below. With no intentional omission of any particular research institution, and without rank as to the volume or relative merit of the results therefrom, the major institutions are listed in Table III.

TABLE III

The Major Research Centers at Which Window Design and Related Elevated Temperature-Pressure Research Has Been Done (1950—1959)

A. France

1. Laboratoire des Hautes Pression,
   Bellevue, Seine-et-Oise, France
2. Laboratory of Physics Instruction
   The Sorbonne, Paris, France.

B. England

1. University of Cambridge
   Cambridge, England
2. Imperial College of Science and Technology,
   London, England

C. Australia

1. High Pressure Laboratory
   Division of Industrial Chemistry, C.S.R.I.O.
   University of Sidney; Sidney, Australia

D. Japan

1. High Pressure Laboratory, Abu-Yama Seismological Observatory, Kyoto University; Kyoto, Japan

2. Osaka University; Osaka, Japan

3. Tokyo Institute of Technology,

   Tokyo, Japan

E. United States

1. University of Illinois, Urbana, Ill.

2. University of Chicago, Chicago, Ill.

3. Harvard University, Cambridge, Mass.

4. Massachusetts Institute of Technology (Lincoln Laboratory, and Laboratory for Insulation Research), Cambirdge, Mass.

5. University of Texas, Austin, Texas

6. California Institute of Technology, Pasadena, Calif.

7. Oak Ridge National Laboratory, Oak Ridge, Tenn.

8. Case Institute of Technology, Cleveland, Ohio

9. Mellon Institute, Pittsburgh, Pa.

10. Jet Propulsion Laboratory, Calif. Institute of Technology, Pasadena, Calif.

11. Physics Department, University of Oregon, Eugene, Oregon

F. Canada

1. University of Toronto; Toronto, P. O., Canada

G. Russia (Complete information not available at the time of publication).

1. Institute of Chemical Physics, Academy of Sciences of the U.S.S.R. Moscow

H. Africa

1. Institute of High Studies, Dakar, French West Africa

PREVIOUS REVIEWS OF THE LITERATURE

There are two previous reviews on this subject. The first is that of Heisig (present ref. No. 39) made in 1952, and the second is that of Murahashi (present ref. No. 21), made in 1956.

The review of Heisig (Aug. 6, 1952) covered 18 references up to 1952. The present review lists 74 references up through 1951. The review of Heisig, while very good, was not complete to that date. In addition, his review received only rather limited inter-company circulation at ORNL.

The relatively recent review of the Japanese worker Murahashi (1956) was not available to the present authors. It must be a fairly good coverage of the literature since it contains 43 references. The present review lists 88 references through 1955. When copies of the review of Murahashi are obtained, it will be made available. If a translation is necessary, it will appear as an AEC-tr-Document.

Thus, the review of Murahashi probable does not contain the large amount of material published during 1956 (some of which is very important) and of course that since 1956. While the review of Heisig lacks about 56 references to the reports prior to 1952, it of course does not include the 37 reports published since then, which are a large fraction of the total research effort in this field.

Kiyama (57) has given a discussion titled "Pressure-Proof Character of Optical Window," which discusses the Poulter window and its merits, and other type windows are also discussed. At the time of this publication the translation from the Japanese had not been received. The Poulter window was used almost exclusively by Kiyama and his co-workers and students. Fortunately, some of Kiyama's work was published in English.

Some of the papers listed in the bibliography prior to the review of Heisig were in some sense reviews, since a number of them covered part of the previous literature. Since a review was not the primary purpose of these papers, the literature review aspect of the papers was not complete, and the papers cannot be considered as reviews. However the literature in all papers consulted has been of great help in tracing other literature on window developments.

DESIGN CONSIDERATIONS

1. The "Poulter" Window

The simplest possible window design and probably the most efficient sealing mechanism for high pressure absorption cells was designed by T. C. Poulter in 1929, and published in 1930. This was also the conclusion that was reached by Heisig in his review in 1952 and by many other workers before and since then. Earlier workers (prior to 1930) had largely used conical windows, and some cylindrical windows mounted in various ways, but all utilizing some type of gasket material between the glass window and the metal support (usually steel). For the gasket material a great number of materials and combinations of materials were used. These included: leather, tin, lead, gun-metal, wax, isinglass, celluloid, India leaf rubber, rubber, fish glue, silver chloride, gold, vulcanized fiber, fibers, ebonite or ivory, Klingerit, paper, and various cements.

It soon became obvious that as the pressure (and, or temperature) was increased, the gasket material started to flow. Since the gasket can flow into the opening over which the window is placed, but cannot flow into the vessel interior due to the pressure, Poulter reasoned that this caused an unequal distribution of pressure on the glass. In addition to this factor, the glass windows were generally supported by a moving surface which tends to rupture the glass surface; this trouble becomes increasingly serious as the pressure is increased. With conical windows, the maximum possible pressure cannot be obtained due to wedging effects. Poulter reasoned that for the minimum <u>strain</u> on the glass window, it must be mounted so that its supporting surface is perpendicular to the resultant force exerted upon it by the liquid (or gas) at elevated pressures. It is also necessary

for the liquid or gas to have free access to the edges of the glass so as to make the total force on the glass as nearly a compression force as is possible. Carrying his analysis of the troublesome factors of previous window designs one step further, Poulter ground optically flat surfaces (accurate to 1×10^{-4} cm or less) on both the window faces and the hardened steel seating surfaces. When the surfaces are thus prepared and placed in contact with one another the window cannot be blown off of the window plug support, and the steel support can be picked up by lifting up on the window.

Earlier workers utilizing the Poulter type of window utilized Canada Balsam or a dilute solution thereof, to facilitate assembly. When the pressure was applied for the first time, the material squeezed out and a glass to metal contact resulted. The window remained in place even when the pressure was removed. However more recent work has indicated that this is in itself undesirable, since this is analogous to putting a gasket, even though slight, between the surfaces. For the use of this type of window at high pressures and temperatures <u>no</u> intervening material should be used.

Poulter found that at room temperatures a quartz or glass window, mounted as was described above, would withstand pressures up to 440,000 psi when used with a paraffin oil pressure transmitting fluid. However, if alcohol, water, ether, or glycerine were used they fractured somewhat below 110,000 psi. He later showed that this was caused by the penetration of the lighter liquids (and smaller molecules) into the window material at elevated pressures, and that the rates of diffusion of such liquids out of the window were so low when the pressure was removed that the glass and quartz were shattered or ruptured by the expanding liquids within the window. He later found that windows made of diamonds did not exhibit this effect.

This phenomenon has not been specifically studied with oriented c-axis sapphire windows but they would tend to approach the behavior of diamonds in this respect much more than that of glass or quartz windows.

When the windows are properly designed and constructed, the Poulter window mount can result in no leak because the intensity of stress on the bearing surface is greater than the hydrostatic pressure by the operation of Bridgeman's unsupported area principle. The base plug holding the optical window can be mounted in at least two ways. If the assembly holding the window is inserted from the outside, the gasket seal is made between the two cylindrical metal surfaces (window mounting plug and cell body) and the gasket. In this case the gasket pressure is applied at right angles to the load producing the gasket pressure, and in addition the screw threads are placed under the full internal pressure load. However, if the window plug (or window alone) is positioned from the inside, the pressure load can be taken by the cell wall directly since the gasket pressure (metal to metal) is parallel to the hydrostatic pressure. This will result in the maximum gasket pressure for a given hydrostatic pressure and bolt load on the assembly.

It is recommended that anyone interested in applying the "Poulter" window to any particular problem, become familiar not only with all of Poulter's work, but also with the other literature on the use of Poulter window since it was developed. In addition, the source material listed in the appendix also serves as a survey and introduction to the general field of high pressure and temperature technology, not only with regard to the use of windows, etc., but also for general technique and many other aspects of this field.

Other merits of the Poulter window and the temperature and pressure limits to which it was proved eminently satisfactory will be discussed below.

2. Other Window Seals

a. Types of Seals Before 1930

As was pointed out above, the work prior to that of Poulter was concerned with both conical and cylindrical windows. Although Amagat was not the first worker to develop a pressure window, he was probably the first worker to undertake a series of intensive researches in this field. He used both conical and cylindrical windows with various packings as have been described. Amagat worked at temperatures up to 100°C using his design. He did some work at higher temperatures (~350°C), but in a specially designed cell with the windows mounted at the end of long tubes (with water cooling around the windows) connected to the high temperature chamber, so that the windows themselves were not heated. Conical windows were also used by numerous other workers, and were found to be usable up to 60,000 psi and about 150°C (and also to liquid air temperatures), depending upon the materials used for the windows and the sealing mechanism. In general, the windows failed by cleaving into sheets along cleavage planes parallel to the optical faces of the window, for the reasons discussed previously. The earlier cylindrical windows were sealed in two general ways, either on the inner face of the window cylinder or between the cylindrical surface (along the length of the window cylinder) and the window housing.

Two other types of window designs more closely approached that of Poulter than any other. The first was that of H. C. Jones (107,108) and his co-workers (1910—1913). He used cylindrical quartz windows (flat but not "optically" polished) which were contained between a recess in the end of the cell, and the window retaining plug. The window retaining plug was held in place by a retaining cap screwed on from the outside. The windows were separated from the cell wall and

the retainer plug by thin gold washers on each side, one of these washers effecting the seal between the cell and the window and the other acting as a buffer between the window and the pressure transmitted by the retaining plug. The cell was gold plated inside.

The work of Jones and co-workers is very remarkable when the differences in the available technology between 1910 and 1959 are considered. He was able to obtain absorption spectra of both aqueous and non-aqueous solutions at 200°C and at pressures greater than 270 atmospheres (simultaneous temperature and pressure). He was the first person prior to the development of the Poulter window to obtain spectra at temperatures as high as 200°C.

The second type of design is exemplified by that of C. V. Raman and K. R. Ramanathan, Phillips, Margri, and others. These workers used conical glass or quartz windows seated without gaskets in a ground-to-match recess in a steel cylinder. Apparently none of these window types were pushed to their limit, since they were used at 0°C to 50°C at pressures up to about 100 atmospheres, for measurements such as the refractive index of compressed carbon dioxide. The design limits of this type of window are not known, but it is certainly not capable of nearly as high a performance as the Poulter design. Bone has used this type of construction for studying gas phase explosions up to 3000°K and at 400 atmospheres pressure, however, no data concerning the rise in the window temperature were given.

b. Types of Seals Since 1930, Other Than the Poulter Design

Since about 80 per cent of all of the work since 1930 has utilized the Poulter technique, there are not a great many other types of designs. Several of the designs utilized various combinations of O-ring type packings with cylindrical

windows, sealing the windows either on the end, or concentrically. In general, this type of seal has been used both for small optical windows and for the long vertical type up to pressures of about 5000 atmospheres. However the maximum temperature that has been utilized is about 125°C. For relatively low pressures, but in excess of atmospheric pressure, cemented and permanently fused on windows have been used.

A design in which the packing was loaded independently of the window mount was made by Caldwell. However he worked at room temperature and to only 300 psi. He reported that the design could be used to higher pressures by choosing the sizes and types of the components. The other design in which the packing is loaded independently of the window is that of Waggener. This design (cf. ref. No. 4) was discussed in the status section and will not be repeated here except to say that it is a spring loaded Teflon gasket seal against a sapphire window that is separated from the titanium cell body by a gold gasket. This design permits the examination of solutions at temperatures up to 250°C (limit) and pressures up to 1000 psi, and possibly up to 3000 psi. This is the first work since that of Jones (up to 200°C, in 1910) to measure the absorption spectra of <u>solutions</u> at temperatures of 200°C, and is the first to extend the temperature limit for solutions to above 200°C. The window design of Waggener is complicated, but is reliable, leak-tight, and safe for operation from 0°C to 250°C (tested, probable to -50°C), and for 10^{-3} to 68 atmospheres (tested, probable to 3000 psia).

The third type of design since 1930 other than the "Poulter" window is not new, but is an application of an older design, the truncated cone type of window. Finkelnburg and Steiner have used the truncated cone window in a <u>ground-to-match</u> recess, effecting the seal with Wood's metal in an off-set near the inside

surface of the window. The window was used at room temperature, and at pressures up to 1000 atmospheres, to study the spectra of compressed gases.

The other application of the truncated cone is that made recently by the Russian worker Ryabini and his co-workers. He used a 15° quartz or glass cone with end diameters of 12.5 and 7.5 mm x 12 mm thick, apparently seated in a ground-to-match recess in the end of a type of gun-barrel shock tube. The spectra of gases were studied by the adiabatic compression of the gas in the barrel by a moving piston. An adiabatic transfer of the piston energy to the gas yields gas temperatures of $9000^{\circ}K$ and pressures up to about 10,000 atmospheres. No experimental details (or literature cited) regarding the window performance, i.e., window, temperature, life, leakage, etc., are given. The window design of Ryabini is also subsequently discussed below.

The last type, the direct seal, on which very little work has been done, will be discussed below in the section on "Future Developments."

3. Temperature and Pressure Limits, "Poulter" Windows

a. Temperature

Windows (of quartz, glass, or c-axis oriented sapphire) mounted in the completely packingless manner as described by Poulter have been used with complete success, and never any sign of leakage from liquid air temperatures up to $1200^{\circ}C$, and of course at numerous other temperatures between these very wide limits.

b. Pressure

This type of window mount has been used at pressures up to 200,000 atmospheres with three stage sodium chloride windows in a special cell mount.

Quartz windows have been used with complete success to pressures in excess of 30,000 atmospheres (~450,000 psi), and the limit for sapphire could be pushed much higher; sapphire (c-axis, oriented) has been used with unqualified success up to pressures greater than 10,000 atmospheres. LiF windows have been used to 4000 atmospheres when similarly mounted.

4. "Limits" for the Simultaneous Use of Elevated Temperatures and Pressures

Since it is usually much more difficult to obtain high temperatures while maintaining a high pressure, some limits which have been obtained using a window mounted exactly as described by Poulter should be discussed. The pertinent information from the present review is tabulated in Tables IVA and IVB. In addition to a tabulation of the temperatures and pressures, the research worker (first author, if more than one), present bibliography reference number, type of window design, window construction material, and the types and physical state of the substances investigated, are also given.

Table IVA-Part 1 lists the designs using the window mounted exactly as is described by Poulter. Part 2 of this table also lists what may be called a "pseudo" Poulter design since the windows are gasketless. In this case all of the windows are divided into two parts; after (a), and before (b) 1930. These window mounts are obviously adequate for the work described in the literature reports, but are of course possibly subject to the limitations and design defects as have been extensively discussed by Poulter and others.

The recent work of the Russian worker Ryabini reports obtaining very high gas temperatures (9000°K) and pressures (~10,000 atmospheres). He used the piston shock-tube technique, and although the compressed gases reached the above described

TABLE IV

A. Temperatures and Pressures* at Which the Poulter-Type Window Has Been Used

1. The True Poulter Mount with Cylindrical Windows.

Reference Number	Author	Temperature	Materials Studied	Pressure	Window Material
13	Coulon	>150°C	Gases, HCl, H_2, Cl_2, CH_4, H_2, CO, HBr, O_2, N_2	6000 atm.	Quartz, sapphire
15	Ewald	70°C	Liquids, Toluene CCl_4	3000 atm.	Quartz or sapphire
16	Ewald	50°C	Water solutions	1500 atm.	Quartz or sapphire
22	Nicholson	60°C	Styrene	3000 atm.	Quartz
25	Robin, J.	1200°C	Gases and metal vapors, Alk. metals, Hg, H_2, A, N_2	1500 atm.	Quartz**
28	Robin, S.	>400°C	Gases, metal vapors	>1000 atm.	Quartz
26	Robin, J.	-150°C to +300°C	Gases	6000 atm.	Quartz
27	Robin, J.	1100°C	Gases and metal vapors	1500 atm.	Quartz**
47	Robin, S.	>400°C	Gases	>1200 atm.	Quartz
30	Phillips, C.S.E.	300°C	$CHClF_2$ and N_2O	3000 atm.	Glass, (?) type
40	Koeller	40°C	CS_2	10,000 atm.	Sapphire or quartz
64	Kuss	40°C	N_2, CO_2, C_2H_4 CH_4	420 atm.	Glass
63	Marsland	50°C	Aq. liquids	8000 psi	Glass or quartz
71	Gibson	65°C	Benzene	1250 bars	Sapphire
78	Michels	100°C	CO_2	2400 atm.	Quartz
35	Turner	0°C to 150°C	Liquids, gases	1000 atm.	Glass
62	Brown	40°C	Aq. solutions	7000 psi	Glass or Quartz

* Applied simultaneously.
** Cell within a cell type of construction.

TABLE IV

A. Temperatures and Pressures* at Which the Poulter-Type Window Has Been Used (Continued)

2. Pseudo Poulter-Type Mount, Conical Windows in a Ground-to-Match Recess.

Reference Number	Author	Temperature	Materials Studied	Pressure	Window Material
a. After 1930					
38	Clayton	window $\leqslant 300^{\circ}C$ expt. $950^{\circ}C$	Ag vapor, A, He	83.3 atm.	Quartz**
42,43	Ryabini	up to $9000^{\circ}K$	Gases	10,000 atm.	Quartz
65	Ch'en	$300^{\circ}C$	Rb vapor, A, He	100 atm.	Quartz**
84	Eiseman	$-180^{\circ}C$	Liq. A and CH_4	500 atm.	Quartz
b. Before 1930					
71	Bone	window (?) explosions, $3000^{\circ}K$	Gases	400 atm.	Quartz
99	Raman	$0^{\circ}C$ to $50^{\circ}C$	CO_2	100 atm.	Glass
101	Phillips, P.	up to $34^{\circ}C$	CO_2	41 atm.	Glass
111	Magri	$0^{\circ}C$ to $17^{\circ}C$	Air	0.0009 to 200 atm.	Flint glass

* Applied simultaneously.

** Cell within a cell type of construction.

TABLE IV

B. Temperatures and Pressures* at Which Gasketed Windows Have Been Used

1. Since 1930

Reference Number	Author	Temperature	Material Studied	Pressure	Window Materials	Remarks
2	Moore	100°C	Gases	10^{-5} mm Hg to 1 atm.	Quartz, glass	O-ring (Neoprene)
4	Waggener	0°C to 250°C (-50°C prob.)	Aqueous solutions	10^{-3} to 68 atm. (up to 200 atm. prob.)	Sapphire	Teflon and gold gaskets, independently loaded.
73	Ruhmkorf	160°C (Buna-N) to 450°C	Hg vapor	10 atm.	Quartz	Buna-N Gasket; 450°C (?) (160°C)
31	Wells	up to 150°C	Hydrocarbons	8000 psi	Ground glass tubes	Rubber O-rings
70	West	-100°C to + 52°C	HCl, gas and liquid	82 atm.	Glass	Lead washers and Bakelite cement
83	Margenau	200°C	Na vapor, A, N_2, H_2	17 atm.	Glass	Lead gasket
8	Ozawa	240°C	C_2H_2 gas	12 Amagat Densities**	LiF	Teflon gasket
74	Vodar	-80°C to +14°C	Liquid HCl	>570 psi	Quartz	Lead gaskets
55	Kleman	200°C	Na vapor, Argon	5 atm.	Jena Glass	Windows fused on
93	Withrow	100°C	Combust. Gases	400 psi	Quartz plates	Cemented; asbestos and porcelain gaskets

2. Before 1930

105,106	Wahl	-147°C to +150°C	CCl_4, Org. compounds	4000 atm.	Jena Glass	Truncated cone, vulcanized fiber and ebonite.
107,108	Jones	up to 200°C	Aqueous solutions	>270 atm.	Quartz	Cylindrical windows, gold gaskets
114	Amagat	up to 100°C	Aq. and Org. liquids	1000 atm.	Quartz	Cylinders, marine glue, celluoid

* Applied simultaneously.

** An "Amagat Density" unit is the ratio of the gas density at the elevated pressure to the density under standard, or normal, conditions (0°C and 1 atm. pressure).

state, there is no indication as to the magnitude of the resulting heating of the windows or their performance or life time. Since the experiments were of necessity of relatively short duration the windows did not attain such temperatures (9000°K), and they must not have experienced a high temperature rise, but they must have withstood the pressures. Few experimental details were given, and no indication is made as to the leaktightness of the windows. One can only infer that they were leak-tight. No mention of the use of sapphire, or of any other previous work on window designs was made by the Russian workers. It was only stated that special design development enabled them to produce the observation windows.

Table IVB contains a similar listing of the work that has been done with both cylindrical and truncated cone windows mounted in different ways with various types and combinations of gaskets. This table is divided into two parts: I, work since 1930; II, work before 1930.

In the two tables IVA and IVB, no reference has been listed that involved work done at room temperature, irrespective of how high a pressure was used (some up to 200,000 atmospheres). In addition, the listings in the tables involve work at temperatures higher than room temperature (taken as 20°C to 25°C), and at elevated pressures, with very few exceptions. These exceptions are of work carried out at low temperatures up to room temperatures in a pressurized system (some of the other reports included, which range from very low to high temperatures at high pressures), and work at an elevated temperature from very low pressures up to atmospheric pressure.

In Table IVB (gasketed windows) the highest temperature that has been obtained is 250°C. The highest pressure attained was 4000 atmospheres, but this does not correspond to the 250°C temperature. The highest pressure used at 250°C is

68 atmospheres, but this design can perhaps be extended to 200 atmospheres at this temperature.

The data is Table IVA (the windows mounted using the Poulter technique) are much more encouraging from the point of view of elevated temperatures and pressures. The highest temperature reported for the true Poulter-type mount is 1200°C, and in addition to work from room temperature up to 100°C, there are several other reports at temperatures above 250°C. The 9000°K figure given by Ryabini for the pseudo Poulter-type design (truncated cone) was discussed above. It is very doubtful that the windows attained even a moderately high temperature. The maximum pressure attained with the use of windows at elevated temperature is 10,000 atmospheres (however, this is obviously not the limit). This pressure does not correspond to the 1200°C temperature.

The highest pressure and temperature that have been attained at the same time to the present date in experiments using optical windows, are those of Robin, Vodar and co-workers. They have obtained, in a sustained manner, the fantastic combination of 1100°C and 1500 atmospheres pressure using quartz windows mounted as designated by Poulter. They report that without doubt the temperature and pressure limits can be increased considerably by using sapphire windows (which they plan to do). Their cell and window design is extremely interesting.

Their cell has been used in two ways. In the first manner of operation the entire unit is heated in a furnace , etc. They report that operation above 450°C and under 1500 atmospheres pressure is difficult, due to the temperature effect on attachments and lines to the cell unit, etc. In the second manner of operation, the cell contains a second inside cell (concentric alumina tubes containing a quartz tube cell closed by 6.5 cm long solid quartz cylindrical windows) which is

electrically heated to 1200°C. The outer cell contains quartz pressure windows mounted in the Poulter manner and located next to the quartz windows in the electrically heated inside cell. When the cell is at an equilibrium temperature of 1200°C both the quartz internal cell windows and the quartz pressure windows mounted in the Poulter manner are at about the same temperature. The end of the pressure window mounting plug is closed by a third quartz window to diminish optical effects of the convection currents of heated air. The cell and window design of the French workers is excellent, and is most ingeneous.

5. Future Developments

There is a considerable need for the development of optical windows to be used for the study of liquid system at temperatures higher than 250°C. After a review of all of the literature on the subject it appears that there are at least four possible approaches to the problem, some of which will very probably be proven to be successful. These will now be listed briefly, and discussed from several points of view.

a. The Poulter-Type Window

In the previous section, the various limits to which the Poulter-type window has been used were discussed. In all of the cases cited from the literature at temperatures higher than 150°C, the materials studied have been gases or metal vapors, up to the very high simultaneous limits of 1200°C and 1500 atmospheres. All studies carried out above 150°C have dealt with gases or metal vapors, while liquids have been studied at temperatures equal to or less than 150°C.

At least to the present authors, it appears that the reason this type of window mount or construction has not been used for a study of liquid systems at temperatures in excess of 150°C is not due to the fact that it would not be feasible, but is due to the fact that most of the interest (as a result of the nature of the problems for one reason or another) has been centered around gases. In the case of liquids there just has apparently been no occasion to study liquids, or any particular reaction, or to make any physical optical measurements on liquids at temperatures greater than that at which some other gasketed cell design was adequate. Or, usually the Poulter design was just used up to as high a temperature as was necessary to obtain adequate temperature or thermodynamic data for the particular experiment. It would appear, with almost certainty, that the Poulter design has in no way reached its temperature limit for the study of liquids.

However, there is a very great need for a design to be used for the study of liquids (corrosive and very radioactive) at temperatures higher than 250°C. Furthermore it is almost certain that none of the designs listed in Table IVB are capable of being taken much higher than 250°C, for various reasons. In view of the phenomenal use of the type of window (first designed by Poulter) for the study of gases, etc. at simultaneous very high temperatures and pressures (with complete success and no leakage) it seems reasonable to conclude that this particular design should certainly be the first one explored for high temperature studies of liquids at temperatures higher than 250°C. This is believed to be true especially in view of the fact that many of the gaseous systems investigated have been concerned with gases of small diameters such as helium, hydrogen, etc., and in view of the fact that the window design has proven to be completely successful for a study of liquids up to tens of thousands of atmospheres at temperatures up to about 150°C.

It is apparent that the best possible window material to use from strength considerations is colorless, synthetic, c-axis oriented sapphire. This material is now commercially available in disk sizes up to at least 3", and in thicknesses of the order of inches, if such dimensions are desirable or necessary, and at reasonable costs. From the standpoint of corrosion (by high temperature water and other materials) sapphire usually offers superior resistance for most systems of interest. From the standpoint of other physical properties sapphire usually will be superior (e.g., properties such as thermal expansion, temperature shock resistance, creep, plastic flow or deformation, etc.). From the standpoint of radiation stability and color center development, both quartz (not all types however) and synethetic sapphire show excellent resistance at high levels of γ, β and neutron irradiations. Only at extremely high levels do complications result, and windows of either material should prove adequate for the containment and observations on circulating streams of some types of fluid fuel nuclear reactors and other elevated temperature experiments as long as the windows are out of the fission neutron field. There are isolated and relatively narrow spectral regions in which slight complications might be expected to occur after exposures of very long duration for both materials, however a detailed discussion of the radiation stability problem is outside the scope of the present report. A very adequate literature on this subject is available.

For the satisfactory functioning of the Poulter window design, one might suspect that the thermal expansions of the window material and of the metal seating and sealing surface would be very important. However, from a perusal of all of the available literature in which the Poulter window design has been used, little mention is made of the relationship of the coefficients of thermal expansion.

If the coefficients are not the same, there must be some lateral movement of one surface over the other at least on the macromolecular or atomic scale. Apparently this must not be too serious a problem from the excellent results reported in the literature in which window materials of various kinds (e.g., quartz of various types, glass (?), Jena glass, Flint Glass, sapphire, alkali halides, alkali fluorides, etc.) have been used with a great variety of metal seating surfaces, such as many types of steels and brasses. One of the best combinations (probably among others) would appear to be a c-axis oriented sapphire disk seated on a polished titanium surface. For such applications, titanium also has other advantages such as excellent general corrosion resistance in addition to strength, creep and temperature resistance. It is interesting, and fortunate, that the coefficients of thermal expansions of titanium and synthetic sapphire in a direction perpendicular to the c-axis are almost exactly the same. The line of sight through the cell windows is along the c-axis of the oriented sapphire disk.

A final point in favor of the Poulter design for the cell window is its inherent simplicity, an important point not to be overlooked. In almost all cases the gasketed type window designs range from moderately to very complicated. The above statements are borne out to some extent by the fact that about 80 per cent of all applications of windows to elevated temperature and/or pressure experimentation carried out since 1930, have been of the same type as that introduced by T. C. Poulter.

b. Gold Foil Gasket Seals

Of all of the gasketed types of window designs that have been used, no material has been used for a gasket at temperatures higher than 250°C. Many other

types of gasket materials have been used, usually at somewhat lower temperatures. The material used up to 250°C is Teflon. However it appears that it will be extremely difficult to push the limit for the Teflon gasketed-type window much above 250°C. Above about 200°C Teflon just perceptibly begins to creep, above this temperature (206°C) Teflon begins to out-gas, giving off small amounts of organic vapors which deposit on cold window surfaces. This effect becomes increasingly more serious as the temperature is increased. At 250°C creep becomes noticeable and is quite serious at 300°C, and a little above 300°C Teflon undergoes a phase transition.

For the study of liquids above 250°C, it therefore appears that if a gasketed type of window is used, some type of gasket more thermostable than Teflon will have to be used. Making the obvious conclusion, one would first suspect that some type of metallic gasket, or another material with the same general properties, would be the answer. The material of first choice would probably be annealed gold gaskets. Gold would be superior from many considerations, too numerous to discuss here. This is not to say however, that gold would be the only possibility, since there are undoubtedly others.

In his work reported in 1910—1913 H. C. Jones et al., used cylindrical windows that were mounted in cylindrical milled recesses with a single gold gasket seal between the cell and window. They were successful to 200°C and 270 atmospheres pressure. No details as to window or metal surface polishing were given, as well as no details as to the type, treatment, etc., of the gold gaskets that were used. The assembly was loaded by direct compression. Waggener has used annealed gold gaskets in conjunction with his Teflon seal.

In future designs there are a number of ways in which the windows could be mounted with only gold gaskets. These include the direct flat surface-to-surface design used by Jones, and various other types of angular seals. It is very probable that a gold gasket type of design could be found that would prove to be safe and leak-tight, as well as serviceable at temperatures higher than 250°C. There is quite a good available literature on the physical properties of various types of gold and gold alloys at elevated temperatures, and in fact, on the design and use of gold gaskets and other types of gaskets at elevated temperatures and pressures.

c. The Pressurized Annulus

In all of the literature reviewed this particular design conception does not appear to have been investigated to any great extent. In essence, this is a cell within a cell, and requires two pairs of windows for a design with a through end-to-end optical light path. Shang-Yi Ch'en (ref. 65) has designed a cell system analogous to this type of design. His internal windows were plane and were made of MgO; the outer ones were pyrex cones seated in ground to match recesses. An approach to the annulus type of design is also that of Robin and Robin (ref. 27). However there is no absolute seal on their inner cell. It was used merely as a container for the substance under study. However, it is not necessary for the inner cell to be surrounded completely by the second cell.

The design can simply be accomplished by a dual chamber at each end of the cell. The innermost side of the chamber at each end of the cell contains an optical window mounted in a manner sufficient to function satisfactorily under a small pressure differential (preferably increasing from the inside of the cell to the annulus. The outside of each end of the cell is then closed with a second

window, which is capable of withstanding the total pressure, e.g., the Poulter-type mount, etc. The space between the windows is then pressurized through an outlet tube. This type of window system design would have numerous advantages.

Both of the windows (at either end of the cell) could be of the same material (e.g., synthetic sapphire), or the inner window (in contact with the cell contents) could be of a different material. This might be desirable for several reasons. The construction material of the internal window might be more corrosion resistant to the system under study than the material used for the outer window. A thinner inner window could be used since it would be under only a relatively small pressure differential, and window materials could be used that would not withstand the pressure differential required of a single window.

The annulus could be pressurized with either a gas or a liquid. The pressurized annulus system would lend itself to a built in leak test system. The gas or the liquid pressurizing fluid could be easily monitored for radioactivity (if the cell system were used for radioactive solutions), or a sudden pressure increase of a certain suitably chosen magnitude could be used as an indication of a leak or leaks. This signal could be arranged to shut the entire system off, if necessary. The pressure differential (e.g., 1 atmosphere or less) could be maintained automatically with the somewhat lower pressure in the annulus. In experiments with liquids where the pressure increases (due either to the liquid vapor pressure, or added gas overpressures) with increasing temperature, the annulus pressure could be increased automatically, but at the same time lag behind the cell pressure by a certain amount.

It is believed that the pressurized annulus technique does have special features to offer, and should be investigated further. The inner window could very probably be sealed with gold foil gasketing.

d. Permanently Sealed Windows

Within recent years there have been considerable advances in ceramics and ceramic metallurgy. There have also been advances in techniques for sealing glass and refractory type materials to metals. If the technology of this type of work has been developed to such an extent that the window materials of interest (quartz, synthetic sapphire, magnesium oxide, spinel, titania, etc.) could be permanently sealed to the body of the cell, with the windows flat and at the proper angle, giving a safe, durable, and leak-tight seal capable of the necessary temperature and pressure requirements, this would be probably be the most satisfactory type of window mount. The earlier work in the literature on this general type of seal consist of glass or quartz windows fused to a cell of the same material. This type of cell construction has not found use at very elevated temperatures or pressures.

Recently, Ceramaseal Inc. (ref. 3) have reported that hermetic seals can be made between synthetic sapphire and metal parts by a process similar to that used for making high-temperature ceramic-to-metal assemblies. A silver-copper brazing alloy is used to form assemblies capable of installation by soldering, brazing or welding techniques. It was reported that current applications of sapphire seal assemblies include wave guide windows for radar equipment, high temperature windows for high vacuum equipment, and ultraviolet studies in the nuclear energy field. As an example, sapphire disks up to 3" in diameter and tubes up to 1/2" diameter have been sealed to tubular metal members of Kovar, nickel-iron, and platinum.

Kivensen, et al., have also reported on a method of mounting absorption cell windows by platinizing the appropriate surfaces of the quartz windows and

soldering directly to the metal cell. They used their windows and cells to only 125 psi at room temperature. Wade has also reported on a method for making direct seals between quartz and synthetic sapphire and metals. He discusses the use of a titanium-cored copper-silver eutectic alloy. There are also other literature available on this general subject.

There are also other possibilities along with these same general types of designs. It may be possible to use a cell of alundum (pure Al_2O_3) to which synthetic c-axis oriented sapphire windows could be sealed, e.g., a type of graded seal. The inside of the cell (either ceramic or metal) could be given a glass type coating with a direct seal between the glass type coating and the window material. In the case of the internally glass coated metal cell, the metal part of the cell would act merely as the pressure container for the interior ceramic or glass layer (to which the windows would be sealed). There is also adequate literature available regarding glass and ceramic coatings for metal, etc., which are serviceable and stable to extremely high temperatures (thousands of degrees). A third possibility would be a hermetic permanent seal between a gold gasket and the window (cf. section "b" above) and perhaps between the metal cell and the gold gasket. For example, some recent work at the National Bureau of Standards has shown that gold may be sealed to quartz, yielding bonds with rather high shear stresses.

To the present authors, it appears that the permanently sealed type of cell and window design has sufficient merit, so that all of the design possibilities should be thoroughly explored, if this is possible. A disadvantage of such a design would be that the windows could not be replaced or easily removed for any manual cleaning that might become necessary.

ARRANGEMENT OF THE BIBLIOGRAPHY

The bibliography itself is arranged chronologically by the date of publication, that is, by the date the particular paper is made generally available to scientific personnel. The date of completion of a published volume, rather than the actual day of publication of the paper or volume issue, is considered to represent the date a paper is available. Certain documents are listed by the actual date stated thereon (usually the date of completion of the writing or typing of the paper). In this arrangement, certain arbitrary decisions have had to be made for convenience in listing. No classified literature on this subject was found, and therefore no such documents are included herein.

The actual references are arranged in a reverse chronological order starting at the present date (April, 1959) and working back to the date of the first paper on the subject, which is 1881 as far as can be determined at the present time. The reverse chronology is further divided into 10 year periods based on divisions of 10 year multiples in both directions from 1900. This arrangement has certain advantages as will be made evident later.

Within each 10 year period the references of each year are grouped consecutively, with the arrangement for more than one entry per year being alphabetical by author. With the bibliography arranged as described above the presentation of the research papers on this subject are in a logical order. The more recent work is presented first and there is no rank as to the relative merit of any particular paper. It is very easy to obtain an overall picture of scientific activity in the field with respect to a numberof parameters, as well as by year, decade, etc.

The major part of all of the references are accompanied by some kind of abstract or annotations. Some of these were copied in part from the original

abstract or were obtained from a review of the paper (cf. appendix). Other annotations were obtained from secondary sources, but usually from the papers themselves. With very few unavoidable exceptions, the original paper of each reference was very thoroughly reviewed. The first part of the abstract gives in a very condensed form the major conclusions regarding the window design itself, etc. For each abstract (where pertinent) this is followed by a listing of the conditions of temperature and pressure to which the window design has proven to be satisfactory. These designations are set apart from the main abstract (and preceeding and succeeding abstracts) so that these limits can readily be ascertained at sight. However in many cases these limits do not represent the design or real limits of the window, but merely represent the limits to which that particular experimenter had worked. The exceptions and ramifications of this aspect of the problem are discussed in the review section. For cases where the temperatures and pressures are included in the abstract statement these are repeated below each abstract. In some cases the nature of the papers do not include statements as to such limits. The inclusion of a complete or partial abstract as well as temperature and pressure data is believed to materially increase the usefullness of the compilation.

It was decided that it would not be feasible or practical to attempt to include a reproduction of the figures and sketches of the cell systems from the literature that is cited. These decisions are felt to be justified in view of the fact that the literature is for the most part readily available, or is reasonably easily obtained at the expenditure of but little time and money.

With the references arranged as described above, each is numbered consecutively starting at the present date and working backwards. For each reference entry

(well separated from other references) the title is given first, followed by the author or authors, and then by the literature reference. Information as to the language, if other than English, is also included. These three items are well set apart so that any one for each reference may be read at a glance.

A small number of the references are available only as Japanese or Russian original papers. Most of these have been or are being translated and are so designated in the appropriate reference. Those being translated will be available very soon as AEC-tr-documents.

Since this review and bibliography covers a single very specific subject, there is no subject index. However, an author index has been found useful and is included immediately following the list of references. Likewise, no numerical report index is necessary, since no patents, and very few government or AEC documents are listed.

An attempt has been made to give clear complete titles for all of the papers as well as the references. An attempt has also been made to follow the abbreviations designated by Chemical Abstracts for the various journals, etc. that are cited.

It is anticipated that a revision of this bibliography will be prepared in the future, when additional work makes this desirable. In connection with this, the authors would greatly appreciate receiving information on errors of omission or commission which have occurred in this compilation and review. It is believed to be reasonably complete up to the present date, but due to the always limited, or even slightly limited, library resources, inadvertent omissions are possible, since an unlimited amount of time could not be spent on this compilation. Care has been taken to insure accuracy and almost all of the references have been directly verified and/or copied. (A listing of the source materials, etc., is given in the appendix).

Grateful acknowledgment is herewith extended to the staffs of the Central Research, Document, and other libraries of the Oak Ridge National Laboratory for their invaluable assistance in identifying and supplying publications, borrowing materials, and verifying many questionable references, and limitless patience. Grateful acknowledgment is also extended last, but by no means least, to Miss P. Coleman for performing the quantities of clerical work and typing occasioned by this compilation.

BIBLIOGRAPHY

BIBLIOGRAPHY

A. Publications located between 1959 and 1950 (incl.)

1. "High-Pressure Techniques"

   Warschauer, D. M. and Paul, W.

   Rev. Sci. Instruments 29, 675-679 (1959).

   The discussion includes a section on optical techniques from many points of view. The use of Sapphire cylinders as window materials, Poulter mountings and the hardness of metal parts are discussed.

2. "Demountable Vacuum Seal for Attaching an End-Plate to a Glass Tube"

   Moore, H. R.

   Rev. Sci. Instruments 29, 737 (1958).

   A Neoprene O-ring is used for the seal. Rotation of a knurled lock-ring causes a 45° bevel on a collar to press against the O-ring, the collar slides freely on the tube and equal pressures are then transmitted by the O-ring onto the surfaces to be sealed - the outer tube surface and the inner surface of the end plate.

   Temperature: up to $100^{\circ}C$

   Pressure: 10^{-5} mm Hg to atmospheric-higher pressures not discussed, designed primarily for low pressures

3. "Sapphire-Metal Seals"

   Ceramaseal, Inc., Box 25, New Lebanon Center, New York

   Rev. Sci. Instruments 29, 454 (1958).

   Hermetic seals can now be made between synthetic sapphire and metal parts by a process similar to that used for making high-temperature ceramic-to-metal assemblies. Sapphire disks up to 3" in dia and tubes up to 1/2" in dia have been sealed to tubular metal members of Kovar, nickel-iron, and platinum.
   Silver-copper brazing alloy is used to form assemblies capable of installation by soldering, brazing or welding techniques without bond failure. Current applications of sapphire seal assemblies include wave guide windows for radar equipment, high temperature windows for high vacuum equipment, and ultraviolet studies in the nuclear energy field. Facilities and design assistance for special requirements are available from the manufacturer.

4. "A Reliable Optical Window for Cells Subjected to Widely Cycling Temperatures and Pressures"

Waggener, W. C. and Tripp, A. M. (Oak Ridge National Laboratory) To be published.

A new type of window (sapphire) was designed for use with high temperature aqueous solutions in spectrophotometer cells. The principle of the window mount involves a spring-loaded Teflon ring-seal in an annulus between the polished cylindrical wall surface of the sapphire window disk (0.725" O.D. x 0.400" thick) and the concentric wall surface of the cylindrical recess in the end of a titanium cell core. The leak tight seal is made independently of the mount which holds the window disk against the end of the absorption cell core.

Temperature: 0° to $250^{\circ}C$ (tested), probable $-50^{\circ}C$ to $250^{\circ}C$ (upper limit is fixed by the physical properties of Teflon and the Inconel-X Springs, etc.)

Pressure: 10^{-3} to 68 atmospheres (tested), probable to 3000 psia.

The spring-loaded Teflon seal mechanism provides features of reliability, leak-tightness and safety. Certain pertinent aspects of this window development work have also been reported as follows:
a) "A Technique for Liquid Phase Spectrometry at Elevated Temperatures and Pressures," "Quantitative Spectrometry of Aqueous Neptunium Ion at Elevated Temperature and Pressure," W. C. Waggener, papers presented at 134th National ACS Meeting, September 1958, Chicago, Ill.
b) W. C. Waggener, "Quantitative Spectrometry of Aqueous Neptunium Ions at Elevated Temperatures and Pressures," J. Am. Chem. Soc. 80, 3167 (1958).
c) W. C. Waggener and R. W. Stoughton, "Adaptation of a Cary Model 14 M Recording Spectrophotometer for Measurements of Aqueous Spectra at Elevated Temperatures and Pressures," Chemistry Division Ann. Progress Report (Oak Ridge National Laboratory), ORNL-2386; Rev. Scientific Instr., in press)

5. "Apparatus for Optical Studies to Very High Pressures"

Fitch, R. A., Slykhouse, T. E., and Drickamer, H. G.

J. Optical Soc. Am. 47, 1015-1017 (1957).

An apparatus has been developed in two stages which permits optical studies to 200,000 atmospheres pressure. The use of NaCl windows permits studies in the near ultraviolet and in the infrared as well as the visible. The design of the pressure cells and of a press suitable to fit a spectrophotometer are described with essential dimensions. A calibration tested against Bridgeman's data to 87,000 atmospheres is given. The desirable harndesses of the metal parts and surfaces are discussed. The windows are of one piece filling three separate sections. The windows are formed within the cell.

Temperature: room temperature, but can probably be increased at the expense of diminished pressure.

Pressure: up to 200,000 atmospheres.

6. "Development of Chemical Studies at Super-High Compressions"

Gonikberg, M. G.

Vestnik Akad. Nauk, S.S.S.R. 28, 50-58 (1957). Russian; translation in progress.

A report is made on the chemical investigation techniques and technological achievements in compression of solid and fluid materials under super-high pressures. (At the time of this compilation the journal was not available for further abstracting regarding windows.)

7. Physico-Chemical Effects of Pressure

Hamann, S. D.

Academic Press, Inc., New York, 1957. Buttersworth Sci. Publ., London.
pp. 25-27 "Optical Windows."

Includes chapters on: Electrical Connections, High-Temperature and High-Pressure, Absorption Spectra, Polarography, etc.

8. "Temperature Effect on Induced Infrared Absorption in Gasseous Acetylene at Pressure"

Ozawa, K.

Rev. Phys. Chem. Japan 27, 9-15 (1957). English

Optical Window-LiF (1.2 cm thick x 1.9 cm dia). Crystal cylinder. Designed by Bridgeman's principle of unsupported area. Teflon gaskets. Electrical internal heating. Cell length, 14 cm.

Temperature: 240°C.

Pressure: ~12 Amagat Densities

9. "Pressure Effects on the Ultraviolet Absorption Spectra of Some Aromatic Hydrocarbons"

Robertson, W. W., Weigang, O. E., and Matsen, F. A.

J. Mol. Spectroscopy 1, 1-10 (1957).

The absorption spectra of liquids up to 6000 bars (~atmospheres) were measured. For a detailed discussion of the cell design see D. S. Hughes and W. W. Robertson, J. Optical Soc. Am. 46, 557 (1956). (Ref. 19).

Temperature: room temperature

Pressure: 6000 bars

10. "Insulated Lead-Through Seals for Use at High Temperatures"

Wade, F.

A.E.R.E. R/R 2271 (May, 1957). (Atomic Energy Research Establishment, Harwell, England

A discussion of metal to quartz and synthetic sapphire seals. The use of a titanium cored copper-silver eutectic alloy is also discussed.

11. "Unsupported Area High Pressure Seal"

Warschauer, D. M. and Paul, W.

Rev. Sci. Instruments 28, 62 (1957).

Topics discussed include: Optical high-pressure bomb with sapphire window. Methods of mounting and sealing window (Poulter technique). Packing materials and gaskets discussed. Hardness of metal components indicated.

Temperature: room temperature

Pressure: ~10,000 atmospheres

12. High-Pressure Technology

Comings, E. W.

McGraw-Hill Book Co., New York, N. Y., 1956 pp. 117-119, "Windows and Sight Glasses"

The Poulter window is discussed.

13. "Infra-red Spectra of Gasseous Mixtures Under High Pressure"

Coulon, R., Galatry, L., Robin, J. and Vodar, B.

Faraday Soc. Discussions, Vol. 22, 22-29 (1956).

A discussion of the spectra of gases and gas mixtures, up to 6000 atmospheres pressure and at variable temperatures higher than 150°C. Large bibliography with 50 references (all references were checked).

Temperature: >150°C

Pressure: 6000 atmospheres

14. The Physical Chemistry of Processes at High Pressures - A General Discussion.

Faraday Soc. Discussions, Vol. 22, (1956).

Numerous interesting and pertinent papers, containing information on optical methods and observations at elevated temperatures and pressures.

15. "Liquid-Phase Free-Radical Dissociations at High Pressure"

Ewald, A. H.

Faraday Soc. Discussions, Vol. 22, 138-143 (1956).

A stainless steel high pressure absorption cell was used with windows constructed on the principle described by Poulter (1932).

Temperature: used up to 70°C

Pressure: up to 3000 atmospheres

16. "The Effect of Pressure on Complex Ion Equilibria"

Ewald, A. H. and Hamann, S. D.

Australian J. Chem. 9, 54-60 (1956).

A stainless steel high pressure absorption cell was used with windows constructed on the principle described by Poulter (1932).

Temperature: not studied specifically, but measurements were made to ~50°C

Pressure: measurements made up to 1500 atmospheres

17. "Equipment for High Pressure Optical and Spectroscopic Studies"

Fishman, E. and Drickamer, H. G.

Anal. Chem. 28,(5) 804-806 (1956).

The Poulter-type gasketless synthetic sapphire window was used to 12,000 atmospheres. Spectra from 0.2 to 5.0 μ. Designed for use with a Perkin-Elmer Single Beam Spectrometer.

Temperature: apparently room, or normal temperature

Pressure: 12,000 atmospheres

18. "Infrared Absorption Cells for Measurements at Different Temperatures"

Funck, E.

Optik 13, 524-528 (1956). German

NaCl windows were used with lead gaskets.

Temperature: up to 250°C

Pressure: up to atmospheric

19. "Apparatus for Obtaining Optical Absorption Spectra at Pressures up to 6000 Bars"

Hughes, D. S. and Robertson, W. W.

J. Optical Soc. Am. 46, 557 (1956).

Sapphire windows, 0.4" thick and 1" dia were used. The windows rest on a flat steel surface and a brass bushing supports a Teflon ring that in turn supports an O-ring.

Temperature: normal room temperature

Pressure: 6000 bars

20. "High Pressure Equipments in Abu-yama Seismological Observatory of Kyoto University"

Kiyama, Ryo

Rev. Phys. Chem. Japan 26, No. 1, 24-39 (1956). English

Contains a list of all high pressure work published from this institution since 1945. Publications in the following cateogries are listed: Apparatus (optical window, packing, etc.); Materials; P-V-T relations; Solubility; Viscosity; Crystal and color centers Infrared Absorption; Colloids; Chemical Reactions; Reaction Rates; Explosions; Preliminary Compressors; Pipes (stress, strain and design considerations); Intensifiers; The Measurements of Pressures; Effect of Plastic deformation upon colloid centers in sodium chloride crystals; Studies on compacted powder crystals, Polymorphic transistion of thallous iodide under pressure.

21. "Windowed Autoclaves"
(A review with 43 ref.)

Murahashi, Shunsuke

J. Soc. High Pressure Gas Ind. (Koatsu Gasu Kyokaishi) 20, 75-82 (1956).

22. "Polymerization of Styrene at High Pressures Using the Sector Technique"

Nicholson, A. E. and Norrish, R. G. W.

Faraday Soc. Discussions, Vol. 22, 104-113 (1956).

High-Pressure absorption cell with windows mounted in the packingless manner described by Poulter. The windows were quartz, 1/2, 3/4 or 1" thick, with optically polished ends.

Temperature: up to 60°C

Pressure: up to 3000 atmospheres

23. "Apparatus for the Study of The Propagation of Ultrasonic Waves in Highly Compressed Gases"

Noury, J.

J. phys. radium 17, 166 (1956). French

Refractive index measurements were made in order to determine the velocity of the ultrasonic waves through the compressed gas. The pressure bomb (pictured) was equipped with two pressure windows made from Calex glass. The windows and the seating surfaces were optically polished and were mounted as was designated by Poulter. The windows were held in place by retaining collars.

Temperature: 25°C

Pressure: 1200 atmospheres

24. "Sodium Chloride and Calcium Fluoride Windows for High Pressure Infrared Spectroscopy"

Parsons, R. W. and Drickamer, H. G.

J. Optical Soc. Am. 46, 464 (1956).

Used sapphire windows for spectroscopic studies of liquids under pressures to 12,000 atmospheres. Halide materials, used with the Poulter type window mount, were studied.

Temperature: normal room temperature

Pressure: 12,000 atmospheres

25. "Perturbation of Electronic Resonance Spectra by Foreign Gases Under High Pressure"

Robin, J., Bergeon, R., Galantry, L. and Vodar, B.

Faraday Soc. Discussions, Vol. 22, 30-38 (1956).

Quartz or sapphire windows were used with a Poulter-type mounting.

Temperature: up to 1200°C

Pressure: up to 1200 atmospheres

26. "An Apparatus for Spectrographic Studies up to 6000 Atmospheres"

Robin, J. and Vodar, B.

J. phys. radium 17, 500-501 (1956). French

Absorption cells, constructed with windows mounted after the manner of Poulter were designed to work at 6000 atmospheres pressure.

Temperature: -150°C to +300°C

Pressure: 6000 atmospheres

27. "An Internally Heated Cell for Spectroscopic Work at High Temperatures and Pressures"

Robin, J. and Robin, S.

J. phys. radium 17, 499-500 (1956). French

Poulter type gasketless quartz windows were used for optical studies with compressed gases.

Temperature: to 1100°C

Pressure: to 1500 atmospheres

28. "Pertubations of Spectral Lines by Pressure; In the Atomic Spectra of Electrically Neutral Particles"
A review, with 154 references.

Robin, Stephane and Robin, Simone

J. phys. radium 17, 143-161 (1956). French

It is stated that the principle problems concern the windows of the absorption cells. The window problem is discussed from the standpoint of elevated temperatures and pressures, for a number of possible window designs, including the very great difficulties encountered if water cooled windows are used. It is concluded that the simplest method is the direct contact of optically polished surfaces, which will repeatedly resist conditions of 400°C and 1000 atmospheres pressure. Internal heating, MgO windows

and the dissolution of materials by compressed gases is also discussed. Literature is cited. (This literature was reviewed).

Temperature: >400°C

Pressure: >1000 atmospheres

29. "Experiments on the Displacement of the Ultraviolet Absorption Edge of Olivine at High Pressures"

Runcorn, S. K.

J. Appl. Physics 27, 598-602 (1956).

The effect of pressure on the fundamental excitation energy of valence electrons in the ferromagnesium orthosilicate, the mineral olivine, is of interest in the theory of the electrical conductivity of the earth's mantle. The experimental determination of this by observation of the displacement of the ultraviolet absorption threashold of olivine up to pressures of about 30,000 bars is described. Thin slices of the mineral were sandwiched between window disks of quartz or sapphire. Sapphire was found to be much superior for the higher pressures.

Temperature: room temperature

Pressure: 30,000 bars

30. "Line Broadening and Dielectric Relaxation in Compressed Gases"

Phillips, C. S. E.

J. Chem. Phys. 23, 2388-2394 (1955).

A steel-pressure bomb microwave absorption cell was designed with thick glass windows for microwave transmission. The windows (and steel seating faces) were polished optically flat and mounted in the manner described by Poulter (Phys. Rev. 40, 860 (1932)). The bomb was designed for 3000 atmospheres pressure at temperatures up to 300°C. (However from other considerations the equipment was used up to 10,000 psi (680 atmospheres) and 102°C).

Temperature: 300°C

Pressure: 3000 atmospheres

31. "Pressure Vessel with Internal Windows"

Wells, F. W. and Roof, J. G.

Rev. Sci. Instruments 26, 403-404 (1955).

Full length (14.5") glass window for pressures to 8000 psi and 300°F, construction and seals are described.

Temperature: 300°F

Pressure: 8000 psi

32. "Spectra of Iodine Solutions. II. The Effects of High Pressures upon Iodine Complexes"

Ham, J.

J. Am. Chem. Soc. 76, 3881-3885 (1954).

A cell was designed for use with a Beckman DU Spectrophotometer. Cylindrical (1/2" x 1/2") windows of artificial unoriented sapphire were mounted flush with the steel window recesses, the final seal being made with Neoprene "O" Rings. This in an interesting paper on other aspects of spectrophotometric high-pressure techniques. Samples were placed in a second cell (which fitted into the main pressure cell with sapphire windows) with cemented quartz windows and a flexible Teflon compression top. This cell was suspended in Heptane (pressure transmitting fluid) within the main cell body.

Temperature: room temperature

Pressure: up to 2000 atmospheres

33. "F-Center Absorption in Alkali Halides"

Jacobs, I. S.

Phys. Rev. 93, 993-1004 (1954).

A cell was designed for use with the Beckman DU Spectrophotometer. This was similar to the cell used by Ham (J. Am. Chem. Soc. 76, 3881-3885 (1954)), and contained sapphire windows with Neoprene "O" Ring packing. One "O" Ring seals both the window and its mount.

Temperature: room temperature (20°C to 25°C

Pressure: up to 5000 atmospheres

34. "Induced Infrared Absorption in Gasseous Acetylene at Pressure"

Minomura, S.

Rev. Phys. Chem. Japan 24, No. 2, 49-55 (1954). English

Windows: KCl (2.4 cm dia x 1.6 cm thick). Designed by the principle of a packingless window, but cement was used to seal between the polished surface of the window and its supporting plug. Dia of free area was 1.8 cm.

Temperature: room temperature

Pressure: used at approx. 24 atmospheres, but previous work indicates service to 250 atmospheres.

35. "Pressure Chamber for Micro-Optical Observations"

Turner, C.

J. Sci. Instruments 31, 9-10 (1954).

A pressure chamber of small dimensions is described for optical observations at pressures up to 1000 atmospheres. The apparatus has been tested for pressures up to 500 atmospheres and for temperatures up to 100°C. It has been used for the measurements of latent heats of transition on small samples of materials. The apparatus was designed throughout, on the lines developed by Bridgeman, and is intended for a pressure range from 1-1000 atmospheres, at temperatures from 0° to 150°C. Poulter type windows (glass) without packing were used, and were ground optically flat.

Temperature: 0° to 150°C

Pressure: 1 to 1000 atmospheres

36. "Infrared Absorption of N_2 and O_2 Induced by Intermolecular Forces"

Coulon, R., Oksengorn, B., Robin, Stephane, and Vodar, B.

J. phys. radium 14, 63 (1953). French

Fluoride windows were used (7 mm thick, 7.5 mm beam), mounted in the manner described by Poulter.

Temperature: room temperature

Pressure: up to 900 atmospheres

37. "Sintillation Counters for Continuous Analysis Under High Pressure"

Drickamer, H. G., Timmerhaus, K. D., Tung, L. H.

Chem. Eng. Progress 49, (9), 503-505 (1953).

An excellent discussion on the design of optical windows for high pressure work with gases and liquids; the use of c-axis synthetic sapphire and the hardness of metal parts are discussed, with particular emphasis on the Poulter type of gasketless Bridgeman unsupported-area window seal.

38. "Pressure Effects of Argon and Helium on the Resonance Lines of Silver"

Clayton, E. D. and Ch'en, Shang-Yi

Phys. Rev. 85, 68-70 (1952).

The cell was similar to that developed by Ch'en (Phys. Rev. 58, 1051-1061 (1940)). The windows were made of clear fused quartz plugs held in place by Nilvar cones, which were kept below 300°C to avoid leakage. The inner absorption cell was 13.3 cm long. Two clear fused quartz rods were inserted into the main pressure tube for the purpose of reducing the convection currents in the light path. These rods also served as the windows for the inner absorption tube.

Temperature: studies made up to 950°C, windows kept $\leq$300°C

Pressure: 83.3 atmospheres

39. "Pressure Vessel Windows for Use at High Pressure"

Heisig, C. G.

ORNL CF-52-8-140, Aug. 6, 1952
Memo to: C. E. Winters

A partial review of the literature up to 1952; 18 references. The technical aspects of the various types of sealing techniques are briefly discussed. A drawing of each type of window is given.

40. "The Effect of Pressure on Self-Diffusion in Carbon Disulfide"

Koeller, R. C. and Drickamer, H. G.

J. Chem. Phys. 21, (2), 267-273 (1952).

Sapphire and Quartz windows were used with a Poulter type gasketless optically flat mounting.

Temperature: studied from 0°C to 40°C

Pressure: to 10,000 atmospheres

41. "Notes on the Practice of Infrared Spectroscopy"

Lord, R. C. McDonald, R. S., and Miller, F. A.

J. Optical Soc. Am. 42 149-159 (1952).

The construction of absorption cells and associated windows for high and low temperature measurements is discussed. Six references to high, and eleven references to low temperature cells are given, and are partially discussed.

Temperatures: High; up to 550°C (gases), 270°C liquids. Low, down to 4°K

Pressure: up to ~ atmospheric

42. "Optical Properties of Gases at High Temperatures and Super-High Pressures"

Ryabini, Y. N., Sobolev, N. N., Markevich, A. M., and Tamm, I. I.

Zh. eksper, teor. Fiz. 23, No. 5 (11) 564-575 (1952). Russian. Available as translation AEC-tr-2599.

Studied the luminescence of argon heated to several thousand degrees by adiabatic compression. In the apparatus (no pictures or schematic given cf. ref. 43), the window had the form of a truncated cone (angle 15°), fitted with a ground joint into the metal top of the tube, so that it became firmer by the compression. The thickness of the window was 9 mm, its diameters 12.5 and 7.5 mm. Windows were made of fused quartz or of glass. No mention was made of packing material, and the window was apparently packingless. No literature or window development, etc. was given and no mention was made of experimental difficulties, window stability, etc.

Temperature: up to 9000°K (gas). Window temperature (?) (not high).

Pressure: up to 5500 kg/cm^2 (~ atmospheres)

43. "Super-High Pressures and High Temperature Obtained by the Method of Adiabatic Compression"

Ryabini, Y. N.

Zh. eksper. teor. Fiz. 23, No. 4 (10) 461-467 (1952). Russian; translated. CCT-752; Consultants Custom Translations, Inc., 227 W. 17th St. New York 11, N. Y.

An illustrated description of an apparatus for obtaining super-high pressures (up to 10,000 kg/cm^2) in gases at high temperatures. The principle of operation is that of adiabatic compression. It is claimed that the apparatus can be used for the optical properties and electrical properties and electrical conductivity of gases at super-high pressures and high temperatures, and of their compressibility.

The essential part of the apparatus is a "gun"-barrel, 365 mm long, 25.6 mm bore, provided with a specially designed piston. A diagram of the apparatus is given. The window (a cone) is as described in ref. 42.

Temperature: high, perhaps to 9000°K (gas). Window temp. (?) (not high)

Pressure: up to 10,000 kg/cm^2 (~ atmospheres)

44. "The Strength of Single Crystals of Inorganic Salts"

Kiyama, Ryo and Inoue, K.

Rev. Phys. Chem. Japan 21, 78-81 (1951). English

The strengths of single crystals of NaCl, KCl, and LiF were measured to determine the pressure ranges for optical windows; they can be used to ~400, 250, and 4000 atmospheres respectively. LiF has many excellencies which can be used as optical windows over a very wide pressure range. Data is given on plastic flow, protrusion into openings and crushing and cracking strengths.

Temperature: room temperature

Pressure: 250, 400 and 4000 atmospheres

45. "The Bursting of Glass Tubes by Inner Hydrostatic Pressure"

Kiyama, Ryo and Inoue, K.

Rev. Phys. Chem. Japan 21, 73-77 (1951). English

An excellent paper: The method of connection of glass to metal in a high-pressure vessel was designed and discussed. Formula given for calculating bursting pressure. When dia ext/dia int >2, Soda line glass can be used to 300 atmospheres. Strained glass tubes are stronger than annealed tubes and are scattered into small fragments uniformly in bursting.

46. "Quantitative Infrared Intensity Measurements. I. Carbon Monoxide Pressurized with Infrared-Inactive Gases"

Penner, S. S. and Weber, D.

J. Chem. Phys. 19, 807-816 (1951).

Three types of high pressure cells are described in reasonable detail, two for static measurements, and one for mixing gases during measurements. The windows are quartz or rock salt windows mounted with either Neoprene or Teflon gaskets. In two designs the windows are mounted within a recess in the pressure chamber, and in the third, the windows are recessed with gasket mounts in a larger end plate that is in turn bolted and gasketed to the cell.

Temperature: measurements made at room temperature, probably useful at higher temperatures.

Pressure: up to 1000 psig quartz; up to 300 psia (20 x 40 mm)

47. "Apparatus for Absorption Spectrographic Studies of Compressed Gases up to 1200 Kg/cm^2"

Robin, Stephane

J. chim. phys. 48, 415-422 (1951). French

This excellent paper discusses the use of pressure windows in detail, as well as the fine points of grinding and polishing the surfaces optically flat. Various types of bombs are considered, all of which have quartz windows mounted exactly as designated by Poulter, without any gasket material, and in accordance with the principle of the unsupported area. Variable space cells are also discussed. Many other related aspects of high-temperature high-pressure spectral work is also discussed.

Temperature: higher than $400^{\circ}C$

Pressure: >1200 kg/cm^2 (~ atmospheres)

48. "Integrated Absorption of the Fundamental of CO from Measurements Using Self-Broadening of Rotational Lines"

Weber, D. and Penner, S. S.

J. Chem. Phys. 19, 974-975 (1951).

A very interesting design of a small infrared absorption cell, with a variable path length, was constructed, and is sketched. The quartz windows are separated by accurately machined stainless steel spacers. The leak-tight seals are made with O-rings.

Temperature: room temperature

Pressure: 700 psia

49. "Influence of Foreign Gases at High Pressures on the Infrared Absorption Band of Methane at 3.3 μ"

Welsh, H. L., Pashler, P. E. and Dunn. A. F.

J. Chem. Phys. 19, 340-344 (1951).

Reflection type cell, variable space cell (5×10^{-4} to 4.0 cm) with internal tantalum mirror. Fused quartz window, 0.38 thick x 2.46 cm dia, mounted in the Poulter fashion. Free window area, 0.8 cm.

Temperature: room temperature

Pressure: up to 600 atmospheres

50. Sight Glasses and Windows

Perry, J. H. Chemical Engineers Handbook

McGraw-Hill, New York, 1950 pp. 1252-1253

The Poulter window and three other designs are briefly discussed.

B. Publications located between 1949 and 1940 (incl.)

51. "The Shock Tube: A Facility for Investigations in Fluid Dynamics"

Bleakney, W., Weimer, D. K. and Fletcher, C. H.

Rev. Sci. Instruments 20, 807-815 (1949).

A 4" x 18" x 38' shock tube is described, as well as the necessary auxillary equipment. Windows are mounted in the tube, and they are high quality optically flat with uniform thickness. They are 5" in dia, 7/8" thick, and are mounted by means of Wood's metal seals to steel rings which in turn fit into the openings in the wall of the tube. The whole combination is flush with the inside surface and a rubber gasket on the outside seals the steel ring to the wall so that the system is vacuum tight.

Temperature: not discussed, probably room temperature

Pressure: not discussed, the pressure difference between the sections of the tube range from ~0 to 1 (P_L/P_H) atmosphere

52. The Physics of High Pressure

Bridgeman, P. W.

G. Bell and Sons, London, 1949 pp. 57-59, "Glass Windows"

Along with several window designs the type of window seal designated by Poulter is discussed in particular.

53. "Some New Techniques in the Construction of Spectrographic Absorption Cells"

Kivensen, G., Roth, A., and Rider, M.

J. Optical Soc. Am. 39, 484-486 (1949).

Cell windows were of quartz; flat circular plates. The seal involved platinizing the quartz and soldering directly to the metal.

Temperature: room temperature

Pressure: 100 to 125 lb/in.^{2}

54. "Ultra Pressure VIII. Material Flow of Attachments of High Pressure Apparatus"

Kiyama, Ryo

Rev. Phys. Chem. Japan 20, 73-75 (1946). English

Polished surfaces of glass or quartz and steel were set without any cementing or packing materials, the author succeeded in setting two pieces only by pressing them hard. NOTE - If there are any adhesive materials, it will be a cause of leakage, because polished surfaces will be destroyed in consequence of the flow of intermediate materials. As (for) the same reason, the polished surface of steel is necessarily as hard as transparent materials.

55. "The Broadening of Na Lines by Argon"

Kleman, B. and Lindholm, E.

Arkiv, Mat. Astr. och. Fys. 32, 1 (1946). English

Absorption cells made entirely of glass were used. Plane end windows of Jena glass were used. The cells were heated in a furnace.

Temperature: 200°C

Pressure: up to 5 atmospheres

56. "Studies on High Pressure Gaskets"

Uchida, Shun-Ichi and Suezawa, Yoshitada

Rev. Phys. Chem. Japan 20, 91-97 (1946). English

An excellent theoretical and practical discussion of high pressure gasketing methods. Theoretical considerations based upon nonuniform distribution of initial gasket pressure have led to a set of equations of more general applicability than the usual ones with these equations the numerical values requisite in the design of a gasket of the simple type can be found.

57. "Pressure-Proof Character of Optical Window"

Kiyama, Ryo

Rev. Phys. Chem. Japan 19, No. 1, pp. 1-42 (1945) (in Japanese; translation in progress) Ultra Pressure: 1-7, cf. English Index Page. No. 3, pp. 17-20, English Summary, p. 20.

A discussion of the Poulter-type window and its merits. Other windows are also discussed. cf. Eng. Summary, p. 20.

58. "Packing"

Kiyama, Ryo

Rev. Phys. Chem. Japan 19, No. 1, pp. 21-25 (1945) (in Japanese; translation in progress). Ultra Pressure: No. 4, English Summary p. 25

The materials used for packing decide the size and type of packing. Sealing is performed by the method of automatic compression by pressure greater than the inner pressure.

59. "Sight Glass Design Eliminates Breakage by Improved Method of Sealing"

Caldwell, W. F.

Chem. Met. Eng. 51, (12) 116, (1944).

The window design is intricate, and utilizes several V-rings and packings

Temperature: room temperature

Pressure: to 300 psi

60. "On the Design of Apparatus for the Chemical Experiment Under High Pressure"

Kume, T.

Rev. Phys. Chem. Japan 17, No. 1, Review Section, pp. 1-11 (1943). Japanese, no English Summary (Translation in progress)

In addition to the work of other authors, the work of Poulter is discussed.

61. "The Effects of High Pressure on the Inversion of Sucrose and the Mutarotation of Glucose"

Sander, F. V.

J. Biol. Chem. 148, 311-319 (1943).

A steel tube that was copper, silver, and nickel plated was used as a reaction vessel. Each end was cut in such a way that a self-sealing end cap could be used. Each cap contained 7.5 mm thick plate glass windows permanently sealed to the end cap. No diagrams or details as to the type of window mount are given.

Temperature: 20°C

Pressure: >3000 atmospheres

62. "The Pressure, Temperature Relations of Bacterial Luminescence"

Brown, D. E., Johnson, F. H., and Marsland, D. A.

J. Cell. Comp. Physiol. 20, 151-167 (1942).

The apparatus is not discussed, but is diagrammed. The window was apparently mounted in the packingless manner as was originated by Poulter.

Temperature: up to 40°C

Pressure: to 7000 psi

63. "The Effects of Pressure on Sol-Gel Equilibria, with Special Reference to Myosin and Other Protoplasmic Gels"

Marsland, D. A. and Brown, D. E.

J. Cell. Comp. Physiol. 20, 295-305 (1942).

The pressure bomb (pictured) contained four identical windows, all apparently mounted in the packingless manner that was originated by Poulter.

Temperature: <50°C

Pressure: up to 8000 psi

64. "The Kerr Effect and Ordering of the Molecular State in High Density Gasses and Liquids"

Kuss, E. and Stuart, H. A.

Physik. Z. 42, 95 (1941). German

Windows: Cylindrical glass windows (30 mm dia transmitting area) seated in interior milled recess of steel tube, and seated with Canada Balsam. Pressure seal made by application of Bridgeman's principle of the unsupported area.

Temperature: 25°C to 40°C

Pressure: up to 420 atmospheres

65. "Broadening, Asymmetry and Shift of Rubidium Resonance Lines under Different Pressures of Helium and Argon up to 100 Atmospheres"

Ch'en, Shang-Yi

Phys. Rev. 58, 1051-1061 (1940).

An intricate window design for a cell within a cell. The inner cell chamber for the Rb was closed with MgO windows (3/4" dia x 1/8" thick) by pressing the window against the sharp beveled edge of the tube with a screw cap. These windows did not have to withstand the full pressure, and were under little pressure differential.
The outer pressure windows were conical and were made of pyrex (2 cm thick x 3/4" dia, 5° cone angle). Leakage occurred at an angle greater than 7°. The window was seated in a ground-to-match end in a Kovar tube. A very thin aluminum gasket was used and the window was seated at 250°C. The Kovar tube was silver soldered to the outer, steel, window retaining plug. A, He, and H_2 were used.

Temperature: 300°C

Pressure: up to 100 atmospheres

66. The Design of High Pressure Plant and the Properties of Fluids at High Pressure

Newitt, D. M.

Oxford, New York, 1940 pp. 92-97

The design of glass and transparent quartz windows are discussed, particularly the design of Poulter. A high-pressure liquid level indicator using quartz windows is also discussed.

C. Publications located between 1939 and 1930 (incl.)

67. "Some Properties of White Sapphire"

Freed, S., McMurry, H. L. and Rosenbaum, E. J.

J. Chem. Phys. 7, 853-859 (1939).

Plane transparent windows of synthetic white sapphire (corundum; Al_2O_3), as large as 2" x 1/2" x 1/16" were obtained at reasonable cost. They show excellent transmission throughout the visible spectrum and down to 1435 Å. They were uninjured by 15 hrs. contact with liquid and gaseous HF.

68. "The Broadening and Displacement of the Central and Higher Potassium Series Lines by Helium at High Pressure

Fuchtbauer, C. and Heesen, W.

Z. Physik 113, 323 (1939). German

Cylindrical quartz windows were mounted to a pressure cell, by being contained between two flanges. The window was mounted between rubber gaskets on either side and the window flange was similarly mounted to the pressure tube. The tube (176 cm long) was heated to 530°C in the middle portion but the windows did not become hot since they were water cooled.

Temperature: windows (room temperature) expt: 530°C

Pressure: 55 atmospheres

69. "Viewing Tubes for High Pressure"

Roebuck, J. R. and Miller, E. E.

Rev. Sci. Instruments 10, 179 (1939).

An oversize tube of polished transparent plastic (Bakelite) is put into a slotted steel supporting tube by cooling in liquid air. At room temperature, the thermal expansion creates such a compressive stress that the estimated internal pressure is 700 atmospheres. The window is absolutely reliable.

Temperature: room temperature

Pressure: 400 to 700 atmospheres; 1000 atmospheres theoretical

70. "The Influence of Temperature and Pressure on the Infrared Absorption Spectrum of Gasseous and Liquid Hydrogen Chloride up to the Critical State"

West, W.

J. Chem. Phys. 7, 795 (1939).

Glass windows: 20 mm thick x 25 mm clear aperture. The windows were mounted with lead washers and Bakelite cement.

Temperature: -100°C to +52°C

Pressure: to 82 atmospheres

71. "The Influence of Temperature and Pressure on the Volume and Refractive Index of Benzene"

Gibson, R. E. and Kincaid, J. F.

J. Am. Chem. Soc. 60, 511-518, (1938).

A steel bomb absorption cell similar to that of Gibson (J. Am. Chem. Soc. 59, 1521-1528 (1937)) was used. Sapphire windows mounted after the manner of Poulter were used. The window plug mounts were sealed to the bomb body via 45° cut copper washers against an angular face of the window plug.

Temperature: from 25°C to 65°C

Pressure: to 1250 bars

72. "The Study of Extreme Pressures and their Importance in the Investigation of Engineering Problems"

Poulter, T. C.

J. Applied Phys. 9, 307-311, (1938).

Among many other aspects of high pressure research that are discussed, pressure windows and their use are discussed, including problems encountered in their use. A bibliography is given covering most of the work by Poulter, his students, and his co-workers.

73. "Concerning the Self- and Foreign-Pressure Broadening in the Branch of the Mercury Resonance Line at 2537 Å"

Ruhmkorf, H. A.

Ann. Physik. 33, 21-51 (1938). German

Glass cells with plane quartz windows were used to contain the Hg. Up to 10 atmospheres pressure and 160°C, the pressure windows were gasketed with Buna-N rubber and a steel tube was used for the cell. The windows were quartz plates (no mounting details were given). The cell was heated in an oven that was closed with quartz windows. Work was also done at

temperatures up to 450°C. No details of window gaskets, or the mounting technique are given.

Temperature: up to 160°C (Buna-N gaskets); up to 450°C (? gaskets)

Pressure: up to 10 atmospheres

74. "Infrared Absorption Spectra and Raman Spectra of Liquified HCl Gas"

Vodar, B., Freymann, R. and Ta, Yeou

J. phys. radium 9, 282-286 (1938). French.

Quartz windows were used. This is an interesting design using interior window retaining plugs, lead sealing rings were used for the major retaining plug and window seals.

Temperature: -80°C to +14°C, upper limit?

Pressure: >570 psi

75. "The Effect of Pressure on the Absorption and Optical Activity of Water"

"The Effect of Hydrostatic Pressure on Polarization in an Optical System"

Zinser, R. H.

Phys. Rev. 50, 1097 (1936). Trans. Kansas Acad. Sci. 41, 241 (1938).

Poulter windows (1.9 cm thick) were used in these studies.

Temperature: room temperature

Pressure: up to ~700 atmospheres

76. "A Method for Sealing β-Magnesia Windows into Steel Spectroscopic Absorption Furnaces and a Needle Valve for Controlling the Evacuation of Such Furnaces"

Brice, R. T.

J. Optical Soc. Am. 8, 209, (1937).

Three methods of sealing and mounting MgO optical windows for high temperature spectroscopic work are discussed. The best method involves grinding a β-MgO window (1/2" dia x 1/4" thick) to a 1° taper, followed by polishing of the edges. A bar of Al (Cu) was then bored out with an identical inside taper and the window then pressed into the bored recess. The

Al bar was then turned down until the thickness of the Al was 0.020" around the window. The window thus protected by an Al band was then fitted into a steel tube similarly bored out. The tube can be made as a bolt and be sealed into the pressure vessel via gaskets. Two methods of gasket sealing with Al, Cu and Ni are discussed.

Temperature: up to 587°C

Pressure: atmospheric, apparently not studied

77. "The Compression of Solutions of Certain Salts in Water, Clycol and Methanol"

Gibson, R. E.

J. Am. Chem. Soc. 59, 1521-1528 (1937).

A steel pressure bomb was fitted with two quartz windows. The windows and faces of the stainless steel plugs which held them in place were ground optically flat and the windows were mounted in the manner of Poulter. This proved to be very satisfactory and there was <u>never any sign of leakage</u>.

Temperature: 25°C

Pressure: up to 1000 bars

78. "The Effect of Pressure on the Refractive Index of CO_2"

Michels, A. and Hamers, J.

Physica 4, No. 10, 995 (1937).

A steel absorption cell whose window mounting surfaces were ground optically flat were used. Quartz windows were used and were mounted as described by Poulter.

Temperature: up to 100°C

Pressure: up to 2400 atmospheres

79. "The Displacement of Principal Series Lines of Rubidium by The Addition of Rare Gases"

Ny, Tsi-Ze and Ch'en, Shang-Yi

Phys. Rev. 51, 567-574 (1937).

Quartz windows were mounted in ground-to-match caps that screwed onto a 100 cm steel tube. The window cylinders had one end beveled at about 30° from the cylinder surface. The windows were then seated using lead gaskets. Steel retaining rings

were used to hold the quartz into position. The window plug seal was also made with lead.

Temperature: windows were water cooled - other measurements were made in the middle of the tube at 317°C

Pressure: ~15 atmospheres

80. "Sapphire and Other New Combusion-Chamber Window Materials"

Calingaert, G., Heron, S. D. and Stair, R.

S. A. E. Journal 39, 448-450T (1936).

The transparency, mechanical strength, chemical resistance and installation of synthetic quartz, spinel, sapphire and periclase and of fluorite and rock salt windows are described. The design of windows for the observation of the interior of combustion chambers is discussed. Resistance to the chemical action of the combustion products. Sapphire is not attached by any products of combustion. The windows were cylindrical, with beveled edges. The two flat surfaces were polished whereas the edges were only ground to a fairly smooth finish. The use of the beveled joint with a soft annealed aluminum gasket gave a perfect seal without setting up of any of the strains that are evident in the flat-disk type of window. Sapphire was one of the most promising materials where cost was not a primary factor, up to about 5 microns. For longer infrared wavelengths other materials show better transmission but poorer mechanical properties.

81. "Spectrometer for Studies at High-Pressures"

Lyons, W. J. and Poindexter, F. E.

J. Optical Soc. Am. 26, 146-148 (1936).

Instrument used consisted of a liquid prism confined between glass walls, the whole being encased in a cylinder of thick walls, through which narrow, horizontal slits for the entrance of light, are cut. Windows waxed (while hot) to steel lugs. Principal of the unsupported area was used.

Temperature: room temperature

Pressure: to 1823 atmospheres

82. "The Absorption Spectra of Oxygen Limited (Restricted) by Mutual Exchange Forces"

Salow, H. and Steiner, W.

Z. Physik 99, 137-158 (1936). German

Cells similar to those of Finkelnburg and Steiner (Z. Physik 79, 69-88 (1932), were used, for higher pressures than 30 atmospheres, up to 1000 atmospheres. Up to 30 atmospheres pressure three 250 cm tubes were used in series. They were closed with 5 mm thick quartz plates, apparently fused to the tube body.

Temperature: room temperature

Pressure: 1000 atmospheres

83. "Pressure Effects of Foreign Gases on the Sodium D-Lines"

Margenau, H. and Watson, W. W.

Phys. Rev. 44, 92 (1933).

The pressure bomb, a steel pipe 33" x 1 5/8" with a 1" bore, was fitted with glass windows 1 cm thick held on the end by overlapping nuts threaded to the tube. Lead ring gaskets were used and were prevented from lateral expansion by sections of thin wall steel tubing fitted into the main tube and end nuts. A, N_2 and H_2 were studied.

Temperature: 200°C

Pressure: 0 to 17 atmospheres

84. "Absorption Spectra at High Pressures and at Low Temperatures. The Transparency of Argon and Methane"

Eiseman, B. J.

J. Am. Chem. Soc. 54, 1778-1781 (1932).

The apparatus is discussed in details. Quartz windows of the truncated cone design were used. They were ~8 mm dia, 3° taper, and 1 cm thick. They were seated in ground-to-match recesses in steel tubes.

Temperature: -180°C

Pressure: up to 500 atmospheres

85. "Concerning the Absorption Spectra of Highly Compressed Oxygen and the Existence of the O_4-Molecule"

Finkelnburg, W. and Steiner, W.

Z. Physik 79, 69-88 (1932). German

A steel cell with 20 mm wall thickness was used, with cell lengths ranging from 21 to 250 cm. Quartz windows were used with 20 mm dia light path. The thick windows (slightly conical) were ground to fit the steel recess in the window plug (removable) and were seated by the use of Wood's metal in a slight off-set near the inside surface.

Temperature: room temperature

Pressure: to 1000 atmospheres

86. "Apparatus for Optical Studies at High Pressures"

Poulter, T. C.

Phys. Rev. 40, 860-869 (1932).

Simplified piston packing, electrode insulation, temperature control and a compact and safe construction of pressure equipment are described with particular reference to systems for optical studies at high pressures.
Equipment for optical studies at pressures as high as 30,000 atmospheres and some of their limitations and peculiarities are described.

Temperature: room temperature
Pressure: 30,000 atmospheres

87. "The Lens Effect of Pressure Windows"

Poulter, T. C. and Benz, C. A.

Phys. Rev. 40, 872-876 (1932).

The lens effect of high pressure optical systems involving glass or quartz windows has been studied and found to be due to four primary causes. (1) Pseudo-lens effects due to temperature gradients following changes of pressure. (2) Bulging of the outer surface of the pressure window. (3) Pseudo-lens effects due to unequal distribution of strain in the window. (4) The difference of index of refraction of the material in the cylinder and that of the window combined with the bulging of the inside surface of the window. These effects were measured and methods for their correction outlined.

88. "Diamond Windows for Withstanding Very High Pressures"

Poulter, T. C. and Buckley, F.

Phys. Rev. 41, 364-365 (1932).

Diamond windows were tested and found to withstand much greater pressures than glass or fused quartz (up to 21,500 atmospheres) particularly when water and alcohol solutions are used to transmit the pressure to the windows.

Temperature: room temperature

Pressure: 21,500 atmospheres

89. "The Effect of Pressure on the Index of Refraction of Paraffin Oil"

Poulter, T. C., Benz, C. A. and Ritchey, C.

Phys. Rev. 41, 366-367 (1932).

A refractometer for measuring the index of refraction of liquids under very high pressure is described. The values of n obtained for glycerol and for paraffin oil together with the constants for the Lorenz-Lorenz relation $[(n^2-1)/(n^2 + 2)] \times (1/d) = K$ are given. A gasketless window mount is used.

Temperature: room temperature

Pressure range: up to 14,000 atmospheres

90. "The Permeability of Glass and Fused Quartz to Ether, Alcohol and Water at High Pressures"

Poulter, T. C. and Wilson, R. O.

Phys. Rev. 40, 877-880 (1932).

The permeability of glass and fused quartz to water, alcohol, and ether, and its relation to pressure windows was studied. These liquids penetrate to considerable depths if the pressure is maintained for as long as 15 min, in which case the pieces of glass or quartz are shattered if the pressure is rapidly released. However, if the pressure is released over a period of several days no breakage occurs. The behavior of pressure windows in contact with different liquids probably depends upon the penetration of the liquids in the glass or quartz.

91. "Dispersion and Refractive Index of Nitrogen Measured as Functions of Pressure by Displacement Interferometry"

Bennett, C. E.

Phys. Rev. 37, 263-275 (1931).

A rather complex gasketed glass disk window was used. The glass disk was cemented into a thin-walled steel cap that was carefully machined to fit the disk.
de Khotinsky cement was used and the window was further gasketed to the tube cell with rubber. A steel outside washer was cemented to the window mount.

Temperature: $0^{\circ}C$ to $30^{\circ}C$

Pressure: 100 mm Hg to 1 atmosphere

92. "Concerning the Absorption Spectrum of Dissolved Mercury"

Reichart, H. and Bonhoeffer, K. F.

Z. Physik 67, 780-789 (1931). German

This rather intricate design involves a cell within a cell. The inner cell is a quartz tube whose end windows are 3 mm thick plane quartz windows fused onto the tube. The windows will withstand a pressure differential of 20 atmospheres.

The steel pressure bomb was also fitted with a pair of windows to withstand 200 atmospheres. These windows (quartz cylinders, 8 mm thick) were seated in a milled recess in a brass screw-in plug with sealing wax. The brass retainer plug was mounted with lead gaskets. (No mention was made of optical polishing but no gasket was used between the seating surface and the window face except sealing wax). The type of wax, etc. was not specified.

Temperature: inner cell — $250^{\circ}C$
outer cell windows (?), (not high)

Pressure: 200 atmospheres

93. "Photographic Flame Studies in the Gasoline Engine"

Withrow, L. and Boyd, T. A.

Ind. Eng. Chem. 23, 539-547 (1931).

A quartz window (12.7 cm x 0.952 cm wide) was cemented into a tubular tapered window retainer that was fitted into the cylinder head. Several cements were used (litharge-glycerine, porcelain with asbestos, etc.)

Temperature: $100^{\circ}C$

Pressure: up to 400 psi

94. "The Effect of High Pressure on the Near Infrared Absorption Spectrum of Certain Liquids"

Collins, J. R.

Phys. Rev. 36, 305 (1930).

Windows: (a) quartz or glass cylinders were used with rubber and other packing materials with retainer rings and seals (b) Poulter windows (5/16") were used satisfactorily with a Canada Balsam cement between the polished surfaces of the window and the metal retainer plate.

Temperature: room temperature

Pressure: up to ~8000 atmospheres

95. "A Glass Window Mounting for Withstanding Pressures of 30,000 Atmospheres"

Poulter, T. C.

Phys. Rev. 35, 297 (1930).

The window is gasketless. The window (optically polished) rests on a polished surface of a hardened "high-speed" steel disk, containing a hole for light beam transmission.

Temperature: not discussed, prob. room temperature

Pressure: 30,000 atmospheres

96. "A Study of Phosphorescent Zinc Sulphide Screens and Radioactivity Under Extremely High Pressure"

Poulter, T. C. and McComb, H.

Iowa Academy of Science, Abstracts 37, 311-312 (1930).

These measurements were made possible by the use of optically polished gasketless glass or quartz windows that were described earlier by Poulter.

Temperature: room temperature

Pressure: 30,000 atmospheres

97. "Some Recent Developments in High Pressure Windows"

Poulter, T. C. and Wilson, R. O.

Proc. Iowa Acad. Sci. 37, 299-302 (1930).

An excellent discussion of window mountings and supports, for both the truncated cones and the Poulter gasketless window. Reasons for window failures at various pressures in contact with different solvents are also discussed.

D. Publications located between 1929 and 1920 (incl.)

98. Gasseous Combustion at High Pressures

Bone, W. A. Mewitt, D. M. and Townend, D. T. A.

Longmans Green and Co., London, 1929

"High-Pressure Quartz Windows" are discussed briefly, pp. 66-72. Windows of unstrained quartz were used in the form of truncated cones 1" thick, 1" dia with a taper of 3/32" per inch. The window is seated into a ground-to-match in the steel window retaining plug and held in position by a collar. An asbestos-graphite washer between the collar and the outer edge of the window serves to make a gas tight joint.

Temperature: gaseous explosions, yield temperature up to at least 3000°K, windows were not affected. Window temp. (?)

Pressure: 400 atmospheres

99. "The Molecular Scattering of Light in Carbon Dioxide at High Pressures"

Raman, C. V. and Ramanathan, K. R.

Proc. Roy. Soc. (London) 104A, 357-368 (1923).

Measurements were made on gases, liquids, and vapors. Conical thick glass windows were used, and were seated in a ground-to-match conical recess in a steel cylinder.

Temperature: 0°C to 50°C

Pressure: 1 to 100 atmospheres

100. "The Effect of Pressure on Optical Absorption"

Wick, F. G.

Proc. Am. Acad. Arts Sci. 56, 557-573 (1923).

High pressure cylindrical optical plate glass windows were used, mounted inside a concentric rubber washer which was fitted into the steel cylinder. This rested against a steel bearing surface (via a paper washer) containing a 3/16" hole for the light beam.

Temperature: room temperature

Pressure: up to 3500 atmospheres

101. "The Relation Between the Refractivity and Density of Carbon Dioxide"

Phillips, P.

Proc. Roy. Soc. (London) A97, 225-240 (1920).

Conical thick glass windows were used, and were seated in ground-to-match conical recesses in a gunmetal chamber.

Temperature: 34°C

Pressure: up to 41 atmospheres

E. Publications located between 1919 and 1910 (incl.)

102. "The Light Scattered by Gases: Its Polarization and Intensity"

Strutt, R. J.

Proc. Roy. Soc. (London) A95, 173 (1918-1919).

Windows: conical glass plugs (truncated cones) were seated in ground-to-match conical recesses in brass screw caps (seated to threaded steel tube via lead washers). The windows were seated in a soft wax.

Temperature: ~21°C

Pressure: up to 150 atmospheres

103. "Determinations of Refractive Indices of Gases under High Pressure: I. The Dispersion of Hydrogen"

Siertsema, L. H. and DeHass, M.

Physik. Z. 14, 568-574 (1913). German

Windows: Plate Glass Cylinders (8 mm thick). Packing at atmospheric pressure side, brass ring-paper disk; at inside high pressure area; Klingerit packing between inside window surface and a steel window separating cylinder.

Temperature: 11°C to 20°C

Pressure: up to 82 atmospheres

104. "The Change in Certain Absorption Spectra in Different Solvents"

Merton, T. R.

Proc. Roy. Soc. (London) A87, 138-147 (1912).

Spectra were measured up to 750 atmospheres pressure; no changes due to pressure were observed. No increase in temperature was made. The apparatus used consisted of a steel vessel provided with thick conical glass windows, and was connected to a Bourdon Pressure Gauge. The apparatus was not discussed in detail.

Temperature: room temperature

Pressure: 750 atmospheres

105. "Physio-Chemical Determination at High Pressures by Optical Methods: I. Apparatus for Optical Determinations at High Pressure"

Wahl. W.

Trans. Roy. Soc. (London) A212, 117-148 (1912).

Windows: Truncated Jena Glass cones, vulcanized fiber washers were used with a conical mantle of ebonite.

Temperature: liquid air to +150°C

Pressure: to ~4000 atmospheres

106. "Physico-Chemical Determinations at High Pressures by Optical Methods"

Wahl, W.

Proc. Roy. Soc. (London) A87, 152-153 (1912).

Contains a brief discussion of optical windows (truncated cones) of 20 mm thickness and their mounting and packing. The windows were made from Jena Glass, and vulcanized fiber washers were used with a conical mantle of ebonite.

Temperature: liquid air to +150°C

Pressure: up to ~4000 atmospheres

107. The Absorption Spectra of Solutions as Affected by Temperature and by Dilution: A Quantitative Study of Absorption Spectra by Means of the Radiomicrometer

Jones, H. C. and Guy, J. S.

Carnegie Institution Publ. No. 190 (1913). Chapter II pp. 5-8 "Experimental Methods"

A steel absorption cell was designed similar to that developed by Jones and Strong; the cell was constructed so that the windows were mounted in removable plugs, so that they could be removed for easy cleaning. Both the plug and the window mountings were made with gold gaskets.

Temperature: above 200°C

Pressure: >275 atmospheres

108. The Absorption Spectra of Solutions of Comparatively Rare Salts, Including Those of Gd, Dy, and Sm. The Spectrophotography of Certain Chemical Reactions and the Effect of High Temperature on the Absorption Spectra of Non-Aqueous Solutions

Jones, H. C. and Strong, W. W.

Carnegie Institution Publ. No. 160 (1911). Chapter II pp. 27-31 "Experimental Methods and Apparatus"

The absorption cells were of tool steel and were heavily copper plated and then gold plated over all interior surfaces. The windows were of glass or quartz and were cylindrical plates 2.5 cm in dia, mounted to the steel cell via gold gaskets.

Temperature: up to 200°C

Pressure: up to >270 atmospheres

109. The Absorption Spectra of Solutions. A Study of the Absorption Spectra of Solutions of Certain Salts of K, Co, Ni, Cr, Er, Pr, Nd, and U as Affected by Chemical Agents and by Temperature

Jones, H. C. and Strong, W. W.

Carnegie Institution Publ. No. 130 (1910). Chapter II pp. 19-22 "Experimental Methods"

Describes work between 0°C to 90°C, and discussed planned work on a cell being constructed for work on the effect of high temperatures on absorption spectra using a closed gold-lined steel cell, to have quartz windows.

Temperature: 0°C to 90°C

Pressure: atmospheric pressure

F. Publications located between 1909 and 1900 (incl.)

110. "The Effect of Pressure Upon Arc Spectra, No. 1, Iron"

Duffield, W. G.

Phil. Trans. Royal Soc. A208, 111 (1908).

Glass ground-to-match truncated cone windows were used and were seated in a ground-to-match steel tube.

Temperature: ~ room temperature

Pressure: 100 atmospheres

111. "The Refractive Index of Air with Reference to Its Density"

Magri, L.

Physik. Z. 6, 629 (1905). German

Windows: Conical flint glass plugs (truncated cones) seated in ground-to-match conical recesses. Windows (~1.5 cm length) were seated with marine glue.

Temperature: $0^{\circ}C$ to $17^{\circ}C$

Pressure: 0.0009 to 200 atmospheres

112. "Index of Refraction of Air"

Gale, H. G.

Phys. Rev. 14, 1-16 (1902).

Glass plate windows were mounted via rubber gaskets to the ends of tubular metal cells by steel plates appropriately bolted together.

Temperature: room temperature

Pressure: 20 atmospheres

113. "Measurements on the Magnetic Rotation of the Planes of Polarization in Liquified Gases Under Atmospheric Pressure: II. Measurements with Methylchloride"

Siertsema, L. H.

Proc. Amsterdam Acad. Sci. 5, 243-247 (1902) (Koninklije Akademic van Wetenschappen te Amsterdam)

Very interesting spectral observation cell for liquid substances such as methyl chloride. Plane glass plates used as windows, some sealed with India-rubber leaf as packing and some with fish glue. cf. Reports of Amst. Acad. Sci. 5, 305 (1896-1897) for description of work involving a pressurized system.

G. Publications located prior to 1900

114. "Reports on the Elasticity and Expansibility of Liquids at Very High Pressure" also reported in: Amagat, E. H., Notice sur les Travaux Scientifiques de E. H. Amagat, Paris, 1896

Amagat, E. H.

Ann. Chim. phys., Series 6, 29, pp. 68-96 (1893). French Section 3: Apparatus for Elevated Temperatures, "Methodes des Regards."

Windows: Quartz cylinders (1 cm dia, 2 cm long) seated in an internally milled brass recess with marine glue. The brass window retainers is seated to the main body with a washer of celluloid.

Temperature: 100°C, up to 360°C (?)

Pressure: up to 1000 atmospheres

115. "Influence of Pressure on the Refractive Index"

Rontgen, W. C. and Zehnder, L.

Wiedemann's Ann. 44, 24 (1891). German

Optical observations at high pressures were carried out with windows consisting of plane glass plates sealed to the pressure tube with either sealing wax or isinglass.

Temperature: 0°C to 30°C

Pressure: about one atmosphere

116. "The Absorption-Spectrum, Luminous and Ultra-Violet of Large Masses of Oxygen"

Liveing, A. and Dewar, E.

Phil. Mag., Series 5, 26, 286 (1888).
Proc. Roy. Soc. (London) A46, 226 (1889).

Windows: Truncated cone quartz plugs were seated in ground-to-match gunmetal caps. Windows were seated with wax.

Temperature: room temperature

Pressure: up to 260 atmospheres

117. "On the Experimental Determination of the Index of Refraction of Liquified Gases"

Bleckrode, L.

Proc. Roy. Soc. (London) A37, 339-362 (1881).

Flat polished sections of thick-wall capillary tubing was seated to steel by the use of perforated smooth leather packing, with the use of a lead or tin washer.

AUTHOR INDEX

All authors of all papers, books, etc., that are cited in the list of references are included here. No distinction is made between the principal author and other authors for any given paper, since there is no assurance that uniformity in listing the first author for a particular paper as the senior author is followed. The Numbers refereto the number of the individual listings in the list of references.

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APPENDICES

A. SOURCES CONSULTED

1. Chemical Abstracts: complete review up through 1956 Subject Index.

2. Nuclear Science Abstracts, complete Indexes, Vol. 1 through Vol. 13, No. 6A, March 31, 1959.

3. AEC Card Catalogs - complete survey, classified and unclassified document listings.

4. Physics Abstracts (Science Abstracts, A, Physics), 1950 through 1958.

5. ORNL - Central Research Library Card Catalog.

6. Books, ones with pertinent sections as listed in the bibliography.

7. Former bibliographies.

8. J. Optical Soc. Am.; Subject Indexes from 1949 to the present date.

9. Rev. Sci. Instruments; Subject Indexes from 1949 to the present date.

10. Ch'en, Shang-Yi and Takeo, M., "Broadening and Shift of Spectral Lines Due to the Pressure of Foreign Gases," (A review with 195 references). Rev. Modern Phys. 29, 20-73 (1957).

    The literature cited in this review was reviewed for pertinent references on window design work at elevated temperatures and pressures.

11. Margenau, H. and Watson, W. W., "Pressure Effects on Spectral Lines," (A review with 93 references). Rev. Modern Phys. 8, 22-53 (1936).

    The literature cited in this review was also reviewed in the manner indicated for the previous item. Other than these two and the following item, it was not possible to review the extremely large literature on pressure broadening of spectral lines. Only a small amount of pertinent literature was found, the majority of the work having been carried out at a low-to-normal temperature and at pressures usually lower than atmospheric.

12. Robin, Stephane and Robin, Simone, "Pertubations of Spectral Lines by Pressure; In the Atomic Spectra of Electrically Neutral Particles," (A review with 154 references). J. phys. radium 17, 43-161 (1956).

    The appropriate literature cited in this review was checked. Some literature concerning work at elevated temperatures and pressures was found.

13. Bridgeman, P. W., "Recent Work in the Field of High Pressure," (A review with 674 references). Rev. Modern Phys. 18, 1-93 (1946).

This most excellent review was checked thoroughly. Among the many topics discussed are:

a. Miscellaneous Techniques (pressure windows)
b. Optical Effects of High Pressure
   1. The effect of pressure on the index of refraction.
   2. Photographic effects of high pressure.
   3. Miscellaneous optical effects of high pressure.
c. Chemical Effects of High Pressures

All of the pertinent literature cited in this review paper was surveyed.

14. Bridgeman, P. W., "Recent Work in the Field of High Pressures," American Scientist, 31, 1-35 (1943).

15. Poulter, T. C., "The Study of Extreme Pressures and Their Importance in the Investigation of Engineering Problems," J. Applied Phys. 9, 307-311 (1938).

A discussion, including some material on optical windows, with a bibliography of the work by Poulter and his co-workers.

16. Campbell, I. E., ed., High-Temperature Technology, John Wiley and Sons, New York, 1956, 526 pp.

17. Hall, H. T. and Kistler, S. S., "High Pressure Developments," Annual Reviews of Physical Chemistry, H. Eying, ed., Ann. Reviews Inc., Palo Alto, Calif., 1958, pp. 395-417.

18. Hornig, D. F., "Spectroscopic Studies on Reactions at High Temperature," Molecular Spectroscopy; Conf. report, London, Oct. 28-29, 1954. G. Sell, ed., The Institute of Petroleum, London, England, pp. 183-191.

19. Conference on Molecular Spectroscopy, Procedings of the Institute of Petroleum Hydrocarbon Research Group, London, Feb. 27-28, 1958, ed. by E. Thornton and H. W. Thompson. Pergamon Press, New York, 1959; also published as Spectrochimica Acta Vol. 14, 1958.

a. "The Shock Tube as a Source for Studies of Emission and Absorption Spectra," Clouston, J. G. and Gaydon, A. G., pp. 66-78, 24 references.

With the exception of this review, (18) above, and some other miscellaneous literature, time did not permit a thorough review of shock tube investigations. For the most part the shock tube studies have dealt with pressures in the two separate portions of the tube that are very low and about, or somewhat above, atmospheric. Windows are usually placed in the low pressure end of the tube, however these are of such a design and construction so as to not come under the subject of this review. There are some exceptions, concerning work at high pressures and these are included herein.

b. "Spectroscopic Study of Inter-molecular Forces in Gaseous Mixtures," Vodar, B., pp. 241-265, 48 references. (All of the pertinent references were checked).

c. "Infra-red Spectra of Compressed Gases," Ketelaar, J. A. A., pp. 265-277, 30 references. (All of the pertinent references were checked).

20. UCRL-5083, "Bibliography on High Pressure Systems and High Pressure-High Temperature Systems; Techniques, Apparatus and Experimental Data," J. F. Lakner, Comp. (Univ. of Calif. Radiation Laboratory, Livermore, Calif., Unclassified Document) Jan. 10, 1958.

This is a good general review of some of the important work in this field. However there is very little overlap between the review by Lakner and the present review, since very little optical work was covered. Approximately twenty-five per cent of the literature cited is that published by Bridgeman. The review is in general, slanted toward non-optical chemical and physical studies of materials, minerals, etc.

21. Kovacick, V. P., et al., The Impact of High Temperature Technology, Harvard University, Graduate School of Business Administration, 1958.

22. Conference on Extremely High Temperatures, 1st; Boston, Mass., March 18-19, 1958. ed. Fischer, H. and Mansur, L. C.; sponsored by Air Force Cambridge Research Center, Electronics Research Directorate. John Wiley and Sons, Inc., New York, 1958, 258 pp.

23. High Temperature - A Tool for the Future, Proc. of the Symposium sponsored by the Stanford Research Institute and the University of California, Berkeley, Calif., June 25-27, 1956, Stanford Research Institute, Menlo Park, Calif., 258 pp.

24. "Les Hautes Temperatures et Leurs Utilisations en Chimie," P. Lebeau and F. Trombe (Director of Research, CNRS), et al. 2 vols., Masson et Cie, Editeurs, Paris, 1950, 1397 pp.

25. Physico-Chemical Effects of Pressure, Haman, S. D., Academic Press, Inc., New York, 1957. Buttersworth Sci. Publ., London.

26. High-Pressure Technology, Comings, E. W., McGraw-Hill Book Co., 1956.

27. The Physical Chemistry of Processes at High Pressures - A General Discussion. Faraday Soc. Discussions, Vol. 22, 1956.

28. The Physics of High Pressure, Bridgeman, P. W., G. Bell and Sons, London, 1949.

29. The Design of High Pressure Plant and the Properties of Fluids at High Pressure, Newitt, D. M., Oxford Univ. Press., 1940.

30. Gasseous Combustion at High Pressures, Bone, W. A., Newitt, D. M., and Townend, D. T. A., Longmans Green and Co., London, 1929.

31. Carnegie Institution Publications No. 130 (1910), 160 (1911), and 190 (1913). cf. bibliography references for Jones, H. C., Strong, W. W., and Guy, J. S.

The sources listed above have been covered to the extent designated. However a very fruitful source of information has been obtained by the retracing of the cited literature in various papers listed in the reference section of this review, and by tracing work of the various workers who had published in the field. In almost all cases, all of the pertinent literature cited in every paper given in the bibliography was reviewed in so far as this was possible.

B. SUBJECT HEADINGS SEARCHED

The various subject headings that were searched for pertinent information, including those which have been found to be most productive are listed. On occasion, other subject headings were probably searched, however the main ones are as follows:

Absorption
Absorption, by rays or waves
Absorption, light
Absorption, pressure effects
Absorption cells
Absorption spectra
Alumina
Apparatus
Cells
Ceramics, etc.
Corundum
Faraday effect
Fluorite
Gaskets
Golds
High-Pressure
High-Pressure systems
High temperature
High-Temperature systems
Light transmission
Magnesium Oxide
Optical materials
Optical windows
Periclase
Pressure
Pressure vessels
Quartz; fused, natural
Refractive index
Refractories
Rock salt
Sapphire
Seals
Seals and Glands
Silica, fused, vitreous
Spinel
Spectra
Spectrochemistry
Spectrographs
Spectrography
Spectrometers

Spectrophotometers
Spectrophotometry
Spectroscopes
Spectroscopy
Spectrum
Temperature
Thermometry
Thermostats
Titania
Ultraviolet absorption
Vacuum seals
Windows

C. POSSIBLE SOURCES NOT COVERED

As a result of the somewhat limited time that could be spent on this compilation and review, and due to the tremendous quantity of available scientific and technical literature, a decision had to be made with respect to the sources covered. There are however, some other sources which might possibly contain some other pertinent literature or an important paper. Those sources, for which time has not permitted coverage to the present date, are as follows:

1. The Engineering Index
2. The Industrial Arts Index
3. Analytical Abstracts
4. Bull. of Br. Sci. Instr. Res. Association
5. Indexes to J. Sci. Instruments.

There are, no doubt, other sources that are not listed here that might in some way yield pertinent information on this subject. It has not been possible to review but a small portion of the biological literature. The Biological Section of Bridgman's large review was reviewed as far as time permitted this. Most of the pertinent literature found has employed the Poulter type of window mount.

D. FUTURE LITERATURE WORK

In addition to a continued perusal of various kinds of current literature, additional literature work should probably include a review of the following, or of the unpublished indexes when they become available.

1. Chemical Abstracts, Indexes for 1957, 1958, etc.
2. Nuclear Science Abstracts, 1959, etc., Vol. 13, No. 6B, et seq.

Additional work could include a review of the following:

3. Science Abstracts, A, Physics: prior to 1950
4. 1 through 5 in C above.

If the available time and personnel permit it, an effort will be made to keep a compilation of the available literature on this subject up to date. Supplementary literature work on the material listed above has been initiated by the library staff personnel. When, and if, enough additional pertinent information is obtained, a report supplement will be issued.

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